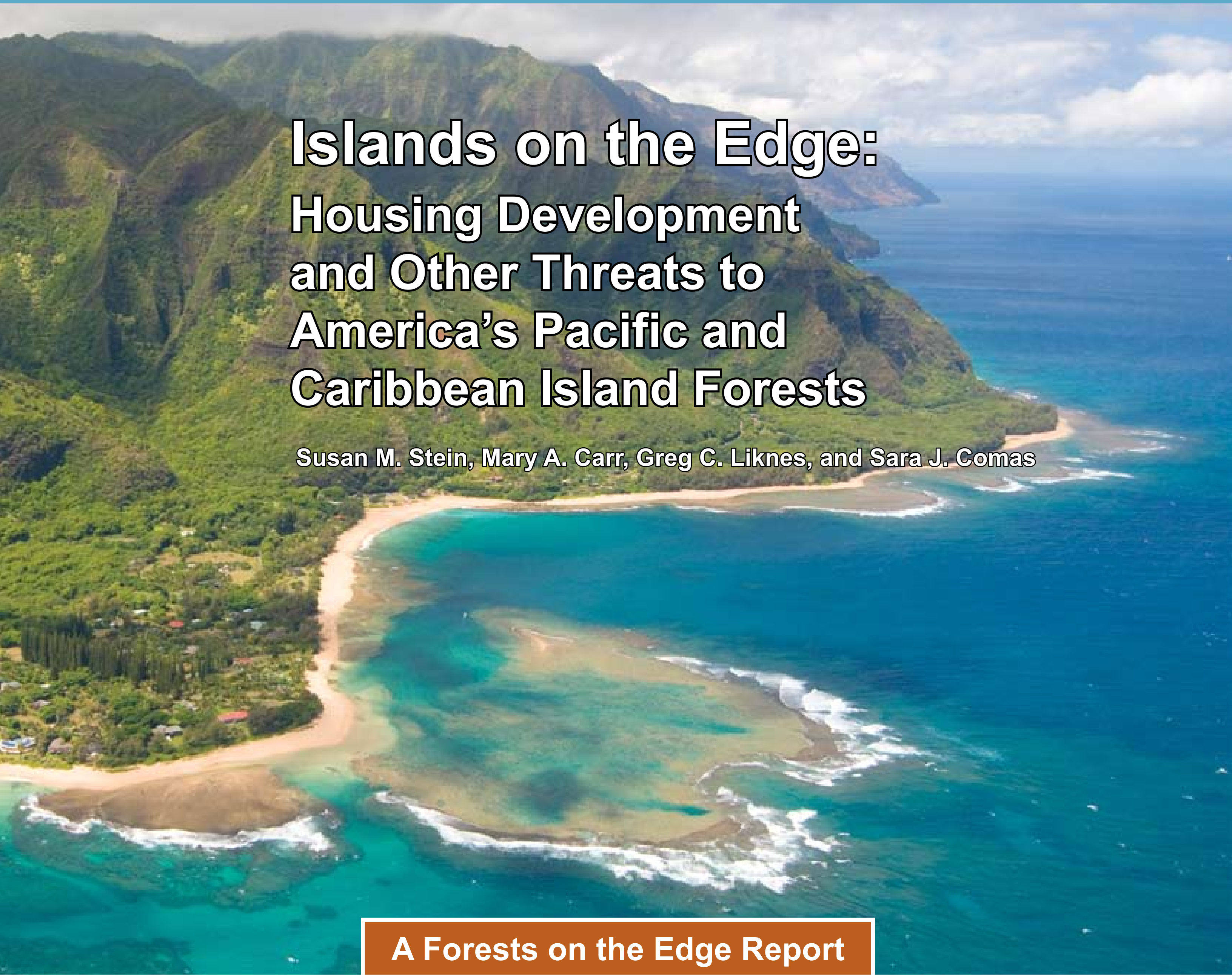
USDA

United States Department of Agriculture

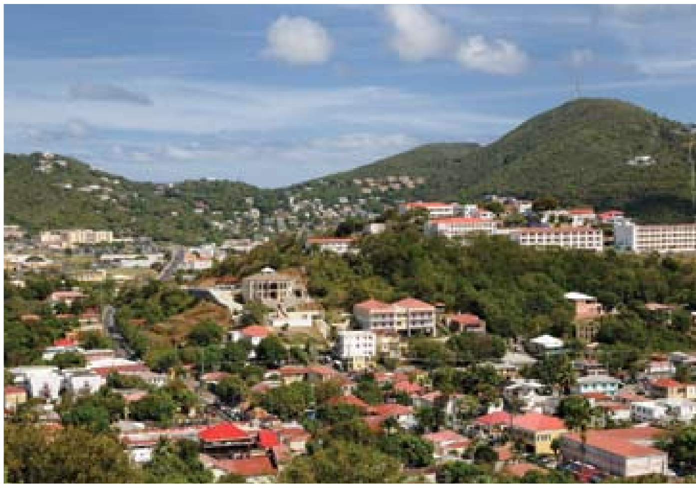


Islands on the Edge:

Housing Development and Other Threats to America's Pacific and Caribbean Island Forests

Susan M. Stein, Mary A. Carr, Greg C. Liknes, and Sara J. Comas

A Forests on the Edge Report



Forest Service | Northern Research Station | State and Private Forestry | General Technical Report NRS-137 | August 2014

ABSTRACT

Stein, Susan M.; Carr, Mary A.; Liknes, Greg C.; Comas, Sara J. 2014. Islands on the edge: housing development and other threats to America's Pacific and Caribbean Island forests: a Forests on the Edge report. Gen. Tech. Rep. NRS-137. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 55 p.

This report provides an overview of expected housing density changes and related impacts to private forests on America's islands in the Pacific and Caribbean, specifically Hawaii, Guam, American Samoa, the Commonwealth of the Northern Mariana Islands, Puerto Rico, and the U.S. Virgin Islands. We discuss the vulnerability of island forests to conversion for housing development, introduction and spread of invasive species, and risk of uncharacteristic wildfire, among other concerns. Our maps and projections suggest that in localized areas from 3 to 25 percent of private forest land is likely to experience a substantial increase in housing density from 2000 to 2030. Resource managers, developers, community leaders, and landowners should consider the impacts of housing development and invasive species on ecosystem services in coming decades.

Key Words: housing density, tropical forests, subtropical forests, ecosystem services

Photo by J.B. Friday.

AUTHORS

Susan M. Stein is the director of U.S. Department of Agriculture's National Agroforestry Center, and was formerly coordinator of private forest land studies for the U.S. Forest Service. She can be contacted at sstein@fs.fed.us. **Mary A. Carr** is a technical publications editor, U.S. Forest Service, Publishing Arts, Olympia, WA. **Greg C. Liknes** is a research physical scientist, U.S. Forest Service, Northern Research Station, St. Paul, MN. **Sara J. Comas** is a natural resource specialist, U.S. Forest Service, Cooperative Forestry Staff, Washington, D.C.

Hanalei Valley, Hawaii. Photo by Skibreck, istockphoto.com.

INTRODUCTION

The Pacific and Caribbean islands that are U.S. States, territories, or otherwise affiliated with the United States include virtually all the Nation's tropical forests as well as other forest types including subtropical, coastal, subalpine, dry limestone, and coastal mangrove forests. Although distant from America's geographic center and from each other—and with distinctive flora and fauna, land use history, and individual forest issues—these rich and diverse ecosystems share a common bond of change and challenge.

Island forests are subject to pressures that are similar to those on the mainland, including conversion of forest for housing, agriculture, and industry; introduction and spread of invasive species; and risk of uncharacteristic wildfire. But islands by their nature, with relatively small or constrained land areas and fresh water limitations, can be more vulnerable than mainland areas to such impacts.

This report provides an overview of expected housing density changes and related impacts on America's Pacific and Caribbean island forests. These areas are often overlooked in forest assessments owing to insufficient or incompatible data. Specifically we discuss forests located on:

- Pacific Islands[1]: Hawaii, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands
- Caribbean Islands: Puerto Rico and the U.S. Virgin Islands

[1]We do not include discussion of other Pacific islands affiliated with the United States, such as the Republic of the Marshall Islands, Federated States of Micronesia, and Republic of Palau, because sufficient data are not available to provide housing density projections for these areas.

About Forests on the Edge

Forests on the Edge (FOTE) is a project developed by the U.S. Forest Service in conjunction with universities and other partners. The project aims to increase public understanding of the contributions of and pressures on America's forests and to create new tools for strategic planning. This report is one of several FOTE reports that identify areas across the Nation where private forests might change because of housing development and other factors. Although previous reports have focused on the conterminous 48 United States, this report focuses solely on Pacific and Caribbean island forests.

For each area, we present an overview of forest geography and human population trends; selected forest issues and priorities as identified in recent assessments; and maps and projections of housing density in coming decades. Case studies highlight specific places and situations that illustrate the trends or issues relevant for the area under consideration.

PRIVATE FOREST VALUES: BENEFITS AND CHALLENGES ON THE ISLANDS

In the contiguous 48 States, more than half the forests are privately owned (Smith et al. 2009); in the Pacific and Caribbean islands described in this report, the proportion of privately owned forest varies but is as great as 87 percent (Table 1). Regardless of their extent, private forests play a key role in protecting water quality, furnishing diverse habitats for fish and wildlife, providing the raw materials for timber products and other forest goods, and sustaining valuable ecological functions such as flood and climate regulation across the landscape[2] (Smail and Lewis 2009).

Private forests on the islands are particularly important to biological diversity and the supply of water, wood, recreation, and social values for people (West. For. Leadership Coalition 2010). These islands support highly diverse native ecosystems with unique and often endangered plant and animal species, significant coral reef systems, and human populations that are substantially dependent on traditional subsistence lifestyles (Cannarella 2010, Carpenter et al. 2007, U.S. Forest Service 2007).

[2] Such goods and services are often referred to as "ecosystem services;" for more information, visit the Forest Service ecosystem services Web site: http://www.fs.fed.us/ecosystemservices.

Table 1. America's subtropical and tropical islands[a]

Islands	Total land area[b] (acres)	Existing forest[b] (acres)	Existing forest[b] (percent)	Percent of forest privately owned[c]	Population (2010)[d]
Pacific					
Hawaii	4,125,125	1,676,516	41	46	1,360,301
Guam	133,966	63,663	48	69	159,358
American Samoa	47,123	23,868	51	85	55,519
Commonwealth of the Northern Mariana Islands	75,139	49,948	67	78	53,883
Caribbean					
Puerto Rico	2,187,577	1,020,400	47	87	3,725,789
U.S. Virgin Islands	84,226	53,278	63	83	108,612

[a] Republic of the Marshall Islands, Federated States of Micronesia, and Republic of Palau are not included in this report due to insufficient data.

[b] NOTE: Acreages and percentages of total land area and forest cover presented in this table reflect data analyzed for this project. They may differ from statewide resource assessments, FIA data and reports, or other sources because of differing ways of classifying and calculating forest land area. Because forest land definitions vary by location, local expertise was consulted to determine which land cover or vegetation categories in the data layers should be considered forest. See appendix for details. Land cover can change rapidly; the data used for this report represent snapshots in time for the purposes of modeling and analysis.

[c] Percentages of private forest reflect a combination of data for land cover as described in the Methods section and ownership data from Theobald (2005).

[d] U.S. Census Bureau (2011a-e). Population data for 2010 are provided here and in the text to provide a glimpse of recent population numbers. However, the analysis for this report was based on Theobald (2005), which used data from the 2000 census; updated housing density data for the trust territories were not available at the time of this analysis.

Forests in Hawaii are critical for supplying clean water. Photo by twildlife, istockphoto.com.

The exceptional benefits provided by tropical and subtropical island forests include (U.S. Forest Service 2007):

- Rich array of flora and fauna often found nowhere else in the Nation or the world
- Diverse human cultures knowledgeable about sustainable agroforestry systems and cultural uses of forest products that could help guide future management of continental areas
- Forest ecosystem services such as fresh water aquifers and river systems, reef protection, and shoreline shelter and protection
- “Early warning” indicators for global warming, sea-level change, storm frequency and severity, environmental degradation, and effects of climate and environmental change
- Unique opportunities for scientific research in the ecology and sustainable management of tropical and subtropical forests

Although each island is different, the forest products and ecosystem services they support are at risk when forest land is altered or lost. Some islands experience temporary or permanent population booms resulting in direct conversion of private forests to housing and other developments. Many islands serve as conduits for the movement of people and invasive species back and forth between mainland and island, contributing to the spread of nonnative plants and animals that can disrupt

What Are Private Forests?

