Current Forest Conditions in the US-Affiliated Pacific Islands

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COVER PHOTOS
UPPER LEFT: Coconut grove, Kona, Hawai'i Island, Hawai'i. Photo by: J.B. Friday
UPPER RIGHT: Flower of *Bruguiera gymnorrhiza,* a species of mangrove in Palau.
Photo by: J.B. Friday
LOWER RIGHT: Ko'olau Range on O'ahu Island, Hawai'i. Photo by: Rachel Neville
LOWER LEFT: Upland forest on the island of Pohnpei, Federated States of Micronesia.
Photo by: Conservation Society of Pohnpei

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ABSTRACT

This report summarizes the current research and issues affecting the health of the forests of the US-Afilliated Pacific Islands (USAPI): Hawai‘i, American Sāmoa, the Republic of the Marshall Islands (RMI), the Federated States of Micronesia (FSM), the Republic of Palau, Guam, and the Commonwealth of Northern Marianas (CNMI). This report provides a summary of current research on the ecosystem services of upland forests, agroforests, commercial forests, coastal and mangrove forests, and urban forests in the USAPI, the impacts on those forests, and management actions being undertaken to mitigate negative impacts. The guiding themes of the report were taken from discussions with USAPI forestry managers, published research, and Forest Action Plans. Forest Actions Plans, written in 2010 as a requirement of the 2008 Farm Bill, identified the highest priorities for forest resource management and strategies to achieve forest management goals. Invasive species, climate change, erosion, deforestation, storms, and poor tree care are all issues affecting USAPI forests.

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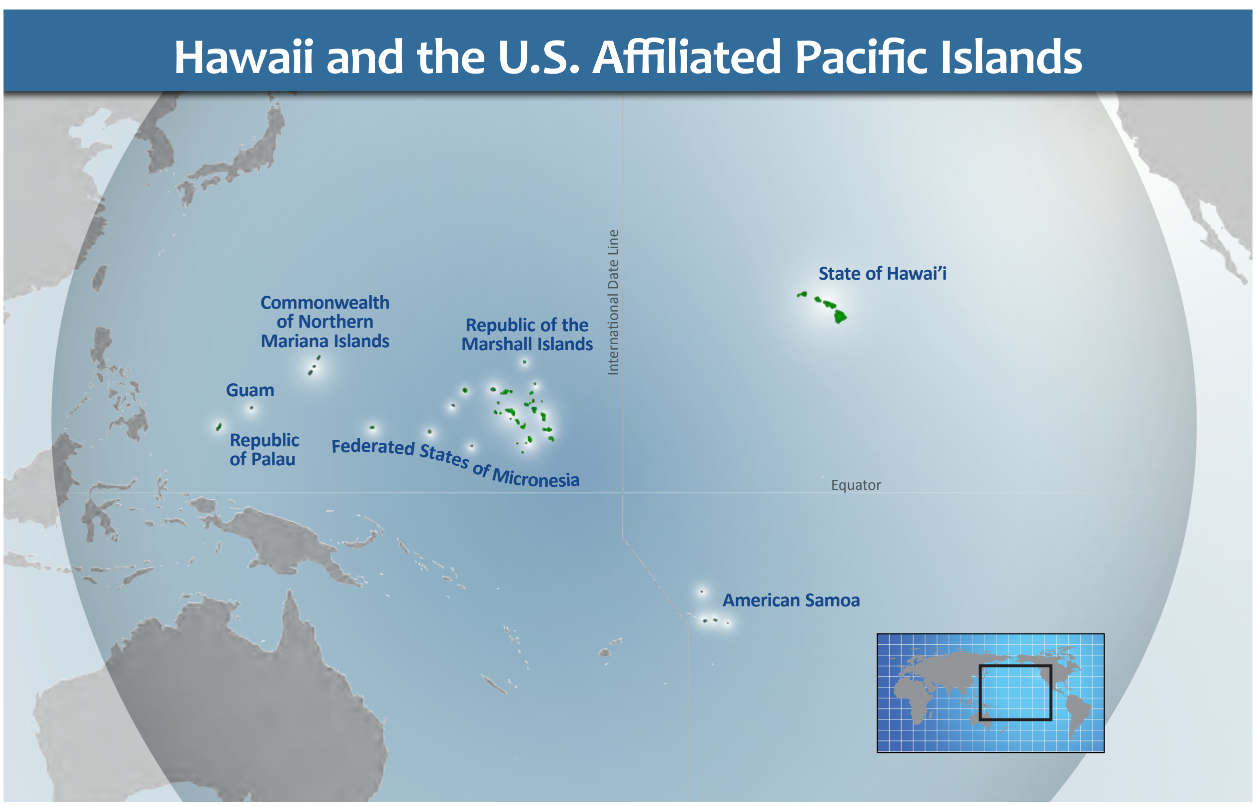
Native 'ohi'a forest near Thurston Lava Tube, Hawaii Island, Hawaii. Photo by J.B. Friday

Executive Summary

In the US-Affiliated Pacific Islands (USAPI) — Hawai‘i, American Sāmoa, the Commonwealth of the Northern Marianas (CNMI), Guam, Republic of Palau, Federated States of Micronesia (FSM) and the Republic of the Marshall Islands (RMI) — healthy forests are essential to all elements of life. Upland forests allow rainwater and cloud condensation into island aquifers, renewing the fresh water supply. Tree roots anchor the soil and keep sediment from harming the coral reefs on which subsistence fisheries depend. Agroforests sustained dense populations, prior to European contact, using traditional farming techniques. Commercial forests create rural jobs. Coastal forests and mangroves break the force of waves and storm surges, protecting the islands from severe weather. Urban forests are also coastal forests and reduce stormwater run-off from settling on coral reefs. The ecosystem services these forests provide are key to the ability of island residents to survive rising sea levels and changing precipitation patterns.

Climate change is affecting the health of all forest types. Keeping forests as healthy as possible by addressing invasive species, deforestation and urbanization should increase their resiliency to climate change. The USAPI are working to do this by identifying which mangroves will be most resilient to sea level rise, controlling invasive species, developing agriculture methods that will protect crops from saltwater and working to conserve terrestrial forest resources.

Invasive plants are a destructive force in USAPI forests that change forest structure and diminish ecosystem services. Invasive plants expand into native forests and replace them with a novel species assemblage comprised entirely of alien species. This has already happened in Hawai‘i, where native species are absent or occur only rarely in many lowland forests. Disturbances, such as fire or storms, may facilitate invasion, but are not necessary. Once forest structure changes, ecosystem function diminishes. Alien species may be less able to direct rainwater



Native forest in Palau. Photo by J.B. Friday

and cloud droplets into the aquifer, potentially decreasing the water supply. Invasive trees also promote erosion if they have shallow root systems. Vines smother inland forests and the food trees important in agroforests.

USAPI forests host many endemic tree species that are highly vulnerable to invasive insects and pathogens, which can often bring a host species perilously close to extinction. Both Guam and Hawai'i have experienced situations where an invasive pest, specializing in a particular plant genus, attacked an island or regional endemic within that genus; lack of resistance to the pest resulted in high levels of host mortality. Biological control programs have been successful in controlling several of the worst invasive insects, but more than one natural enemy is often needed to prevent tree mortality and also maintain plant reproductive capacity. Some of the extremely damaging invasive insects were only described after they became invasive in a new habitat. This complicates and delays implementation of a biological control program since determining where the organism is from must occur prior to searching for natural enemies. Strong biosecurity programs are needed to complement classical biological control and other pest management programs.

Feral ungulates including pigs, sheep, deer, and cows are also a problem, particularly in Hawai'i. Ungulates eat and trample vegetation, spread invasive species, and promote erosion by

Flower of ʻŌhiʻa (Metrosideros polymorpha). Photo by J.B. Friday

compacting soil. In CNMI and Guam, hunters set fires to forests to encourage grass to grow and lure deer within hunting range. Across the USAPI, partnerships built around invasive species control or watershed protection have brought together agencies and departments. These partnerships have been successful at working together to bring some notorious invasive species under control.

Urbanization and conversion to agriculture threaten upland forests although data are not available for current trends. Storms and typhoons cause damage that forests could likely recover from were it not for the presence of invasive species. Invasive plant growth is stimulated in areas where light gaps occur as a result of storm damage. Trees weakened by alien pests and pathogens are also more vulnerable to storm damage.

Traditional agriculture systems known as agroforestry, an intermixing of trees and other crops, are key to food security in FSM and RMI. Areas in FSM that have supported food-producing taro crops for generations have been ruined by seawater intrusion. During high water events from storm surge, and/or high sea levels from La Niña conditions, salt water has washed or seeped into groundwater, killing crops and turning the delicate freshwater lenses saline. Islanders on low-lying atolls may be forced to abandon their homelands where sea level rise makes agriculture impossible.

Several invasive pests attack agroforestry crops and important species in the urban canopy. The little fire ant (*Wasmannia auropunctata*) has a sting painful enough to disrupt harvesting in agroforests and where introduced will change the way islanders interact with their forests. Trainings in early detection and rapid response for little fire ant and other ant species have been conducted in the USAPI. Coconut is attacked by many different pests including the coconut rhinoceros beetle (*Oryctes rhinoceros*), which invaded Guam in 2007 and was discovered in Hawai‘i in early 2014.

Commercial forests are not a primary component of forestry in the USAPI. Local woods are used for building materials, but there is no commercial logging at the scale similar to that in the continental United States. There is an ongoing effort to commercialize koa (*Acacia koa*) in Hawai‘i, but this has been hampered by pest issues, the most prominent being koa wilt (*Fusarium oxysporum*). Research efforts are ongoing and have resulted in the development of wilt-resistant koa. The value of young koa in woodworking needs to increase in order for koa to become commercially viable. Demonstration projects with young koa may help to increase its marketability. The rising price of Indian sandalwood (*Santalum album*) has increased interest in the commercialization of Hawai‘i's endemic sandalwood species. Electricity fueled by eucalyptus species is being developed in Hawai‘i but is not yet operational.

Mangroves and coastal forests are important for storm protection and the roots of mangroves act as nurseries for some species of fish. Mangroves are not native to Hawai‘i and are considered an invasive species there. In the rest of the USAPI, mangrove forests have been lost to development and harvesting in some areas. Mapping and monitoring mangroves can help identify forest health trends, loss of habitat, and may also be useful in determining the causes of decline. Mapping and delineating of mangrove boundaries has been completed in American Sāmoa, FSM, CNMI, Palau, and Guam. Mangrove conservation is a part of conservation plans in much of the USAPI.

Urban forests provide cooling and shade and soak up storm water runoff. While urban forests provide important services, the ornamental plants used in urban forests can also be a source of invasive plants. The Hawai‘i Pacific Weed Risk Assessment (HPWRA) and Plant Pono program is a free service to landscapers, nursery owners, and the general public that assesses the risk of certain species to become weedy based on their biological characteristics and invasive history elsewhere. Poor pruning techniques and invasive insects are also a problem for USAPI urban forests.

USAPI forestry departments are implementing successful programs to meet the challenges facing their forests, but much work remains. There is ample energy and creativity in the USAPI to deal with the problems facing their forests, but increasing technical assistance delivery and stable or increasing funding sources are needed to implement effective methods of protecting forest health in these unique tropical systems. Attention to the following issues will result in improving the health of Pacific island forests (refer to Appendix 1).

- There is a lack of data available to define and prioritize management actions.
- Resources and capacity in the islands needs to increase.

- Biosecurity/quarantine systems are not sufficient to protect islands from newly arriving invasive pests.
- Increased preparedness for known invasive species could mitigate damage.
- Biological control is a vital tool that could be used more effectively.
- Increased regional cooperation among island groups and with international entities, including the US federal government, is needed.
- Tree care in urban settings needs improvement
- The importance of island forests, the threats they face, and successful management need to be effectively communicated, both within island communities and to an international audience.

Limestone forest on Tinian, Commonwealth of the Northern Marianas. Photo by: Vic Guerrero, Jr.

Pohnpei upland forest. Photo by: Conservation Society of Pohnpei

Introduction

This is the first Forest Health Report for the US-affiliated Pacific Islands (USAPI): Hawai'i, American Sāmoa, Republic of the Marshall Islands (RMI), Federated States of Micronesia (FSM), Republic of Palau, Guam, and the Commonwealth of Northern Marianas (CNMI). There are approximately 1.9 million acres of USAPI forests spread across millions of square miles of ocean. It is not a lot of forest when thinking in continental terms, but what they lack in size they make up for in importance. USAPI forests make the basics of life in the USAPI possible.

The forests of the USAPI provide water, food, fiber, recreation, lumber, and jobs. Upland forests maintain hydrological systems, ensuring an adequate freshwater supply. Agroforests, traditional agriculture systems that mix trees and other crops, provide food, fiber, and medicine. Commercial forests create rural jobs. Coastal and mangrove forests protect the shorelines of the islands. Urban forests make USAPI cities more livable by providing cooling and shade and lessen the amount of stormwater runoff that pollutes coral reefs. All these forests provide habitat for native wildlife. The native plant species in these forests, some of which are endemic to one island group, are important to cultural practices and the history of the islands. Without these species, part of the islands' history and culture would be lost.

The top forest health priorities for each USAPI forestry department are listed in the "Islands at-a-Glance" section. The priorities are similar among the USAPI. Increasing climate change resiliency is a common theme, especially in the low-lying islands that are already experiencing extreme high tides. Invasive plants are a top concern for most of the USAPI. Biosecurity, the idea of keeping invasive species of all taxa from invading, needs to be as strong as possible to protect island forests. Erosion, both in the uplands and along the coasts, deforestation due to population increase and urbanization, feral mammals, wildfires, and poor tree care in agroforests and urban forests, are other threats.

This report provides a summary of current research on the ecosystem services of forests in the USAPI, the impacts on those forests, and management actions being undertaken to mitigate negative impacts. The guiding themes of the report were taken from discussions with USAPI forestry managers, published research, and Forest Action Plans. Forest Actions Plans, written in 2010, as a requirement of the 2008 Farm Bill, identified the highest priorities for forest resource management and strategies to achieve forest management goals. This report relied heavily on research published by scientists at the Institute of Pacific Island Forestry (IPIF, USFS) and data from the Forest Inventory and Analysis (FIA-USFS) program. Invasive species are a major issue throughout the region, but this report is not a catalogue of species, rather, individual species are used as examples of broader themes.

Mangroves on Pohnpei, Federated States of Micronesia. Photo by: Rich Mackenzie

Islands At-a-Glance

This section includes an overview of each of the US-Affiliated Pacific Islands including vegetation maps, statistics and forest health priorities for each forestry department.

American Sāmoa *rainforest. Photo by: National Park of American* Sāmoa

American Sāmoa At-a-Glance

Forests are essential to life on American Sāmoa. Samoans rely on their forests for medicine, food, clothing, canoes, fishing gear and traditional building materials. American Sāmoa's upland forests prevent erosion, which is essential for good-quality drinking water. Littoral strand forest provides a physical barrier from storms. The island's mountain peaks support stunted vegetation that harvest cloud droplets and direct them into the aquifer. 30% of American Sāmoa's native plants are endemic to the Sāmoan Archipelago. Over 250 alien plant species have been introduced and many of those are invasive. Invasive plants are replacing American Sāmoa's native forest at a rapid rate and these species will soon alter forest structure and reduce ecosystem services if they are not effectively managed.

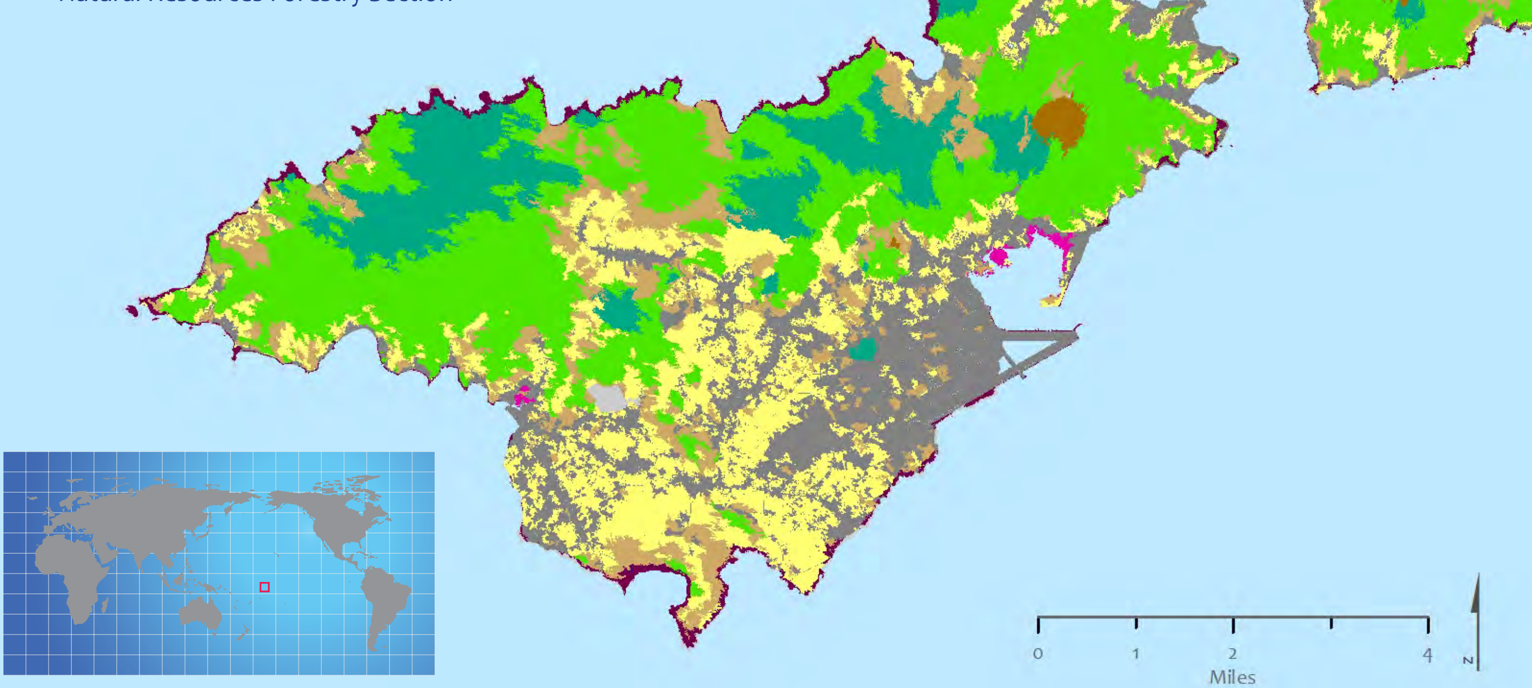
Word for forest in Sāmoan: **Vaomatua**

Top Forest Health Issues:
- Invasive plants
- Deforestation and forest conversion
- Poor tree care in agroforests and urban forests

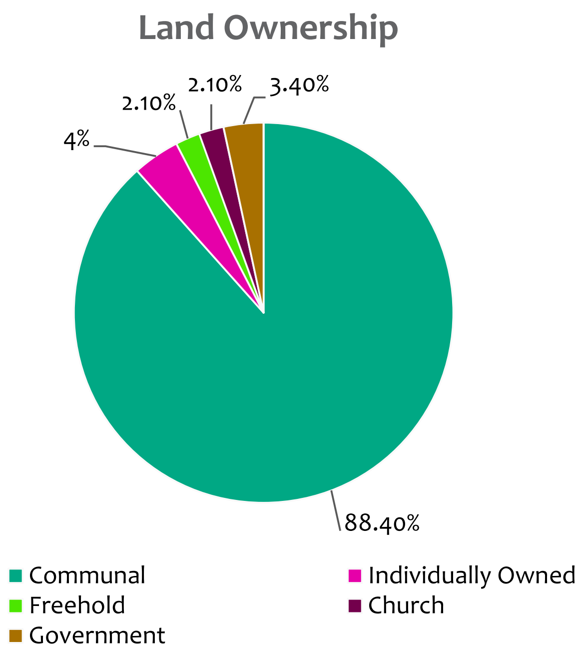
Land tenure system:
- Mostly communal, owned by extended families, with some private ownership.

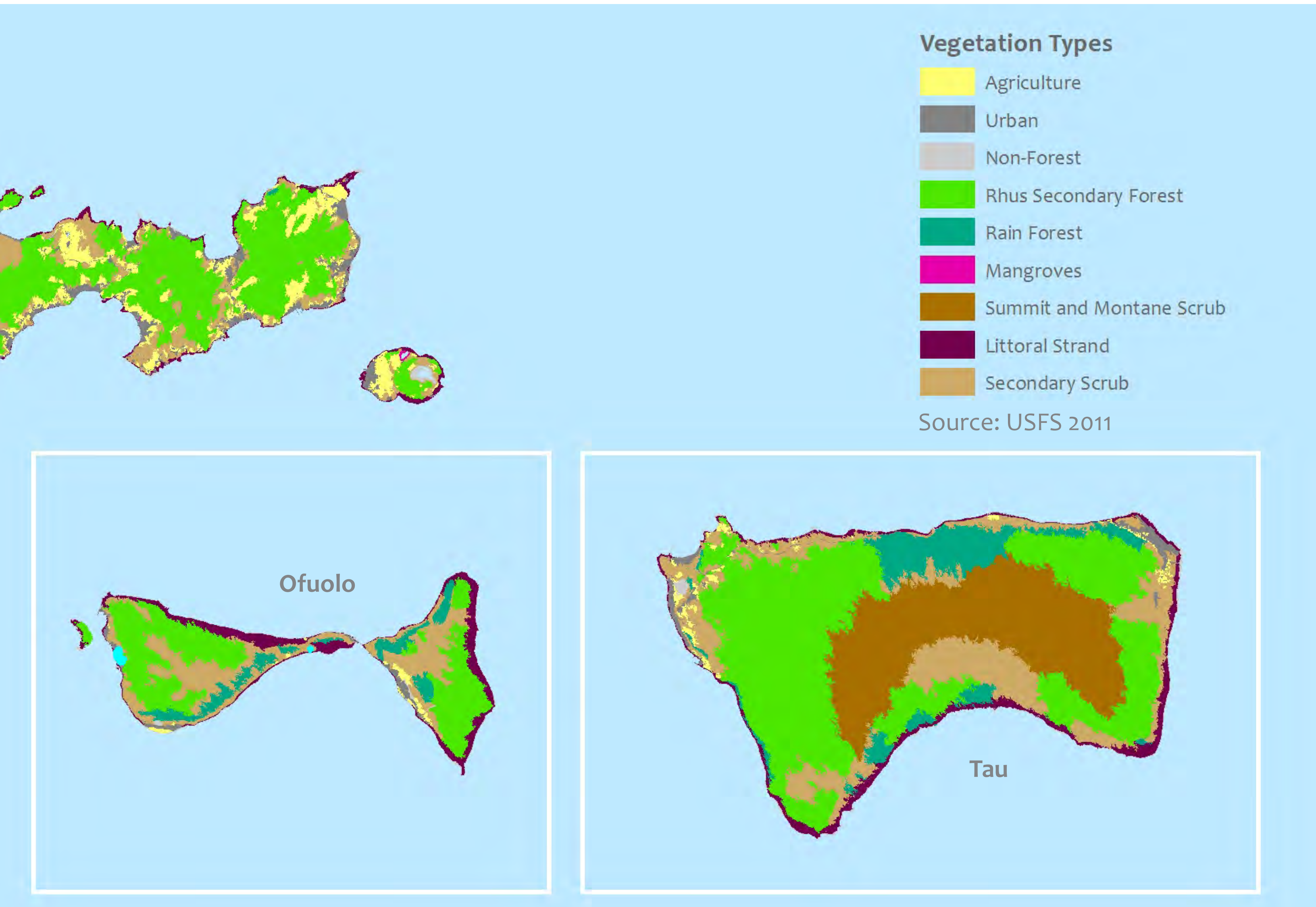
Relationship to U.S.:
- Territory

Forestry Department:
- American Sāmoa Community College Division of Community and Natural Resources Forestry Section



Acres of forested land:	43,691
Total land area in acres:	48,434
% forested:	90%
Number of islands:	Five volcanic islands and 2 atolls
Highest elevational point:	Mt. Lata—3,166 ft.
Population in 2010:	55,519



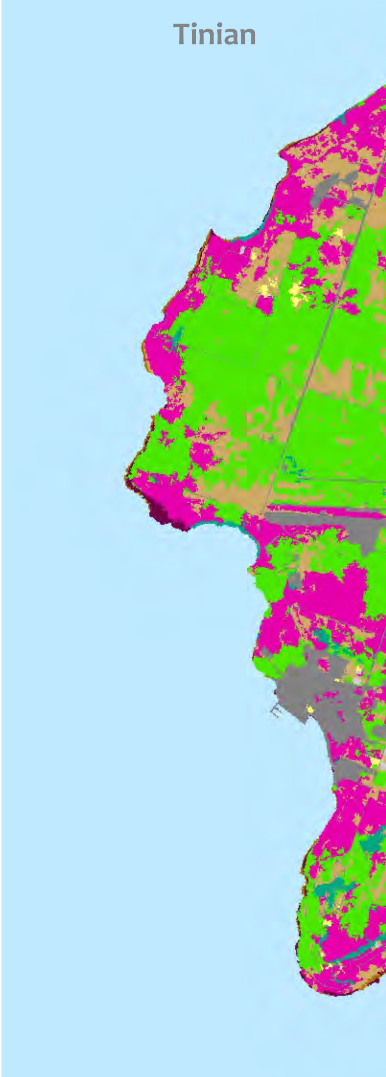


Commonwealth of the Northern Mariana Islands (CNMI) At-a-Glance

CNMI has experienced 350 years of disturbance: colonization by foreign governments, WWII battles, and typhoons. The Spanish and then the Germans cleared forestland to grow coconuts and sugar. The islands of Saipan and Tinian experienced heavy fighting and bombing during WWII. An alien legume Leucana leucocephala, known locally as tangantangan, was aerially seeded on Saipan and Tinian to prevent erosion and restore the soil. Today this species forms monospecific thickets that make up 28% of forested land on the populated islands of Rota, Saipan and Tinian. Despite this disturbance, CNMI's native forest species still persist, but they must compete with a host of invasive plants and feral browsing ungulates.