Private forests are forest lands owned by individuals, families, corporations, organizations, tribes, or the forest industry. Public forest lands are those owned by Federal, State, or local governments. Public forests are not available for residential development but can be affected by increased housing density on or near their boundaries (Stein et al. 2009).

ecological cycles and displace native species. All the islands considered here are vulnerable to the effects of climate change, especially with regard to sea level rise, hurricanes, and droughts.

Like their mainland counterparts, private forest owners on America's Pacific and Caribbean islands are frequently under economic and societal pressure to sell their land for development or other uses (Alig 2007). However, market-based approaches that provide landowners with economic incentives to retain and conserve forest lands may not be widely available, understood, or accepted. Finding the right balance among often divergent values for private forests can be an enormous challenge for island forest landowners and managers.

METHODS: HOW WE STUDIED HOUSING DENSITY CHANGES ON ISLAND FORESTS, 2000 TO 2030

To assess the potential for increased housing development to occur on private forests, we constructed maps with geospatial data layers that represent: (1) projected housing density changes between 2000 and 2030, (2) land ownership, and (3) land cover. We used geographic information systems (GIS) software to combine the data layers and identify private forest lands and projected housing density changes on those lands. Additional details on methods are provided in the appendix.

Housing Density

As in previous Forests on the Edge studies, the terms housing development and increased housing density refer to an increase in the number of housing units[3] per unit area on rural lands such that the housing density shifts from either the rural I or rural II categories to a higher density category (Stein et al. 2007, 2009; Theobald 2005), where:

- **Rural I** is 16 or fewer housing units per square mile;
- **Rural II** is 17 to 64 housing units per square mile[4]; and
- **Exurban-urban** is 65 or more housing units per square mile.

Housing density projections were prepared by David Theobald, using the approach described in Theobald (2005). The projections are based on several factors, including past and current statistics on housing density and population[5], past growth patterns, road densities,

[3] A single family household is considered to be a unit, as is a single building with multiple households. Seasonal homes not occupied as primary residences are included in this analysis.

[4] 64 units per square mile is roughly equivalent to 1 unit per 10 acres; 16 units per square mile is roughly equivalent to 1 unit per 40 acres.

[5] This analysis is based on population and housing density data from Theobald (2005), which was based on the 2000 U.S. Census (Census Bureau 2001a–c) as a baseline; 2010 housing density data for the trust territories were not available at the time of this analysis.

Urban Forests on the Islands

Urban forests are particularly important on tropical islands, where they provide essential green infrastructure for diverse lowland and coastal plant and animal communities. These forests are the first line of defense from catastrophic storms and inland water runoff. These forests also reduce city temperatures by providing shade, provide refuge for migrating birds, reduce air pollutants, contribute to carbon sequestration, and supply a host of other ecological and social benefits (Cannarella 2010).

Footbridge in a mangrove forest, Aguirre State Forest, Guayama, Puerto Rico. Photo by Magaly Figueroa, U.S. Forest Service, International Institute of Tropical Forestry.

and locations of urban areas. For American Samoa's Tutuila island only, we also used methods described in Lim et al. (2010) to apply an elevation threshold to the housing density model to preclude development in areas above 100 meters (328 feet) elevation (see appendix for details).

Housing density projections for islands based on current models and data can be thrown off by unforeseen population shifts. Islands can experience variable population bubbles as people alternate between small and large islands depending on fluctuating circumstances such as changing climate or rising sea levels; global economies; and human needs related to jobs, health care or education.[6] Because of their highly unpredictable nature, such irregular population fluxes over time were not factored into the islands housing density projection models.

Sayafe (*Melochia villosissima* var. *compacta*), a beautiful shrub found in Guam. Photo by Daniel W. Clark.

Land Ownership and Forest Cover

Private forest ownership reflects a combination of data for land cover from various sources and ownership data from Theobald (2005). Forest land definitions for most islands varied by location, so local experts also were consulted to determine which land cover or vegetation categories in the data layers should be considered forest. For Hawaii, we used the LANDFIRE vegetation database (USDI and USDA 2013). For the Commonwealth of the Northern Mariana Islands, Guam, and American Samoa, we used vegetation layers mapped by satellite imagery compiled by the U.S. Department of Agriculture (USDA), Forest Service (Liu and Fischer 2006a, 2006b, 2007). For Puerto Rico except Mona Island, we used the National Land Cover Data (NLCD) database (Homer et al. 2007, based on Kennaway and Helmer 2007); for Puerto Rico's Mona Island, we used Martinuzzi et al. (2008). For the U.S. Virgin Islands, we obtained land cover from satellite imagery (Kennaway et al. 2008). See the appendix for more detail on how mapped categories were aggregated into forest or nonforest classes.

[6] Personal communication from K. Friday, 2012, cooperative forester, U.S. Department of Agriculture, Forest Service Pacific Southwest Region and Pacific Southwest Research Station, State and Private Forestry.

Mapping and Monitoring Island Land Cover

A consortium has been formed by Federal, State, and local governments to map land cover changes for certain Pacific islands and territories. The project uses geospatial technology and remote sensing data (such as high-resolution satellite imagery) to map island vegetation. Completed maps, data, and reports are shared with partners and made available to the general public. For details, visit the Pacific Southwest Region Web site at http://www.fs.usda.gov/detailfull/r5/forest-grasslandhealth/?cid=fsbdev3_046690&width=full.

Forest Trends, Issues, and Priorities

Information about forest and population trends, forest resource issues, and priorities was largely gleaned from the 2010 statewide assessments of forest resources (known as "SWARS") reports, which were created for each State, U.S. territory, and U.S.-affiliated island as a requirement of the 2008 Farm Bill (Food, Conservation, and Energy Act of 2008). The assessments identify priority forest issues and landscapes as the basis for developing a strategy across all ownerships to "conserve working forests, protect forests from harm, and enhance public benefits from trees and forests."

Molokai, Hawaii. Photo by Unclegene, istockphoto.com.

HAWAII

The Hawaiian Islands consist of eight large islands (Hawaii, Maui, Lanai, Molokai, Kahoolawe, Oahu, Kauai, and Niihau) and 124 small islands, reefs, and shoals. Located in the Pacific Ocean, more than 2,000 miles from the nearest continent, the Hawaiian archipelago is among the most isolated places on the planet (USGS 2005). Hawaii is the only tropical island that is also a U.S. State.

Hawaii's Forests and Population Trends

About 41 percent (1.7 million acres) of Hawaii's land area is forest (Table 1); two-thirds of the forest land is considered native. About 46 percent of Hawaii's forest is privately held, while most of the remainder is managed by the State (Gon 2006).

Hawaii's forests reflect its geological history and extreme climatic contrasts, which yield a wide range of ecosystems from subalpine forests, to lowland and montane rainforests, to mesic (moderately wet) forest, to lowland dry forests and coastal forests. The Hawaiian Islands contain more than two-thirds of the global life zones delineated by Holdridge (1947). On some islands, climatic gradients range from desert to rainforest to alpine communities in the span of fewer than 20 miles (U.S. Forest Service 2011). The composition of most plant communities in Hawaii is determined by a combination of climate and elevation (Wagner et al. 1999). Tree species most common to Hawaii's wet tropical forests include a myrtle (Myrtacae) species, *Metrosideros polymorpha*; and a legume (Fabaceae) species, *Acacia koa*. Other important plants include the tree fern *Cibotium glaucum*, and numerous species in the coffee family (Rubiaceae) such as *Psychotria hawaiiensis* and *Coprosma* spp.

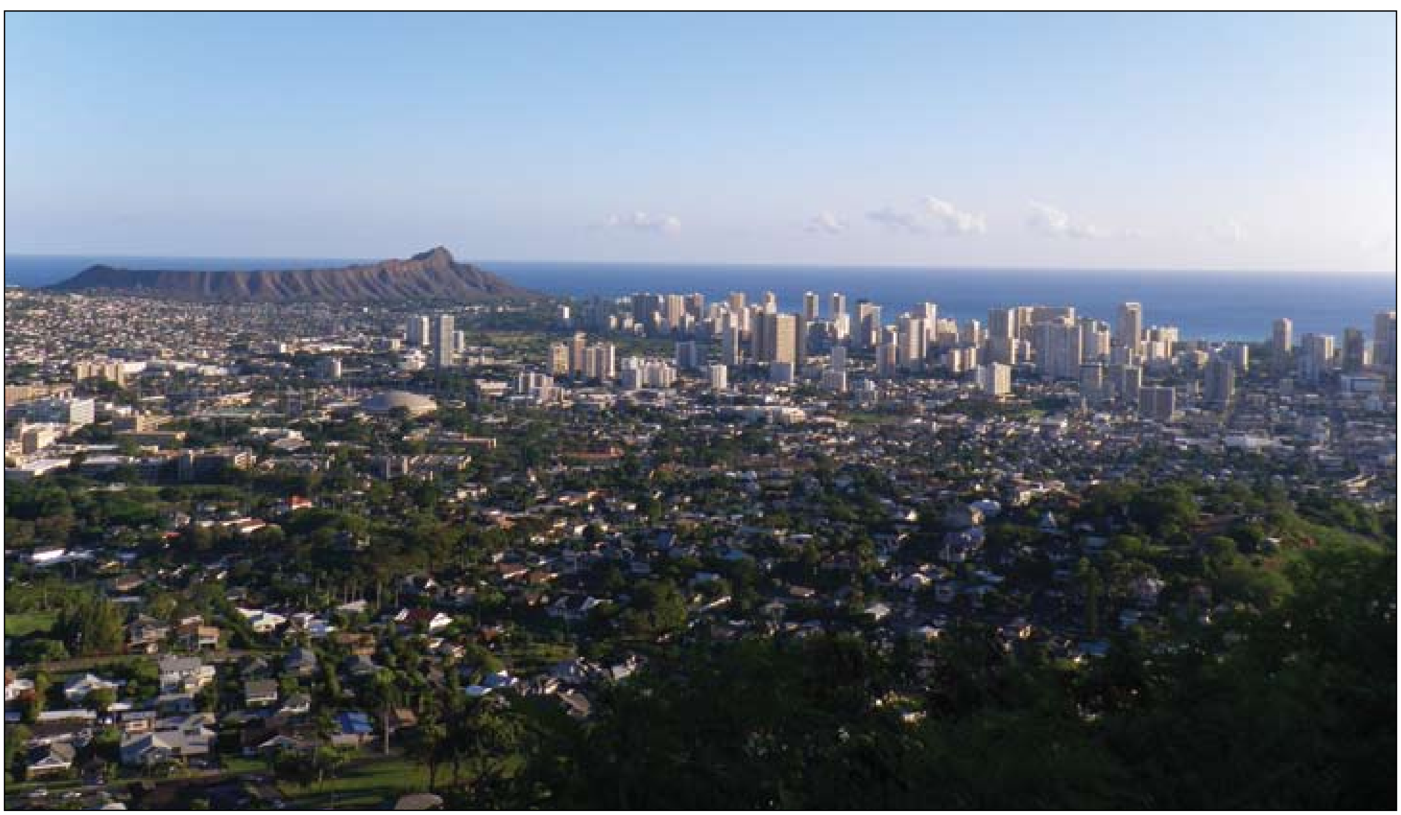
This breadth of habitats supports some of the world's most unique examples of tropical biodiversity, much of it endangered (Wagner et al. 1999) or found nowhere else on earth. Some 90 percent of Hawaii's 10,000 native species of plants and animals are found only in the Hawaiian archipelago (U.S. Forest Service 2011). These extraordinary forests are sources of fresh water, forest products, recreational opportunities, and spiritual and cultural values as well.

Hawaii's residents number about 1.4 million people (U.S. Census Bureau 2011a), 70 percent of whom live in Honolulu. The State's population is estimated to have grown 12.3 percent between 2000 and 2010 (U.S. Census Bureau 2011a). In Hawaii, 48 percent of all land is zoned for conservation, 47 percent is zoned agriculture, and 5 percent is zoned urban (Cannarella 2010). However, urbanization is occurring at a rapid pace on most non-urban zoned lands across the State. This is particularly true of the island of Hawaii, where the 24 percent population increase from 2000 to 2010 was the highest in the State (U.S. Census Bureau 2011a).

Native *Psychotria hawaiiensis*, Hawaii Island, Hawaii. Photo by J.B. Friday.

On some smaller islands, human population tends to decrease over time as people move from smaller islands to larger ones in search of jobs, health care, and educational opportunities.[7]

[7] Personal communication from R.J. Cannarella, 2012, forester, Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife Planning and Information Services.



As seen in this view above Honolulu, Oahu, Hawaii's lowland wet forests are almost gone, in part due to development. Photo by J.B. Friday.

Hawaii's lowland wet forests are almost gone, with many of the last remaining patches found on the eastern, windward sides of the largest islands (Zimmerman et al. 2008). More than 90 percent of dryland forests in Hawaii have also been lost, primarily to conversion for pasture, spread of invasive species, and increased wildfire (Bruegmann 1996). The remaining fragments of dry forest—which contain more than 25 percent of Hawaii's threatened and endangered species—are heavily degraded by deforestation, land development, fire, over-grazing, and invasive plant species such as fountain grass (*Pennisetum setaceum*), which is capable of carrying fire into areas not usually prone to fires (Cabin et al. 2000).

Conversion of forest lands to nonnative ecosystems is perhaps the greatest threat to Hawaii's dry forests, rather than direct loss of forest cover to housing development; many agricultural subdivisions are well-managed, and stringent zoning laws help mitigate direct impacts from development and urbanization.[7]

Montane wet forests are currently the most healthy native ecosystem and are the only forests to harbor significant populations of Hawaii's rare native avifauna. However, these forests also are pressured at higher elevations by nonnative pasture grasses and at lower elevations from lowland invasive woody species.

Forest Resource Issues and Priorities

- **Invasive species**
  The introduction and spread of invasive nonnative species of plants and animals—including weeds, insects, pathogens, and vertebrate animals—dominate Hawaii's forest resource issues (U.S. Forest Service 2011). More than 300 native Hawaiian species are known to be extinct; these include more than 50 percent of all native birds, more than 60 percent of snails, and more than 10 percent of all of the known flora (Wagner et al. 1999). All of the archipelago's imperiled plants and birds are threatened by nonnative species (Wilcove et al. 1998). Even in places where human population has decreased, particularly on smaller islands, invasive species introduced by former residents may be invading and spreading now because of lack of management when people move out.[8]

[8] Personal communication from S. Mann, 2012, forestry program manager, Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife.

Endangered by Invasive Species

Hawaii comprises only 0.2 percent of the Nation's land mass but contains 30 percent of the Nation's federally listed endangered species (Cannarella 2010). Loss of habitat due to impacts from invasive species is one of the principal factors affecting the 437 plant and animal threatened or endangered species in Hawaii (U.S. Fish and Wildlife Serv. 2012). Invasives can be rapidly introduced and spread by housing development and related activities. Conversion to nonnative species in Hawaii typically follows disturbance such as clearing for agriculture or urban development. Human modification of habitats in Hawaii is primarily responsible for the distribution of several plant weeds that have become widespread on degraded lands, such as strawberry guava (*Psidium cattleianum*), albizia (*Falcataria moluccana*), and Christmasberry (*Schinus terebrinthifolius*).

Federally endangered Hawaiian crow or 'Alala (*Corvus hawaiiensis*). Photo by Daniel W. Clark.

All of Hawaii's imperiled plants, birds, and some other animals, such as this rare Oahu tree snail (*Achatinella curta*) and endangered Kokio (*Kokia drynarioides*) are threatened by nonnative species. Photos by Daniel W. Clark.

- **Water quality and quantity**

  "In Hawaii, the most valuable product of the forest is water, rather than wood" (Cannarella 2010). Water quality and quantity are being significantly affected by human activities and land use changes such as urbanization and diversion of water for increasing urban populations, complicated by wildfire, pollutants, and invasive species (Cannarella 2010).

- **Wildfire**

  Most native species in Hawaii evolved without fire and do not recover well after wildfires (Canarella 2010). Over the past century, human-induced changes to ecosystems and human-caused ignitions have led to increased wildfire frequency and size (Cordell, no date; LaRosa et al. 2008). Throughout the State, the average acreage burned increased fivefold and the average number of fires increased sixfold from the early (1904-1939) to the mid (1940-1976) part of the 20th century (Cuddihy and Stone 1990). In particular, a serious grass-fire cycle has become established; introduced plants, particularly grasses, are often more fire-adapted than native species and are able to invade numerous habitats after a fire, further increasing the frequency and/or intensity of fires (Cannarella 2010; Cordell, no date). Erosion, particularly on steep-sided watersheds, is increasing as a consequence of fire, further reducing the integrity and biodiversity of Hawaii's watersheds (Cannarella 2010).

- **Urban and community forestry**

  Hawaii's urban forest has a mixture of young and mature canopies, and some newer urban areas have few or no trees. Frequent tree damage problems include topping, trimming, and poisoning of street trees; dumping of hot charcoal at the base of park trees; and asphalt or concrete proximity damage to root systems, among other impacts of urbanization (Cannarella 2010).

Prescribed burns, as seen here in Oahu, are used to prevent damage to forests and native species from wildfire. Photo by U.S. Army Garrison-Hawaii, Flickr.

Frequent urban tree damage includes topping, trimming, vandalism, and poisoning of street trees. Photo by Angelina Earley, Flickr.

Development Projections

About 8 percent (~ 65,000 acres) of Hawaii's private forest land is projected to experience a substantial increase in housing density from 2000 to 2030, such that the category will shift from very rural (rural I) to less rural (rural II) or to urban-exurban (Fig. 1). Substantial housing increases are projected for localized areas of each of Hawaii's five largest islands. Most of these areas are located close to or just inland of coastal areas and include the windward (wet) coast on the Island of Oahu; the Puna, Hilo, and Hamakua districts on the Island of Hawaii; the east end of Molokai; and the north shore region of Kauai. Almost all the native wet forest at risk from housing development is in the Puna District.[9] Development increases are also projected for the leeward (dry) coastal areas. However, the impact of this leeward development on forests should be minimal because these areas have been largely deforested for more than a century.[9]

[9] Personal communication from J.B. Friday, 2012. Extension forester, University of Hawaii at Manoa, College of Tropical Agriculture and Human Resources.

Montane wet forests, such as this forest on Kauai's Mount Waialeale, are the healthiest native ecosystem found in Hawaii. Photo by Sheri Mann, State of Hawaii, Department of Land & Natural Resources.

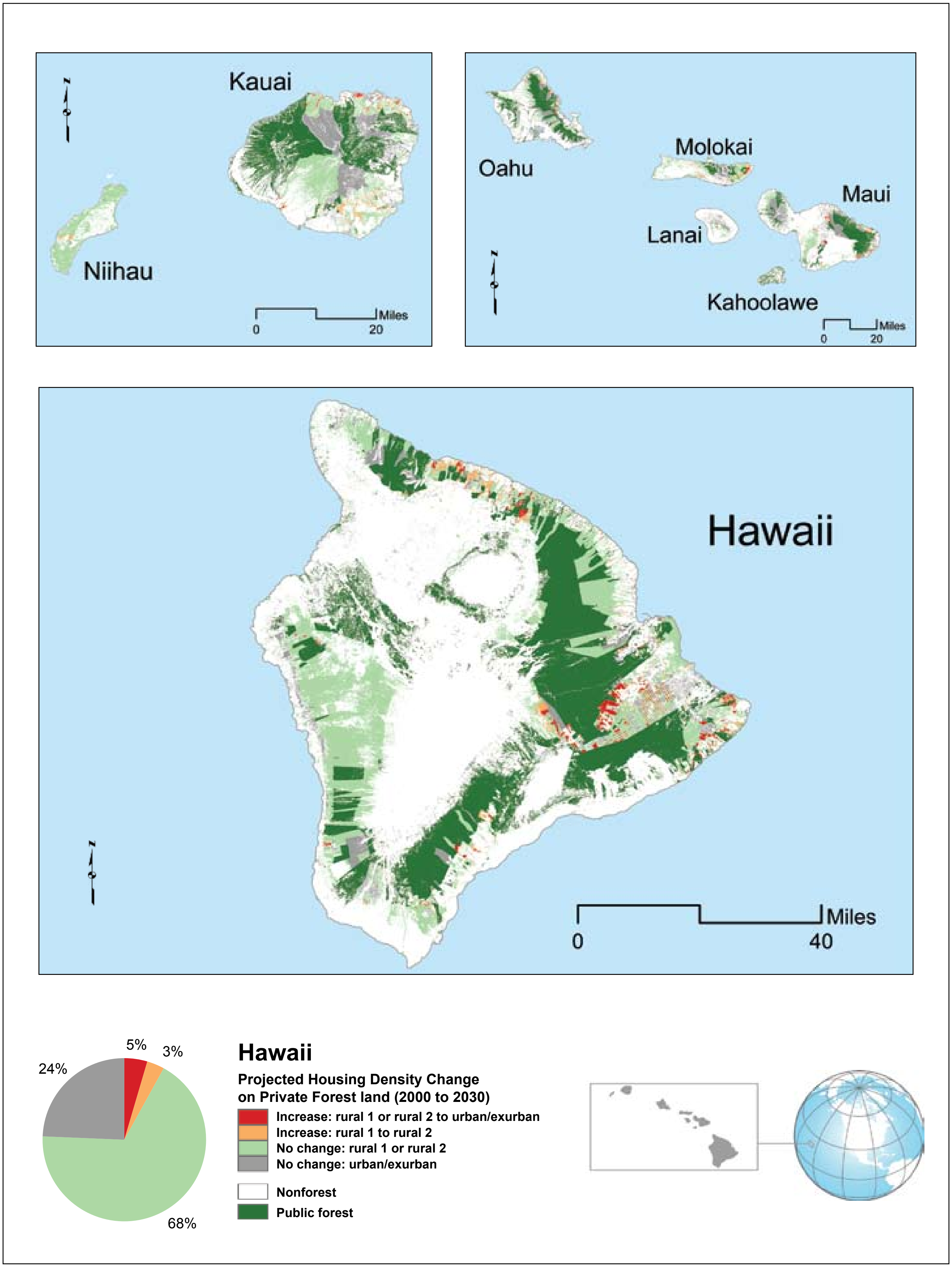


Figure 1.—Maps show projected housing density change on private forest land in Hawaii between 2000 and 2030 along with public forest and nonforest areas. Pie chart reflects the percentage of private forest land area in each of the mapped change classes.

Gall Wasps, Be Gone!
The End is Near for an Invasive Species in Hawaii

Hawaii has reason to celebrate a stunning success in combating invasive species through "biocontrol"—the use of host-specific natural enemies in weed or pest management.

The gall wasp, *Quadrastichus erythrinae*, has plagued Hawaii since 2005 and has had extremely adverse effects on the State's native tree, *Erythrina sandwicensis*, also known as coral tree or tiger's claw, as well as an introduced ornamental tiger's claw tree, *Erythrina variegata*. Thousands of trees had died off: "We really had the possibility of losing one of our native trees," explained Hawaii State Entomologist Neil Reimer in an interview with The Maui News in 2010 (Dingeman 2010).

Eurytoma erythrinae to the rescue! This African wasp is a natural predator of the gall wasp and was distributed widely in Hawaii beginning in 2008, with immediate impact (Heu et al. 2008). The predatory African wasps easily overcame the destructive gall wasp population, and the native tiger's claw trees began to recover. By 2010, Reimer remarked that the gall wasp "is not coming back" (Dingeman 2010).

The use of biocontrol strategies promises to be a sustainable way to control the damaging effects of invasive species in the Pacific Island region. For more information visit http://www.spc.int/en/about-spc/members.html.

Additional sources: J.B. Friday (see footnote 9); Hawaii Dept. of Agric. 2008; Secretariat Pacific Community 2010

Gall wasp damage on Indian coralbean (*Erythrina variegata* L.). Photo by Albert Mayfield, U.S. Forest Service, Bugwood.org.