Word for forest in Carolinian: **Walu'wal**
Chamorro: **Halom tano**

Acres of forested land:	50,218 (Saipan, Tinian, and Rota)
Total land area in acres:	75,407 (Saipan, Tinian, and Rota)
% forested:	66%
Number of islands:	3 inhabited (Saipan, Tinian, and Rota), 10 uninhabited
Highest elevational point:	Agrihan Island (uninhabited)—3,166 ft. Rota (inhabited)—1,611 ft.
Population in 2010:	53,883

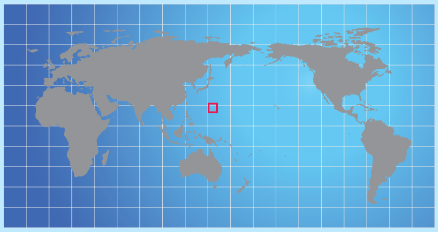


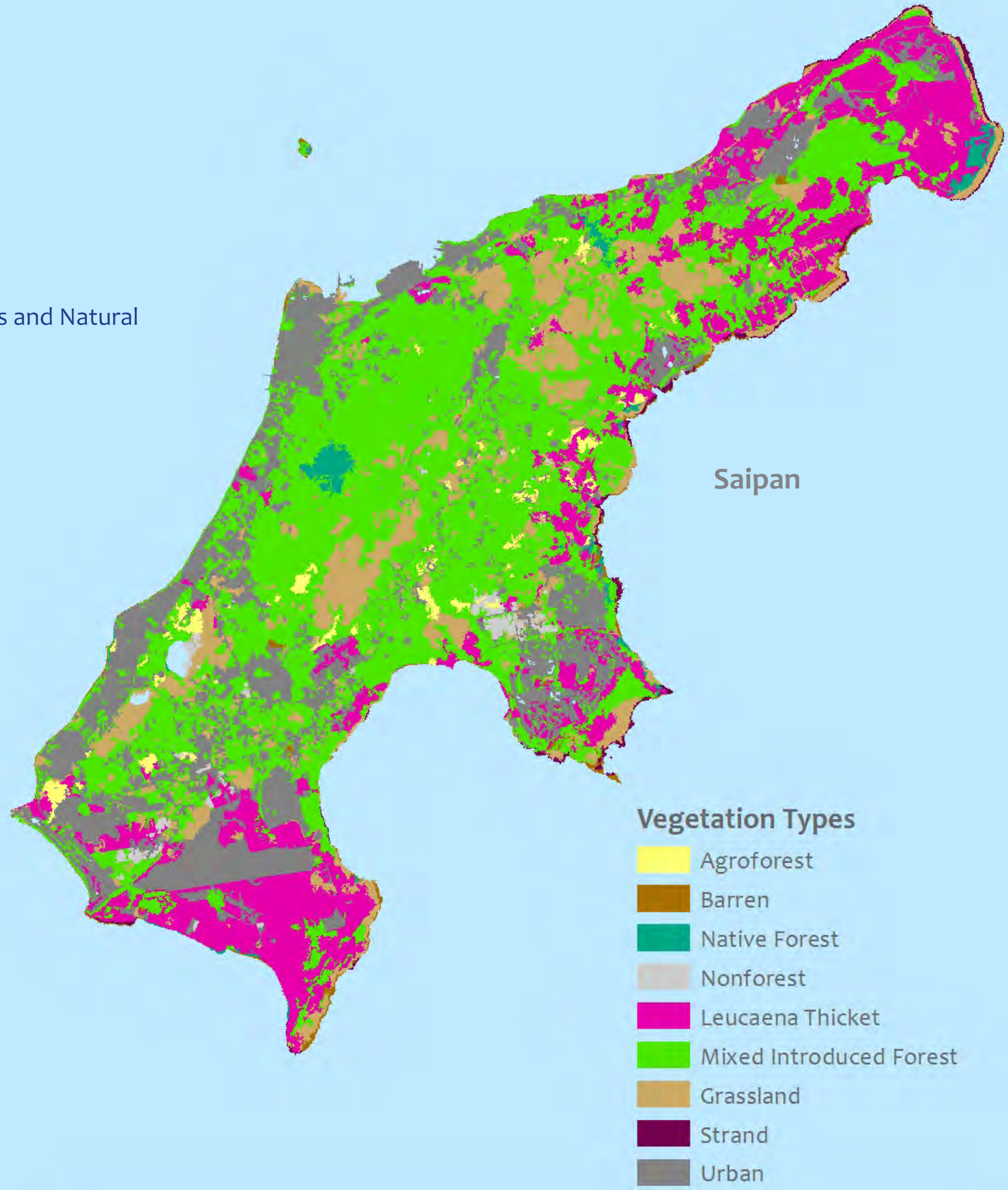
Top Forest Health Issues:
- Invasive plants
- Invasive plant pests
- Biosecurity

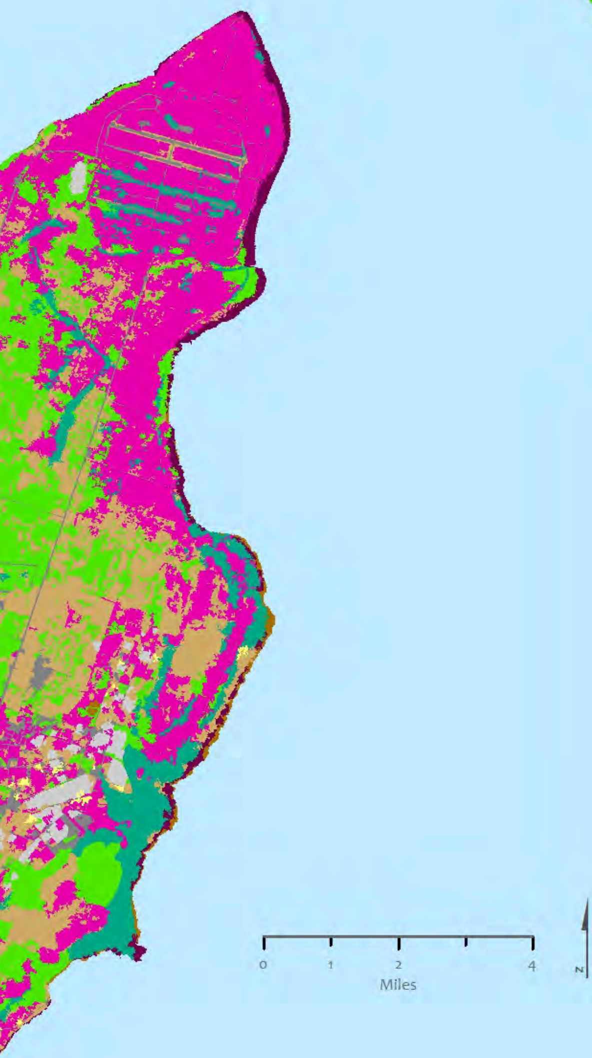
Land tenure system:
- Private ownership

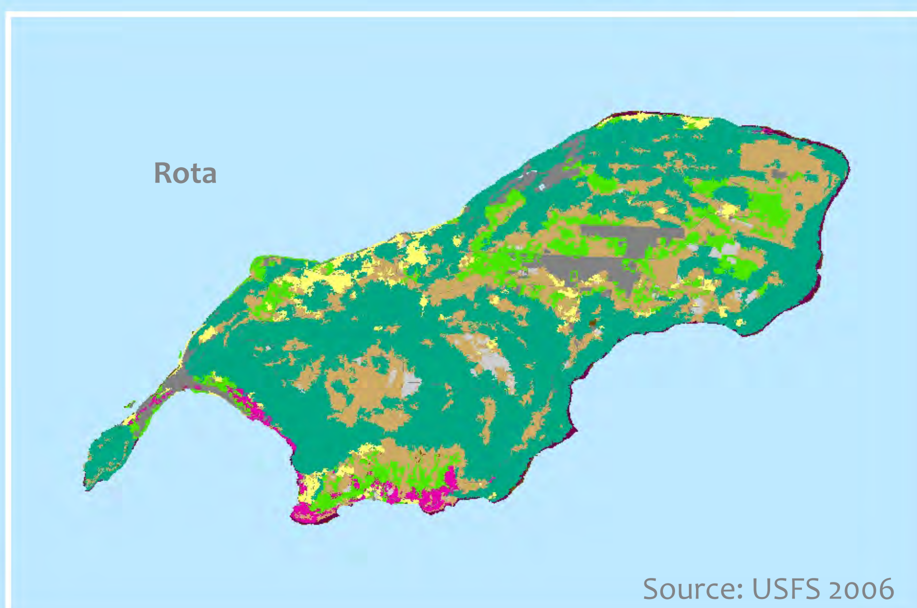
Relationship to U.S.:
- Territory

Forestry Department:
- CNMI Forestry (Department of Lands and Natural Resources—Division of Agriculture)









Federated States of Micronesia (FSM) At-a-Glance

FSM has already experienced food and water shortages as a result of seawater inundation from extreme tides and drought. Agroforests are the key to FSM citizens' food security and their ability to withstand climate change. The residents of some islands have already had to abandon their homelands because sea level rise has ruined the islands' freshwater lenses that support agriculture. The forests of FSM contain 90 species of endemic plants (Costion and Lorence 2012). Remnant patches of Chuuk's native forests still survive on steep ridges and on the summit of Mt. Winipot. The cloud forests of Pohnpei and Kosrae are the lowest elevation cloud forests in the world and provide habitat for 30 species of tree snails, 24 species of birds and 3 species of endemic flying foxes (The Nature Conservancy date unavailable).

Top Forest Health Issues:

Strengthening food security in order to increase climate change resiliency.

Deforestation

Invasive plants

Land tenure system:

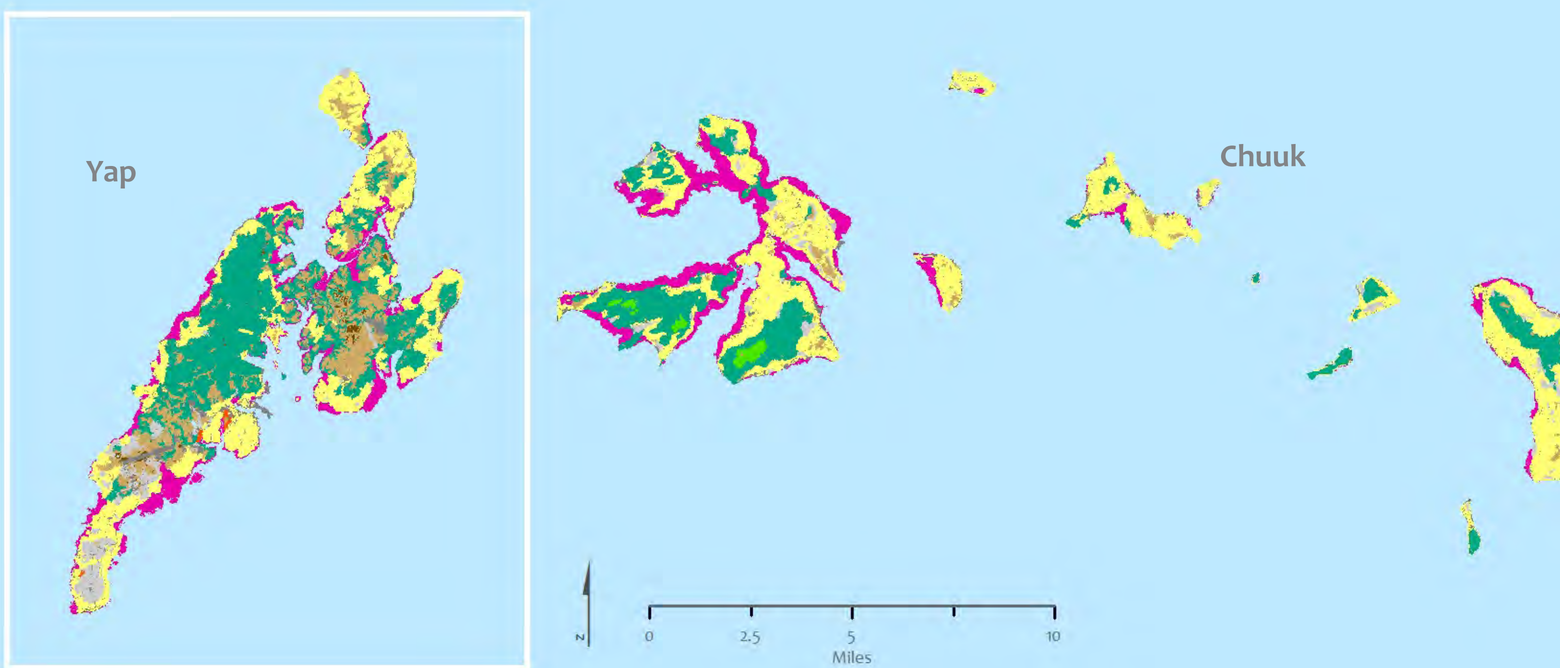
Some private ownership along with traditional forms of land tenure that vary by state.

Relationship to U.S.:

Compact of Free Association

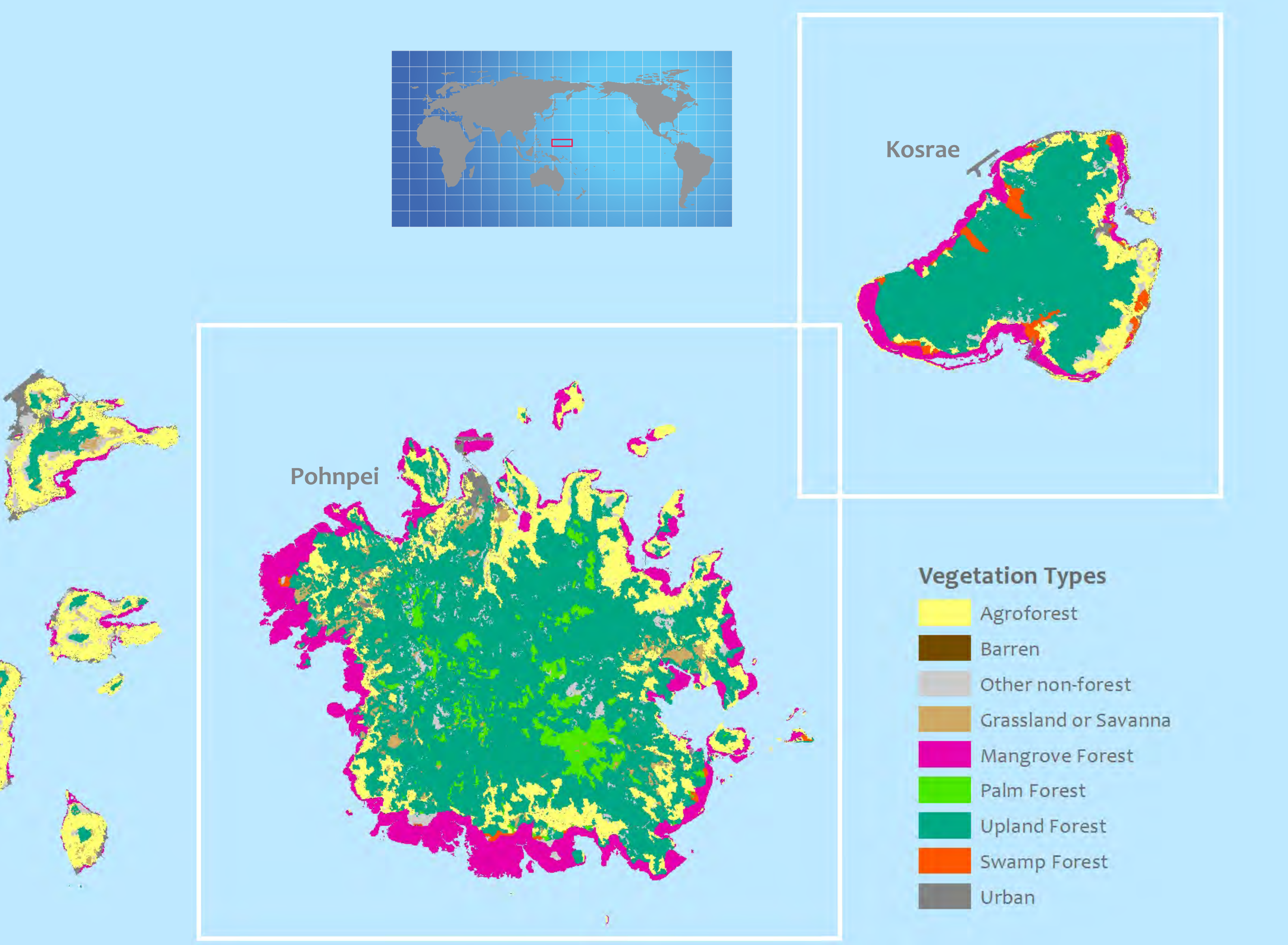
Forestry Department:

Department of Resources and Development, Agriculture and Forestry Unit



Languages spoken in FSM: 9
Word for forest in FSM Pohnpei: **Nan Wehl**
Yapese: **Gargear, Lawaay, Maapaan**
Kosraen: **Innimac, Insikuck, Insahk**
Chuukese: **Iránnap, Wénnap**

Acres of forested land:	143,466 (Yap, Chuuk, Pohnpei, Kosrae)
Total land area in acres:	161,917 (Yap, Chuuk, Pohnpei, Kosrae)
% forested:	89%
Number of islands:	65 inhabited and another 542 uninhabited islands, islets and reefs stretching 1,700 miles east to west and divided into the four states of Yap, Chuuk, Pohnpei and Kosrae
Highest elevational point:	Pohnpei, 2,533 ft.
Population in 2010:	111,364



Source: USFS 2007, 2008, 2009, 2010

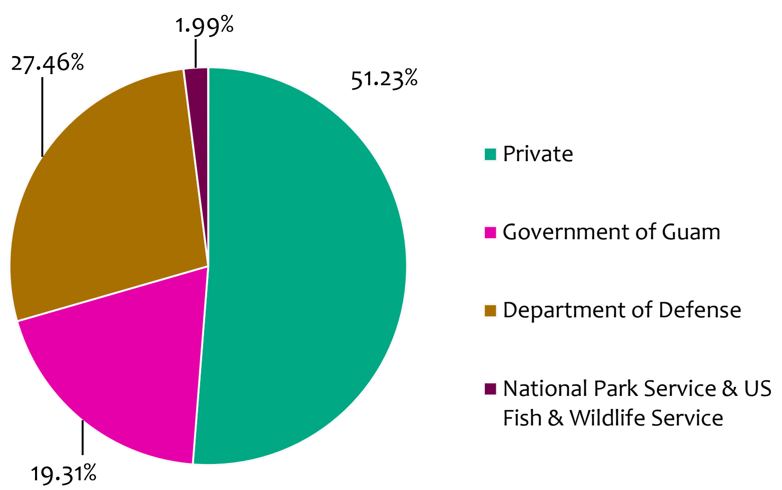
Guam At-a-Glance

Guam's forests have endured centuries of natural and anthropogenic disturbance. Typhoons are a natural disturbance event and Guam's forests are naturally short statured in reaction to the frequent storms that pass through. Extensive clearing for sugar and coconut plantations occurred during Spanish and German colonialization. Two major battles were fought on the island during WWII. Post-war construction further fragmented Guam's forests. To combat erosion and repair the soil, an alien legume Leucaena leucocephala, known locally as tangantangan, was planted extensively and now forms dense thickets over parts of the island. Nevertheless, Guam's native forests still persist, but their habitat is fragmented, many of their pollinators went extinct due to the brown tree snake and invasive vines smother vegetation and prevent regeneration.

Word for forest in Chamorro: **Halom tano**

Acres of forested land:	63,833
Total land area in acres:	135,660
% forested:	47%
Number of islands:	One inhabited, and one uninhabited
Highest elevational point:	Mt. Lamlam, 1,332 ft.
Population in 2010:	159,358

Ownership of Forested Land



Top Forest Health Issues:

- Invasive plants
- Biosecurity
- Erosion
- Relocation of military personnel to Guam known as the Guam Buildup

Land tenure system:

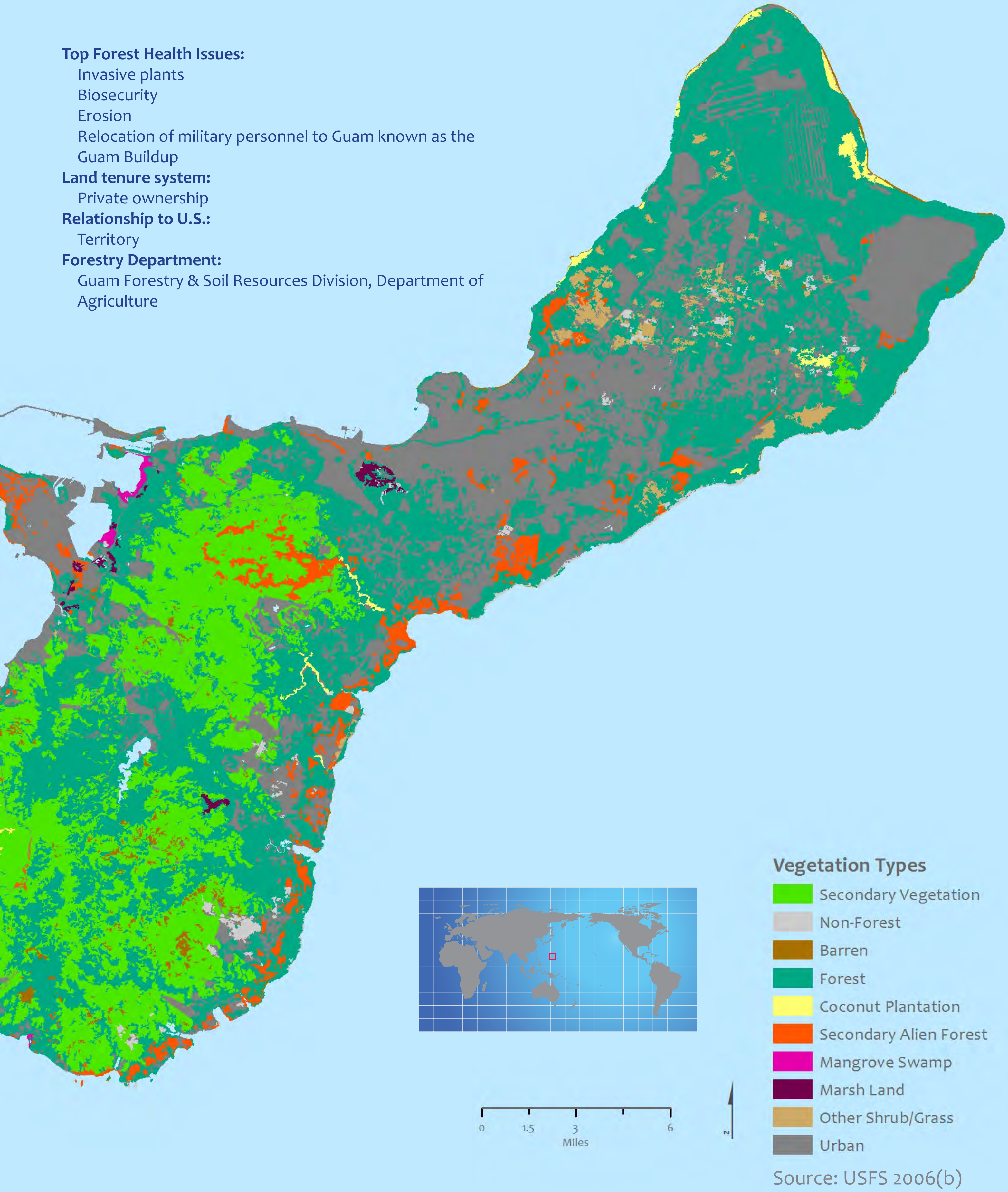
- Private ownership

Relationship to U.S.:

- Territory

Forestry Department:

- Guam Forestry & Soil Resources Division, Department of Agriculture



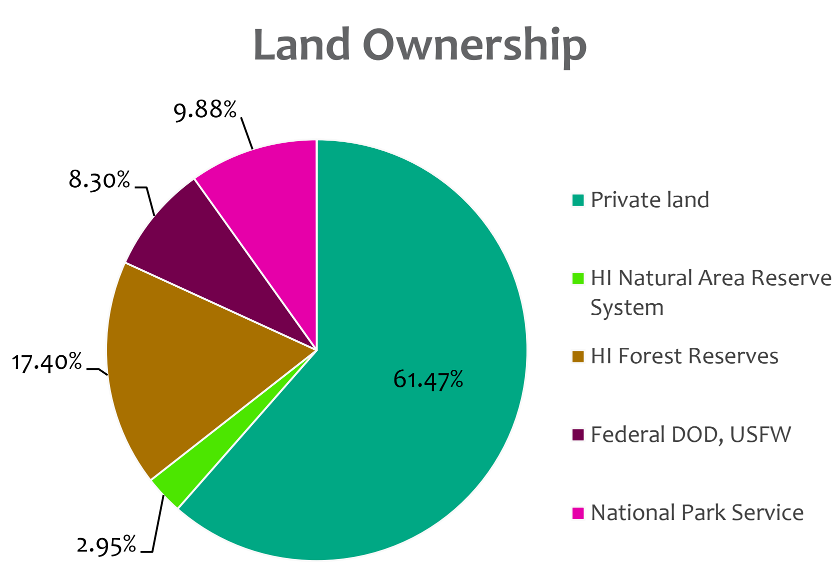
Source: USFS 2006(b)

Hawai‘i At-a-Glance

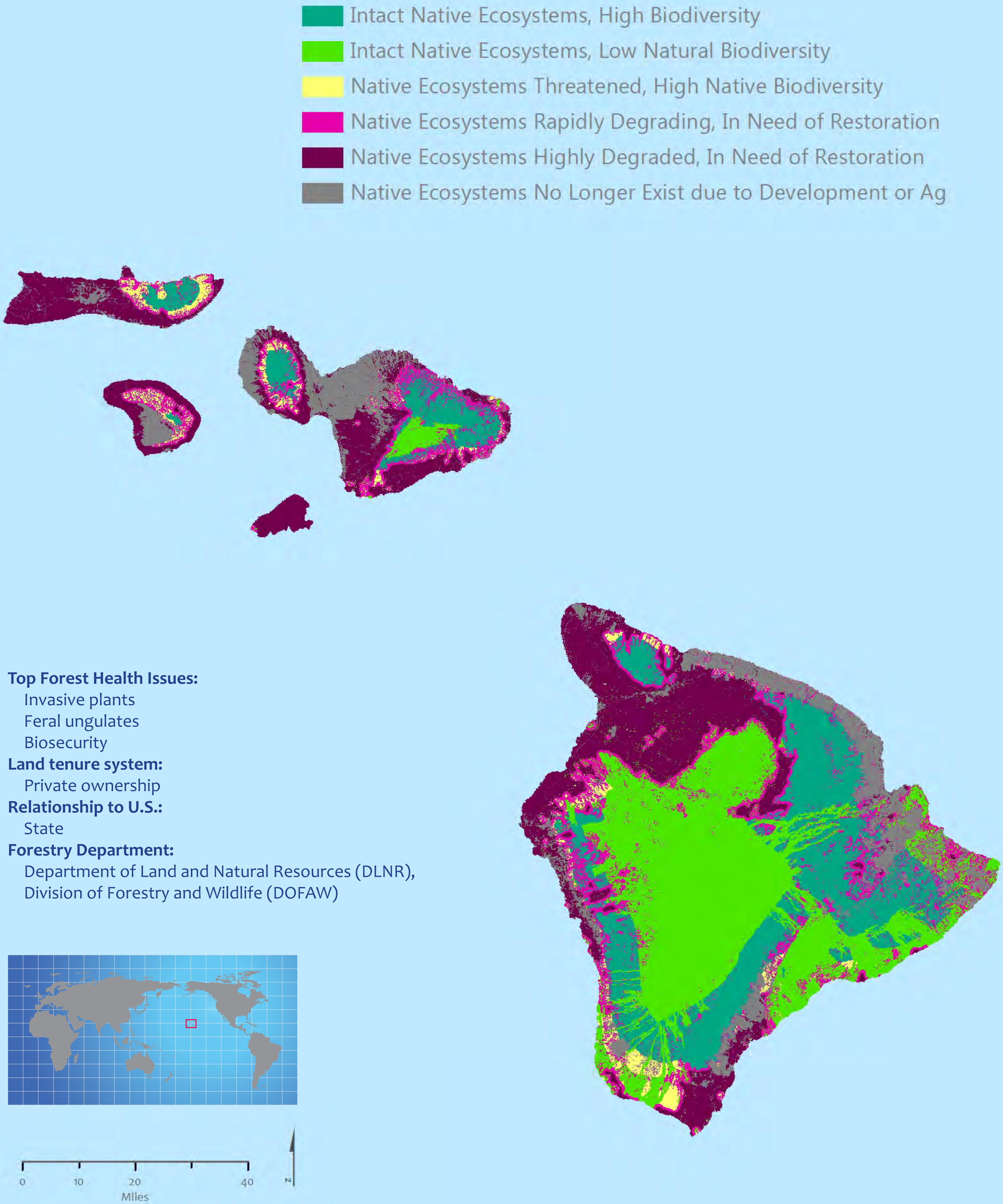
Hawai‘i's high elevation means that climates that range from the "wettest spot on earth" to deserts occur over the archipelago. Hawai‘i's forests are as diverse as its climate and each ecosystem has its own endemic species. And yet, despite this spectacular natural heritage, during the late 19th and early 20th centuries, Hawaiian forests were cleared and replaced with novel forests comprised of tree species from every corner of the earth but Hawai‘i. Today, it is possible to walk along lowland forest trails and not see any native Hawaiian plants. 41% of the flowering plant species on the U.S. Endangered Species List are found in Hawai‘i. The first territorial forester of Hawai‘i, Ralph Hosmer, said that the most valuable resource from Hawai‘i's forests was water rather than wood, and that holds true today. Keeping Hawai‘i's forests healthy is essential to the archipelago's water supply.

Word for forest in Hawaiian: **Nahele**

Acres of forested land:*	native forest: 951,646 acres
	alien secondary forest: 726,969 acres
Total land area in acres:	4,038,210 (Kaua‘i, O‘ahu, Maui, Moloka‘i, Lana‘i, Hawai‘i Island)
Number of islands:	7 inhabited, 4 uninhabited
Highest elevational point:	Mauna Kea, 13,796 ft.



*Acreages for Native Forest and Alien Secondary Forest were calculated using the intersection of two GIS layers: LANDFIRE's Existing Vegetation layer and LANDFIRE's Biodiversity layer.



Top Forest Health Issues:
Invasive plants
Feral ungulates
Biosecurity

Land tenure system:
Private ownership

Relationship to U.S.:
State

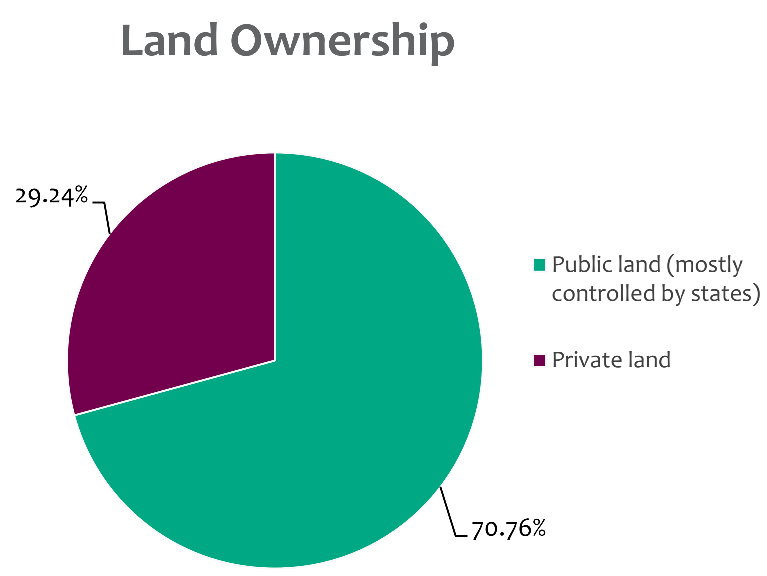
Forestry Department:
Department of Land and Natural Resources (DLNR),
Division of Forestry and Wildlife (DOFAW)

Republic of Palau At-a-Glance

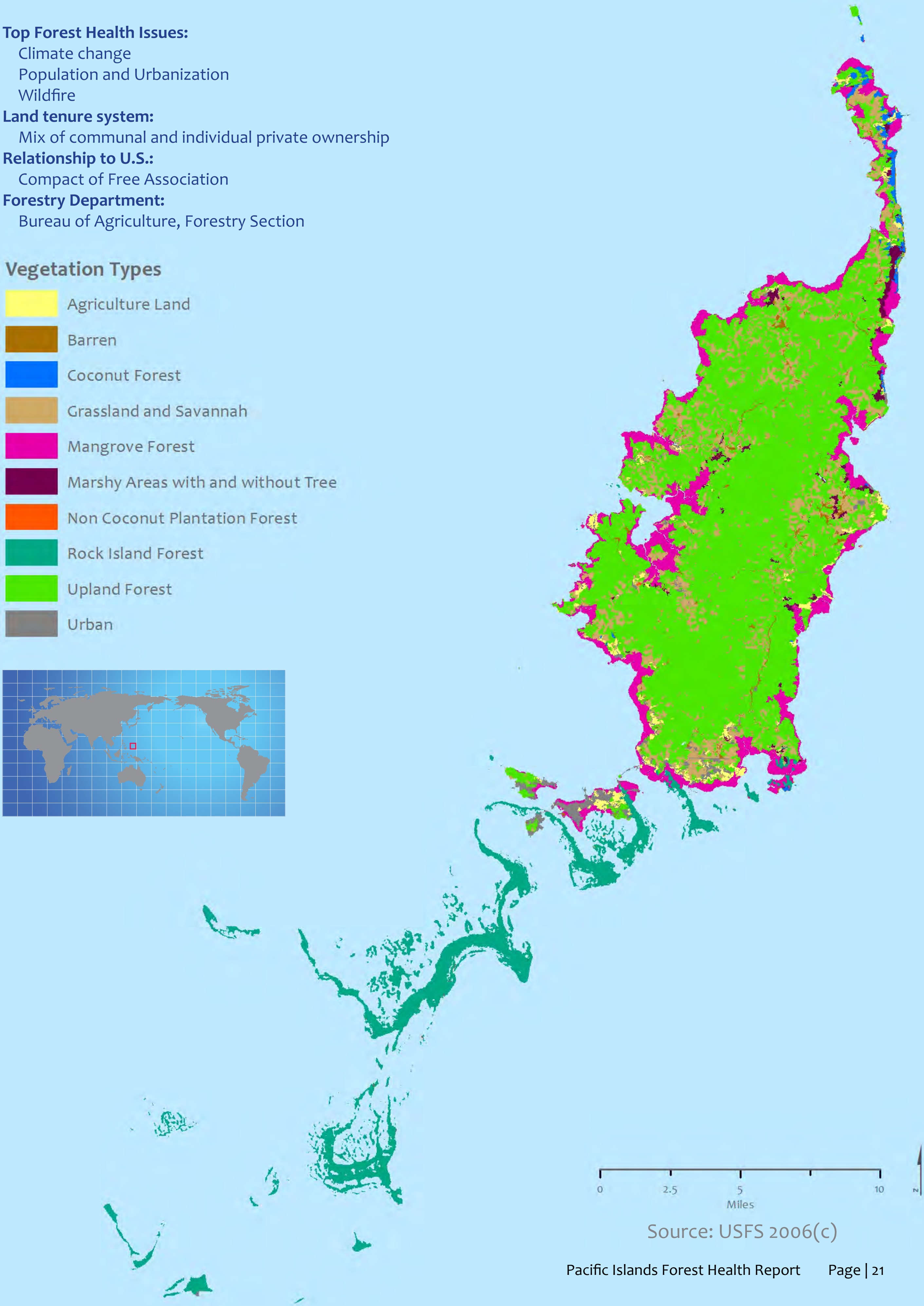
The interior volcanic forests of Palau are dense, multilayered and structurally complex (Donnegan et al. 2007). There are at least 150 plants endemic to Palau and endemic trees account for 45% of relative basal area in mature forests (Endress 2002). A forest survey of Babeldaob Island found 349 plant species in lowland, swamp, limestone, marsh, mangrove and coastal forests. Two hundred forty-nine of these were native (Kitalong 2008). Agroforests and mangroves are also important forest types. Climate change will cause grave problems for Palau and healthy mangrove, interior and agroforests will be essential to Palau's ability to adapt to weather changes and sea level rise.

Word for forest in Palauan: **Cherreomel**

Acres of forested land:	90,685 (Babeldaob, Koror, Peleliu and Angaur)
Total land area in acres:	110,028 (Babeldaob, Koror, Peleliu and Angaur)
% forested:	82%
Number of islands:	Nine inhabited plus more than 700 islets stretching over 435 miles from north to south
Highest elevational point:	Mt. Ngerchelchuus, 715 ft.
Population in 2010:	20,518



Top Forest Health Issues:
Climate change
Population and Urbanization
Wildfire
Land tenure system:
Mix of communal and individual private ownership
Relationship to U.S.:
Compact of Free Association
Forestry Department:
Bureau of Agriculture, Forestry Section



Source: USFS 2006(c)

Republic of the Marshall Islands (RMI) At-a-Glance

Forest description: Agroforests are essential to the food security of the Marshall Islands. The Marshallese have developed over 50 cultivated varieties of bōb (*Pandanus tectorius*) that are used for both food and fiber and it is an important component of agroforests along with breadfruit, coconut and banana. The Marshallese have exported copra—the dried meat of the coconut—for many years and coconut plantations occur over much of the Marshall Islands. Mangroves occur in the Marshall Islands but they are not as important to coastal protection and resilience to climate change as the coastal forests. Coastal forests stabilize coastal soils and protect interior forests and agroforests from dessicating salt spray.

Words for forest in Marshallese:

- Breadfruit forests: **ma**
- Climax forests dominated by *Pisonia grandis* and *Neiosperma oppositifolium*: **kanal** or **kojbar**
- *Pemphis acidula* forest: **kone**
- Windward forest: **janar**

Acres of forested land:	23,252 (Ailinglaplap, Arno, Jaluit, Kwajalein, Liekiep, Majuro, Maloelap, Mili, Rongelap, and Wotje)
Total land area in acres:	33,212
% forested:	70%
Number of islands:	Over 1,225 small low-lying coral islands, islets and table reefs clustered in 29 atolls across 750,000 square miles of ocean. These atolls run in two parallel island chains known as Ratak (Sunrise) and Ralik (Sunset)
Highest elevational point:	15-20 ft.
Average elevation of most islands:	7 ft.
Population in 2010:	54,439

Top Forest Health Issues:

Climate change
Invasive species
Coastal erosion

Land tenure system:

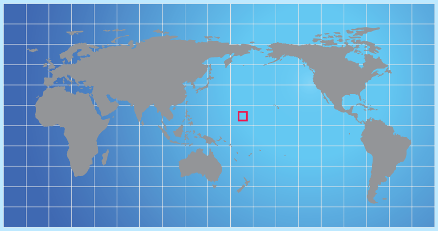
Private ownership under customary forms of land tenure. Family leaders, called iroij for men and leroij for women, establish rules and manage land and resources to provide for all the people (Reimaan National Planning Team 2008).

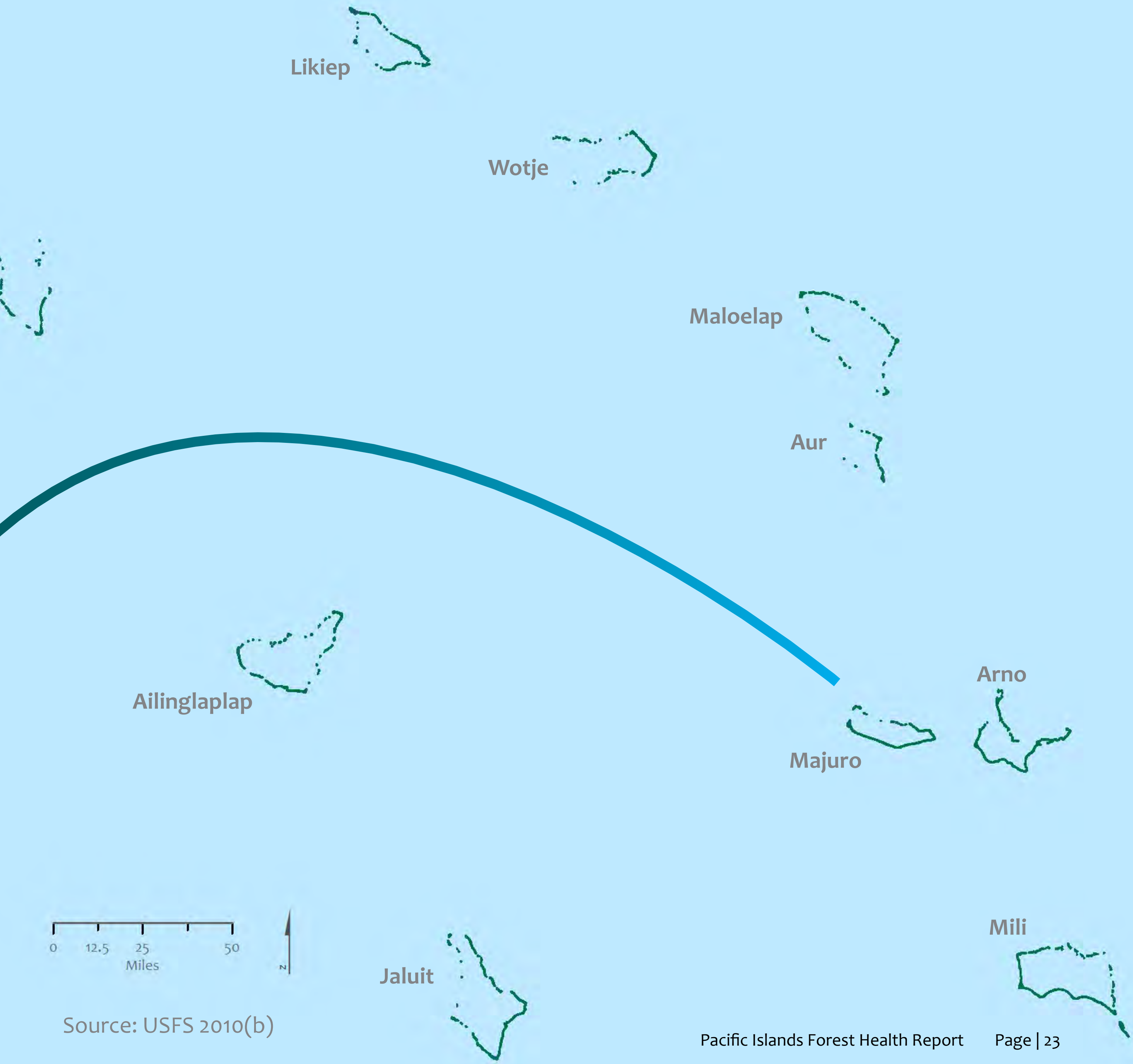
Relationship to U.S.:

Compact of Free Association

Forestry Department:

Ministry of Resources and Development





Source: USFS 2010(b)

View from highest point on O'ahu Island, Hawai'i, Mt. Ka'ala. Photo by: Rachel Neville.

Land Tenure

Land tenure systems vary across the US-Affiliated Pacific Islands (USAPI) between individual private property ownership similar to that in the continental United States, clan-owned estates governed by intricate rules of inheritance, and public land owned by various levels of government. Land tenure may affect forest health in a variety of ways. Each island group's specific tenure system has features that affect the ability to set aside and manage land for conservation and watershed values, but also provides opportunities for innovative partnerships that lead to more collaborative land use planning. Clear, secure, permanent tenure facilitates decisive management but is often associated with resistance to government regulation in the name of landowner rights. Decision-making rights shared by numerous parties who do not reach consensus, or unclear tenure status, can hinder management activities, or can enable *de facto* conservation if modern development does not proceed. Absentee landowners may leave land unmanaged, allowing weeds, pests, and diseases to spread.

American Sāmoa, the Republic of Palau, the Federated States of Micronesia (FSM), and the Republic of the Marshall Islands (RMI) recognize indigenous tenure systems for some or all of their lands. Most of these islands do have procedures for surveying and titling land in fee simple private ownership, but expansion of this system has not reached most forested lands. Guam, the Commonwealth of the Northern Marianas Islands (CNMI), and Hawai'i have systems more similar to the continental US; these systems are not indigenous and were introduced to these islands by force or coercion (MacGrath and Wilson 1987).

Land under indigenous land tenure systems is seldom bought and sold for modern currency. Therefore, putting land into conservation requires a different mechanism than simply having a government or private entity purchase the land. For example, the National Park of American Sāmoa was established on communal land under a 50-year lease agreement; the US Park Service does not own the land (American Sāmoa FAP 2010). Intact traditional land tenure systems may already observe a "taboo" (e.g., *kapu* in Hawai'i or *bul* in Palau) protecting certain resources or certain areas; communities may agree to revitalizing such systems as a form of modern conservation.

All forested land in the Marshall Islands, or as they are known in Marshallese, Aelōn̄ Kein, are privately owned under customary forms of land tenure and the Constitution of the Marshall Islands enshrines traditional forms of ownership (Reimaan National Planning Team 2008). In American Sāmoa, land tenure is mixed. 88.4% is communally owned by extended families or *aiga*. Each *aiga* is headed by a *matai*, or chief (American Sāmoa FAP 2010). In Palau, 71% of the land, which includes most forested land, is under the jurisdiction of Palau's 14 states (Palau FAP 2010) which are modern governments associated with traditional communities. Areas set aside for conservation in Palau's Protected Areas Network (PAN) are community-managed (Palau Conservation Society 2012).

The land tenure system in Yap, FSM is governed by complex rules of obligation and inheritance that dictate access rights for different categories of family members and the responsibilities of those with the power to grant those rights. Land holdings of a *tabinaw* consist of different resource areas such as woodlands, taro wetlands, fishing areas, yam gardens, grassy uplands, and stands of coconut, and are often not contiguous (Mahoney 1958).

In Chuuk state, most forested land, including mangroves, is privately owned (FSM FAP 2010). In Pohnpei, land ownership is a mix between private and state-owned. Demarcating the boundary line of the island's central watershed (to which the government asserts ownership) has required negotiations with municipal government and traditional leaders because the proposed boundary intersects privately-owned lands. (FSM FAP 2010).

Kosrae's land tenure system is based on individual ownership. During WWII, Kosrae was occupied by the Japanese who drew an arbitrary line around the forested mountain summits of the island. All lands above the "Japanese line" were taken away from their rightful owners and declared to be community forests. The Kosrae constitution now allows the return of land above the Japanese line to descendants of the original owners. This policy may result in additional clearing of upland forests that are crucial to maintaining soil stability and watershed functions (FSM FAP 2010). Throughout the Federated States of Micronesia, land cannot be sold to non-FSM citizens. Conservation easements are only just beginning to be used as a tool for conservation (FSM FAP 2010), with one in place in Kosrae.

Land tenure in CNMI is based on individual ownership. The Commonwealth of the Northern Marianas has designated certain forest lands as Commonwealth Forests which are managed using sustained yield principles and are managed by the Forestry Section under the Department of Lands and Natural Resources. Private land is owned by individuals and there is an ongoing process of distribution of public land to private landowners or leaseholders of Chamorro or Carolinian descent. The use of an assigned area of land for farming and dwelling marks the establishment of an almost permanent right to land ownership (CNMI FAP 2010).

Twenty-five percent of Guam is managed by the US Navy and Air Force and the Department of Defense (DOD) has interest in 11 of Guam's 19 watersheds. Forests cover 46% of the 34,048 acres under DOD management. Ten percent of Guam's forested area may be lost to development associated with the planned relocation of Marines from Okinawa, Japan to Guam (Guam FAP 2010). Guam also has land reserved for long-term leases to residents of Chamorro descent.

Hawai'i's land tenure system is based on individual ownership. Hawaiian Homelands are available for lease to residents of Hawaiian descent. Beginning in the early 1900's, Hawai'i's sugar planters grew concerned about the decrease in the water supply, due to widescale deforestation caused in part by feral ungulates. They urged the government to protect the most important forested lands for water recharge as "conservation districts" (Hawai'i FAP 2010). Much of the land within the conservation district is state owned, but there are also large tracts of privately owned land. In 2012, the conservation district included an estimated 1,973,846 acres—over 48% of the total land area in the state (State of Hawai'i Data Book 2012). Both public and private activities within the conservation district are regulated by the State of Hawai'i.

Upland Forests

Upland forests of the US-Affiliated Pacific Islands (USAPI) are unique plant communities that exist nowhere else in the world. Islanders use the native trees and plants in these forests for traditional cultural practices and some species play prominent roles in the epic narratives of the islands (Gon 2012). Native forests provide important ecosystem services such as replenishing the islands' aquifers, preventing erosion, and protecting coral reefs. Without these forests, life on these islands would not be possible. Invasive plants, clearing for agriculture and development, feral ungulates and other invasive animals, invasive plants, insects and pathogens, cyclones, fire, and climate change all impact native forests.

Without these forests, life on these islands would not be possible.

Ecosystem Services of Upland Forests

Healthy forests in the uplands are essential to keep coral reefs healthy and freshwater supplies abundant. These forests provide habitat for the islands' endemic birds, insects, and few mammals, and shelter incredible species richness and diversity.

Healthy Coral Reefs

Upland and coastal forests are critical to maintaining the health of coral reefs and the sustainability of local island fisheries. On the island of Moloka'i in Hawai'i and in American Sāmoa, a brown ring of muddy seawater around the island is a common sight after a heavy rain due to erosion (American Sāmoa and Hawai'i FAPs 2010). Soil and nutrients settling on the reef can stress corals and make them susceptible to disease. Intact native forests anchor soil and prevent it from washing into streams and settling on reefs.

Pasia Setu collects fruits of Syzygium corynocarpum (seasea in the Samoan language) for propagation purposes on the grounds of American Sāmoa Community College, Tutu'ila, American Sāmoa. Plant species belonging to the genus Syzygium are very important to Samoans and are used for food, medicine, landscaping, and wildlife habitat. Photo by: Jolie Goldenetz Dollar

"…in Hawaiʻi, the most valuable product of the forest is water, rather than wood. It follows that the conservation of its watersheds by keeping them permanently clothed with forests, is there the chief duty of the forester". The same can be said of all the USAPI.

Water Supply

Native forests are essential to the USAPI to direct rain into aquifers that supply islands with freshwater and break the force of rain that would otherwise wash soil into streams and onto coral reefs. Upland forests gather droplets from the clouds that constantly surround them. Mt. Pioa in American Sāmoa translates to "Rainmaker Mountain" in Sāmoan, alluding to the clouds that often shroud the summit (Craig 2009). The elfin forest on this mountain harvests droplets from these clouds and directs them into the aquifer. Ralph Hosmer, the first territorial forester of Hawaiʻi said that "…in Hawaiʻi, the most valuable product of the forest is water, rather than wood. It follows that the conservation of its watersheds by keeping them permanently clothed with forests, is there the chief duty of the forester". The same can be said of all the USAPI.

Biodiversity

Many of the plant species that make up the forests of the USAPI are endemic to that island group. A unique plant community can be found at the summit of Mt. Lata on American Sāmoa. Hawaiʻi's mesic and wet native forests are dominated by ʻōhiʻa (*Metrosideros polymorpha*) and koa (*Acacia koa*), both of which are endemic to Hawaiʻi. Some of Hawaiʻi's endemic species are so specialized that they occur on only one mountaintop or in one valley.

Despite the profound disturbances that Guam's native forests have undergone, they still persist on limestone soils in northern Guam and in ravines, sheltered depressions, and river drainages in southern Guam (Guam FAP 2010). The percentage of native and alien secondary forests have not been calculated, but pure examples of Guam's native forests are rare (Donnegan et al. 2004). A vegetation survey of 455 acres of northern Guam found 41 genera from 27 families, with 71% of those genera indigenous to Guam (Morton, Amidon and Quinata 2000). Guam's forests contain many species endemic to the Marianas and some that are endemic to Guam.

Two endemic species to the Commonwealth of the Northern Mariana's (CNMI) forests, *Serianthes nelsonii* and *Osmoxylon mariannense*, are federally listed as endangered (CNMI FAP 2010). The Republic of Palau's forests are known for their high species diversity and endemism. The interior volcanic forests are dense, multilayered, and structurally complex (Donnegan et al. 2007). A forest survey of Babeldaob Island found 349 plant species in lowland, swamp, limestone, marsh,

Palila depend on māmane seeds for survival. Photo by: Keith Swindle

mangrove, and coastal forests. Two hundred forty-nine of these were endemic (Kitalong 2008). The most numerous species in the upland forests of the Federated States of Micronesia (FSM) is a Micronesian endemic, *Syzygium stelechanthum* (Donnegan et al. 2006). The forests of FSM contain 90 species of endemic plants (Costion and Lorence 2012).

These forests are important habitat for wildlife, much of it endemic to one island. These species have evolved to depend on the unique forests in the USAPI and cannot survive without them. For example, the māmane (*Sophora chrysophylla*) forests of Mauna Kea in Hawai'i occur at 6,000 to 9,000 feet and are critical habitat for the federally-listed palila (*Loxiodes bailleui*). The cloud forests of Pohnpei and Kosrae in FSM are the lowest elevation cloud forests in the world and provide habitat for 30 species of tree snails, 24 species of birds, and 3 species of endemic flying foxes (The Nature Conservancy date unavailable).

Ninety percent of the world's population of Newell's shearwaters (*Puffinus newelli*), nest in the undergrowth found in the upland forests on the island of Kaua'i. The thick mats of ferns found at the summits of Mt. Pioa in American Sāmoa provide nesting habitat for the Tahiti petrel (*Pseudobulweria rostrata*). These seabirds spend most of their lives at sea, but return to the same place to nest throughout their 50-year lifespan.

Threats to upland forests

Invasive plants, deforestation, feral ungulates, native and invasive insects, diseases, fire, drought, climate change, and tropical cyclones are factors that degrade forest health across the USAPI. Climate change will exacerbate these effects and cause extinctions of some of the USAPI's unique forest species (Fortini et al. 2013).