Flat limestone plateau with abrupt cliffs dropping to the ocean in Guam. Photo by U.S. Forest Service, Pacific Southwest Region, State & Private Forestry.

GUAM

Located in the north Pacific Ocean, about three-quarters of the way from Hawaii to the Philippines, Guam has a tropical marine climate, with a distinct dry season January to June. The northern half of the island is flat limestone plateau with abrupt cliffs dropping to the ocean; the southern portion has rolling to mountainous terrain and deeply weathered volcanic soils (Donnegan et al. 2004a, Mafnas 2010), where numerous watersheds are drained by 96 rivers (Mafnas 2010). Guam is surrounded by a species-rich reef system supporting more than 5,000 marine species (Mafnas 2010).

Guam's Forests and Population Trends

About 48 percent (~ 64,000 acres) of Guam's 134,000 land acres are forested (Liu and Fischer 2006b); some 69 percent (~ 44,000 acres) of forest land is privately owned (Table 1). Approximately 18 to 20 percent of Guam is urban or developed land (Donnegan et al. 2004a, Mafnas 2010), including roads, towns, airstrips, and military facilities.

Nearly three-quarters of Guam's forest is a limestone forest type, supporting such species as breadfruit (*Artocarpus mariannensis*), banyan (*Ficus prolixa*), aggag (*Pandanus tectoris*), and an open scrub-forest found on steep slopes and cliffs dominated by *Cordia subcordata*. Volcanic forests on the southern portion of the island are vegetated with a mix of grassland and patchy forest; the forest tends to follow river drainages, ravines, and other topographic features. Common ravine forest trees include pugua (*Areca catechu*), banyan, pago

(*Hibiscus tiliaceus*), aggag, and other species including the introduced and now widespread tangan tangan (*Leucaena leucocephala*). Areas of swamp, mangrove, and marsh are also found on Guam. Trees tend to be relatively small (5- to 10-inch diameter) owing to disturbance by typhoons, human land use practices, invasive weeds and insects, and historical timber harvest (Donnegan et al. 2004a). Pure examples of Guam forest types are now rare, and the forests tend to be mixtures with dense, low thickets of secondary species predominating (Donnegan et al. 2004a, Mafnas 2010).

The population of Guam in 2010 was around 159,000, an increase of nearly 3 percent from the 2000 Census population (Census Bureau 2011c) and nearly triple what the population was in 1960 (Mafnas 2010). Guam faces a substantial increase in temporary and permanent population—to more than 250,000 people—associated with a proposed U.S. military buildup expected by 2014 (Mafnas 2010, Marler and Moore 2011, U.S. Dept. of Defense 2010).

Since Western colonization in the 16th century, Guam has changed from a mostly forested environment to a highly fragmented landscape, especially in the south, where older forests are generally restricted to ravines, valley bottoms, and on steep slopes (Mafnas 2010). Although total amount of forest cover has been relatively constant since the 1950s, the condition of the forest has declined owing to urban development, storm damage, wind, fire, and other factors. The urban landscape—with increasing urbanized zones and associated roads, shopping centers, and parking lots—has expanded markedly into some forested areas (Mafnas 2010).

Sella Bay, Guam. Photo by Jonesee02, istockphoto.com.

The breadfruit (*Artocarpus mariannensis*) found in Guam's agroforests is an important staple crop. Photo by EhPoint, istockphoto.com.

Guam urbanization. Photo by U.S. Forest Service, Pacific Southwest Region, State & Private Forestry, Flickr.

Since western colonization, Guam has changed from a mostly forested environment to a highly fragmented landscape. Photo by ziggy_mars, istockphoto.com.

Forest Resource Issues and Priorities

- **Invasive species and feral animals**

  Introduction of nonnative species and diseases has resulted in the loss of 9 of the 12 bird species that once made up the entire native avian community of Guam (U.S. Fish and Wildlife Ser. 2012). Development (including shipping of construction materials and landscaping plants and other activities) is contributing to the introduction and spread of invasive species—notably the Asian cycad scale (*Aulacaspis yasumatsui*), the coconut rhinoceros beetle (*Oryctes rhinoceros*), and numerous fungi and bacteria—thus altering forest structure, composition, and resilience to other disturbance processes (Mafnas 2010, Marler and Moore 2011). Development has also helped introduce feral animals including deer, pigs, and snakes, which can clear forest floors or damage trees (Strieker 1998). Perhaps more destructive than all development-related invasive species combined, however, has been the introduction and spread of the brown tree snake (*Boiga irregularis*), which is widely regarded as the major factor affecting Guam's birds.[9]

- **Wildfire**

  Wildfires, mostly human-caused, are a major cause of upland degradation and deforestation on Guam, threatening existing forests and interfering with the establishment and expansion of native forests (Mafnas 2010). A severe grass-fire cycle is affecting Guam's dry forests and shrubland, in which invasion of flammable nonnative grasses increases fine fuel loads and increases the likelihood of fire ignition and spread; fire further kills the native vegetation, the grasslands expand every year, and native forest decreases (Cordell, no date; J.B. Friday[9]). When fire removes the grass cover, subsequent rains can cause severe erosion.[9]

The brown tree snake (*Boiga irregularis*) near a trap and up close. Photos by USDA, APHIS.

Cycas micronesica: Ancient Species Threatened by Hitchhiking Insects

Believed to be the oldest of the seed-bearing plants, cycads can help us better understand the biology of many plant species, as well as links between human disease and environmental toxins (Marler et al. 2007). Only a few cycad species still exist. One cycad found only on Guam and other Marianas Islands, *Cycas micronesicais*—known locally as *fadang*—is rapidly diminishing in numbers, owing in part to introduced invasive insects that have hitchhiked to the island on cycads imported from Hawaii for landscaping (Smith 2007, Terry and Marler 2005). Among the introduced pests is the Asian cycad scale, *Aulacaspis yasumatsui*, which was first found in urban plantings on Guam in 2003 (Smith 2007, Terry and Marler 2005) and now threatens the survival of a once dominant forest plant on Guam (Marler et al. 2007). With no known natural enemies on the island and a climate that favors the insect's rapid reproduction and widespread distribution (Smith 2007), the scales cover and devour cycad leaves, cones, and developing seeds; a mature plant can die within a year of infestation (Terry and Marler 2005). The "epidemic mortality" in the Guam population of *C. micronesica* has prompted urgent conservation efforts (Marler et al. 2007).

Fadang (*Cycas micronesica*), one of Guam's rare and endangered species. Photo by Daniel W. Clark.

- **Water quality and supply**

  Removal of forest vegetation for road construction, off-road vehicle use, and building sites is contributing to increased erosion and degraded water quality. Water resources on the island vary based on the distinctive geologies of northern and southern Guam; eroded sediment—which can adversely affect water quality, aquatic habitat, and reef communities—is of particular concern in the south of the island (Mafnas 2010).

- **Forest conversion**

  Although direct impact from increased housing density is not the major factor driving conversion of forest land on Guam[10], proposed housing development and other activities related to the military buildup alone is expected to directly remove about 5,000 forested acres, about 9 percent of Guam's total forested area, by 2014 (Mafnas 2010). Impacts on Guam's forest recreation resources in the affected areas are expected to be substantial, along with impacts on local archaeological sites and water quality (Marler and Moore 2011, U.S. Dept. of Defense 2010). Loss of such extensive forest cover will not only affect the viability of Guam's forests but is also likely to increase the threats from invasive species and wildfire (Mafnas 2010).

[10] Personal communication from J. Lawrence, 2012, U.S. Department of Agriculture, Natural Resources Conservation Service, Pacific Islands Area-West.

Forests are critical to Guam's water supply. Photo by Leksele, istockphoto.com.

Development Projections

About 25 percent (~ 11,000 acres) of Guam's private forest land is projected to experience a substantial increase in housing density from 2000 to 2030, such that the category will shift from very rural (rural I) to less rural (rural II) or to urban-exurban[11] (Fig. 2). These housing density increases are projected to occur in localized areas across Guam, and particularly within about 2 miles of the coastline. Notable areas for such development include coastal areas north of Inarajan, as well as several areas along the coast and just inland between Pago Bay and Pagat point.

[11] The housing density projections used for this report (Theobald 2005) are based on past population trends and do not reflect the expected increase in population due to the military build-up.

Forest conversion in Guam. Photo by U.S. Forest Service, Pacific Southwest Region, State & Private Forestry, Flickr.

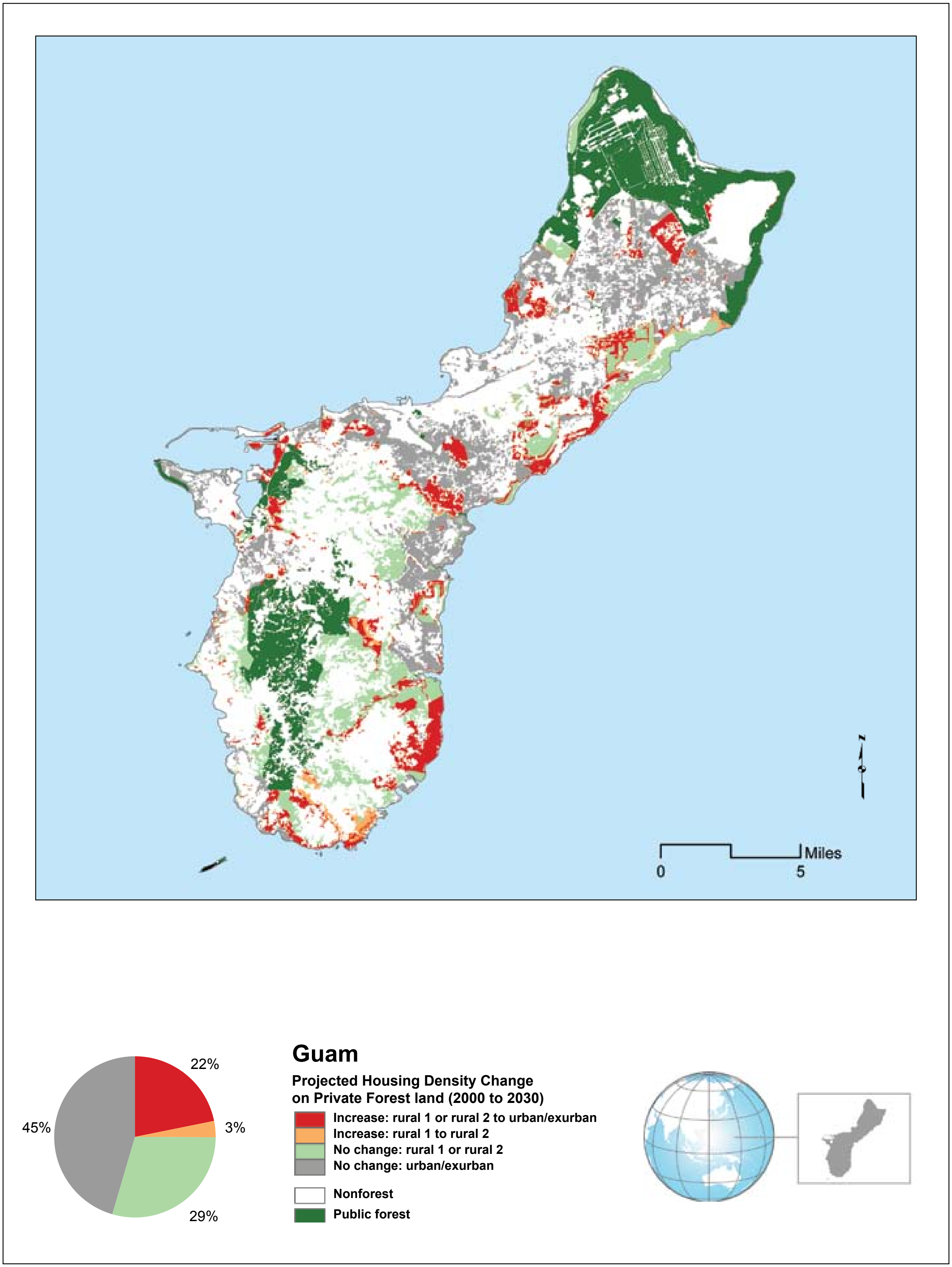


Figure 2.—Maps show projected housing density change on private forest land in Guam between 2000 and 2030 along with public forest and nonforest areas. Pie chart reflects the percentage of private forest land area in each of the mapped change classes.

A Pig Derby, Young Champions, and the Micronesia Challenge in Guam

The first ever pig derby, held in Guam in 2012, creatively wove together key elements of what is called the "Micronesia Challenge" to involve youth and citizens in the conservation of island marine and terrestrial resources.

The Challenge—a pledge among five Pacific island governments, including Guam and CNMI—was launched in 2006 to conserve at least 30 percent of the near-shore marine resources and 20 percent of the terrestrial resources across Micronesia by 2020. Included in the Challenge is a Young Champions of Micronesia Challenge program, which has enthusiastically mentored more than 20 local youth in issues of resource conservation.

Young Champions blog about issues related to marine and terrestrial resources and participate in educational outreach to other students and the community. They also participated in and helped to facilitate the 2012 Pig Derby, hosted by the Guam Department of Agriculture and the Guam Coastal Management Program. The derby's goal was to use celebration and education to raise awareness about the feral pig population, which is contributing to erosion and the destruction of native forests.

Feral pig. Photo by USDA, Flickr.

Christine Camacho of the Guam Coastal Management Program explained the purpose of the event: "The earth month 2012 pig derby is inspired by going local. We want to combat invasive species and at the same time celebrate our uses of pig within our culture so the pig derby itself will be followed by a pig cook off" (Ridgell 2012). All licensed hunters were welcomed to participate in hunting the feral pigs of the island over 2 days. Numerous pigs were hunted and community capacity was enhanced as the people of Guam came together to address an issue that has far-reaching effects on the island's ecosystem.

In addition to raising awareness among its youth, Guam has achieved remarkable progress toward the overall Challenge goal. As of 2011, Guam had protected some 13 percent of marine resources and 23 percent of terrestrial resources. The program on Guam, with its unique approach, continues to grow as citizens of all ages directly address ecological issues through restoration of native plant species and other activities.

Additional sources:

Global Island Partnership Website:
https://www.cbd.int/island/glispa.shtml

Micronesia Challenge Website:
http://themicronesiachallenge.blogspot.com/p/about.html

Pago Pago Harbor in the distance, American Samoa. Photo by Bruce C. Johnson, Jr., Flickr.

AMERICAN SAMOA

American Samoa, part of a larger group of islands known as the Samoan archipelago, is the only U.S. territory south of the equator. Located in the South Pacific Ocean, about half way between Hawaii and New Zealand, America Samoa is a group of five inhabited volcanic islands (Tutuila, Aunu'u, Ofu, Olosega, and Ta'u) and two remote atolls (Rose, Swains). The main islands of American Samoa are steep mountains that emerge from about 2 to 3 miles below the sea surface (Craig 2002). The climate is hot, wet, and humid, with an annual rainfall of about 129 inches at the airport on Tutuila and more than 200 inches in the mountains (American Samoa Community College 2010, Craig 2002).

American Samoa's Forests and Population Trends

American Samoa's total land area is about 48,000 acres; about half of the land (~ 24,000 acres) is forest cover, 85 percent of which is privately owned (Table 1); most private land is held communally by the church, by extended families, or individually by "freehold" owners (American Samoa Community College 2010). Even the National Park of American Samoa—which covers about 13 percent of the territory's land area—is not owned by the Federal Government but was established on communal land under a 50-year lease agreement between the National Park Service and a local group, which retains ownership of the land (American Samoa

Community College 2010). Some 7 percent of American Samoa is classified as urban, generally in areas where lowland rain forest previously existed (Donnegan et al. 2004b).

Owing to the warm temperature and year-round rainfall, the natural vegetation of American Samoa is tropical rainforest; native forests extend from the seashore to the mountain peaks (American Samoa Community College 2010). Forest types include lowland rainforest—found on ridges, slopes, in valleys, and on lowland lava flows—which supports tree species such as tava, or island lychee (*Pometia pinnata*); asi toa, or Malaysian apple (*Syzygium inophylloides*); and tamanu (*Calophyllum neo-ebudicum*). Montane rainforest is high-elevation, often steeply sloped forest (greater than 1,640 feet) characterized by high precipitation; the dominant canopy species is the native and endemic maota mea, or rose mahogany (*Dysoxylum huntii* Merr. ex Setchell) (Donnegan et al. 2004b). Cloud forest and scrub are limited to the highest elevations on Ta'u and Olosega, in areas generally blanketed by clouds and mist; this forest type is cooler and wetter than montane rain forest and is dominated by tree ferns and the endemic *Reynoldsia pleiosperma* (Donnegan et al. 2004b).

Along the undisturbed coastal areas, a narrow strip of littoral forest helps stabilize coastal areas, protects soils from erosion, filters water runoff, and provides habitat for numerous wildlife species including flying foxes, seabirds, and nesting sea turtles (American Samoa Community College 2010, Donnegan et al. 2004b). Mangrove forest, valuable as a storm buffer and water filter, occurs along coastal areas on only two islands, Tutuila and Aunu'u, particularly in sheltered lagoons and protected estuaries (American Samoa Community College 2010, (Donnegan et al. 2004b). American Samoa also contains about 3,106 acres of urban forests, concentrated in and around villages on the southwest lowland plains of Tutuila (American Samoa Community College 2010).

The current population (~ 56,000 in 2010) represents a decrease of about 3 percent from the 2000 Census population (Census Bureau 2011b). However, prior to 2000, the population had been growing at 2.1 percent per year, 96 percent living on Tutuila (Craig 2002). Urban lands expanded from 5 percent of the total land area to 7 percent from 1985 through 2001 (Donnegan et al. 2004b).

To'ito'i and fasa native coastal scrub forest, Tutuila, American Samoa. Photo by J.B. Friday.

More than 80 percent of American Samoa's forests are privately owned. Photo by LisaInGlasses/istockphoto.com.

American Samoa still possesses some of the most pristine and intact forests in the South Pacific, but these forests and their biodiversity are at risk of being degraded or lost (American Samoa Community College 2010). Important forest habitats have been cleared and replaced by agriculture and development, primarily on the lower, gentler slopes as well as in upland rain forest where soils permit agricultural use. Forest land declined by about 3 percent between 1985 and 2001 (Donnegan et al. 2004b), and of the 40 acres of lowland lava flow rainforest identified in 2002, only 28 acres remain, representing a 30 percent decrease in less than a decade (American Samoa Community College 2010). Mangrove forests declined by 18 percent during that same period (Donnegan et al. 2004b), and a 2009 study estimated that only about 89 acres of mangrove forest remain out of 122 acres identified in 2003 (American Samoa Community College 2010).

Forest Species—Big Relationships on Small Islands

American Samoa's forests support fewer than 500 native flowering plant species and ferns, about 44 bird species, and only 3 mammal species, all bats. Although few in number, these island species have exceptional ecological value. Nearly 30 percent of Samoa's flowering plants are found nowhere else outside the Samoan archipelago, and five of these exist only on American Samoa. Consequently, forest plants and wildlife are highly dependent on each other. The rare "mamuma" or many-colored fruit dove, for example, eats fruit from forest trees such as the native banyan, for which the bird is an important pollinator and seed disperser. Only a few banyan trees remain on the Tafuna Plain on Tutuila, and they are vulnerable to removal for increasing development.

—Source: Craig 2002

Flying fox (*Pteropus samoensis*). Photo by Daniel W. Clark.

Forest Resource Issues and Priorities

- **Invasive species and feral animals**
  Among the greatest risks to American Samoa's native rainforest—even areas too remote or steep to be cultivated or developed—is the spread of exotic invasive plants. Forests are also affected by introduced pigs, which are spreading invasive plants, damaging understory vegetation, and destroying riparian areas (American Samoa Community College 2010).

- **Water quality and quantity**
  As forests have been cleared for agriculture and development, the water flow into streams is increasing, washing large amounts of exposed unstable soil—including agricultural fertilizers and pollutants—into streams, which flow onto coral reefs. These effects are intensified by American Samoa's rugged topography and high frequency and intensity of rainfall year round. Further, American Samoan wetlands are threatened by filling for development (American Samoa Community College 2010).

- **Sustainability of urban forests**
  Scarcity of flat land suitable for building has resulted in the replacement of urban forests by structures and roads. Exotic plants imported for urban landscapes have invaded some of the remaining urban forest, along with insects and diseases that are affecting nonnative plants (American Samoa Community College 2010).

False kava (*Piper auritum*), Tutuila, American Samoa, resembles kava (*Piper methysticum*) but is difficult to control and outcompetes true kava plants. Photo by J.B. Friday.

Forests have been cleared for agriculture, such as this taro field, which results in washing large amounts of exposed unstable soil—including agricultural fertilizers and pollutants—into streams and eventually coral reefs. Photo by tropical.pete, Flickr.

Development Projections

About 3 percent (~700 acres) of American Samoa's private forest land is projected to experience a substantial increase in housing density from 2000 to 2030, such that the category will shift from very rural (rural I) to less rural (rural II) or to urban-exurban (Fig. 3). Substantial housing increases are projected to occur in some rural private forests along the northern coastline of Tutuila where elevation is below about 300 feet (see appendix), and in a few scattered areas near existing population bases with established roads. The Tafuna Plain of Tutuila also is likely to undergo development and consequent changes to tree cover[9]; however, our dataset classifies that area as agricultural or urban and therefore was considered nonforest for this analysis.

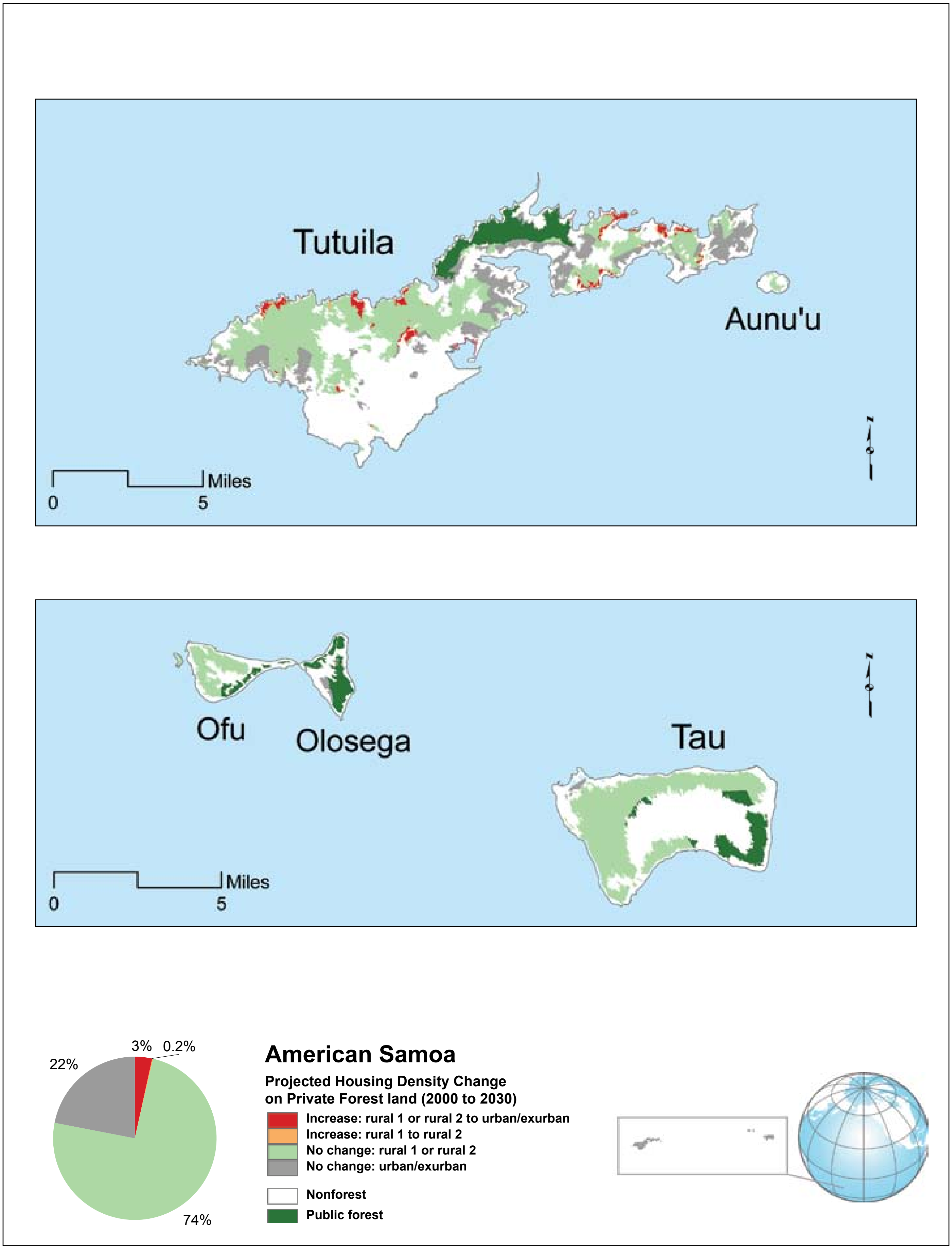


Figure 3.—Maps show projected housing density change on private forest land in American Samoa between 2000 and 2030 along with public forest and nonforest areas. Pie chart reflects the percentage of private forest land area in each of the mapped change classes. The “Increase: rural 1 to rural 2” category (orange) does not appear on the pie chart because the corresponding value, 0.2%, is too small to be visible.