Invasive Plants

Invasive plants are a destructive force that can, if left unmanaged, permanently damage ecological function. Invasive plants completely change forest structure, degrade watershed function, replace unique native forests with monotypic stands of exotic plants, and may drive some endemic tree species to extinction. When introduced trees replace native ones, a completely new forest structure is formed that may not provide the same level of ecosystem services. Disturbances, such as clearing for agriculture or fire, may facilitate invasion by invasive plants, but some species are capable of replacing dominant forest species without any disturbance at all.

The transformation of native ʻōhiʻa (*Metrosideros polymorpha*) forest to monospecific stands of strawberry guava (*Psidium cattleianum*) has been studied in Hawaiʻi by researchers at the US Forest Service's Institute for Pacific Island Forestry (IPIF). Albizia (*Falcataria moluccana*), a nitrogen-fixer, moves into young ōhiʻa forests and alters the substrate, making it possible for strawberry guava to then fill in the understory. This demonstrates how invasive plant species from two different continents (albizia is from Asia and strawberry guava from South America) can develop new novel relationships and invade native forest without prior disturbance (Hughes and Denslow 2005).

Left: Miconia calvescens in Onomea, Hawai'i Island, Hawai'i. Photo by: Maui Invasive Species Committee.
Right: A hillside covered in Merremia peltata in Auto Village, Tutu'ila, American Sāmoa.
Photo by: Jolie Goldenetz Dollar

Landscape-level changes in forest structure may change the dynamics of how roots hold soil, how much runoff can be absorbed, and how much water can be harvested from cloud droplets. Studies in Hawai'i are examining how island hydrology might be affected if native forests are replaced with exotic species. *Miconia calvescens*, a primary target for invasive species removal in Hawai'i, may induce erosion in areas where it dominates. Miconia shades out and effectively removes the understory, leaving bare ground. It has a shallow root system and its unusually large leaves funnel rain to the ground with a higher velocity than 'ōhi'a dominated forests. During a study to calculate raindrop velocities rolling off miconia leaves, researchers measured the largest raindrops of any species they had yet encountered (Giambelluca et al. 2009).

The morphologies of exotic tree species may also be less efficient than native trees at intercepting rain and harvesting cloud droplets from the mists that cloak upland forests. A study on Hawai'i Island found that native-dominated 'ōhi'a forest intercepted 454 mm more cloud water than strawberry guava dominated forests (Takahashi et al. 2011). A worst-case scenario is that once the native forest is replaced, a novel forest structure will direct less water into the islands' aquifers.

Exotic fire-adapted grasses have replaced seasonally dry forests with alien grasslands in some areas of the USAPI. These grass species move into the understory and increase fuel loads. Once fire occurs, the grass species quickly regenerate and suppress native species regeneration. A study site in Hawai'i Volcanoes National Park had little recruitment of native trees 37 years after fire

NPAS volunteers eradicating tamaligi (also known as albizia (Falcataria moluccana).
Photo by: National Park of American Sāmoa

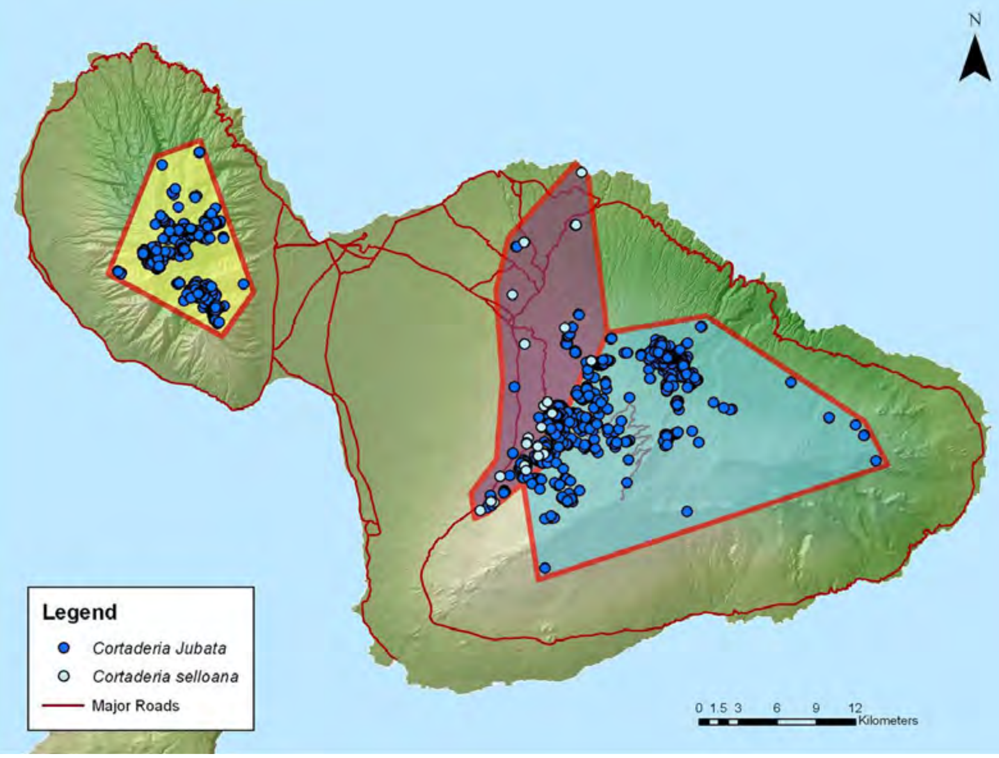
MISC Field Crewmember removing Miconia calvesens. Photo by: Maui Invasive Species Committee

(D'Antonio, Hughes and Tunison 2011). The few trees that are left, live with a highly flammable, non-native understory and the forest is more vulnerable to fire than if it was dominated by native species. Yap, Palau, and CNMI are attempting to control *Imperata cylindrica*, which is also a fire-adapted exotic grass. Other USAPI island forests are at risk for this scenario as well.

USAPI forestry managers have cited invasive vines such as *Mikania micrantha* and *Merremia peltata* as particularly problematic. Vines add additional weight that may break tree branches and damage the main stem, strangle the tree by cutting off access to sunlight, and inhibit tree regeneration. Large forested areas covered with vines are common on Guam after typhoons create openings (Perry and Morton 1999). Forestry Inventory Analysis (FIA-USFS) data show that in CNMI, 44.1% and in Palau, 41% of tree damages were associated with vines in the crown (Donnegan et al. 2011, 2007). In FSM, RMI, and Guam, vines in the crown were associated with 27%, 22%, and 16% of tree damages, respectively (Donnegan et al. 2011 (b), 2011(c), 2004). Large areas of the Pohnpei uplands are smothered with vines (FSM FAP 2010). In CNMI, regeneration of native limestone forest is suppressed by smothering vines (Guerrero 2014).

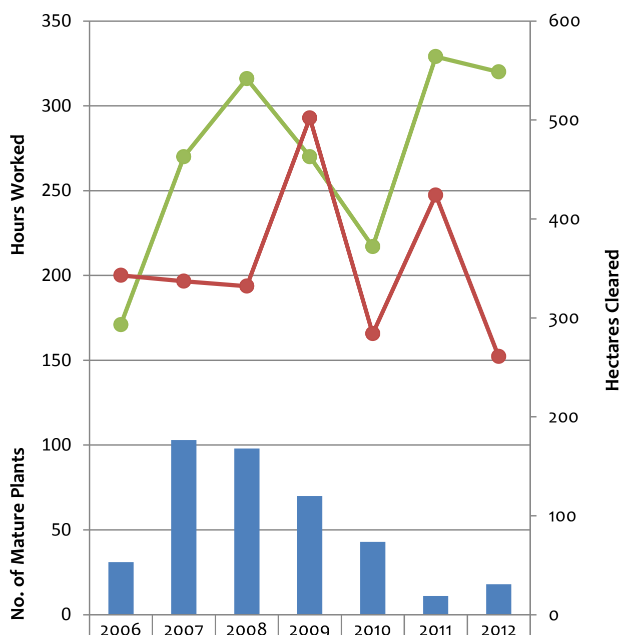
Management Actions to Address Invasive Plants

Hawai'i's Invasive Species Committees (ISCs) have successfully stopped the spread of some of Hawai'i's most destructive weeds. The ISCs began as a response to the discovery of the watershed-destroying weed, *Miconia calvescens,* in Hawai'i. Since their founding in the late 1990's and early 2000's, they have taken on the control and eradication of other invasive plants, rapid response to new invasive species, including little fire ant incursions, and participated in policy-making at the county and state level. Because the ISCs focus on incipient species, they tend to work in the lower elevation secondary forests of Hawai'i. By controlling invasive plants that have been introduced to residential areas and recently invaded wildlands, they protect the native–



dominated uplands from the most ecosystem-altering weeds.

Statewide, the ISCs have eradicated 22 species of invasive plants. On Kaua‘i, O‘ahu, and Maui, the ISCs have stopped the spread of pampas grass (*Cortaderia* spp.) and miconia (*Miconia calvescens*) and at least 32 other plant species. Although the status of species on each island varies, they are under intensive control programs and are not spreading beyond their known range. In the 25,000 acre Wao Kele O Puna Forest Reserve on Hawai‘i Island, ISC field crews have reduced the number of mature miconia from 378 to 72 over six years. On O‘ahu, field crews have reduced the number of mature miconia trees from 40 in 2002 to only 5 in 2012. The designated search area of 26,500-acres must be covered every three years because miconia seeds remain viable in the soil for at least 16 years (Meyer 2009).



	2006	2007	2008	2009	2010	2011	2012
Mature Plants	31	103	98	70	43	11	18
Hours	171	270	316	270	217	329	320
Hectares	343	337	332	502	284	424	261

Top: Pampas grass management areas in Maui. Bottom: Graph indicationg the decline in number of mature pampas grass plants.

The goal for most of the ISCs' species is eradication island-wide and therefore the Hawai‘i ISCs work extensively on private property. ISC crews will request permission to survey residential property, golf courses, and other lands to remove invasive ornamental plants. The ISCs have been able to remove pampas grass (*Cortaderia* spp.) from almost every golf course on O‘ahu and several private residences. On Hawa‘i Island, the ISCs have been able to remove rubbervine (*Cryptostegia madagascariensis*) from two-thirds of the known locations, most of which were private property. ISC crews regularly survey and control for pampas grass on residential properties in East Maui. The number of mature pampas grass plants there has dropped to 18 in 2012 from a high of 103 in 2007.

The ISCs have also begun innovative early detection programs that survey nurseries and roads and assess species that should be eradicated by ISC field crews. The early detection programs work with the Hawai'i Weed Risk Assessment program to identify which species have the greatest chance of becoming ecosystem-altering weeds and are feasible to eradicate. So far, 2,287 species have been assessed. The ISCs receive critical support for their work from Forest Health Protection (US Forest Service).

The Yap Invasive Species Task Force reduced the only known site of cogon grass on Yap (*Imperata cylindrica*) from 30 acres in 2001 to only 2 acres in 2007 (FSM FAP). In 2014, it was largely undetectable, but crews still need to revisit and find occasional recruitment. Because the task force has been so successful, finding the few that regenerate is like "looking for a needle in a haystack" (Ruegorong 2014). Cogon grass is a fire-adapted species and Yap is one of the USAPI islands dry enough that wildfires are a constant threat, so this near-eradication is a very meaningful success. The Invasive Species Task Force of Pohnpei (iSTOP) has eradicated octopus tree (*Schefflera actinophylla*) and has cleared 94% of the sites where other target species are located (Conservation Society of Pohnpei 2013).

Ongoing albizia (*Falcataria moluccana*) control on American Sāmoa has been successful in restoring native forest. This giant, nitrogen-fixing tree can quickly take over native forests. An eight-year study looked at forest succession in areas where albizia had been killed by girdling. Because the albizia had not yet formed monospecific stands and native Sāmoan successional species were still present, removing the albizia allowed the native species to close the overstory, preventing albizia from germinating (Hughes, Uowolo and Togia 2012).

A pilot project by American Sāmoa Forestry is identifying ways to map invasive plants with remote-sensing methods. Red bead tree (*Adenthera pavonina*) was chosen as the target species because it is easily identifiable in the canopy. The team used mosaic WorldView-2 8-band pan-sharpened satellite imagery made available through the Pacific Island Imagery Consortium and were able to identify the species from enhanced visualizations of satellite images. American Sāmoa Forestry staff ground-truthed the remotely sensed points and found them to be accurate enough to use this method to detect other invasive canopy species (Liu and Gurr 2012).

Classical biological control has been successfully utilized for a number of established invasive plant species in the USAPI. A scale (*Tectococcus ovatus*) has been released in Hawai'i at demonstration sites to control strawberry guava (*Psidium cattleianum*). The scale causes decreased fruiting of strawberry guava, but does not kill the tree. The goal of this work is to establish this insect in strategic places to slow the spread of strawberry guava. Hawai'i Department of Agriculture (HDOA) released three different insects on O'ahu to control ivy gourd (*Coccinia grandis*) in 1996, 1999, and 2005. The first two insects, the ivy gourd vine borer (*Melittia oedipus*) and the ivy gourd leaf-mining weevil (*Acythopeus cocciniae*), successfully established. Establishment was less successful for the third, a gall weevil (*Acythopeus burkhartorum*). The three together have reduced ivy gourd populations and the weed is now restricted to small areas and is no longer a forest threat (HDOA 2014).

Guam has released several biological control agents for various weeds. Two have been released for *Chromolaena odorata*, three (including *A. cocciniae* and *M. oedipus*) for ivy gourd (*Coccinia grandis*); and eight for *Lantana camara* (Guam FAP). A moth, *Pareuchaetes pseudoinsulata,* working together with a gallfly, *Cecidochares connexa*, have effectively suppressed *C. odorata* thickets in CNMI (Muinappan et al. 2004 and Guerrero 2014). Natural enemies of *C. odorata* have been released on Palau, Yap, and Chuuk, but it is unclear whether the organisms have established on these islands and what the effect on *C. odorata* has been (Muinappan et al. 2004). A species of thrips, *Liothrips urichi*, was released on Tutuila, American Sāmoa in 1974 and appears to prevent Koster's curse (*Clidemia hirta*) from achieving ecological dominance (Cook 2001).

CNMI Forestry counts monitoring of biological controls and beneficial insects as a primary invasive plant control activity, but on other islands, post-release monitoring of biological controls has not been a regular practice. It often takes more than one agent to exert effective control and monitoring can help determine this more quickly. Monitoring will also provide data about biological control successes to use in outreach to the public.

Many people still think that modern biological control programs will have the same disastrous results as the introduction of mongoose to Hawai'i in 1883. The release of *T. ovatus* in Hawai'i was complicated by a public outcry that was fueled in part by the belief that biological control has not been an effective invasive species management tool in the past. The suspicion extended to those who worked in conservation and invasive species management. Monitoring and sharing of biological control program results will help to garner financial and public support for future releases.

Feral Ungulates

In Hawai'i, feral pigs, mouflon sheep, two species of deer, feral goats, and feral cattle are a landscape level threat to the health of native Hawaiian forests. Feral ungulates suppress forest regeneration by browsing and eating seedlings and kill mature trees by stripping bark (Scowcroft and Sakai 1983). They promote erosion by trampling vegetation and compacting soil, and spread

Feral ungulates contribute to erosion and the spread of invasive plants by trampling and clearing vegetation. Photo by: Rachel Neville

Hunter with feral sheep in Hawaii. *Photo by: Hawai'i Department of Land and Natural Resources*

invasive plants by transporting seeds and creating light gaps (Stone 1985; Banko et al. 2012). Pigs in particular have been called "the major current modifiers of Hawaiian forests" (Stone 1985).

In CNMI and Guam, Philippine deer (*Cervus mariannus*) and feral pigs browse in the remaining limestone forests, ingest and trample plants, and carve out mud wallows from the surrounding forest. Areas that contain endangered plant species have been fenced and the ungulates removed (Morton Amidon and Quinata 2000). Hunting is also an important part of local culture on these islands and although there is no data to measure the effect of hunting on ungulate populations, extensive signs and damage by ungulates suggests that it is not enough to protect native limestone forests (Perry and Morton 1999).

Management Actions to Mitigate Threats from Feral Ungulates

Recreational hunting alone does not exert enough control to stop the forest degradation that ungulates cause. Building fences and eradicating the animals within is the primary way of protecting forests from ungulates. Hawai'i's hunting community has strongly opposed ungulate management efforts in the past. Hunting, especially for feral pigs, is a part of local culture in Hawai'i and many hunters consider it an essential part of their personal food security. Management actions that include fences, removing animals, and sometimes even just designating an area as protected are perceived by hunters to reduce the amount of game and deny access to hunting areas.

The Hawai'i Department of Forestry and Wildlife (DOFAW) and conservation organizations are making efforts to provide opportunities for hunters to participate in eradication efforts and to retain access to historical hunting areas, as well as access areas that have previously been restricted. In addition, DOFAW is conducting outreach to educate hunters about the forest destruction caused by feral ungulates.

Hawai'i's Division of Forestry and Wildlife (DOFAW) has begun implementation of a Watershed Initiative to protect Hawai'i's watersheds from feral ungulates and invasive plants. The Hawai'i Legislature funded the initiative with $5 million in FY 2013 and $8.5 million in FY 2014 to fence 38,000 acres of priority watershed and buffer areas. Watershed funding has also supported the planting of 20,000 seedlings planted as restoration to heal the damage caused by ungulates.

Guam Forestry has worked with other agencies to sponsor pig derbies that invite local hunters to remove as many pigs as they can over a specified number of days. The events are combined with outreach and education about the damage feral ungulates cause.

Invasive Insects

The most serious insect pests of ecological concern in the USAPI are non-native. Endemic plant species are particularly susceptible to damage and mortality from non-native insects as they may have little or no resistance to the pest. Pests that cause minor damage to a continental tree species can cause death of island endemic species. In some situations, dominant canopy or understory species are attacked resulting in landscape-level impacts. High levels of tree mortality causes ecological harm to the forest and also impacts island cultures since many of the species have specific cultural uses.

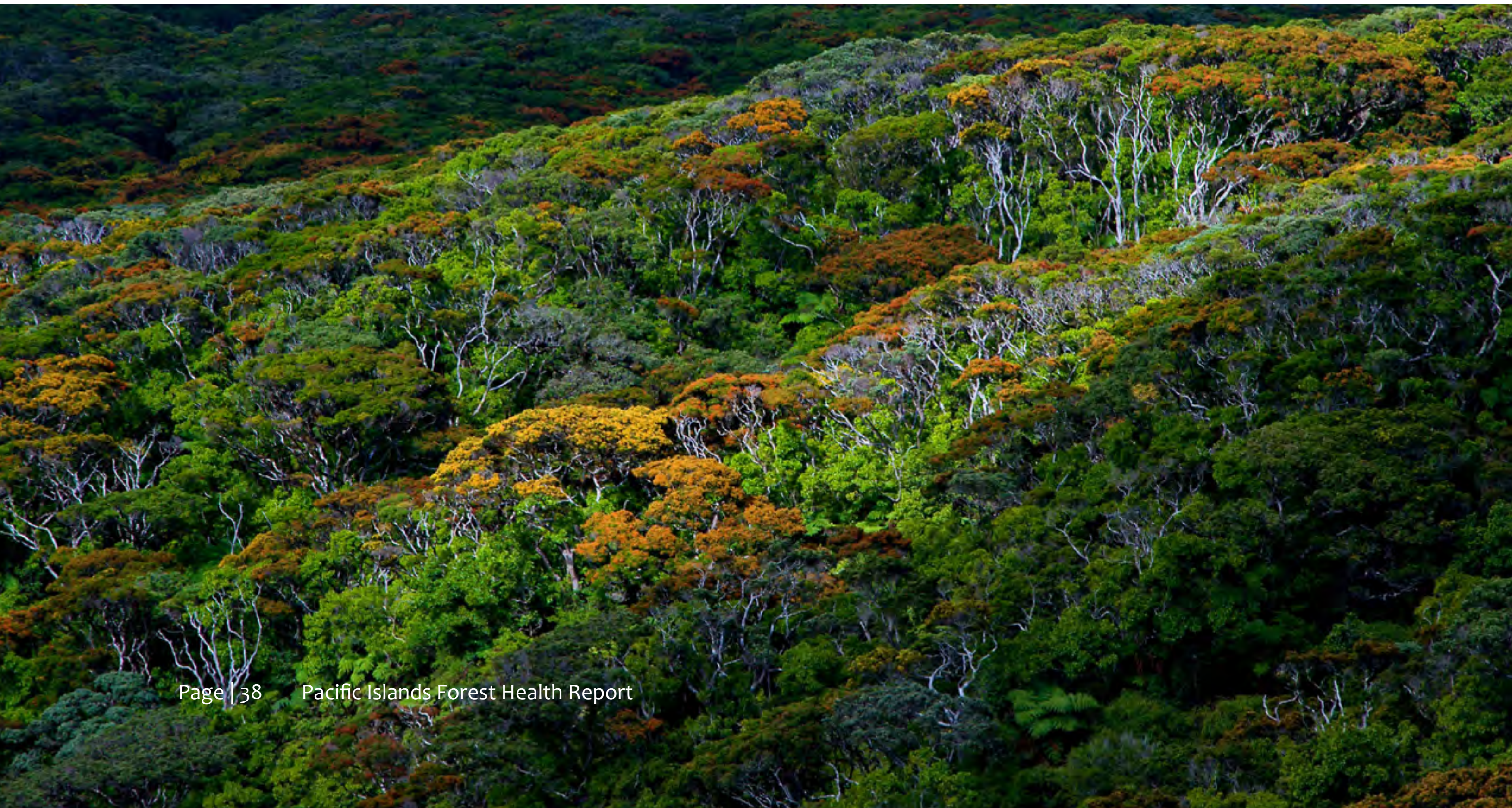
Two forest pests that have significantly affected the health of dryland forests in Hawai'i are the erythrina gall wasp (*Quadrastichus erythrinae*) and myoporum thrips (*Klambothrips myopori*). The erythrina gall wasp (EGW) dispersed rapidly through the state in 2005 and attacked Hawai'i's endemic coral tree, the wiliwili (*Erythrina sandwicensis*) as well as several exotic coral trees planted in urban areas. These exotic erythrina, planted in urban areas and used as windbreaks, resulted in year round host material for EGW and served as initial hosts; had the non-natives not been there, EGW may not have been as devastating to native wiliwili. Wiliwili is a dominant tree in Hawai'i's dry forests and in some places, up to 40% of the trees were killed by the gall wasp (Kaufman et al. 2013). The death and defoliation happened so quickly that forest managers feared the species might be lost and a statewide seedbank was created.

Naio damage caused by myoporum thrips.
Photo by: Leyla Kaufman

Naio (*Myoporum sandwicense*) is a biologically and culturally important species of dry forests that could be extirpated on Hawai'i Island by myoporum thrips (*Klambothrips myopori*). Myoporum thrips were unknown to science before California officials noticed that the exotic myoporum species planted in residential areas and along freeways were dying. The thrips species was finally described in 2007 (Mound and Morris 2007). By then however, it had probably already made its way to Hawai'i. In late 2008, groundskeepers on Hawai'i Island noticed damage to a low growing native variety of naio frequently used in landscaping. Subsequent delimiting surveys determined that the thrips were already widespread on Hawai'i Island (USFS 2013).


Left: Cycas micronesica in northern Guam without signs of insect infestation.
Right: Cycas micronesica in northern Guam infested with Asian cycad scale (Aulacaspis yasumatsui).
Photos by: Sheri Smith

A similar ecological disaster is happening in Guam. Fadang (*Cycas micronesica*) a native cycad tree that was the most abundant tree species over 5 inches in diameter in 2001 (Donnegan et al. 2004) may go extinct by 2019 due to an introduced pest (Marler and Lawrence 2012). Asian cycad scale (*Aulacaspis yasumatsui*) invaded Guam in 2003, and by 2006 so many fadang had died that the International Union for Conservation of Nature listed the species as endangered (Marler et al. 2006). The scale was first discovered on ornamental *Cycas revoluta* plants and



ʻŌhiʻa is a dominant tree in native Hawaiian forests. Photo by: G.T. Larson that is the presumed host for this pest (Moore et al. 2013). Asian cycad scale was detected in 2008 on ornamental cycads in Koror, Palau, where *Cycas micronesica* also occurs. Palau's most important population of *C. micronesica* is on the Rock Islands to the south; the scale has not yet dispersed there (Cave et al. 2013).

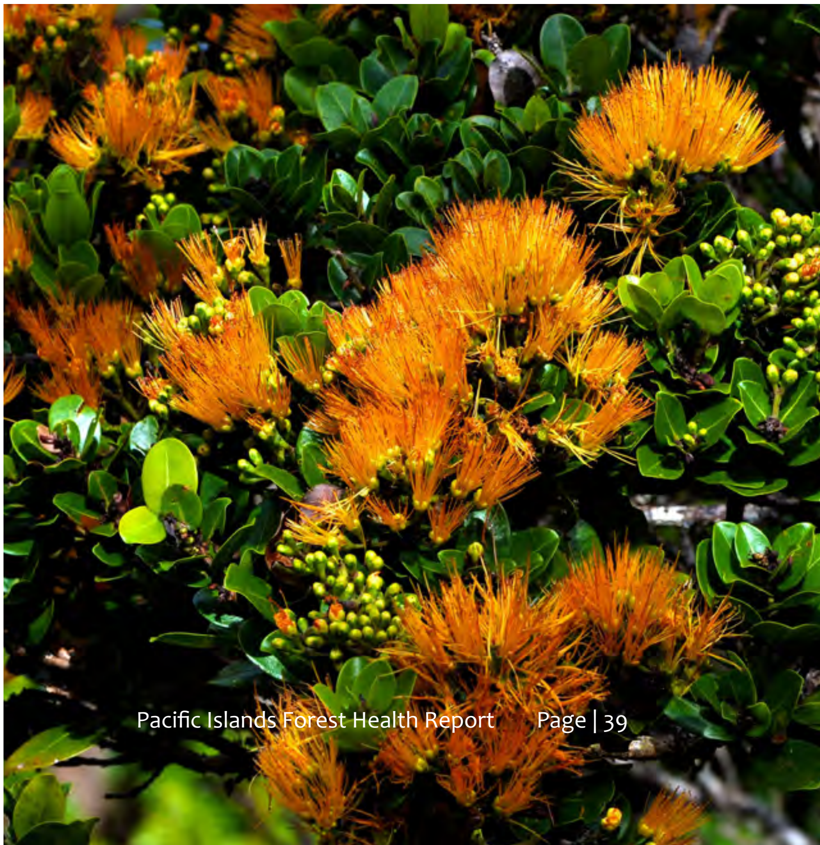
Alien ant species can make profound impacts on the forest ecosystems of the USAPI. The agroforestry section of this report describes the impact of one species—the little fire ant (*Wasmannia auropunctata*) but many alien ant species can affect forest function. Much of the biota of the USAPI evolved without ants and the introduction of ant species can have profound changes on these ecosystems (Wilson 1996). Ants may cause an increase in the numbers of homopterans (scale insects) to such an extent that they damage forest flora. On Palmyra Atoll, a U.S. Fish and Wildlife Service Refuge, sooty mold from ant-tended scale infestations has caused repeated leaf drop in *Pisonia grandis* forests and the canopy has decreased by 50% (Krushelnyky, Loope and Reimer 2005). *P. grandis* is one of the dominant tree types in Marshall Island forests. It has been noted that scale infestations may skyrocket long after an ant has been introduced, suggesting that ants may need a compatible species of scale insect to have this effect (Krushelnyky, Loope and Reimer 2005).

Invasive Pathogens

ʻŌhiʻa (*Metrosideros polymorpha*) forests cover 988,000 acres of the Hawaiian Islands and the species makes up approximately 80% of remaining native Hawaiian forests (Loope 2010). It is endemic, provides food and habitat for Hawaiʻi's endemic birds, and figures prominently in the rituals surrounding the practice of traditional hula (Nelson-Kaula 2012). Hawaiians revered ʻōhiʻa as essential to their water supply. A Hawaiian chant refers to the connection between ʻōhiʻa and water and the word ʻōhiʻa is drawn from the two words *ʻohi* and *ʻia* which mean to gather water (Nelson-Kaula 2012). Losing ʻōhiʻa would be ecologically and culturally devastating for Hawaiʻi.

In 2005 a new rust appeared on ʻōhiʻa and other species in the *Myrtaceae* family. The most susceptible species, introduced rose apple (*Syzgium jambos*) experienced widescale dieback, but Hawaiʻi's native ʻōhiʻa has remained largely unaffected. The disease was eventually identified as *Puccinia psidii*, a rust fungus native to Brazil, and established in Florida and the Caribbean. In Hawaiʻi, the rust did not affect *Myrtaceae* species that were susceptible in other locations, most notably, common guava, the species from which *P. psidii* was first described. This led local scientists to suspect that there are multiple strains of the rust and that another introduction could be more damaging to ʻōhiʻa (Loope 2010).

Unusual orange variety of ʻōhiʻa. Photo by: G.T. Jarson



Mortality of rose apple from myrtle rust (Puccinia psidii) in Hawai'i. Photo by: J.B. Friday

Management Actions to Mitigate Threats from Invasive Insects and Pathogens—Biosecurity

The most cost-effective way for the USAPI to protect their forests from invasive insects and pathogens is to strengthen biosecurity through effective outreach and education, preventive techniques, pathways analyses, inspections, tight quarantines and adequately funded rapid response teams. Hawai'i has been a pioneer in quarantine, going back to when the islands were an independent monarchy. In 1888, King David Kalākaua banned the import of coffee plants to protect Hawai'i's coffee plantations from coffee rust and other diseases. Similar restrictions were instituted for bromeliads to protect pineapple and for grasses to protect sugarcane. These laws, which are still in force in 2014, are credited with protecting these crops from diseases that have ravaged them elsewhere. The state's forestry and agriculture agencies are working together to enact similar quarantines to protect Hawaiian forests.

The pest invasions described in this report illustrate the difficulty of guarding against known pests. The cycad scale had already invaded Florida in the 1990's and Hawai'i in 1998. Scientists on Guam rightly predicted that the scale would arrive in Guam and devastate fadang and published these predictions in local media. Recommendations to restrict imports of ornamental cycads went unheeded. However, enacting quarantines alone may not be enough. Palau stopped imports of ornamental cycads to protect its *C. micronesica* but the scale still arrived there in 2008 (Cave et al. 2013).

It should also be noted, however, that two of Hawai'i's most problematic pest species, the erythrina gall wasp and myoporum thrips, were either new or unknown when they invaded. The erythrina gall wasp was only described a year before it reached Hawai'i and myoporum thrips were unknown to science when they invaded California. Although it was not described or named at the time, officials in Hawai'i were aware that a new thrips species was active in California, and would probably arrive in Hawai'i soon. HDOA reacted quickly to implement a classical biological control program for the erythrina gall wasp, but it still took years. Steps to strengthen quarantine measures against known pests are important, but the USAPI must also be able to prepare for unknown and undescribed pests. Improved early detection for pests on ecologically important trees, strong biological control capacity, and increased communication with other tropical regions may help prevent invasions and limit resource damage.

Micronesian Biosecurity Plan

The Micronesian Biosecurity Plan (MBP) is an initiative funded by the Department of Defense to mitigate the impact that the relocation of U.S. Marines from Okinawa, Japan to Guam (known as the Guam buildup) will have on the regional biosecurity of the USAPI. The buildup will significantly increase the flow of cargo and people to and from Guam thereby increasing the risk of pest introductions that could be harmful to forests. The Department of Defense has provided $3.7 million to create an MBP that will proactively address marine, terrestrial, and freshwater invasive species risk to Guam, CNMI, FSM, Palau, RMI, and Hawai'i. The first phase consisting of port inspection evaluations and risk analyses on pathways, vectors, and targeted invasive species has been completed. The second phase will create a Strategic Implementation Plan that will propose policies and actions to achieve regional biosecurity. It will be left to the participating governmental agencies who will have the responsibility for implementation.

US Forest Service Hawai'i Pest Risk Assessment

In order to better prepare Hawai'i for pests that may cause considerable damage to the state's important forest species, the US Forest Service is in the process of preparing a Pathway Pest Risk Assessment for 13 of Hawai'i's most important tree and understory species. This should help inspection agencies prioritize inspections and decrease the incidences of known pests from coming into Hawai'i, as well as support stricter rules for quarantine efforts. Several of the recommendations in the report would apply to all of the USAPI.

Research and Quarantine to Protect 'Ōhi'a:

The US Forest Service has initiated a collaborative project to identify different genetic strains of *P. psidii* and to find out to what degree 'ōhi'a are susceptible to them. Results confirm that the strain in Hawai'i is a single genotype. Experiments in Brazil tested the susceptibility of 'ōhi'a to different rust strains and found that three of the five strains tested were highly virulent causing a 29% increase in mortality six months after infection (Silva et al. 2014). This means that if one of these more virulent strains were introduced, the dominant tree in Hawaiian wet forests could suffer severe mortality. The state is working on a rule that will ban imports of *Myrtaceae* plants. Once this rule is in place it is hoped that the USDA Animal and Plant Health Inspection Service will make similar restrictions for international imports so that Hawai'i will have both state and federal quarantine measures in place.

Management Actions to Mitigate Threats from Invasive Ants—Biosecurity and Rapid Response Training

Efforts to prevent invasive ants focus on strengthening inspection, quarantine and rapid response to keep ant colonies from establishing. Successful ant eradications are possible if the infested area is small enough but not logistically feasible once a species has established in a forest. The Pacific Ant Project is providing technical assistance and early detection training focusing on the little fire ant (*Wasmannia auropunctata*) which is discussed in the agroforestry section of this report

Management Actions to Mitigate Threats from Invasive Insects—Biological Control

The success of pest eradication is often highly dependent on early detection and rapid response. Once an insect establishes—meaning that it is reproducing and dispersing itself to new locations—eradication becomes much more difficult and expensive. The invasive insect will move faster than rapid response crews can keep up with it. Additionally, if detection and eradication tools and techniques have not been developed, eradication will often not be successful. For these reasons, and due to environmental concerns over the use of pesticides, biological control is often favored as a long-term pest management strategy. Forestry and agriculture agencies in the USAPI have done a remarkable job of finding, testing and releasing natural enemies to combat invasive pests. Often multiple types of biological control agents are required to limit plant mortality and protect reproductive tissues. Biological research and testing is expensive and requires specialized expertise.

Eurytoma erythrinae, a parasitoid of the erythrina gall wasp, was released in 2008. Plant injury caused by gall wasp has decreased and wiliwili trees are no longer dying in large numbers. Four years after the biological control agent was released, the number of new tree shoots infested decreased from 95% to 20% (Kaufman et al. 2013). However, infestation rates in flowers and seedpods are still high enough that seed production is not occurring. Another natural enemy, a chalcid wasp (*Aprostocetus nitens*) collected in Africa, is currently being tested in Honolulu. Hopefully, it will further control the gall wasp and reduce wasp numbers, particularly in flowers and seed pods, resulting in viable seeds and improved regeneration (USFS 2013). Seed predation by an invasive bruchid beetle (*Specularis impressithorax*) also impacts wiliwili regeneration (USFS 2013).

When the myoporum thrips infestation was discovered on Hawaiʻi Island, Hawaiʻi Department of Agriculture (HDOA) immediately halted inter-island imports of naio. Although to date, the thrips have not been detected beyond Hawaiʻi Island they have killed 75% of the naio in monitoring plots (King et al. 2013). The Department of Land and Natural Resources has funded studies to determine that the thrips are native to Tasmania. However, funding has not been available to research potential natural predators. An associated endemic native wasp, *Polynema nanum*, has been observed preying on the thrips and University of Hawaiʻi researchers are determining if

Rhyzobius lophanthae is a biocontral agent for Asian cycad scale. Photo by: Aubrey Moore

they can establish breeding populations and potentially release it as a biological control agent (Kaufman 2014).

On Guam, two years after the Asian cycad scale was detected, managers released a natural predator, *Rhyzobius lophanthae* to control the scale (Moore et al. 2013). The situation is similar to the Erythrina gall wasp biological control in that *R. lophanthae* has decreased scale numbers enough to prevent mature fadang from dying, but not enough for the trees to reproduce. *R. lophanthae* is not active closer to the ground and cannot fit in to all the cracks and crevices on a fadang where the scale can hide. For these reasons, fadang seedlings continue to be attacked and killed by the scale despite the presence of established and active populations of *R. lophanthae* (Marler and Lawrence 2012). Two additional parasitoids have been released but failed to establish. Another predator, *Aphytis lignanensis* is currently being tested and will be released soon (Moore 2013). An additional invasive insect is also affecting cycad health; plant injury caused by the invasive butterfly *Chilades pandava* increases as the cycad scale numbers decrease. It is unclear how much damage the butterfly will inflict once the cycad scale is controlled (Marler 2013(b)). On Palau, *R. lophanthae* was quickly released after a cycad scale infestation was discovered in Koror. The predator appears to have reduced scale populations enough that ornamental cycads show no obvious signs of infestation or damage (Cave et al. 2013).

Management actions to mitigate threats from all taxa—Invasive Species Outreach

Outreach to educate the general public about all types of invasive species is critical to program success across the USAPI. Effective outreach can reduce the number of invasive plants imported and used by the public, increase detection of invasive species by the general public, and increase the number of private landowners that allow surveys and removal of invasive species from their lands. Over time, outreach can build public support and funding for inspection and quarantine measures and invasive species control programs.

In Hawai'i, the Coordinating Group on Alien Pest Species has worked with nursery and landscaping associations to adopt codes of conduct regarding invasive species. According to these codes of conduct, Hawai'i's landscaping industry and botanical gardens have

Students take a walk through American Sāmoa Community College's forest nature trail, Tutu'ila, American Sāmoa. Photo by: Jolie Goldenetz Dollar

agreed to not use invasive, ecosystem-altering plants. Outreach to hiking clubs and hunter groups has resulted in the detection of miconia trees that were later removed by field crews. The parent of a child that had participated in a Maui Invasive Species Committee outreach program was integral to the early detection of the little fire ant on Maui. The parent worked with a person that had been bitten by an ant with an unusually painful sting and encouraged the person to report it right away. The parent knew the description of little fire ant and what to do from helping his child survey his backyard for ant species. The early detection resulted in the successful eradication of the ant on Maui. CNMI forestry works closely with schools and youth organizations to educate students about the unique natural heritage of CNMI and the threats posed by invasive species.

Management actions to mitigate threats from all taxa—Invasive Species Partnerships

Interagency invasive species partnerships that bring together landowners, agriculture, quarantine, forestry, conservation, and research agencies are crucial to island-wide biosecurity. Invasive species do not respect land ownership boundaries and are detrimental to a wide variety of ecosystems (e.g. native, agricultural, etc.). Therefore, multi-agency collaboration and partnerships are required to effectively detect and combat them. Across the USAPI, partnerships have formed to address invasive species policy and to coordinate early detection, monitoring, control and outreach. A list of these partnerships is on the next page.

Deforestation

All the USAPI native forests are threatened by deforestation from increasing development pressure. However, there are not enough data to quantify historical trends or to track how much is being lost. The FIA-USFS tracks forest loss, and as future data are collected, this measure can be tracked over time.

American Sāmoa Forestry has stated that invasive plants and deforestation are the primary threats to their native forests. American Sāmoa lost an estimated 3% of its forested land between 1988 and 2001 (Donnegan et al. 2004(b)). Currently, the amount of land at risk for development can be estimated. On the main island of Tutuila, only 18,626 acres have a slope of less than 45%. It is likely that these acres will be in demand for agriculture and development as the population increases. Eventually, it is likely that people will move into places that are very steep and only marginally suitable for development. Clearing forests on steep slopes will further increase erosion (American Sāmoa FAP).

On Pohnpei, FSM, deforestation was becoming a severe problem in the upland Watershed Forest Reserve due to farmers clearing trees for sakau, a traditional ceremonial drink consumed throughout the Pacific that is made from the roots of the *Piper methysticum* plant. In response, the Conservation Society of Pohnpei and The Nature Conservancy began the Grow Low Program that provided seedlings and training to farmers to get more production out of sakau grown at lower elevations. Together with enforcement, this program reduced the number of sakau clearings from 600 in 2002 to only five in 2007 (Conservation Society of Pohnpei 2012).

Development pressure is happening in Hawaiʻi as well. Forty-seven percent of Hawaiʻi Island's, 2.57 million acres are zoned for agriculture (State of Hawaiʻi Data Book 2012), which means

Invasive Species Partnerships in the USAPI

- **American Sāmoa Invasive Species Team**: An interagency group, including the National Park of American Sāmoa and local agencies. Conducts on-the-ground control work.
- **Coordinating Group on Alien Pest Species (CGAPS)**: Provides a forum for information sharing and policy coordination among state, federal, and private invasive species managers.
- **Guam Invasive Species Council (GISC)**: Formed by an act of the Guam Legislature, the GISC is made up of Guam's agriculture, port, and natural resource agencies. It is tasked with developing an invasive species management plan and advising the legislature on invasive species issues.
- **Hawai'i Invasive Species Council (HISC)**: Provides a forum for state agencies involved in invasive species management to coordinate statewide invasive species policy. Members are the heads of state agencies and state legislators.
- **Hawai'i Watershed Partnerships (WPs)**: Partnerships that bring together the public and private landowners within a watershed to conduct resource management across boundaries. Watershed Partnerships control feral ungulates and invasive plants.
- **Invasive Species Committees of Hawai'i (BIISC, MISC, MoMISC, OISC, KISC)**: Island-based partnerships on Hawai'i Island, Maui, Moloka'i, O'ahu, and Kaua'i that bring together public and private land managers and natural resource agencies. ISC field crews work on public and private land to control invasive species island-wide. The ISCs also participate in local and statewide policy making.
- **Invasive Species Team of Pohnpei (i-STOP)**: a cross-sector multiagency team working on priority invasive species identified in the Pohnpei Invasive Species Strategy.
- **Kosrae Invasive Species Taskforce (KIST)**: An interagency working group that seeks to coordinate action on invasive species, raise awareness, and build capacity.
- **National Invasive Species Committee (Palau)**: Independent committee that advises the President of the Republic of Palau and his cabinet. It is made up of government agencies and the Palau Conservation Society. The committee coordinates response plans, public awareness, and investigates methods to reduce, contain, and eradicate invasive species.
- **Pacific Invasives Learning Network (PILN)**: a regional Pacific network of island-based invasive species managers and practitioners that provides a mechanism for capacity building, information sharing, and links to technical expertise.
- **Pacific Invasives Partnership (PIP)**: The invasive species working group of the Roundtable for Nature Conservation in the Pacific Islands. PIP is the umbrella regional coordinating body for agencies working on invasive species in more than one country of the Pacific.
- **Pacific Plant Protection Organization**: A regional forum that is part of the International Plant Protection Convention, hosted by the Secretariat for the Pacific Community. The group meets to discuss plant protection and quarantine matters and contributes to global issues such as developing and endorsing phytosanitary standards.
- **Regional Micronesian Invasive Species Council (RISC)**: Provides information to the Micronesian Chief Executives (CNMI, Guam, FSM, Palau, and RMI) on invasive species and biosecurity issues and coordination, planning, and overall leadership for the jurisdictional invasive species programs. Members are appointed by Micronesian Chief Executives.
- **Yap Invasive Species Task Force (YIST)**: Multi-agency collaboration that conducts on-the-ground control work.

these lands can be developed for agriculture and housing. Housing developments require permits; logging or agriculture on private land does not, even if the forest is native. The Nature Conservancy Hawai'i estimates that approximately 400,000 acres of native ecosystems (not all are forest acres) are zoned for agriculture and may be at risk for development.

Guam is facing a sudden increase in population with the transfer of military personnel from Okinawa to Guam (known as the Guam buildup). The population growth associated with the buildup may at times be as high as 30,000 people, including military personnel and temporary workers brought in to build additional infrastructure (Guam ROD 2010). The Final Environmental Impact Statement (FEIS) for the Guam buildup identifies 2,063 acres of forest that will be impacted from construction activities related to the buildup, however Guam Forestry identified 5,432 acres, out of a total of 56,496 forested acres, that are at risk of deforestation from the buildup and associated activities (Guam FAP).

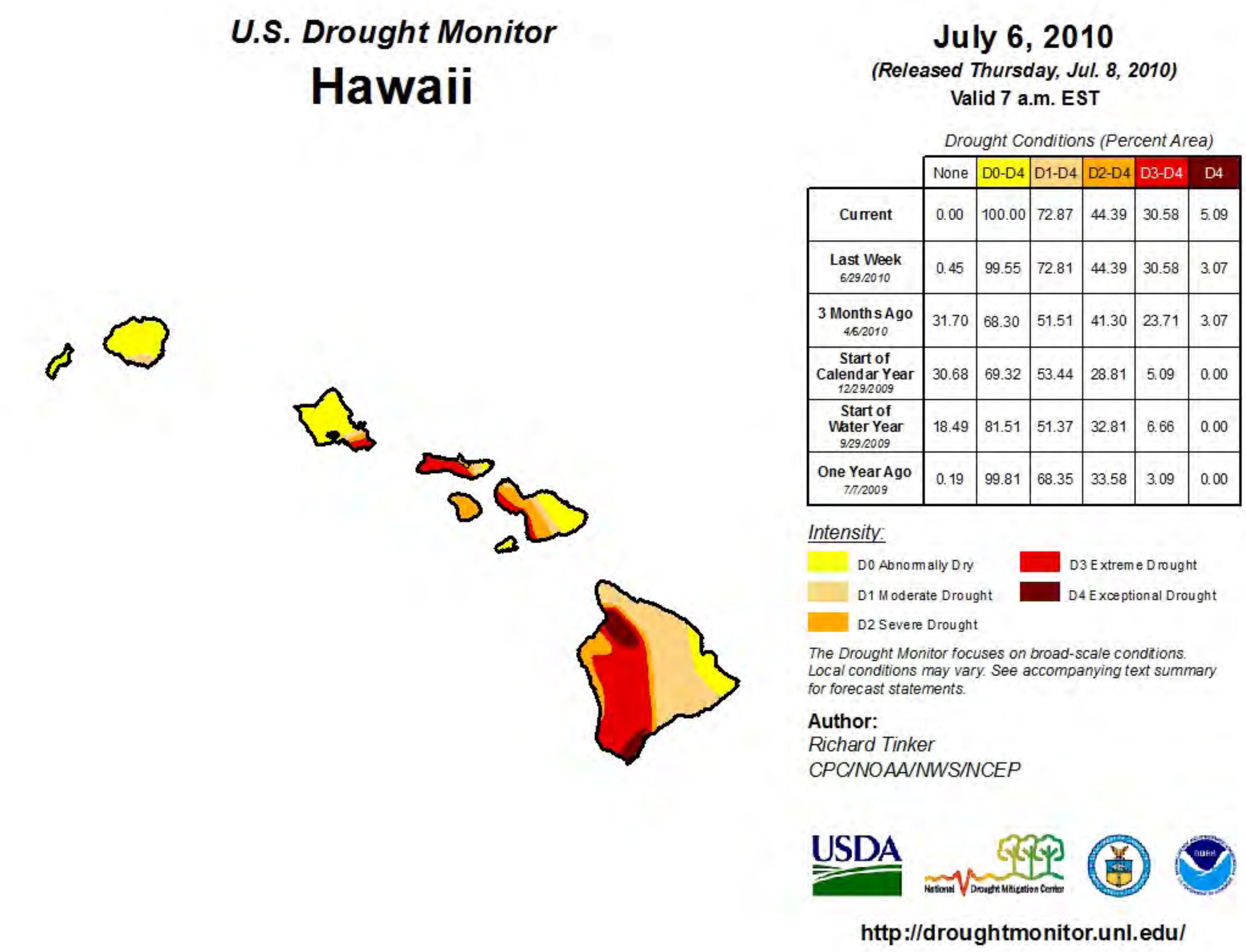
Management Actions to Mitigate Deforestation

Areas set aside for conservation in Palau's Protected Areas Network (PAN) are community managed and the states and communities that own PAN sites agree to manage them for conservation and to create and follow a management plan (Palau Conservation Society 2012). The Belau Watershed Alliance (BWA) is a consortium of nine Palau states whose mission is to "protect, conserve and restore the water resources of Belau through collaborative outreach, education, networking, science, information sharing and technical assistance by and for the communities of the island" (Palau Conservation Society 2012). The BWA provides a forum for states that share a watershed to coordinate watershed planning (Palau FAP 2010).

The Micronesia Challenge is a collaborative effort of FSM, RMI, Palau, Guam, and CNMI to effectively conserve 20% of their terrestrial resources and 30% of their near shore marine resources by 2020. The Micronesia Challenge not only identifies lands that should be spared from development, it also builds public support and raises money for management of those lands (Micronesia Challenge 2012). An important part of the Challenge is to create monitoring frameworks to ensure that protected areas continue to be ecologically healthy. Each of the five jurisdictions is working towards the goal, with Palau having conserved 19.6% of its terrestrial resources; FSM 15%, CNMI 9%, and RMI 16% (PCS & TNC 2011).

Drought

The US drought index has classified the leeward sides of Hawai'i and Maui Islands as having moderate to extreme drought conditions every year between 2008 and 2013. The drought was most acute in 2010, and parts of the Big Island were classified as being in an exceptional drought, which is the highest category on the scale. The unique and rare dryland forests are most affected by the drought, and it is these forests that have also been impacted by erythrina gall wasp and myoporum thrips. Data are not available to quantify the effects of the drought on tree health, but it can be assumed that drought-stressed trees would be less able to survive browsing by feral sheep in the Mauna Kea Forest Reserve and by axis deer on Maui. Lack of rainfall may weaken and stress native forest trees, but it also increases a forest's vulnerability to fire. They may also be more susceptible to the effects of insects and pathogens. Although not much can be done to alleviate the effects of the drought, limiting plant injury caused by



pests and feral ungulates, and preventing new invasive pests from establishing, could help increase forest resiliency.

The other USAPI are also vulnerable to drought. During El Niño years, tradewinds tend to decrease and as a result precipitation may also decrease. In 1997 and 1998, a strong El Niño affecting FSM caused a drought so severe that residents required emergency food and water (Fletcher and Richmond 2010).

Fire

Native ecosystems in the USAPI are not fire-adapted and fire is not a natural part of forest processes. With the exception of fires ignited by lightning strikes (which are very rare) and active volcanoes (only in Hawai'i), wildland fires in the USAPI are started intentionally by people. Juvenile fire starters, deliberate fire starts by hunters to flush out game, along with expected escapes from agricultural burning make up the majority, if not all, of the fire occurrences in the USAPI (Mahoney 2014). Grasslands have been created where people have burned forest to clear the land for agriculture and where alien grasses have moved into forest understory. Lack of rainfall may weaken and stress native forest trees, and increases a forest's vulnerability to fire.

Fama St. Ordot fire on Guam, May 11, 2012. Photo by: Guam Forestry

Although FSM and Palau are thought of as humid tropical islands, dry seasons in Yap and Palau, and droughts during El Niño years, are accompanied by fire. During the same 1998 drought mentioned above, there were daily fires throughout Babeldaob Island (Palau FAP 2010). A similar drought in 1983 and 1984 led to wildfires on Pohnpei, Chuuk, and Kosrae. Wildfires affected an estimated 50% of the Pohnpei upland forest during this time (FSM FAP 2010). Yap is the driest state in FSM and wildfire is an ongoing problem there, not just during droughts. Twice in the past 30 years, fires during drought periods burned 22% of Yap (FSM FAP 2010).

Arson is a severe problem in CNMI and Guam. Hunters regularly set fire to grasslands to stimulate new growth and attract game (CNMI and GUAM FAPs 2010). Eighty percent of fires on Guam are caused by arson (Guam FAP 2010). These arson fires are frequent and prevent the natural regeneration of forests and increase sedimentation rates that degrade water quality.

In Hawai'i, alien grasses, especially guinea grass (*Megathyrsus maximus*) and fountain grass (*Cenchrus setaceus*), provide high-intensity fuels to wildland fires. Between 2008 and 2012, 21,952 acres burned in Hawai'i. This number may seem small compared to mainland forest fires, but they have occurred in forests with extremely rare plants and given the small size of the islands, these fires can have a large impact.

Management Actions to Prevent Fire

There appears to be a misunderstanding about the causes of fire in the USAPI. Many communities in the USAPI do not know that the majority, if not all, fires are started intentionally. Recent work in the USAPI has shown that two types of data are useful in working with communities to inspire them to work to prevent deliberate fire starts. Photos and maps that explain the connection between fires upslope and the health of coastal waters seems to resonate with local communities and data that shows the location of fire starts can help villages understand that causes of fire and how to prevent them (Mahoney 2014). The US Forest Service's Southwest Region Fire and Aviation Management office has recently been working with the Pacific Fire Exchange, Hawaii Wildfire Management Organization, and the Institute of Pacific Island Forestry to develop a strategic plan for fostering a better understanding of human dimensions and how that translates into a fire prevention message for the Pacific (Mahoney 2014).

Storms

The frequency of typhoons varies across the USAPI. Between 1996 and 2006, eleven typhoons with winds over 100 mph passed within 180 nautical miles of Saipan Harbor (Naval Research Laboratory 2008). Typhoons strike Guam on average every 4.7 years, although as of 2013, Guam had not experienced a major typhoon since 2002 (Marler and Lawrence 2012). Native forests on Guam are naturally stunted in response to frequent hurricanes, and surveys have recorded weather as a primary damage agent (Donnegan et al. 2004).