Case Study

Healthy Seedlings for Healthy Forests: Workshop in American Samoa

Tree seedling nurseries don't always get acknowledged as critical components of any conservation or restoration effort. In July 2012, Diane Haase, western nursery specialist for the U.S. Forest Service, and J.B. Friday from the University of Hawaii Forestry Extension, conducted a week-long nursery training workshop in American Samoa. The workshop focused on enhancing the ability of the nursery at American Samoa Community College—the sole source of seedlings for urban and rural forestry restoration on the island—to produce healthy seedlings for reforestation, native forest restoration, agroforestry, riparian/coastal land stabilization, and urban beautification.

About 25 people attended the workshop, expressing individual goals that included:

- Learning more to help the community
- Applying new information to seedling production and "out-planting" practices (the planting of seedlings raised in a greenhouse or nursery into the field)
- Growing healthy plants locally rather than importing them from off-island

As a result of the workshop, American Samoan forestry staff members have a stronger understanding of plant production technology, which they can apply to future nursery production. The workshop also offered opportunities for the organizers to interact with forestry greenhouse staff and learn more themselves about the culture and environmental habitats of American Samoa.

—Source: Haase 2012

Forest Service nursery specialist Diane Haase (right) demonstrates testing procedures for nursery growing media. Photo by J.B. Friday.

Forestry program staff at a field site where plants have been out-planted from the nursery. Photo by Diane Haase.

Bird Island Marine Protected Area, Saipan. Photo by Daniel W. Clark.

COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS

The Commonwealth of the Northern Mariana Islands (CNMI) is a chain of 14 volcanic and limestone islands located in the Pacific Ocean, about three-quarters of the way between Hawaii and the Philippines (U.S. CIA 2010). The warm and humid climate is marked by moderate trade winds and little seasonal variation (Liu and Fischer 2006a, U.S. CIA 2011). Most soils on the three largest islands of Saipan, Rota, and Tinian are limestone, while a small portion of soils on the northern islands are volcanic (Com. North. Mariana Is. For. (CNMI) 2010, U.S. CIA 2010).

CNMI's Forests and Population Trends

CNMI has a land area of about 75,000 acres, 67 percent (~ 50,000 acres) of which is forested; some 78 percent of CNMI forest land is privately owned (Table 1). The original native forests of these islands were mixed, including dry season deciduous forest on lower limestone terraces and moist forest on higher terraces (CNMI Forestry 2010).

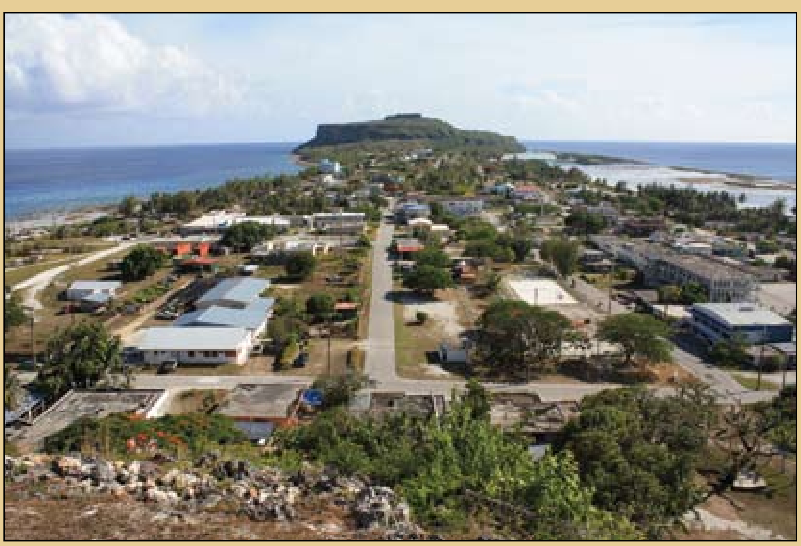
The most intact and extensive primary forests in the Commonwealth are found on the island of Rota, while native forests on the islands of Saipan and Tinian have largely been replaced by plantations (*Acacia* and sugar cane) and secondary forest (CNMI Forestry 2010, Liu and Fischer 2006a). On Saipan, remaining native forest occurs only in small isolated fragments on steep slopes on low elevations and in higher elevation conservation areas (Gillespie n.d.).

Contemporary forests are a mixture of native and nonnative species, primarily in smaller tree size classes, with intact fragments of native limestone and ravine forest (Donnegan et al. 2011). Native limestone forests, while not pristine, contain relatively high numbers of native species including kafir lime (*Citrius hystrix*), Hawaiian screwpine (*Pandamus tectorius*), and the endemic shrub *Guamia mariannae*. Ravine forest vegetation—found on the southernmost part of Rota where the volcanic core has weathered into highly dissected and sheltered ravines—is primarily swordgrass (*Miscanthus floridulus*) savanna mixed with shrubs and trees such as betel nut (*Areca catechu*) and breadfruit (*Artocarpus altilis*). Common nonnative species found in mixed native/nonnative forests include tangan tangan or white leadtree (*Leucaena leucocephala*), cynometra (*Cynometra ramiflora*), and banyan or strangling fig (*Ficus prolixa*).

Saipan is the largest island (~ 29,000 acres) and supports about 48,000 people (Census Bureau 2011d). About 5,500 people live on Rota (~ 20,000 acres) and Tinian (~ 25,000 acres) (CNMI Forestry 2010, Census Bureau 2011d). An expanding tourist market spurred construction and manufacturing industries between 1980 and 1997, when CNMI's population nearly quadrupled, from 16,780 to 63,000 (U.S. EPA 2008). That development boom resulted in an escalation in housing starts and the construction of many hotels, resorts, apartments, golf courses, and commercial businesses (U.S. Environ. Prot. Agenc. 2008), with the population peaking in 2000 at 69,221 (Census Bureau 2011d). However, the 2010 Census revealed a population of about 53,500 people, a 22 percent decrease from 2000, apparently due to declining tourism and loss of manufacturing industries (CNMI Forestry 2010, Census Bureau 2011d).

Native vegetation of CNMI has been conspicuously altered in large part by a long history of human occupation and agricultural activities, and by climatic disturbance (Donnegan et al. 2011). Saipan and Tinian in particular experienced significant forest destruction during World War II, followed by commercial and residential development (CNMI Forestry 2010). After World War II, the islands were aerially seeded with the fast-growing leguminous tree, *Leucaena leucocephala* (CNMI Forestry 2010), which is now widespread and self-perpetuating (Donnegan et al. 2011). In the 1980s, overall, the islands were still largely forested, although native forests common to the natural limestone was dominant only on Rota; Saipan and Tinian were largely occupied by introduced tree species and secondary vegetation (Liu and Fischer 2006a).

In recent decades, the most important land use changes have involved rapid conversion of forests to agriculture and urban uses; between the late 1970s and early 2000s, the Northern Mariana Islands lost 6 to 7 percent of its forest cover (Donnegan et al. 2011). Despite recent population and economic downturns, the three most populated islands of CNMI are still said to be experiencing heavy pressure on remaining lands from "massive expansion and construction of the urban areas" (CNMI Forestry 2010).



SongSong village, Rota, CNMI. Photo by Michael Lusk, Flickr.

Forest Resource Issues and Priorities

- **Water quality and quantity**

  In some areas of CNMI, there is either too little or too much water. On Saipan, for example, water shortages (and incursions of salt water into the water supply) are related to urban development in watersheds and over-pumping from existing wells. Other areas of Saipan are subject to flooding during heavy rainstorms and typhoons, due in part to development in natural floodplains, removal of vegetation, and construction of buildings that affect runoff (CNMI Forestry 2010).

- **Invasive Species**

  Currently the scarlet gourd (*Coccinia grandis*) is the most invasive and serious threat to the health of CNMI forests, particularly scrub forest; a recent introduction (early 1990s), the scarlet gourd has spread to more than 80 percent of Saipan. As on other Pacific islands, coconut rhinoceros beetle (*Oryctes rhinoceros*) and Asian cycad scale (*Aulacaspis yasumatsui*) are also invasive threats (CNMI Forestry 2010). In the northern islands, feral animals such as goats, pigs, and cows have denuded large expanses of the forest (CNMI Forestry 2010). Weedy vines are beginning to smother the forest canopy throughout the Northern Marianas (Donnegan et al. 2011).

Rainwater collectors, like this one in Saipan, are important for those times when there is insufficient ground water. Photo by Tropical.pete, Flickr.

The invasive coconut rhinoceros beetle (*Oryctes rhinoceros*) is responsible for destroying palm species in CNMI and other Pacific islands. Photo by Rein De Keyser, Flickr.

- **Wildfire**

  Wildfires are common in CNMI; repeated fires on steep slopes contribute to soil erosion and loss of wildlife habitats (CNMI Forestry 2010). Local forestry and fire officials anticipate an increase in wildland fire incidence and activities in coming years due to changing weather patterns and relocation of homes into areas identified as at-risk for wildfire (CNMI Forestry 2010). In savanna areas people regularly ignite fires, which can kill tree seedlings, spread into forested areas, and leave soils exposed to erosion and movement (Donnegan et al. 2011).

Development Projections

About 19 percent (~ 7,600 acres) of CNMI's private forest land is projected to experience a substantial increase in housing density from 2000 to 2030, such that the category will shift from very rural (rural I) to less rural (rural II) or to urban-exurban (Fig. 4). Forests expected to undergo this change are in localized areas, most notably, on Saipan, on a swath of land stretching from Laulau Beach to Marine Beach, and in places to the north and west. Housing density is also projected to increase on Tinian (west of the airport) and on Rota, east of the airport and on a strip of coastal land located in the southwest.