In the last 30 years six major tropical cyclones have struck American Sāmoa. Large areas of forest were stripped of leaves from Cyclone Heta in 2004. Cyclone Olaf (2005) uprooted every tree in some areas of Ta'u island (Craig 2009). Typhoons strike FSM with Yap, Pohnpei, and Chuuk having more storms than Kosrae (FSM FAP 2010). The RMI is outside the main typhoon track, but still experiences heavy storms with coastal surges that wash over vegetation (Donnegan et al. 2011(c)). Few hurricanes have made landfall in the Hawaiian Islands. Hurricane Iniki in 1992 was a category three storm that caused severe property damage on Kaua'i and opened up areas of the forest to invasive species. Tropical storms also bring wind and heavy rains that can damage trees.

Although typhoons cause significant damage, forests that have evolved in this environment can eventually recover were it not for invasive species. Storms spread the seeds of invasive plants or other reproductive material to new areas.

Storm-damaged forest in American Sāmoa.
Photo by: National Park of American Sāmoa

Invasive plants that thrive on disturbance can move into the gaps created by storms. One of the most striking examples of this happened in Tahiti. Back to back hurricanes in 1982 and 1983 caused major canopy clearing events that released the seedbank of *Miconia calvescens* and helped create the monospecific stands seen today (Meyer and Malet 1997). Even on Guam, where the vegetation has evolved with frequent typhoons, the forest is vulnerable due to the number of invasive plants that gain advantage in disturbed areas sooner than native species. Trees that might otherwise withstand hurricane force winds may break if they are weakened by insects or pathogens. *Cycas micronesica* is somewhat resilient to typhoons, but they have been so severely weakened from the cycad scale that a moderate storm could extirpate them before the projected extinction date of 2019 (Marler 2013).

Climate change

Downscaling global climate change models to quantitatively predict regional effects in the USAPI is only just beginning. Models are complicated by the El Niño Southern Oscillation, Pacific Decadal Oscillation, and the Interdecadal Pacific Oscillation. These are atmospheric-oceanic cycles that alter temperature, wind, and precipitation patterns. It is difficult for climatologists to distinguish between these oscillations and background climate changes to make quantitative predictions. However, weather patterns over the past 50 years give an understanding of what to expect in the future (Finucane et al. 2012).

Forests in Palau, Guam, CNMI, and RMI are predicted to experience wetter wet seasons and drier dry seasons, but with overall increases in mean annual rainfall (Keener et al. 2012). These island groups have already identified erosion as a problem so it is likely that higher rainfall may accelerate erosion. In addition, tree species not particularly adapted to drought will be stressed throughout the dry season, and an increased dry season may increase the risk of fire on Palau and FSM. Current models do not predict a drastic change in precipitation in American Sāmoa (Keener, Izuka and Anthony et al.2012).

In Hawai‘i, rainfall will likely decrease during the wet season and increase during the dry season. Winter droughts, like the ones that Hawai‘i has been experiencing for the past few years will occur more often. Overall, annual precipitation is expected to decrease (Keener et al.2012). A transition to a drier climate may weaken native forests. Invasive drought tolerant trees and fire-adapted grasses could gain further competitive advantages in native forests. Drought may cause trees that provide nectar and fruit for endemic birds and bats to stop flowering and fruiting. The current drought on Mauna Kea is at least partly responsible for decreased seed production in māmane (*Sophora chrysophylla*) trees (Fortini et al. 2013). The endangered palila (*Loxiodes bailleui*) is dependent on māmane seeds for food (Banko et al. 2012).

Climate change may already be altering water levels and healthy forests will be essential to mitigating the effects of decreases in precipitation levels. Gauges in Hawai‘i show that the groundwater contribution to streamflow declined between 1913 and 2008. Climate change will likely make this worse as precipitation patterns change (Keener, Izuka and Anthony 2012). Keeping watershed forests intact and healthy will be even more critical to maintaining the islands' water supply as decreased precipitation caused by climate change reduces groundwater supplies.

Hawai‘i's dominant tree species such as ‘ōhi‘a, koa, wiliwili, and naio are all expected to tolerate climatic shifts because they currently occupy multiple climate zones and may be able to migrate higher in elevation (Fortini et al. 2013). However, these species may become less tolerant if climactic shifts are beneficial to the pests and pathogens that attack them. For example, koa wilt and black twig borer (refer to the commercial forestry section) are not considered significant pests in upper elevation natural koa forests, but if these upper elevations become warmer, these pests may begin to significantly damage native koa forests. Managers have observed that the erythrina gall wasp prefers dry conditions. Increased drought could lead to heavier infestations (Kaufman 2014).

Plant extinction will increase with climate change. A vulnerability assessment of Hawaiian plants has modeled a species' ability to migrate higher in elevation and disperse into new areas, tolerate climate changes in its current habitat, and persist in micro-refugia that may remain the same while the macro-climate shifts (e.g. gulleys or valleys). Fortini and others (2013) found that the species most in danger of extinction due to climate change are those species already on the edge due to habitat fragmentation and negative impacts caused by invasive species. Species associated with dry forests had higher vulnerability scores compared to species from any other habitat type. The authors also predict an average 39% decrease in area between current and future climate ranges for all Hawaiian native plant species. This means that species already threatened by invasive species and deforestation will lose 39% of their habitat by the year 2100. The climate range of 49 species of Hawaiian plants will completely disappear by 2100 and these species will likely go extinct if they cannot adapt to a new climate. Another 98 species will retain their climate range, but it will not be connected to the one they currently occupy (Fortini et al. 2013). In addition, a changing climate is predicted to expand the ranges of some of the most notorious invasive plants into Hawai'i's upper elevation areas, where most of the intact native forest currently occurs (Vorsino et al. 2014).

Management Actions to Mitigate the Effects of Climate Change

The Pacific Island Climate Change Cooperative (PICCC) is working to provide scientific data relevant to the USAPI to provide a foundation on which to make management decisions regarding climate change. Implementing the Micronesia Challenge (described above) will result in conserving forested acres in Micronesia and hopefully increase their resilience to climate change by taking steps now to keep forests healthy. Climate change may exacerbate many of the threats listed above. The measures to mitigate current forest threats may also be considered climate change mitigation actions because keeping forests healthy is a way to adapt to future climate shifts.

Strawberry guava (Psidium cattleianum) thicket on Oʻahu Island, Hawaiʻi. Monotypic stands of this species are a common feature of lowland Hawaiʻi forests.
Photo by: Oʻahu Invasive Species Committee

Alien Secondary Forests

The forests of Hawai‘i, CNMI, and Guam, have undergone such massive disturbances that in some areas they have been completely replaced with secondary forests wholly comprised of exotic species. No indigenous trees occur in vast portions of the forests on these islands. In some cases all the vegetation, including herbs and shrubs, is also alien. These altered forests have a profound effect on the islands as they have a completely different structure and may not provide the same level of watershed protection or habitat as native forests. In addition, they serve as seed sources for invasive plants that displace additional native forests and reduce commercial forest productivity. The most accessible forest recreation areas are in the lowlands and are often dominated by alien species, thus disconnecting the populace from their natural heritage.

Guam and CNMI native forests experience intense, natural disturbance regimes from the frequent typhoons that pass through the area. Sixteen typhoons since 1970 have impacted Guam, four of which have been devastating (Guam FAP 2010). Guam’s native vegetation may have developed some resiliency to typhoons, but severe anthropogenic disturbances have replaced native forests with alien ones. Colonial powers replaced traditional agriculture with sugar. By 1922 sugar plantations covered 70% of the usable land in the Northern Marianas (MacGrath and Wilson 1987). Extensive bombing during WWII and military construction afterwards resulted in additional forests being cleared (Perry and Morton 1999). The extensive deforestation left large parts of the islands vulnerable to erosion (Guam FAP 2010). On Guam and in CNMI, tangantangan (*Leucaena leucocephala*) is thought to have been aerially seeded to prevent erosion and now forms monotypic thickets. *Acacia confusa* was planted in CNMI for fuel and now dominates Saipan and Tinian (CNMI FAP 2010).

Savannahs and bare soil, in need of restoration to prevent soil erosion, are a distinct feature of the landscape in CNMI and Guam. Guam forestry is replanting degraded areas with *Acacia auriculiformis* to return nitrogen to the soil and build organic matter. Native trees will be planted in the understory (Santos 2013).

Indigenous Hawaiians cleared portions of forest for agriculture, but the uplands were still relatively intact at the time of European contact in 1778. Commercial harvesting of Hawai‘i’s four endemic sandalwood species began in 1810 and in just 20 years so much mature sandalwood had been cut that the trade completely collapsed (Culliney 2006). Sandalwood still exists today, but not in the numbers it likely had prior to 1830. Shortly after the sandalwood was depleted, cattle ranching began. Settlers razed the forests to create pasture for cattle (Culliney 2006). Cattle grazed the upland slopes on all the islands and denuded the mountains so badly that by 1900, the water in island streams and rivers had either dried up or become undrinkable from sedimentation (Hawai‘i FAP 2010). Sugar planters, recognizing the importance of the water supply to their industry, hired Harold Lyon to replant the forests. Unfortunately, Harold Lyon thought native species were too slow-growing and unsuitable and so replanted the forests with alien species from Asia, Africa, South America, and Australia (Woodcock 2003). Much of Hawai‘i’s low elevation forests are novel species assemblages made up of alien species from almost every tropical region except Hawai‘i. Native vegetation occurs over less than 40% of Hawai‘i’s land area (Hawai‘i FAP 2010).

The extent of degradation in Hawai'i is so profound that disturbance is not necessary for non-native species to eventually dominate the understory, the midstory, and the canopy. Remote sensing studies that mapped forest species and structure on Hawai'i Island found that most invaded areas were connected to a nucleus of exotic dominated forest or formed large stretches of nonnative canopies that appeared to be invasion fronts (Asner et al. 2008).

Shortly after exotic tree species move in to native forest natives are unable to regenerate. A survey of 46 exotic-dominated forest sites on the windward side of Hawai'i Island found that of 268 woody seedlings, only 15 individuals were natives (Mascaro et al. 2008). A study from another forest site where natives dominated the overstory, but alien species had filled in the mid-story, are even more dramatic. Seed rain was predominantly native, but the seedbank was not. Of 17,000 seedlings germinated from soil cores taken from these sites, only two individual seedlings were native (Cordell et al. 2012). These completely different species assemblages create a novel forest structure. Comparisons between native and alien forest structure in Hawai'i found that strawberry guava forest (*Psidium cattleianum*) had almost triple the amount of biomass in the midcanopy, and 55 to 60% less biomass in the overstory and understory. This altered structure only allowed 5% of light into the understory, effectively removing it and creating a biologically impoverished environment beneath the canopy (Asner et al. 2008).

Agroforests

Agroforests are the major form of managed forests of the Federated States of Micronesia (FSM), the Republic of the Marshall Islands (RMI), the Republic of Palau, and American Sāmoa. Each island group has its own unique variations that mix trees and other crops. These systems are deeply interconnected to island history and culture. Forestry managers and stakeholders in FSM and RMI have identified agroforestry as a key component of food security and increasing resilience to climate change (FSM FAP 2010; RMI FAP 2010). However, the ability to produce food is already being compromised by invasive species, rising sea levels, a gradual loss of traditional agroforestry knowledge, and neglect and loss of agroforest crop cultivars. Many low-lying atolls have already become uninhabitable and residents have been forced to abandon their homelands and move to higher islands.

The traditional agroforestry systems of the US-Affiliated Pacific Islands (USAPI) provide food with a relatively small input of labor and without the use of chemical fertilizers, pesticides, or mechanization. Before European contact, these systems supported large populations with no external inputs (Falanruw 1994). USAPI agroforestry often consists of some combination of coconut, breadfruit, and other fruit tree overstory with taro, bananas, yams, sweet potato, bamboo, and sugarcane below. Nitrogen-fixing trees may also be added to the mix to maintain soil fertility. For example, *Erythrina subumbrans*, a tree that does not produce food, but can be used for fiber and medicine, is often grown with taro in American Sāmoa (American Sāmoa FAP 2010). Researchers have recorded 55 species of trees cultivated in Yapese agroforests (Falanruw 1993). Forty different tree species and 131 different breadfruit cultivars have been recorded in the traditional agroforests of Pohnpei (Raynor and Fownes 1993). Chuuk is famous for a breadfruit cultivar that produces year-round (FSM FAP 2010).

A view of agroforestry plots and native forest in Malaeimi Valley, Tutu'ila, American Sāmoa. Photo by: Jolie Goldenetz Dollar

The American Sāmoa Forest Action Plan (2010) has identified clearing land for agroforests as a significant cause of native forest loss and invasive plant spread. Land is cleared and if farmers decide the hillside is actually too steep for agriculture, they abandon the land. Invasive plants quickly move into the cleared area, thrive, and advance into the forest. To discourage this practice, the American Sāmoa Forestry Program promotes agroforestry in urban zones to prevent clearing upslope, and encourages the use of native trees in agroforestry lands adjacent to native forest (American Sāmoa FAP 2010). In FSM however, clearing of secondary and primary forest traditionally took place only when crops planted under a natural forest canopy had begun to establish a canopy. Since land is not cleared all at once for traditional agroforestry, invasive species do not gain such an advantage (Raynor 2014).

The people of Kosrae, FSM, have developed a unique agroforestry system where they cultivate taro and bananas among ka (*Terminalia carolinensis*) wetland forests (Conroy et al. 2011). Ka is a tall, stunning overstory tree with dramatic buttress roots that is endemic to Pohnpei and Kosrae, but only common on Kosrae. In Kosrae's agroforestry plots, ka prevents erosion and shades crops from too much sun. Kosraeans use ka for canoes, lumber, and medicine. Among local residents, ka's endemic status and importance to the culture are widely recognized, and there appears to be strong community support for its conservation (Conroy et al. 2011).

Ecosystem Services and Significance to Nutrition of Agroforests

Agroforests provide some of the same ecosystem services as natural forests, including watershed protection and wildlife habitat. The mixed multi-layer gardens alternated with secondary tree cover on Yap have maintained the island's watershed system (Falanruw 1993). In the RMI,

Left: Grove of Pandanus Tectorius in Hilo, Hawaii. Right: Pandanus Tectorius Fruit. Photos by: J.B. Friday


Agroforestry in RMI. Photos by: Karness Kusto

agroforests are dominated by coconut, breadfruit, and pandanus and are often a nesting area for the endangered Micronesian pigeon (*Ducula oceanica*) (Reimaan National Planning Team 2008). Fruit bats forage in, and help pollinate, several tree species in agroforests in American Sāmoa (Misa and Vargo 1993).

The World Health Organization blames the high incidences of diabetes in the Pacific on the gradual shift from traditional diets supported by agroforestry to imported food such as white rice, flour products, sugar, fatty meats, and sweet processed food (Parry 2010). A nutritional study on Pohnpei found that over half of pre-school children have vitamin A deficiency and a third showed signs of anemia. This example of malnutrition is especially vexing when traditional banana cultivars are nutrient rich and contain provitamin A carotenoid substances (Engelberger et al. 2009).

Threats to Agroforestry and Management Actions to Mitigate

Sea level rise due to climate change may render brackish the freshwater lens under low-lying atoll island coastal areas, making traditional atoll and coastal agroforestry and even modern agriculture impossible. A recent report from the University of Hawai'i on the effects of climate change in FSM put it bluntly; "Food and water are at risk now." (Fletcher and Richmond 2010).

Food and water are at risk now.

Water for drinking and agriculture on low-lying (atoll) islands comes from rainwater stored in catchments and freshwater lenses beneath the ground that float on top of seawater. The freshwater lenses are extremely fragile and may disappear during times of drought if the islands do not receive adequate rainfall to replenish them. Sea level rise has already caused salt water to leak into the freshwater lenses on some islands (Keener et al. 2012). Once freshwater is no longer available, agriculture is impossible and residents will eventually be forced to abandon their home islands.

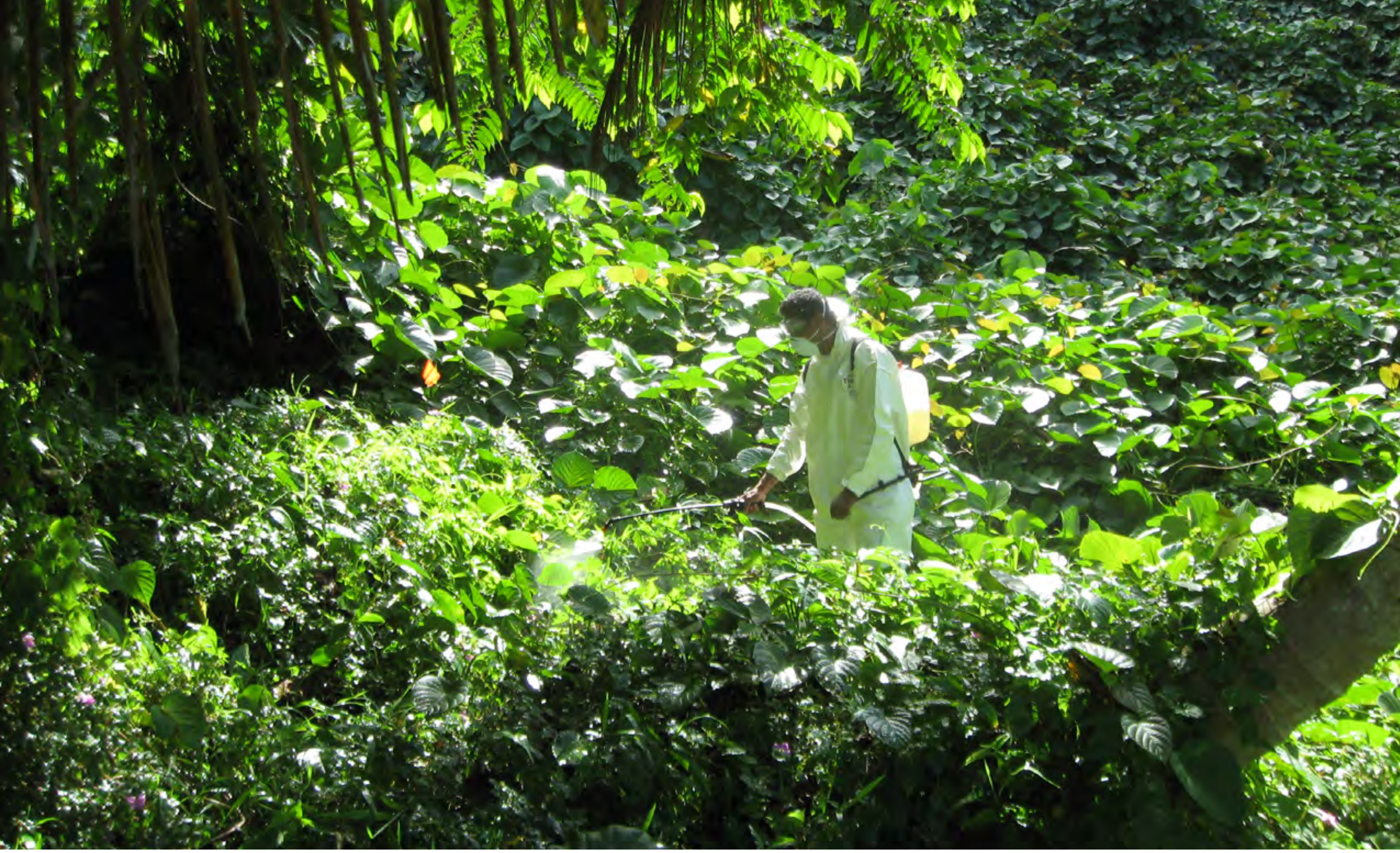
Although base sea level rise has not yet been great, La Niña-dominated conditions in recent decades have resulted in high sea levels in the Western Pacific, providing a foretaste of future

Banana trees that have died as a result of the extreme high tide or "king tide" that washed over Majuro Atoll in RMI in 2014. . Photo by: Republic of the Marshall Islands Ministry of Resources and Development

conditions. Modern practices, such as pumping water from wells, paving over lands that formerly drained into the freshwater lens, and use of freshwater resources for modern amenities, have also affected freshwater supply and depletion. In some locations, freshwater sources are already turning brackish, and people are leaving low-lying atolls for higher islands (FSM andFAP 2010; RMI FAP 2010) as a result of a combination of factors including socioeconomic aspirations and concern about climate and environmental change. In FSM, inundation events affecting atolls and coastal areas resulting from seasonally high tides and/or storm waves in December of 2007, September 2008, and December 2008 caused catastrophic damage. High tides overwashed shorelines and saltwater intruded into taro wetlands. Some of these areas have not recovered and may no longer be suitable for agriculture. RMI experienced storm waves in 2014 that caused so much damage, 1,000 people had to be temporarily evacuated.

Other examples illustrate more long-term effects—agricultural areas in FSM that have been tended for generations are now damaged or destroyed on 60% of inhabited atoll islets (Fletcher and Richmond 2010). On Chuuk, low-lying taro patches have been abandoned due to high salinity in the soil (Raynor 2014). Although the effects of climate change are currently the most visible on taro, tree species that make up traditional agroforestry plots will also eventually die if their roots are continually exposed to saltwater.

Eventually, the higher islands in the FSM and urbanized accessible islands in the RMI will need to accommodate their citizens who are forced to leave their low-lying and remote home atoll



Pasia Setu applies glyphosate to Merremia peltata at an agroforestry site in Auto Village, Tutu'ila, American Sāmoa. Photo by: Jolie Goldenetz Dollar

islands when fresh water is no longer available and funds are no longer available for steady use of desalinization units and food imports. USAPI forestry managers on high islands will need new tools to make traditional agroforestry more productive to meet the increased need for food, while concurrently mitigating the stress that climate change and invasive species cause on these systems (RMI FAP 2010; FSM FAP 2010).

Management Actions to Increase Climate Change Resilience

Islands are taking steps to protect their traditional agroforestry against the destructive forces of climate change with new technology, mapping, and outreach, but many needs remain. Some taro beds on Yap have been lined with concrete to protect them from saltwater inundation (Fletcher and Richmond 2010). The Pacific Adaptation to Climate Change (PACC) program is working on a demonstration project to find saltwater resistant varieties of taro in Palau. Results so far indicate that three varieties have tolerance to salt water. RMI is conducting targeted outreach to raise awareness about the effects of climate change on water supplies and how best to plan for it (PACC 2013).

Invasive Species

Invasive plants lower production in agroforests and are difficult and labor intensive to control. Several species of invasive vines smother important fruit trees, such as banana and breadfruit. Grasses invade taro patches, change the hydrology, and render them unsuitable for taro cultivation (FSM FAP 2010). Once invasive plants establish, controlling them by hand may require more intensive labor than is available or warranted. Some invasive plants do not respond well to herbicides and even if they were effective, they may be too expensive and environmentally damaging. The use of herbicides, and their potential effects, if transported though the ground to the delicate fresh water lenses, are of concern.

Insect pests and pathogens threaten important agroforestry tree species. Pests such as Egyptian fluted scale, breadfruit twig borer, coconut scale, and Caroline fruit fly attack breadfruit. Orange spiny whitefly, leaf miner, black citrus swallowtail butterfly, and black citrus aphid attack citrus (FSM FAP 2010).

Phellinus noxius is an aggressive root rotting pathogen with over 200 host species. Several species of the *Phellinus* genus occur in Micronesia, however, *P. noxius* is the deadliest. This fungus spreads from tree to tree via root systems and kills the cambial tissue of the host tree. Several species important to agroforestry, including breadfruit, betel nut, mango, and ka, are hosts for *P. noxius*. The US Forest Service and *P. noxius* experts from Japan conducted surveys for this fungus in the forests of Palau, FSM, Guam, and CNMI. They determined the fungus is widespread (Cannon 2014).

Damage caused by this fungus does vary between sites and species. For example, in the Two Sisters forests of CNMI, fifty trees of ten different species were killed by this fungus, while in other areas *P. noxius* killed less than five trees (Cannon 2014). *P. noxius* could be spread among agroforestry plots through breadfruit. The disease is common on breadfruit trees and if farmers are collecting root suckers and moving them to another location, they may be spreading the disease (Cannon 2014).

Another pest of concern throughout the Pacific is *Thysanococcus pandani*, a scale that attacks *Pandanus tectorius*. The scale is native to Java and Singapore and was detected in Hana, Maui in 1995 and discovered on O‘ahu in September of 2013. The scale has been intercepted at least five times in California on shipments from Hawai‘i (Gallaher 2013). A biological control program was initiated in 2013 by the Hawai‘i State Department of Agriculture. An initial exploratory trip to Southeast Asia and Australia yielded several candidates, one of which was sent to containment facilities in Hawai‘i for testing.

Islanders throughout the Pacific use the fruit of pandanus for food and the leaves for weaving household goods, clothing, and jewelry. In the RMI, there are over 50 cultivated varieties of pandanus and it is a staple food (Kusto 2013). Pacific voyagers used sails made from pandanus leaves on their voyaging canoes. Hawaiians cultivated pandanus in named groves, the remnants of which are vulnerable to this scale (Gallaher 2013). If the scale reaches Palau, it may prove fatal to that country's endemic pandanus. There are numerous examples[1] of endemic plants that evolved in isolation from the insect pests that attack other species in the same genus. These endemic species, although they are in the same genus as an insect pest's host, have no resistance. What may only cause minor damage to a host that the insect pest evolved with, may cause death to an island endemic host.

1 Several examples are described in the Upland Forests section of this report.

Left: Little fire ant on cocao plant. Photo by: Cas Vanderwoude
Right: Little fire ant workshops held by the Hawai‘i Ant Lab. Photo by: Ross Miller

Thysanococcus pandani does not kill mature trees, but it will kill seedlings and the remnant pandanus groves in Hawai‘i are at risk of dying (Gallaher 2013). Weaving pandanus leaves is an important cultural activity throughout the Pacific. It is done not just to produce household items, but to come together, speak native languages, and to perpetuate culture. The scale will compromise this activity as the damage it causes renders the leaves unfit for weaving (Gallaher 2013).

Agroforestry in the USAPI is under particular threat from the little fire ant (LFA) (*Wasmannia auropunctata*). LFA is native to South America and has been spreading around the Pacific. It will be a particular problem in Pacific agroforests because it thrives in fruit trees, forms multiple queen colonies that result in spectacular population densities, and it stings. Ants rain down on anyone who tries to harvest fruit from an LFA-infested tree. The ants lodge themselves between skin and clothing and their stings cause welts that can last for days. LFA can make gardening and harvesting fruit trees impossible. Additionally, LFA will add another burden for farmers because the ants tend scales and mealybugs that in turn decrease fruit production and reduce tree vigor[2] (Vanderwoude 2012). Although LFA colonies will persist in lawns and in beach habitats, entire colonies can thrive in a tree canopy and not be in contact with the ground surface. Traditional granular baits applied to the ground are ineffective against tree-dwelling ants, making this species difficult to control (Vanderwoude and Nadeau 2009).

2 Ants eat a substance called “honeydew” that scale insects and mealybugs excrete from their bodies. In order to have ready access to honeydew, ants protect scale insects and mealybugs from predators and ant infestations are often accompanied by increases in scale and mealybug populations that are high enough to cause serious plant damage.

Although the impacts of LFA would likely occur first in agroforests, this ant species would also seriously impact the ecology of the islands' natural forests. Natural forests also contain fruit trees that can harbor ants. Birds and flying foxes that forage, roost, and nest in ant- infested trees would likely be attacked by LFA if it were to become established. LFA would also make it difficult to gather cultural and medicinal plants in the forest. This pest has the potential to drastically change ways island people utilize and interact with their forests unless new management techniques are developed.

Management actions to protect against LFA

LFA arrived on Hawai'i Island in 1999 and was discovered on Guam in 2011 (Raymundo and Miller 2012). The rest of the USAPIs are at an extremely high risk of being invaded by this pest. To stop LFA from expanding, the US Forest Service and the Hawai'i Division of Forestry and Wildlife support the Pacific Ant Project, a program of the Hawai'i Ant Lab based in Hilo, Hawai'i. The Hawai'i Ant Lab has created an online ant identification key for Micronesia and conducted trainings in Yap, Pohnpei, and Kosrae, FSM; Saipan, CNMI; Palau, and Guam. Local forestry managers learn rapid response protocols in the event LFA is suspected or detected on their islands. The Lab has also invented innovative techniques to solve the problem of applying bait to reach ants in the tree canopy and conducts outreach for nursery owners and the general public.

Coconut Insect Pests and Pathogens

Coconut (*Cocos nucifera*) is both a cash crop and a pillar of traditional agriculture in the Pacific. Islanders use every part of the coconut tree for every part of their lives. Coconuts provide food, fiber, fuel, oil, medicine, and traditional craft materials. The Yapese say that a person who is dependable, cooperative, and helpful in the community is "like a coconut tree" and the people of Yap have over 300 different uses for coconut trees (People and Plants of Micronesia 2013).

In the RMI, copra, the shredded meat of the coconut, is a cash crop that provides employment and income, especially for smaller, less populated islands (RMI FAP 2010). The RMI Ministry of Resources and Development has created a special program called the "Tree of Life" which aims to increase the value of coconuts and coconut products from the Marshall Islands, reduce dependence of outer islands on imported fuel and copra subsidies, and develop value-added coconut products for local use and export (RMI FAP 2010). Palau is experimenting with a small-scale coconut oil for export industry (Palau FAP 2010).

Coconut trees are an important cultural plant in Hawai'i and were brought there by the original Polynesians. The coconut is one of the most popular landscaping plants in urban areas and is frequently planted in beach parks and other coastal areas. Tourism is an important part of the economy of all the island groups and coconut trees are an important part of the visitor experience. Unfortunately, there are a number of pests and diseases associated with coconut in the Pacific. The USAPI are free of some lethal pests and pathogens that occur in the Caribbean and elsewhere, but being on the other side of the planet is not enough protection in today's inter-connected world. There have been several instances of invasive pests from the Caribbean being transported to the USAPI. For example, the coqui frog (*Eleutherodactylus coqui*) was accidentally transported from the Caribbean in nursery plants, through the continental US to

Coconut grove, Kona, Hawai'i Island, Hawai'i. Photo by: J.B. Friday

Hawai'i, and on to Guam. Strong quarantine measures must be in place to protect the USAPI from pests that are lethal to coconut.

Coconut pests already present in the USAPI

Coconut rhinoceros beetle (CRB) (*Oryctes rhinoceros*) is a pest of coconut and other palms, including betel nut. In coconut, the beetle feeds on shoots and sap in the crown, reducing yield of nuts, damaging the crown, and sometimes killing the tree. Coconut rhinoceros beetle was introduced to American Sāmoa in 1909, Palau in 1942, and Guam in 2007. After initial introduction, Palau lost almost 50% of its coconut trees and coconut was completely extirpated from some islands. (Draft Hawaiian PRA 2013). In American Sāmoa, the fungus *Metarhizium anisopliae* and the *Oryctes* virus are used to control CRB. Damage to coconut trees is still prevalent in American Sāmoa, but the trees produce enough nuts and leaves to meet local needs (Schmaedick 2013). The *Oryctes* virus was also used in Palau and appears to be controlling CRB there, although damage is still visible (Sengebau 2013). *M. anisopliae* and the *Oryctes* virus have been disseminated on Guam with less success than in American Sāmoa. This may be because the beetles are genetically distinct from those in American Sāmoa (Moore 2012). Sanitation is an important part of preventing the spread of this species and outreach to residents encourages proper procedures when moving infested green waste (Moore 2012).

In December of 2013, CRB was discovered at the Joint Base Pearl Harbor-Hickam (JBPHH) military facility near Honolulu International Airport as part of a USDA funded survey. Numerous beetles, larvae, and pupae have since been found via traps or surveys of mulch piles. The source of the beetles is not known. The Hawaiʻi Department of Agriculture and USDA APHIS are leading a multi-agency response to the beetle. At the time of writing this report, the beetle had only been found breeding in mulch piles on JBPHH, and traps have been set up around the island and on the other main Hawaiian Islands to delimit the infestation. Destruction of infested material is underway in an effort to eradicate CRB on Oʻahu; this eradication program will likely be ongoing for several years. The coconut rhinoceros beetle prefers coconut trees, however it may damage other important trees such as hala (*Pandanus* spp.), breadfruit, banana, and native Hawaiian palms (*Pritchardia* spp.).

Coconut termite (*Neotermes rainbowii*) may be native to the Tuvalu island group (Waterhouse 1993) but was detected in Kosrae, FSM in 2013. It is probably the first occurrence of this pest in Micronesia (Moore 2013 (b)). Coconut termites kill coconut trees by hollowing out the trunk so that the tops can snap off in regular tradewinds. There are no known natural enemies and so far the only treatment appears to be application of fungi or nematodes (Waterhouse 1993).

There are at least two dozen other pests of coconut that occur throughout Micronesia including coconut hispid (*Brontispa* spp.), red coconut scale (*Furcaspis oceanica*), coconut scale (*Aspidiotus destructor*), New Guinea sugar cane weevil (*Rhabdoscelus obscurus*), and other species of termites (Muniappan 2002).

Invasive pests of coconut that do not yet occur in the USAPI, but are at high risk to arrive

Coconut mite (*Aceria guerreronis*) is a serious pest in the Caribbean and Florida. It causes premature fruit drop and fruit scarring and distortion (Howard and Moore 2012).

Red palm mite (*Raoiella indica*) attack palms and bananas and has not been detected in the Pacific. It initially turns leaves yellow and can lower fruit production or cause fruits to be very small (Hara and Bento date unavailable).

Lethal yellowing disease and its vector, American palm cixiid (*Haplaxius crudus*). Lethal yellowing disease, as its name suggests, is fatal to coconut and has severely reduced the number of coconut trees in Florida (Harrison and Elliott 2012).

Red palm weevil (*Rhynchophorus ferrugineus*) is widely considered to be the most destructive pest of palms in the world. It not only attacks coconut, but causes considerable damage to landscape and other economically important palms. It could likely devastate the rare, endemic wild palms of the USAPIs. In Oceania, red palm weevil has been detected in Australia, Papua New Guinea, the Solomon Islands, and Western Sāmoa. It is distributed widely around the world, but until recently had not been detected in North America. Unfortunately, researchers have recently discovered red palm weevil in a dying palm in Orange County, California (Center for Invasive Species Research 2013). Hawaiʻi is therefore at high risk for red palm weevil because there is so much shipping traffic from California.

Commercial Forests

Available land and market size limit commercial forestry in the US-Affiliated Pacific Islands (USAPI) to small-scale specialty species such as koa (*Acacia koa*) in Hawai'i and mahogany (*Swietenia* spp.) in the Republic of Palau and American Sāmoa. Managing koa for production is still a nascent industry and faces several challenges from insects and pathogens, lack of port and trucking infrastructure, and various market forces. Several other tree species also have the potential to become commercially profitable but an economically and ecologically sustainable timber industry has not yet developed.

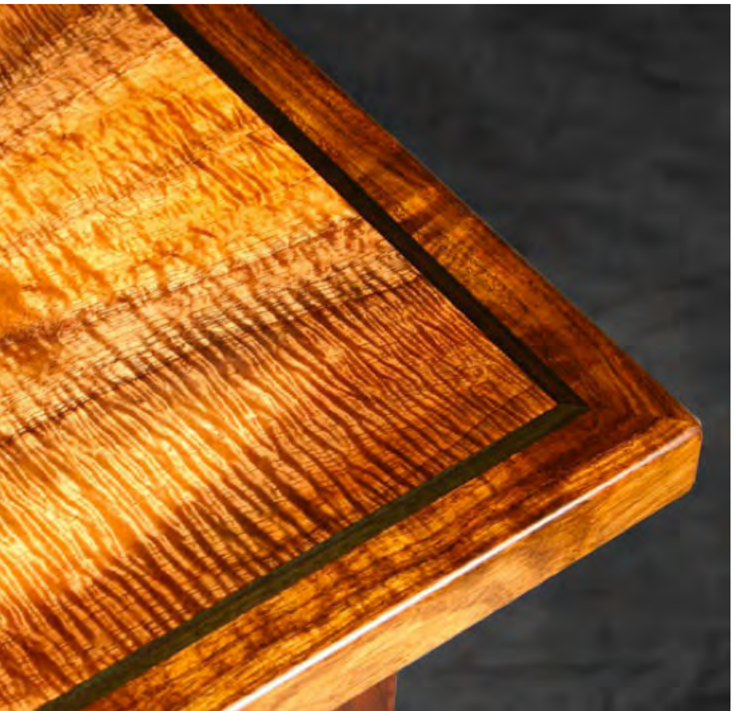
Hawai'i continues to strive to develop forestry as an industry that will bring income and employment to rural parts of the state. Hawai'i has been striving to diversify its agricultural sector following the crash of the sugar industry in the 1980's and a thriving and sustainable forestry sector will be a part of that effort. Biomass plants are being developed on Hawai'i and Kaua'i islands that promise important advancements in the biomass to energy markets.

Hawaiian Koa (*Acacia koa*)

Koa is found on all the main islands of Hawai'i and is endemic to the state. As a dominant or co-dominant species in Hawaiian forests, koa serves important ecological functions and provides shelter and food for endemic and endangered birds and insects. Ancient Hawaiians carved canoes, spears, and surfboards from koa and the wood is still an important part of Hawaiian cultural practices today.

The rich colors and highly figured grain of koa wood have made it the foundation for a vibrant woodworking industry in Hawai'i. Although craftsmen use other Hawai'i-grown woods such as mango (*Mangifera indica*), milo (*Thespesia populnua*), 'ōhi'a (*Metrosideros polymorpha*), and eucalyptus species; koa commanded 75% of the value of Hawai'i grown wood products in 2001 (Friday et al. 2006). Koa lumber commands a high price even in comparison to other exotic specialty woods such as mahogany, sapele, and walnut. Koa's commercial and cultural value

Left: Table made of koa. Photo by: Fogelvik Furniture
Right: Example of artisan woodoworking by Don Albrecht using young koa. Photo by: J.B. Friday



has generated much enthusiasm in Hawai'i to create ecologically sustainable and economically viable koa plantations. However, there are significant challenges to this goal.

Koa forestry is still at an experimental stage, as no commercial plantation has gone through a full rotation (Baker, Scowcroft and Ewel 2009, Friday 2011). Yield and revenues for koa are difficult to estimate before harvest which complicates financial planning (Friday 2011). The value of koa is determined by the figure and color of the heartwood and the straightness of the bole, features which vary wildly among individual trees (Baker, Scowcroft and Ewel 2009). The Institute for Pacific Island Forestry (IPIF) and the UH Mānoa College of Tropical Agriculture and Human Resources (UH-CTAHR) have been testing techniques to encourage straight growth form, but more research needs to be completed. Most koa in use today has been harvested from large, old trees. Despite koa's popularity with local woodworkers, there is no market for small-diameter trees and the cost of milling them exceeds their value. In order for commercial plantations to work, smaller diameter trees will have to become commercially viable (Friday 2011).

Insects and Pathogens on Koa

There are more than 200 pests and diseases associated with koa, but most of these do not cause significant damage (Baker, Scowcroft and Ewel 2009). A few, however, cause enough damage or mortality that they are obstacles to the commercialization of koa. Koa wilt (*Fusarium oxysporum*) is a virulent fungus that causes high mortality in koa at elevations less than 2,500 feet and in trees less than 15 years old (Friday 2011). Commercial plantations are likely to have cohorts of young trees located at lower elevations; therefore, the disease is a major impediment to the commercialization of koa. There is no treatment for koa wilt and genetic resistance is the only way to manage the pathogen in commercial plantations (Baker, Scowcroft and Ewel

Cycloneda sanguinea preying on Acizzia uncatoides (Acacia Psyllid). Photo by: J.B. Friday

2009). The Hawai'i Agricultural Research Center[3] (HARC) is screening koa families from across the state to identify those that are wilt-resistant. HARC has so far identified 74 high-surviving families (Jones 2013).

The invasive black twig borer (BTB) (*Xylosandrus compactus*) is an introduced ambrosia beetle that bores into the trunk and twigs of koa to deposit its eggs. The beetle carries *Fusarium solani*, but this fungus does not appear to be fatal to koa (Daehler and Dudley 2002). Small saplings die from stem breakage caused by the weakness from the beetle's entry holes and galleries. The beetle may limit regeneration in natural forests but it is more abundant at lower elevations (below approximately 2900 feet where plantations are likely to be) and so it is a problem for the development of commercial koa (Daehler and Dudley 2002). Researchers are developing traps and lures for the borer. IPM methods, such as removing other host tree species from koa stands and treating seedlings with systemic insecticides before outplanting are also being tested (Conant et al. 2010).

The acacia psyllid (*Acizzia uncatoides*), also introduced, feeds on the new shoots of koa branches, stunting the growth and causing trees to have a bushy form (Baker, Scowcroft and Ewel 2009). Although the psyllid is not fatal, it may render the tree unfit for commercial use and for cultural uses such as canoe-making. Two species of lady beetles were released as biocontrols for acacia psyllid in 1973. Only one established (Leeper and Beardsley 1976), but it does not exert enough control, so acacia psyllid remains a concern. In August of 2013, a Special Local Needs label was approved for the pesticide Movento (active ingredient spirotetramat) for control of acacia psyllid. The label restricts use to three specific plantations (SLN No. HI-1320002 2013).

3 In cooperation with the US Forest Service, Natural Resources Conservation Service, and the Hawai'i Department of Land and Natural Resources, Division of Forestry and Wildlife.

Left: Close up of the Koa Looper Moth (Scotorythra paludicola)
Right: Defoliation of koa from the koa looper moth. Photos by: J.B. Friday

The native koa looper moth (*Scotorythra paludicola*) causes extensive and high levels of defoliation on koa. The moth is normally present at low levels, but its populations explode at irregular intervals for unknown reasons and defoliate entire stands of koa. There have only been six outbreaks since 1900, and the most recent one began in late 2012 (Hauff 2013). In the past, healthy stands have recovered after being defoliated, but a recovering forest may be more susceptible to acacia psyllid, which feeds on new growth. Invasive plants, including fire-adapted grasses, may take advantage of more open canopy and the nutrient pulse from insect frass, and aggressively take over following koa looper moth outbreaks. UH entomologists are investigating whether pheromones can be used to manage moth outbreaks in commercially valuable koa stands (Hauff 2013).

Programs to Support Sustainable Koa Harvest and Koa Forest Restoration

DOFAW occasionally allows salvage logging of koa on land that it manages, but the majority of koa grown for harvest is on private land. There is new interest in establishing koa timber management areas on state lands for long term growth of koa and other native timbers that would eventually support commercial harvest interests. DOFAW supports sustainable koa silviculture through the state's Forest Stewardship Program and by managing the Hawai'i portion of the US Forest Service Forest Stewardship program. These programs provide funding and technical assistance to owners of non-industrial private forestland. The newly established Tropical Hardwood Tree Improvement and Regeneration Center (TropHTIRC), a partnership between federal, state, public, and private entities, including the US Forest Service, UH-CTAHR, and others, is conducting research on the specific problems confronting koa silviculture (Giardina and Michler 2013).

Left: Cross sections from three different, neighboring 8-year-old koa trees that show the different levels of heartwood development in each. Right: Seeds of koa (Acacia koa). Photos by: J.B. Friday

The Hawaiʻi Forestry Industry Association, UH-CTAHR, the US Forest Service Pacific Northwest and Northern Research Stations, the Department of Hawaiian Homelands, and Kāmehameha Schools and Parker Ranch (two large private landowners) recently partnered on a project to demonstrate the potential of young koa for woodworking. Young koa trees ranging from 25 to 34 years old were harvested, milled, and turned into pieces that were then displayed at venues around the state (Hawaiʻi Forest Institute 2009). Professional woodworkers commissioned to create the pieces agreed that the young wood was lighter in color and less dense than wood from old-growth trees, but most also thought that the young koa had value and could be marketed.

Kapāpala Forest Reserve is a state forest on the southern flanks of Mauna Loa that is being managed for both ecological and cultural purposes. The reserve contains many spectacular koa trees that may be appropriate for carving traditional Hawaiian canoes. DOFAW is working with traditional Hawaiian canoe makers and cultural practitioners to create a process to harvest and replant koa in a culturally and ecologically appropriate manner. A $300,000 grant from the US Forest Service will help repair fences, remove ungulates and invasive plants, and develop a process to select harvestable trees.

ʻIliahi (*Santalum* spp.)

Sandalwood has been a globally traded commodity for centuries and the rapacious harvest of Hawaiʻi's endemic sandalwood species was the first step in the deforestation of Hawaiʻi in the early 1800's (Culliney 2006). (See the Alien Secondary Forests section of this report for a complete discussion). Today, sandalwood is valuable enough that one or two of Hawaiʻi's six endemic species may again become commercially profitable. The price of Indian sandalwood (*Santalum album*) has risen 3,500% over 10 years: from $3,000 per metric ton in 2003 to $109,000 in 2013. Although Indian sandalwood garners the highest price, Australia's endemic sandalwood species (*Santalum spicatum*) sells for $13,200 per metric ton, almost twice the price of copper. Australia exports $26.4 million worth of sandalwood each year (Bell 2013). On Hawaiʻi Island, a consortium of investors reportedly expected to receive $15 million for sandalwood logged from 2,900 acres of privately-owned agriculturally-zoned lands on Hawaiʻi Island (Tummons 2010).

Sandalwood may become a profitable industry in Hawaiʻi that would create an incentive to plant and sustainably utilize this endemic tree species. However, sandalwood is so valuable right now that there may be unintended consequences of its commercialization. A commercial plantation may try to maximize profit by importing and planting the higher value and faster growing Indian species, *Santalum album*. Importing this species increases the risk of an invasive insect or pathogen being introduced to Hawaiʻi that could be fatal to the state's endemic sandalwoods. Importation of sandalwood should be thoroughly examined to determine pest pathways and other concerns associated with importing live plant material.

The list of unknowns with respect to the commercialization of sandalwood in Hawaiʻi is greater than what is known. Current Hawaiʻi law does not require permits for anyone logging sandalwood on land that is zoned agricultural. As a result, the state does not know where or how much sandalwood is being logged (Mann et al. 2013). An inventory to assess the status and distribution of Hawaiʻi's sandalwood on both state-managed forest reserves and private land would provide critical information that could be used to make decisions regarding its management. (Mann et al. 2013). In 2012, the Hawai'i State Legislature passed resolutions that called for the establishment of a task force to examine forestry and regulatory issues surrounding the commercialization of sandalwood.

Eucalyptus (*Eucalyptus grandis* and *Eucalyptus deglupta*)

In the late 1990's through the early 2000's industrial eucalyptus plantations were planted on former sugar cane and pasture lands in Hawai'i. Over 20,000 acres on Hawai'i Island were planted with a variety of eucalyptus, the most common being *Eucalyptus grandis*. Another 4,000 acres on Kaua'i were planted with a mixture of *Eucalyptus deglupta* and the invasive, nitrogen-fixing legume *Falcataria moluccana*. Harvesting of the Hawai'i Island plantations began in 2012 and approximately 480 acres were harvested annually in 2012 and 2013. As of December 2013, 106,000 tons of logs were exported in seven shipments to China, primarily for veneer production. Tree tops and small-diameter logs are being stored pending completion of a biomass energy plant in Pepe'ekeo on Hawai'i Island. Harvest of the Kaua'i plantations is also pending completion of a biomass energy plant on that island. These two biomass plants represent $200,000,000 of investment in the Hawai'i wood products industry (Mann 2013). Hawai'i gets most of its electricity from imported diesel fuel and the state has set a target of achieving 70% clean energy by 2030 (Hawai'i State Energy Office 2013).

Honduran or big-leaf mahogany plantation, Nekken, Palau. Timber from this non-native tree is used locally for carving story boards and local construction. Natural regeneration is thick in the understory. Photo by: J.B. Friday

Although the rust disease *Puccinia psidii* infects many eucalyptus species, especially young plants, the disease has not significantly affected the coppice resprouts of harvested *Eucalyptus grandis* trees on Hawai‘i Island. Cryphonectria canker, an important pest of *Eucalyptus* elsewhere in the world, has been found attacking both *Eucalyptus grandis* and *E. saligna* on Hawai‘i Island.

Other Timber Species

Flooring and molding are also produced in Hawai‘i of locally harvested species. The most common species used is *Eucalyptus robusta*, although *Eucalyptus saligna*, *E. deglupta*, *E. microcorys*, *E. citriodora*, mango (*Mangifera indica*), and other non-native species are also used, as is the native ‘ōhi‘a (*Metrosideros polymorpha*). Bowl turning is a popular use of local woods, including the native kou (*Cordia subcordata*) and milo (*Thespesia populnea*), as well as the Polynesian introduced kamani (*Calophyllum inophyllum*) and the non-native Norfolk Island pine (*Araucaria columnaris* and *A. heterophylla*). After koa, mango, milo, kamani, and local non-native conifers are the most popular species used in local furniture construction.

Timber Management Areas

DOFAW manages Timber Management Areas (TMAs) on Hawai‘i , Kaua‘i, Maui, and Moloka‘i Islands. These TMAs are primarily stocked with non-native tree species, although there are new discussions happening related to establishing native TMAs. The Waiakea TMA near Hilo is approximately 12,000 acres, of which 480 acres are undisturbed native forest. The remaining acres are mostly exotic species such as Queensland maple (*Flindersia brayleyana*), *Eucalyptus saligna*, *Eucalyptus grandis*, Australian red cedar (*Toona ciliata*), and tropical ash (*Fraxinus uhdei*) (DLNR, DOFAW 1998). This area has not been actively managed over the past 40 years. The former vendor that held the license to harvest for nearly 20 years did not act on it due to a number of reasons. Now, however, 1,000 acres are being harvested and the state is seeking vendors for the remaining acres. It is still uncertain which species will be replanted at the site. The site is not suitable for koa as the low elevation and high rainfall make the trees susceptible to koa wilt (Sprecher 2013), although other native species may be considered.

Mahogany on Palau and American Sāmoa

Palau’s Nekken agricultural research station in Aimeliik state provides seedlings and technical assistance for growing big-leaf mahogany (*Swietenia macrophylla*) as well as other species (Palau FAP 2010). The Palau Forest Action Plan identified the need for technical assistance in developing mahogany for commercial export and determining sustainable levels of harvest.

There is a very small scale demonstration area in the Tafuna area on Tutuila behind the American Sāmoa Community College. This is a trial of several species of mahogany, most of which grow quite well. However, little thinning has occurred, so determining growth rates without competition has not been possible. *Theobroma cacao* is planted under some of the mahogany and this agroforestry regime appears to be working well.

J.B. Friday, extension forester with the College of Tropical Agriculture and Human Resources at the University of Hawai‘i at Mānoa, contributed extensively to this chapter.

Native coastal forest of Scaevola taccada and pandanus tectorius in American Sāmoa.
Photo by: J.B. Friday

Luke Senney hiking in Yela Mangroves, Kosrae, FSM.
Photo by: Rich Mackenzie

Coastal and Mangrove Forests

Coastal Forests

The coastal forests of the US-Affiliated Pacific Islands (USAPI) include mangroves, which are adapted to survive with their roots being submerged in brackish water, and littoral strand forests which are made up of hardy species that can withstand continuous salt-spray and intense sunlight. Coastal and littoral forests are important nesting and roosting habitat for sea turtles, seabirds, and other wildlife. Flying foxes, seabirds, and sea turtles use the littoral strand forest that borders American Sāmoa's undeveloped coastlines (American Sāmoa FAP 2010). In the Republic of the Marshall Islands (RMI), coastal forests are important as windbreaks to reduce salt-spray and desiccation of inner agroforests (RMI FAP 2010). Mangroves and littoral strand forests also form physical barriers that provide protection during storms. These forests are also important in reducing stormwater runoff and protecting reef systems from sedimentation.

Mangrove Forests

Mangrove forests are native ecosystems to all the USAPI except Hawai'i, where they are considered invasive[4]. Naturally occurring mangroves can survive in brackish water and support important coastal ecosystems that sustain healthy fisheries, protect coasts, provide communities with wood products, and are a significant source of carbon storage. Despite their importance, mangroves are threatened by sea level rise caused by climate change, overharvesting, development, and storms.

4 Several species of mangrove including *Buguiera sexangula*, *Conocarpus erectus,* and *Rhizophora mangle* have been introduced to Hawai' i; *R. mangle* was introduced as early as 1902 (Malama O Puna 2011). Mangrove roots damage the walls of fishponds, which are historically and culturally important to Native Hawaiians. Studies at an infestation site of *R. mangle* on Hawai'i Island showed that this species creates conditions that favor alien fish at the expense of native ones, excludes coral, decreases water quality, and destroys nesting habitat for four endemic shorebirds (Malama O Puna 2011).

Left: Fa'afo'i Tony Mauga-Lei stands beside mangrove plants which have much cultural and ecological importance in American Sāmoa. Photo by: Jolie Goldenetz Dollar Right: Omekrael Sadang of Palau Forestry measures sediment elevation in order to monitor how mangroves will respond over the next decade to increased sea level rise. Photo by: Rich Mackenzie

Ecosystem Services of Mangrove Forests

Many islanders depend on the mangrove crabs, clams, and fish gathered in mangrove forests (Gilman et al. 2006). Mangroves also act as nurseries for many fish species caught in open water. The complex root structures provide protective nursery habitat and host epiphytes that are important food sources for marine life. The underwater architecture of mangrove roots give fish and crustaceans refuge from predators and the wave energy of storms. (MacKenzie and Cormier 2012).