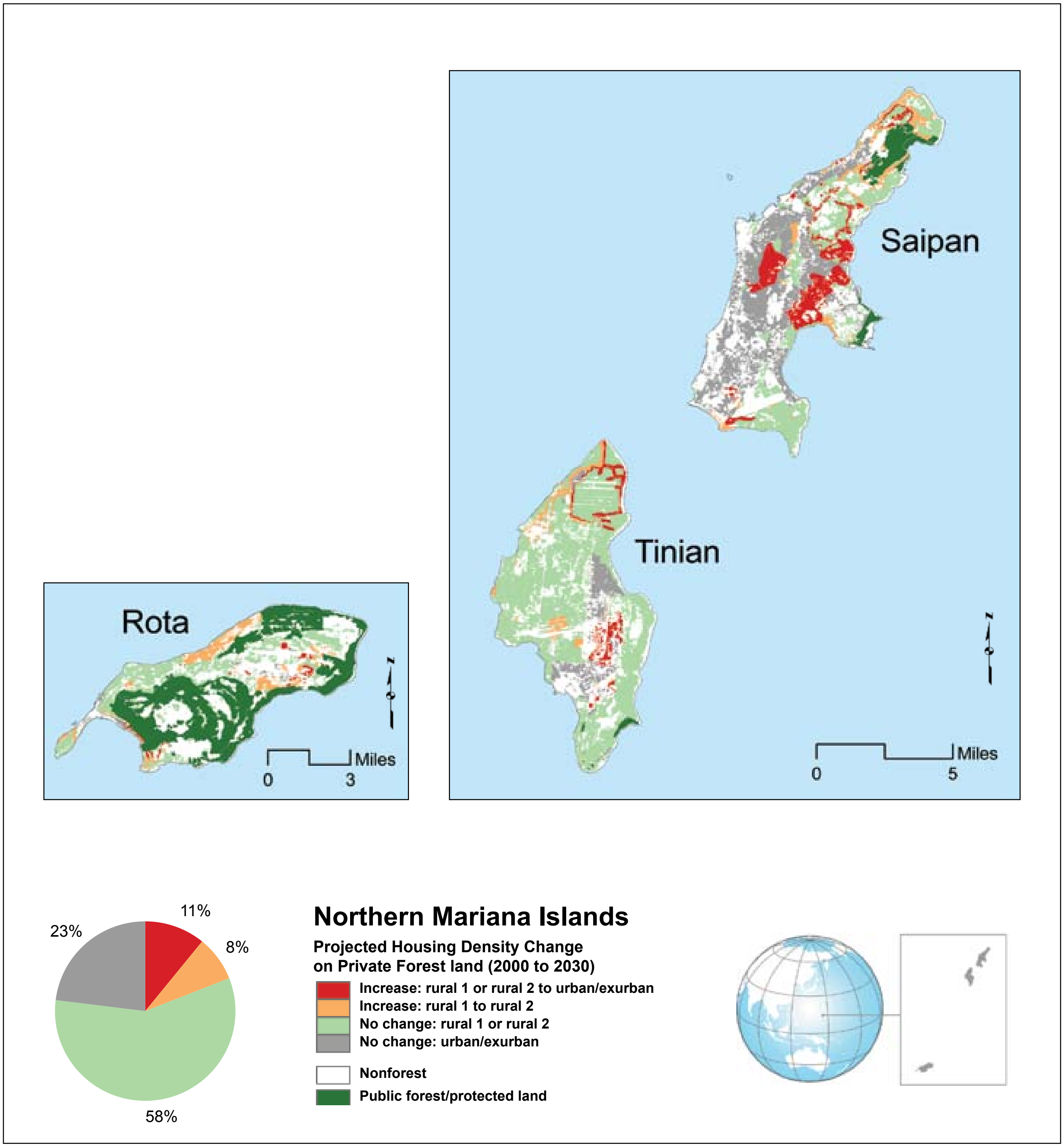


Figure 4.—Maps show projected housing density change on private forest land in Commonwealth of the Northern Mariana Islands (CNMI) between 2000 and 2030 along with public forest and nonforest areas. Pie chart reflects the percentage of private forest land area in each of the mapped change classes.

Species Banking: Offsetting Development Impacts on Saipan's Endangered Birds

The Saipan Upland Mitigation Bank (SUMBA), established in 1998 and administered by the CNMI Division of Fish and Wildlife, is a protected area designed to help conserve the habitat of Saipan's endangered nightingale reed-warbler from the pressures of housing development. The 1,035-acre mitigation bank on the northern portion of Saipan was created in cooperation with the U.S. Fish and Wildlife Service and is the first mitigation bank in the region (Ecosystem Market Network 2010). The protected area will be used to offset unavoidable impacts to the warblers associated with public and private development projects in the surrounding area and will be managed for the protection of the birds and other wildlife in perpetuity (Abbott et al. 2002).

The SUMBA is similar to other mitigation bank systems in the United States, whereby developers whose projects would affect certain resources can purchase credits to protect similar resources through the establishment, restoration, or enhancement of wetlands, streams, or other conservation areas (U.S. EPA 2012). The SUMBA management plan calls for reducing human disturbance, controlling predators, and restoring habitat (Abbott et al. 2002).

The SUMBA will also serve as protected habitat for other threatened and endangered species, including the Micronesian megapode (*Megapodius laperouse*) and the Mariana swiftlet (*Aerodramus bartschi*). Furthermore, the mitigation bank provides habitat for endemic species protected by the CNMI Division of Fish and Wildlife, such as the collared kingfisher (*Halcyon chloris*), Mariana fruit-dove (*Ptilinopus roseicapilla*), and golden white-eye (*Cleptornis marchei*) (Abbott et al. 2002).

The endangered nightingale reed warbler (*Acrocephalus hiwae*) is being protected by the Saipan Upland Mitigation Bank. Photo by Daniel W. Clark.

The United Nations Secretariat of the Pacific Regional Environment Programme has identified next steps for developing a broader site-based conservation program in CNMI, including: (1) increased involvement of local communities, nongovernmental organizations, land users, and other stakeholders; (2) monitoring to understand changes and provide feedback for conservation and policy mechanisms; and (3) maximizing dissemination and use of data to provide insights into reasons for declining populations (UN Secretariat Pacific Reg. Environ. Prgm. 2012).

One of the four distinctive forest types foundin El Yunque National Forest, the Sierra Palm forests are dominated by the Sierra palm (*Prestoea montana*). Photo by Jerry Bauer.

PUERTO RICO

Puerto Rico is the top of a submerged mountain crest located between the Caribbean Sea and the Atlantic Ocean, consisting of the main island of Puerto Rico and additional small satellite islands (Vieques, Culebra, and Mona). Almost three-fourths of the main island of Puerto Rico is mountainous interior; the mountains slope down to a coastal plain (Gallucci 1987). The climate is mild tropical marine, with little seasonal temperature variation (U.S. CIA 2011); many small rivers and high central mountains provide abundant water, although the south coast is relatively dry.

Puerto Rico's Forests and Population Trends

Puerto Rico has a land base of about 2.2 million acres, about 47 percent (~1,020,400 acres) of which was forest cover in 2000[12] (Kennaway and Helmer 2007) about 87 percent of Puerto Rico's forest is privately owned (Table 1). In 2000, about 15 percent of the land was urban and developed land cover (Kennaway and Helmer 2007). About 5 percent of the island was protected to some degree in 1991-92 (Helmer 2004, Kennaway and Helmer 2007); that percentage had increased to about 8 percent by 2012.[13]

[12] Land cover type in Puerto Rico continues to change very rapidly, and both forest cover and percentage of area protected have increased since the years referenced (Lugo 2013).

[13] Personal communication from A.E. Lugo, 2013, Director, U.S. Department of Agriculture, Forest Service, International Institute for Tropical Forestry.

Puerto Rico's diverse forests have developed over alluvial, sedimentary, volcanic, limestone, and serpentine substrates. All forests in Puerto Rico are classified by Holdridge (1947) as subtropical[13]; they support moist broadleaf evergreen and seasonal evergreen forests, as well as deciduous and semi-deciduous forests, cloud forests, forested wetlands, and rainforest (Helmer et al. 2002, Helmer et al. 2008). Puerto Rico's forests include relatively large examples of most of the major Caribbean forest types and constitute a locally and globally valuable ecological resource (Brandeis et al. 2003).

About 750 tree species have been documented in Puerto Rico, about 550 of which are native trees.[13] Introduced species are regenerating naturally in established, maturing forests and on recently abandoned agricultural land (Brandeis et al. 2003); an example is the African tulip tree (*Spathodea campanulata*), which colonized abandoned agriculture and pasture and has become the most common tree on the main island. Examples of native species include American muskwood (*Guarea guidonia*), cabbagebark tree (*Andira inermis*), and pumpwood (*Cecropia schreberiana*). Gumbo limbo (*Bursera simaruba*) is found in the subtropical dry forest life zone and on the tops of limestone hills in much of the moist forest zone, as moisture drains quickly from this substrate. Sierra palm (*Prestoea montana*) is found in the lower montane wet and rain forests; and mangroves in coastal areas, including large patches of white mangrove (*Laguncularia racemosa*) (Brandeis et al. 2003).

Puerto Rico's human population now totals about 3.7 million (U.S. Census Bureau 2011a); an average half a square mile supports about 443 people and nearly 1.86 miles of road (U.S. CIA 2011). Population growth and urbanization over the past two decades has put pressure on Puerto Rican forests, and the landscape has been much altered by human activities (Brandeis et al. 2003).

Development can be seen on the fringes of El Yunque National Forest, near San Juan, Puerto Rico. Photo by Magaly Figueroa, U.S. Forest Service, International Institute of Tropical Forestry.

Camping area, Aguirre State Forest, Guayama. Puerto Rico's forests are a valuable recreational resource for the growing and increasingly urbanized population. Photo by Magaly Figueroa, U.S. Forest Service, International Institute of Tropical Forestry.

Today's 47 percent forest cover is a dramatic increase from a low of 6 percent in the late 1930s and 1940s, when forest clearing for agriculture peaked and the economy began to shift toward industry and other economic pursuits (Kennaway and Helmer 2007). Recently the trend toward forest recovery has slowed, however, and changes in forest area vary among forest types and substrates (Kennaway and Helmer 2007). Furthermore, the notable increase in forest cover in Puerto Rico also has been accompanied by urban expansion, which is influencing the age, type, and distribution of forests on the islands (Helmer et al. 2008).

Puerto Rico's Smaller Islands

Forests on the two islands of Vieques and Culebra differ markedly from those on the main island of Puerto Rico. The subtropical dry forest of Culebra is more open, with smaller trees than the subtropical dry forest on Puerto Rico and Vieques. Forest cover is as high as 85 percent on Vieques and 88 percent on Culebra (Brandeis et al. 2003), but recent studies have shown that the area of urban and built-up or bulldozed lands on these two islands increased by 49 percent during the 1990s (Helmer and Ruefenacht 2005).

Forest Resource Issues and Priorities

- **Forest conversion**

  Rapid land use changes over the past century have included conversion from abandoned agricultural or pasture land to developed uses; conversion of forest is also occurring at increasing rates (Helmer 2004, Helmer and Ruefenacht 2005, Helmer et al. 2008). Of the 16,722 acres of land converted to urban or surface-mined lands from 1991 to 2000, about 22 percent was forest (Helmer et al. 2008). Although total forest cover has actually more than doubled since the 1950s with the shift away from agriculture, unprotected forest areas near or within urban centers continue to be vulnerable to development (Kennaway and Helmer 2007).

  Most (55 to 66 percent) of the forest that has been cleared for land development has been young secondary forest (Helmer et al. 2008). About 13 percent of stands cleared for development was mature secondary forest—including old forest on karst substrate[14] (Brandeis et al. 2003, Kennaway and Helmer 2007).

- **Forest recovery on karst topography**

  About 27 percent of Puerto Rico consists of karst geology (Lugo et al. 2007), including sinkholes, caves, cliffs, alluvial terraces, long and narrow valleys, and limestone hills (Rivera and Aide 1998). Forest recovery has been underway for at least 50 years on abandoned farms in the karst area (Kennaway and Helmer 2007, Rivera and Aide 1998), but the rate of urbanization in the karst is also increasing (Lugo et al. 2007); forest recovery on karst now is threatened by road construction, fires, and commercial and housing development (Rivera and Aide 1998).

Karst forest. Photo by Magaly Figueroa, U.S. Forest Service, International Institute of Tropical Forestry.

[14] Repeated fires and grazing also may be contributing to the maintenance of younger ages of subtropical dry forest (Brandeis et al. 2003).

Conversion of Puerto Rico's forests is occurring at increasing rates. Photos by Magaly Figueroa, U.S. Forest Service, International Institute of Tropical Forestry (left) and TexPhoto, istockphoto.com (right).

Development Projections

About 24 percent (~ 215,000 acres) of Puerto Rico's private forest land is projected to experience a substantial increase in housing density from 2000 to 2030, such that the category will shift from very rural (rural I) to less rural (rural II) or to urban-exurban (Fig. 5). Forests expected to undergo this change are located across interior areas of Puerto Rico, including forests across much of the western half of the main island, as well as forests located in the interior southeast. Much of the forest remaining around the Maricao State Forest is projected to experience a substantial increase in housing density, as is land adjacent to several other State forests and pockets of private rural forest located adjacent to the El Yunque National Forest.