Mangrove forests form a physical barrier that helps to protect islands from storm surges and tsunamis. Trees in the mangrove forests of Kosrae, FSM can reach heights nearly 100 feet tall (Hauff et al. 2006). Mangroves not only protect islands from the sea, but their roots trap sediments that would otherwise run off into the ocean and smother coral reefs. Trapped sediments offset the constant decrease in elevation that happens to islands as a result of erosion. This soil accretion is a crucial service that slows down coastal erosion caused by climate change induced sea-level rise (Krauss et. al 2010).

Studies from Yap and Palau have contributed to the literature on carbon storage and have shown that mangroves and the deep muck beneath them store approximately twice as much carbon per hectare as tropical moist upland forests in Brasil and Mexico (Kauffman et al. 2011). This means that when mangroves are cleared, they release a disproportionate amount of carbon for their land area as the muck decomposes. Studies estimate that mangrove deforestation worldwide generates 10% of annual carbon emissions even though they only occupy 0.7% of tropical forest area (Donato et al. 2011).

Threats

As sea levels rise as a result of climate change, the seaward edge of mangrove forests will convert to open water. Mangroves can migrate landward if buildings, roads or naturally steep terrain do not block their path (Gilman et al. 2006). They may also survive rising sea levels if enough sediment is deposited to offset the increased depth (Krauss et al. 2010). However, if neither of these conditions is met, mangroves will be lost.

Island residents harvest mangrove timber for fuel, construction, tools, and traditional art (Ewel 2010). One study on mangrove harvest rates on the island of Kosrae, FSM found that harvest rates were 10% over 10 years and that one species of mangrove, *Rhizophora apiculata*, was preferred over others. However, rates varied widely depending on how close the mangrove stand was to a village or road (Hauff et al. 2006). People also cut channels through mangrove forests for access to their homes from the sea (FSM FAP 2010 and Cannon 2014).

Mangroves are cleared for road construction and new roads may impact the hydrology and open up new areas to harvesting. Palau lost 321 acres of mangrove forests due to construction of the national highway (Palau FAP 2010). Palau Forestry estimates that Palau has been losing 9.8 acres of mangroves annually over the past 40 years. Mangroves were lost to landfills, development, aquaculture, and construction of a new national highway. Despite this, mangrove acreage overall in Palau is growing due to an increase in mangrove forests in Airai Bay. The bay is silting up and aerial photographs show that between 1968 and 2005 mangrove cover within Airai Bay nearly doubled from 1,038 acres to 1,952 acres (Palau FAP 2010). Unfortunately, the new mangrove areas are encroaching on sea-grass bed habitat that is beneficial for some fish species. Local fishermen have expressed concern that the mangroves are outcompeting seagrass bed habitat (Kitalong 2014).

Mangroves along a tide creek, Palau.
Photo by: Rich Mackenzie

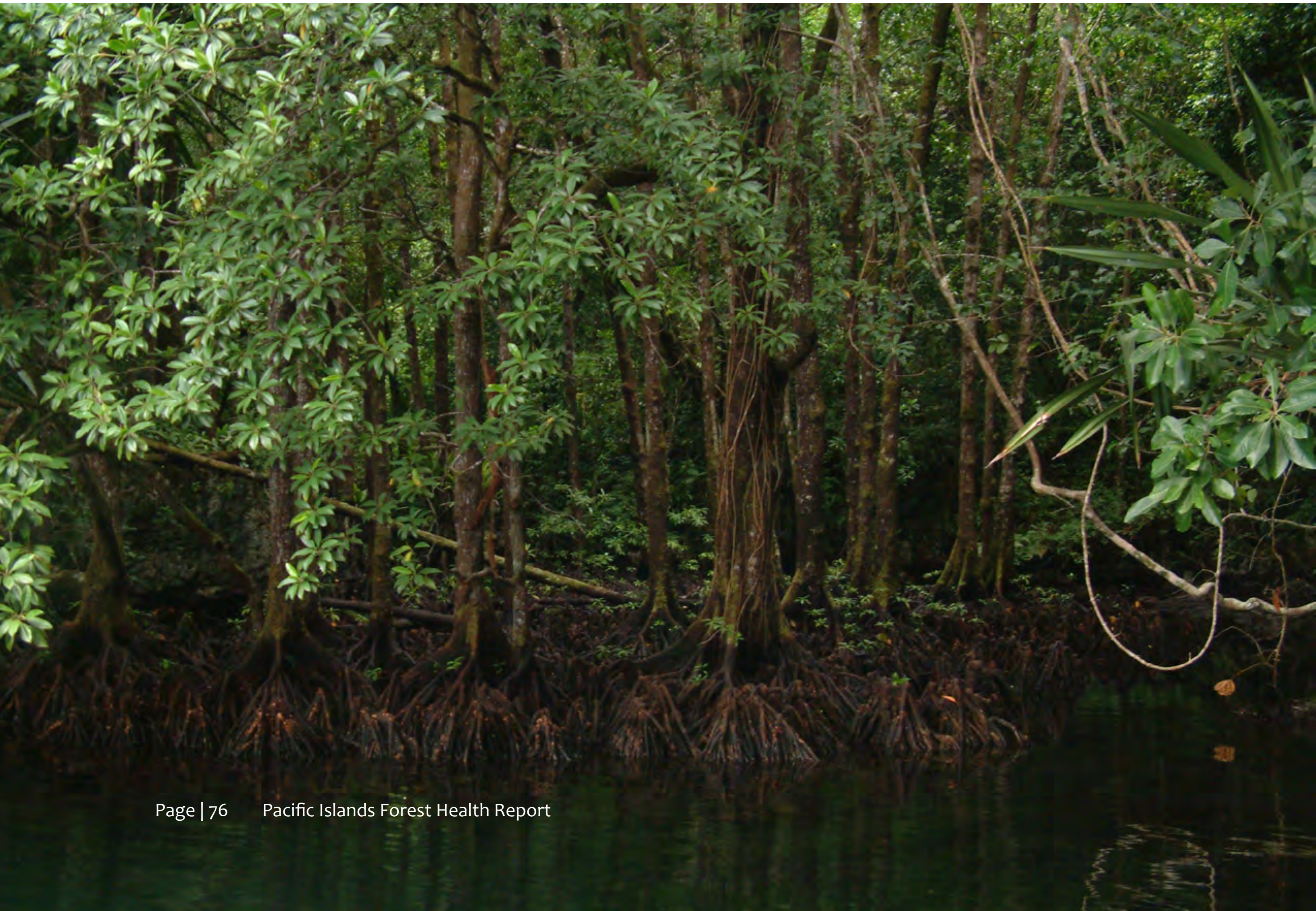
Forest Inventory Analysis (FIA-USFS) data collected in 2001 show that American Sāmoa lost 18% of its mangrove forests between 1988 and 2001 (Donnegan et al. 2001). In 2002 and 2003, American Sāmoa Forestry conducted a comprehensive assessment of mangroves in which they estimated that five acres of mangroves are lost annually to development, agriculture, and fill (Bardi and Mann 2004). At this rate, all of American Sāmoa's mangroves will be gone by 2028 (American Sāmoa FAP 2010).

Illegal dumping, development, and pollution are also a problem. A preliminary rapid assessment of mangrove forests in American Sāmoa found that some mangrove forests were so heavily covered with trash that the thick layer of garbage prevented seedling regeneration (Bardi and Mann 2004). Construction can alter water flows contributing to mangrove dieback. Piggeries that border mangrove forests may also threaten mangroves in American Sāmoa as the waste is flushed into the mangroves. The effect that high nutrient levels have on mangroves is not well understood (Bardi and Mann 2004).

Storms

Mangroves are important as buffers for storm surges and even tsunamis. Mangroves are the first physical barrier that the ocean encounters when approaching land and mangroves can

Bruguiera ymnorrhiza a species of mangrove in Palau.
Photo by: J.B. Friday



suffer severe damage from these events. For example, a 6.2 acre mangrove forest in American Sāmoa was severely damaged from two cyclones that passed through in the early 1990's (Bardi and Mann 2004). Older stands that may be somewhat weakened from disease are more fragile. Liu (2013) found that Yap's (FSM) mangroves declined by 8.93% between 2003 and 2010 and gaps were detected in over half of Yap's mangrove stands. Managers suspect that Typhoon Sudal, which swept through Yap in 2004, is the main culprit. Trees with open wounds after the storm would be more susceptible to butt rot diseases caused by *Phellinus* and *Ganoderma* spp. and some die-off would therefore occur in the years after the storm (Cannon 2014).

Management actions to mitigate threats

Mapping mangroves and monitoring their health can help identify and prevent decline. Among the USAPI, the availability of mangrove data and planning varies. Mapping and delineating of mangrove boundaries has been completed recently in American Sāmoa, CNMI, Palau, and Guam. It is still incomplete in the atolls of the RMI (Gilman 2006). Mapping was completed for most of the high islands of the FSM in the 1980's (Falanruw et al. 1987, Falanruw et al. 1987(b), MacLean et al. 1986, Whitesell et al. 1986). Mangroves are a focus of RMI's National Conservation Area Plan (Reimaan National Planning Team 2008). On Guam, mangroves are

A view of native forests with mangroves from Pala Lagoon, Nuuuli Village, Tutu'ila, American Sāmoa.
Photo by: Jolie Goldenetz Dollar

restricted to two places: Apra Harbor and Achang Bay. The mangroves in both these areas are protected as marine preserves, but there is no active monitoring program (Santos 2013). The mangroves of CNMI are protected inside a park (CNMI FAP 2010).

Palau Forestry Section, the Institute of Pacific Island Forestry (IPIF), and the Palau International Coral Reef Center (PICRC) are working together to measure the rate at which the mangrove forest floor is rising or falling relative to sea level rise on Babeldaob, Palau's largest island. The objectives of this work are to 1) identify mangroves that are keeping up with or exceeding sea level rise and that should be prioritized for conservation, 2) identify mangroves that are not keeping up with sea level rise and that require a more active management plan, and 3) to more accurately model impacts of sea level rise to inform coastal management plans or strategic plans to adapt or respond to climate change (MacKenzie 2013). This project is part of the Micronesia Challenge, a region-wide effort to effectively conserve 20% of terrestrial resources by 2020.

Urban Forests

The majority of the population of the US-Affiliated Pacific Islands (USAPI) lives along coasts. Urban forests are therefore also coastal forests that help to mitigate the impacts of high population densities along coastlines. Honolulu, Hawai'i's largest city, has the most intensively managed urban forest in the USAPI. Urban and community forests elsewhere in the USAPI differ from those in the continental United States in that they are intertwined with and sometimes double as traditional agroforests, coastal forests, and mangroves. Urban trees provide food, medicine, fiber, fuel, and the perpetuation of traditional cultures.

In the Republic of the Marshall Islands (RMI), the bulk of the urban forest canopy is agroforest (RMI FAP 2010). In Yap, Federated States of Micronesia (FSM), the urban and community forests extend from town to village through agroforests and into natural forests where the Yapese collect medicines (FSM FAP 2010). In the Republic of Palau, the Urban and Community Forestry Council funded a survey in the urban states of Koror and Airai and found that Palauans had 26 different uses for 56 different species of urban trees. Trees in the most densely populated areas of Palau were used for lumber, medicine, drink, firewood, housing, chewing, furniture, flower leis, spices, spears, animal food, holding the soil, wrapping materials, brooms, pillow filling, slingshots, shelter, benches, glue, and basket weaving (Palau FAP 2010). Highly managed agroforests are not a component of the urban forest canopy in Hawai'i, but locals still collect fruit and lei flowers from public trees.

Urban plantings in a road median on Maui.
Photo by: Heidi Bornhorst

Lion's Park in American Sāmoa.
Photo by: Jolie Goldenetz Dollar

Urban and community forests also serve to educate islanders about their unique natural heritage. There are tree species in the USAPI that are not found anywhere else on earth and showcasing native species where people live is important for creating community support for conserving upland forest ecosystems. American Sāmoa is planning to demonstrate shoreline stabilization using native plants (American Sāmoa FAP 2010). Majuro and Kwajalein atolls, where approximately 75% of the population of the Marshall Islands lives, plans to promote the planting of heritage tree species as part of its Urban and Community Forestry Strategic Plan (RMI FAP 2010). Guam Forestry is also planting an endangered tree that grows well in urban areas to educate the public about Guam's indigenous flora.

The demands of growing trees in urban areas and the desire to use trees that are widely recognized around the world as part of the quintessential tropical palette may lead landscapers to avoid using unique native plants in favor of more common species that are used all over the world, some of which may become invasive. There are several examples in Hawai'i of ornamental species becoming ecosystem-changing weeds. Miconia (*Miconia calvescens*), fountain grass (*Cenchrus setaceus*), and pampas grass (*Cortaderia* spp.) are a few of the most notorious examples. These species were planted as ornamentals by private landowners and eventually spread into natural areas. Importing new species is risky as they may become invasive in new habitats.

Ecosystem Services of Urban Forests

Urban trees can control the amount of polluted stormwater runoff that settles on the coral reefs of the USAPI. Leaves and branches intercept and store rainfall, and root growth and

White terns lay eggs and raise young in the urban forest of downtown Honolulu.
Photo by: Keith Swindle

decomposition increase the rate and capacity at which water percolates through the soil (Vargas et al. 2007). Honolulu's average annual rainfall—22.2 inches—falling over 1,000 square feet of impervious surface generates approximately 13,505 gallons of stormwater runoff annually (CWRM 2008). A study of Honolulu's trees found that a sample of 43,817 trees consisting of 26 different species intercepted on average 5.9% of that amount of stormwater, or approximately 798 gallons annually (Vargas et al. 2007).

Tropical urban forests provide wildlife habitat as well. For example, in Honolulu, the wide limbs of monkeypods planted along Kalākaua Avenue are nest sites for white terns (*Gygis alba*). White terns may prefer the large trees in Honolulu's urban canopy because they provide some protection from predators (Vanderwerf 2003).

In the USAPI, where the sun is very strong all year long, urban trees are also important for cooling and shade (Vargas et al. 2008). Trees can result in reducing air conditioning costs and carbon emissions. The analysis of the benefits of Honolulu's urban trees mentioned above calculated that the sample of 43,817 urban trees in Honolulu (approximately 19% of the total urban trees on the island of O'ahu) reduce atmospheric CO_2 by 3,340 tons annually through avoided energy use and carbon sequestration (Vargas et al. 2007).

Threats

Invasive insects and pathogens are often first detected in the urban forests, thus the urban forests become sentinels for insects and pathogens that can move into upland forests. In October 2012, lobate lac scale (*Paratachardina pseudolobata*) was discovered infesting a ficus tree in a

2006 Urban and Community Forest Project on Ebeye, Republic of the Marshall Islands.
Photo by: Republic of the Marshall Islands Ministry of Resources and Development

historic park. The Hawai'i Department of Agriculture (HDOA) has documented an additional 32 host species, including six native plants. HDOA is monitoring the effects to determine future management actions (USFS 2013). The scale was discovered in Florida in 1999 and has since infested 307 host plants in 52 different families. The scale infests branches and twigs, sometimes becoming so dense they form a dark lumpy crust. Sooty mold associated with the scale can cover the branches and sometimes the leaves. In Florida, susceptibility varies widely between species, but in natural areas it has killed Florida's native wax myrtle at some sites. The scale species was newly described in Florida and its origin has not yet been determined, making it difficult to pursue a biological control program as a management option (Howard et al. 2010).

The little fire ant and cycad scale, discussed in the Agroforestry and Upland Forests sections of this report respectively, established in Hawai'i and shortly afterwards were detected on Guam. Guam is at risk for any pest already established in Hawai'i (and vice versa); given the wide host range of lobate lac scale, this pest will likely cause damage in Guam's urban and natural forests upon arrival and establishment.

American Sāmoa has suffered from an invasion of the Seychelles scale insect (*Icerya seychellensis*) that attacked breadfruit and other urban trees, but has since been effectively controlled by releases of natural enemies (American Sāmoa FAP 2013). On Guam, the coconut rhinoceros beetle has caused considerable damage to coconut trees, which is important to agroforestry,

Kawananakoa Elementary School Tree Planting.
Photo by: Heidi Bornhorst

but also makes up part of the urban canopy. Coconut trees have been removed from parks and urban areas due to the extent of their damage. More details on coconut rhinoceros beetle can be found in the Agroforestry section of this report.

Hurricanes, typhoons, and heavy storms can damage the urban canopy so severely that their ability to protect coral reefs by soaking up stormwater runoff is disrupted. A study conducted in Palm Beach County, Florida found that three hurricanes between 2004 and 2006 caused a 17% loss in tree canopy cover, which in turn led to an additional 146 million gallons of stormwater runoff (American Forests 2007). In the USAPI, urban forests are also coastal forests, and are therefore extremely vulnerable to climate change. If storm frequency and intensity increase as a result of climate change, urban trees will be physically damaged. Drought will stress urban trees, potentially making them more susceptible to insect and disease pests. Parks and community green spaces are often located near the ocean in the USAPI and these could be lost as sea level rises.

Management Actions to Mitigate Threats

A way to address the use of invasive species in Hawai'i's urban forest is through the Hawai'i Pacific Weed Risk Assessment (HPWRA) and Plant Pono program. The HPWRA is a free service to landscapers, nursery owners, and the general public that assesses the risk of certain species to become weedy based on their biological characteristics and invasive history elsewhere. The service was originally funded by the USDA Forest Service through Hawai'i's urban forestry program, Kaulunani, and is now supported by the Hawai'i Invasive Species Council. Over 1,400 plant species have been screened as of 2013 (DLNR 2013). Plant Pono[5] is an outreach program that builds upon the information already accumulated by the HPWRA, and in working with urban landscapers, has compiled a list of alternative plants and trees that have been assessed as being a low-risk for becoming invasive. The Plant Pono website lists these species and makes recommendations on which landscape needs they would be most suited to fill (Plant Pono 2011).

Well-maintained urban trees will be better able to withstand invasive species, storms and climate change. All the USAPI forestry departments have determined that training tree-workers to bring their arborist skills up to international standards is necessary. The American Sāmoa Forest Action Plan (2010) cited poor pruning as a precursor to trees becoming infected with disease in its urban forests. In FSM, workers will sometimes remove trees entirely to make way for construction instead of just pruning them (FSM FAP 2010). All the USAPI cited the need to develop and implement best management practices for urban forestry. The US Forest Service has provided arborist training to all the USAPI, however, training programs will need to be ongoing to maintain and increase capacity.

5 *Pono* is a Hawaiian word meaning correct behavior or righteousness.

Arbor Day celebration at Maui Nui Botanical Gardens.
Photo by: Heidi Bornhorst

Conclusion

The forests of the US-Affiliated Pacific Islands—the Commonwealth of the Northern Marianas (CNMI), Guam, Republic of Palau, Federated States of Micronesia (FSM), Republic of the Marshall Islands (RMI), American Sāmoa, and Hawai‘i—are unique and diverse. These forests provide ecosystem services that make life on the islands possible. Upland forests keep soil healthy and maintain the islands' hydrological systems. They provide food, fiber, medicine, and lumber. The islands' endemic tree species are essential to indigenous cultural practices. Agroforestry is an agricultural system traditional to the USAPI that provides food and some of the benefits of upland forests such as erosion control and wildlife habitat. Commercial forestry is generally small-scale in the USAPI but has the potential to provide economic opportunities for residents there. Coastal and mangrove forests break the force of tidal surges and are habitat for juvenile fish that are an important local source of food. Urban forests are also coastal forests. They protect reefs by reducing stormwater runoff and keep cities cooler by providing shade.

Invasive plants, insects, pathogens and mammals are landscape level threats to forest health in the USAPI. All can potentially change forest structure and diminish the ecosystem services forests provide. Historical evidence from Hawai‘i, Guam, and CNMI shows how vulnerable USAPI forests can be. Native forests can be completely replaced with alien plant communities. Climate change threatens all forest types and islanders, especially in RMI and FSM, are already feeling the effects on their fresh water supplies and food security. Forest fires are a problem and the majority of them are intentionally set. Deforestation and erosion can lead to such depleted soils that trees can no longer grow, leading to a cycle of erosion that requires a massive undertaking to remedy.

Unfortunately, these threats will intensify in the future. The results of climate change will be felt more acutely as global temperatures rise. The flow of goods to the USAPI will likely increase and so will the risk of new plant species, pests and pathogens entering the islands. Despite the immense challenges, there is good reason for optimism. USAPI forestry departments and their partners are implementing innovative programs that protect forests and engage the community. Invasive species partnerships across the USAPI have stopped the spread or eradicated some of the world's most notorious invaders. The quick release of biological controls has saved endemic tree species from extinction. Public engagement has halted deforestation and encouraged landscapers to choose non-invasive plants. Research is ongoing to increase food security and resilience to climate change. While much has been lost on these islands, there are still significant intact, functioning forests to protect. Indeed, the island communities have nowhere else to turn for the valuable services forests provide.

Appendix 1

There is a need to build capacity, make or maintain social and professional connections, and increase societal knowledge and support of the importance of USAPI forests, and their health, not only to those living in the USAPI, but to the rest of the world. Attention to the following issues will address these needs and result in improving the health of Pacific island forests.

1. **There is a lack of data available to define and prioritize management actions.** Forest health data for the USAPI are scarce. New technologies using remote sensing data are being explored and might offer cost effective means to map pests and pest-caused damage and monitor forest change over time. Examples like the red bead mapping project in American Sāmoa demonstrate the usefulness of such technology. Reliable data can also help policy makers determine funding priorities. Improved record keeping, data input and management, and the development and use of consistent monitoring protocols can also provide additional information regarding forest health.

2. **Resources and capacity in the islands needs to increase.** Most of the USAPI do not have the financial resources or capacity to adequately manage their forests and mitigate forest health threats. They, and to a lesser degree Hawai‘i, rely heavily on US federal funding. Finding other funding sources, especially as the availability of US federal dollars declines, will be important for forest management and to mitigate forest threats. This endeavor, however, is complicated by lack of capacity in some forestry departments to seek out alternative sources of funding and write competitive proposals. Grant writing and project/program management capacities (including budgetary and financial) need to be improved for island programs to be successful. Tourist fees, taxes on land purchases, and import cargo fees are some examples of funding sources that have been used successfully in the region for natural resource management and biosecurity. Private foundations and NGOs are another funding source, but require capacity at the local level to be successful.

3. **Biosecurity/quarantine systems are not sufficient to protect islands from newly arriving invasive pests.** All of the islands lack adequate biosecurity safeguards at points-of-entry. USDA AHPIS has a Plant Inspection Station on Guam, but no inspectors to staff it. Imports currently come into the territory uninspected by Federal PPQ staff. Hawai‘i’s Department of Agriculture has been starved of resources with the decline of large agricultural commodities like sugar and pineapple. While to some degree solving these issues is up to local governments, the US federal government and other organizations can help support local biosecurity systems. Risk assessments, public education, inspector training, pest identification and detection training, and regional communication on newly arriving pests are all areas where outside entities could assist. The unique ecosystems and economies of these islands should be recognized and considered when determining federal and state quarantine regulations and procedures.

4. **Increased preparedness for known invasive species could mitigate damage.** Some of the invasive insects and pathogens described in this report could have potentially been prevented with improved quarantine and early detection/rapid response. The loss of Guam's endemic *fadang* to cycad scale in particular may have been avoided. The scale was active in Hawai'i and yet, non-native cycads from Hawai'i continued to be imported into Guam. In addition, steps to reduce the likelihood of establishment can sometimes be taken, such as removal of susceptible hosts from ports-of-entry. Hawai'i's invasive species committees have been successful with detecting and responding to invasive plants, but effective programs that focus on insects and disease pests are a larger challenge. Early detection systems are critical, but when pests are not yet described or detection tools are not developed or are ineffective, challenges are immense. Rapid response plans for invasive species should be written to facilitate an organized and structured response to an incursion. Having a source of emergency funds immediately available can also be critical to bridge the gap until federal or other funding becomes available. Finally, educating the local population and tourists about the threat of invasive species should help reduce the accidental import of invasive species.

5. **Biological control is a vital tool that could be used more effectively.** The use of classical biological control to control damaging, wide-spread pests is often the only long-term management option. In Hawai'i, where there is a long history of biocontrol, containment facilities are small, outdated, and provide only limited ability to conduct the required research. International collaboration on the initial exploratory and non-target testing phases could partly alleviate this situation. For example, by conducting non-target testing off-shore where expensive containment facilities are unnecessary. Improved coordination on the regional scale, especially with countries in possession of strong biological control infrastructure such as New Zealand and Australia, is also needed. Many targets, where biological control agents might be effective, are shared by Pacific islands and pooling resources is an obvious, more effective strategy. Additionally, documenting successes and failures with post-release monitoring programs is critical to fully realize benefits from existing agents. Unfortunately, monitoring is frequently neglected. In addition, improved public understanding and support of biocontrol as a safe, effective management tool is needed. In Hawai'i particularly, the cumbersome regulatory process makes releasing biological control agents extremely time consuming. This, combined with under-staffed departments and a skeptical public, can indefinitely delay crucial projects.

6. **Increased regional cooperation among island groups and with international entities, including the US federal government, is needed.** The Pacific islands are a diverse region of many distinct languages as well as sometimes complicated governmental and international jurisdictions. Although the islands share many similarities, including forest health threats, coordinating among them can be a difficult challenge. Many of the issues raised in this report rely on improved coordination among the islands and with various international partners including the US government. Some islands in the south Pacific are under Australian and New Zealand assistance programs and several

entities exist that focus on issues related to forest health. The Secretariat of the Pacific Regional Environmental Program sponsors two invasive species networks: the Pacific Invasive Learning Network (PILN) and the Pacific Invasive Partnership (PIP). These networks work with all USAPI jurisdictions to enhance communication among invasive species professionals in the Pacific, but participation by the US, including Hawai'i, is largely absent. Not only is there no one at the federal level working in the larger Pacific island region on these issues, participation by federal employees is hindered by State Departments rules which can limit participation in international fora. Alternative ways to engage in region-wide coordination on invasive species and other forest health issues should be sought.

7. **Tree care in urban settings needs improvement (sanitation, pruning, tree worker education and training, ordinances).** Providing appropriate care for urban trees is necessary for healthy urban forests. Many islands lack trained professionals to prune and care for trees. The US Forest Service offers arborist training in the islands but more sustained work and commitment by island forestry personnel in this area is needed. Educating communities about the importance and care of trees in villages and other public places would help foster pride in trees and reduce neglect.

8. **The importance of island forests, the threats they face, and successful management need to be effectively communicated, both within island communities and to an international audience.** It is of vital importance that island communities, their leaders, as well as outside funding entities understand the importance of forests to island sustenance. Sustained efforts are needed to tell the stories of these islands and the forests they rely upon to a wider audience. In Hawai'i, much of the success the state has had with invasive species programs can be attributed to public perceptions, as well as acknowledgement by leaders of program importance. Many islands do not have the education, outreach, and public relations staff to do this. Assessing public outreach and education needs and subsequently working with partners (US Forest Service, WFLC, contractors, etc.) to develop materials can fill some of the gaps.

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