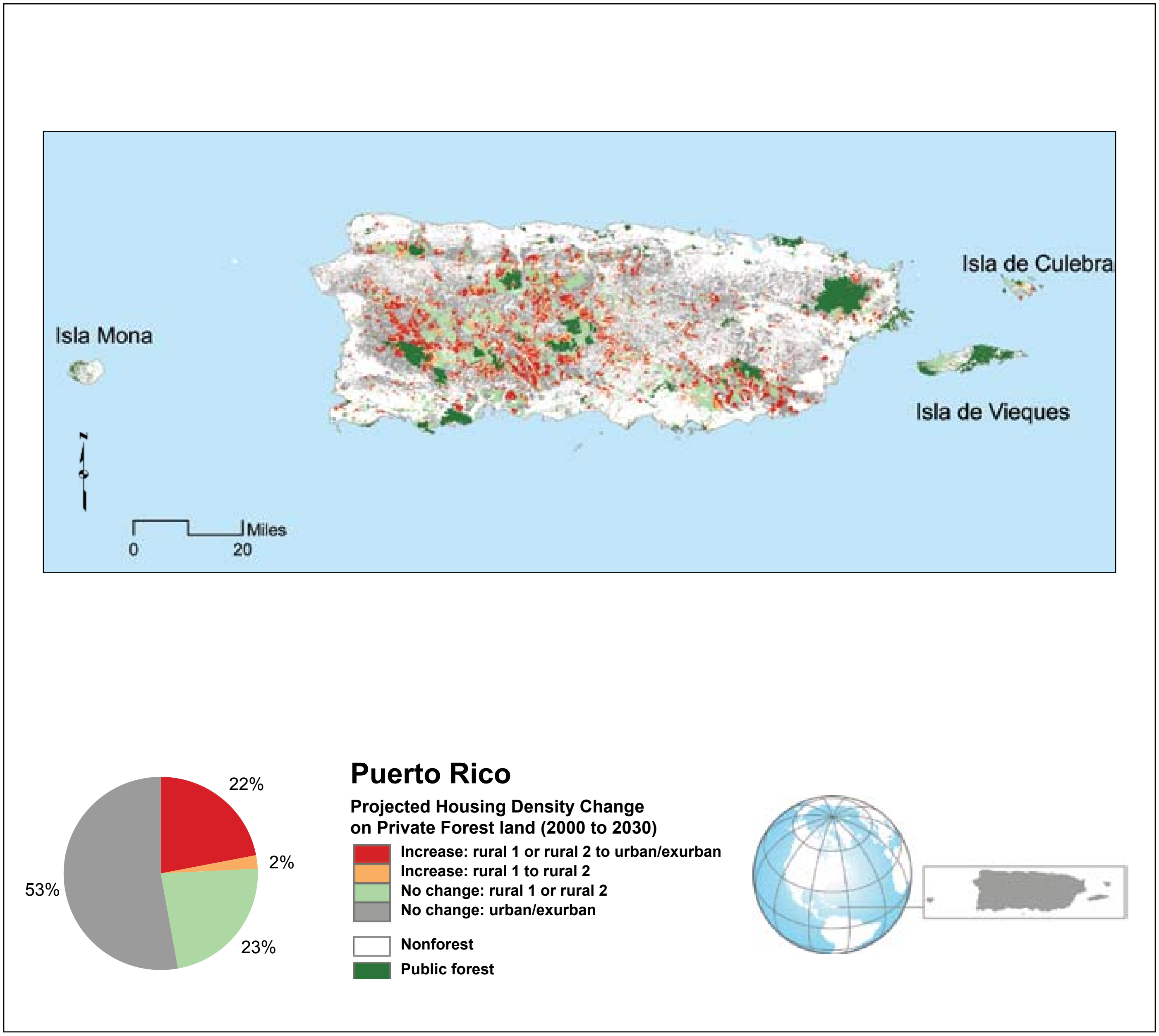


Figure 5.—Maps show projected housing density change on private forest land in Puerto Rico between 2000 and 2030 along with public forest and nonforest areas. Pie chart reflects the percentage of private forest land area in each of the mapped change classes.

Collaboration for Conservation: The Humacao Joint Priority Landscape

In the southeastern corner of Puerto Rico, a collaborative effort known as the Humacao Joint Priority Landscape is bringing area communities together to help prevent the loss of forests threatened by urban sprawl.

Endorsed by the Natural Resource Conservation Service, the Puerto Rico Department of Natural and Environmental Resources (DNER), the U.S. Fish and Wildlife Service, and the U.S. Forest Service—and further supported by landowner organizations and other groups—the Humacao project seeks to protect numerous forest benefits, including:

- Habitat for endemic species such as the Puerto Rican parrot (*Amazona vittata*), Puerto Rican boa (*Epicrates inornatus*), and Puerto Rican rock frog (*Eleutherodactylus cooki*)
- Watershed conservation, restoration, and improvement of forest health on properties within the several important watersheds in eastern Puerto Rico
- Conservation of forest cover within the buffer and protection boundaries of the El Yunque National Forest, Puerto Rico State Forests, Natural Refuges, and other important ecosystems
- Conservation practices to reduce soil erosion and improve water quality

The project uses tree planting, forest improvement practices, and education to promote forest conservation, habitat restoration, reduction of pest and disease occurrence, improvement of soil condition, carbon sequestration, and improvement of degraded ecosystems.

"Educational efforts include capacity building and specialized training opportunities for tree-care professionals, community representatives, and the Puerto Rico DNER personnel," said Magaly Figueroa, natural resource specialist for the International Institute of Tropical Forestry (IITF). She noted that joint priority landscapes provide further opportunity to leverage State, Federal, and private partner resources on behalf of important private landscapes.

Joint Priority Landscapes for Puerto Rico were identified in the Puerto Rico Assessment and Strategies (Puerto Rico DNER 2011). The Humacao project subsequently was launched by the Forest Stewardship and Urban Community Forestry programs of the U.S. Forest Service in Puerto Rico. These programs focus on providing technical and management planning assistance to private landowners within the Humacao region, and on educating children in kindergarten through grade 12 about the importance of forest stewardship.

Additional sources: U.S. Forest Service 2012; personal communication from M. Figueroa, 2012, natural resources specialist, U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry

Forests near El Yunque National Forest are among those benefitting from conservation efforts of the Humacao Joint Priority Landscape. Photo by Tana Wood.

St. John, U.S. Virgin Islands. Photo by Kee Tron, istockphoto.com.

U.S. VIRGIN ISLANDS

The U.S. Virgin Islands (USVI), part of the Caribbean's Lesser Antilles, encompass dozens of islands and cays, the largest of which are St. Croix, St. Thomas, and St. John. The climate is mostly subtropical, with a hot and humid rainy season from May to November and a dry season more tempered by trade winds; the islands are vulnerable to substantial damage from storms (Kennaway et al. 2008). USVI geological substrates include alluvial, sedimentary, volcanic, and limestone layers (Chakroff 2010).

U.S. Virgin Islands Forests and Population Trends

Forest covers about 53,000 acres or about 63 percent of USVI's total land area (~ 84,000 acres) (Table 1). St. John has the highest percentage of forest land (92 percent), followed by St. Thomas (70 percent), and St. Croix (50 percent) (Brandeis and Oswalt 2007, Kenneway et al. 2008). With the exception of the Virgin Islands National Park, which encompasses and protects some 65 percent of land on St. John, most USVI forests are privately owned (Kennaway et al. 2008) (Table 1).

The forests of the three islands are somewhat different but the two major forest types are subtropical[15] moist forest (~ 22,000 acres) and subtropical dry forest (~ 31,000 acres) (Brandeis and Oswalt 2007, Chakroff 2010), mostly secondary growth (Kennaway et al. 2008). As elsewhere in the Caribbean, the interaction between trade winds and steep topographical gradients can lead to changes in forest types over short distances (Kennaway et al. 2008).

[15] As defined by the Holdridge system of life zone classification (see footnote 13) (Lugo 2013).

The subtropical moist forests include evergreen forest found at higher elevations with substantial rainfall and clouds and in riparian corridors and valleys at lower elevations with sufficient fresh water. These forests support numerous shrubs, vines, epiphytes, and more than 100 tree species, including early successional black olive (*Bucida buceras*), sandbox tree (*Hura crepitans*), and silk-cottonwood (*Ceiba pentandra*) (Brandeis and Oswalt 2007, Chakroff 2010).

Subtropical dry forests include lowland semi-deciduous and drought-deciduous forests that vary widely in structure and are heavily influenced by rainfall, slope and aspect, prevailing winds, and sea spray (Chakroff 2010). USVI dry forest species include gumbo limbo tree (*Bursera simaruba*), Jamaican caper (*Capparis cynophallophora*), orange manjack (*Cordia rickseckeri*), lignum vitae (*Guaiacum officinale*), and frangipani (*Plumeria alba*). Other USVI forest types include moist tropical forest and coastal mangrove forests.

U.S. Virgin Island forests are located in one of the world's "biodiversity hotspots." They are highly valued for their scenic beauty, as well as for their contribution to cultural and ecological services including rainwater infiltration, soil stabilization, and forest-related arts and crafts. They also provide vital wildlife habitats, such as critical wintering grounds for migrating neotropical birds and habitats for several species of bats, USVI's only native mammals (Chakroff 2010).

Shade-tolerant epiphytes, shrubs, and vines develop beneath the mostly closed canopy. Examples of indicator tree species of the dry forest are gumbo limbo tree (*Bursera simaruba*), Jamaican caper (*Capparis cynophallophora*), orange manjack (*Cordia rickseckeri*), lignum vitae (*Guaiacum officinale*), and frangipani (*Plumeria alba*) (Chakroff 2010).

About 109,000 residents live year-round in the U.S. Virgin Islands (U.S. Census Bureau 2011e), with a recent population growth rate of 8 percent (Chakroff 2010). The islands are host to more than 2 million visitors annually (Brandeis and Oswalt 2007, Chakroff 2010). Ninety-five percent of Virgin Islanders live in an urban environment; urban and developed land area on the three major islands covered about 14,000 acres in 2000, and urban growth has increased further over the past decade at the expense of forested areas (Kennaway et al. 2008).

Forest structure, ecosystem function, and species composition of USVI forests have been strongly influenced by forest clearing (Kennaway et al. 2008). Only fragments of USVI's original old-growth forests remain because of past aggressive land clearing and agricultural activities (Brandeis and Oswalt 2007, Chakroff 2010, Kennaway et al. 2008). Although the islands may have been 90 percent forested prior to European colonization (Brandeis and Oswalt 2007), by 1800 only about 5 percent or less of the forest cover remained, having been cleared primarily for sugar cane

Cape May warblers are neotropical birds that rely on low-elevation Caribbean forests for winter habitat. Photo by Gharrold, istockphoto.com.

Intact Island Forests Provide Biodiversity "Hotspots"

The Caribbean Basin is a global biodiversity hotspot—a biologically rich area whose plant or animal habitats have been sharply reduced. Caribbean islands and their forests provide invaluable habitats for resident birds and vital wintering grounds for many neotropical migrant songbirds, including declining species of warblers such as the Cape May warbler (*Dendroica tigrina*), blackthroated blue warbler (*D. caerulescens*), and prairie warbler (*D. discolor*). The U.S. Virgin Islands is home to some 315 threatened and endangered terrestrial species.

—Source: Brandeis and Oswalt 2007

and cotton agriculture (USVI Dept. of Agric. 2010). With abandonment of agriculture from the 1800s to the early 20th century, forests gradually recovered (Brandeis and Oswalt 2007, Kennaway et al. 2008). However, in the past decade, young secondary forests have been increasingly cleared for expansion of urban areas, dispersed housing developments, and expansion of resorts, golf courses, and other tourism-related infrastructure (Brandeis and Oswalt 2007). Between 1994 and 2004, 11 percent of St. Croix's subtropical dry forest was lost, while St. Thomas lost 13 percent of its subtropical dry forest (Brandeis and Oswalt 2007).

Forest Resource Issues and Priorities

- **Forest loss to development**

  The decrease of forest cover from 1994 to 2004 illustrates that past gains in USVI's forest cover are being lost (Brandeis and Oswalt 2007). Unprotected low-elevation forests face the greatest danger of deforestation due to development pressure (Kennaway et al. 2008). Contiguous forest (large patches of forest that are close although not always adjacent to other forest patches) and transitional forest (areas that are changing to forest from agricultural or other uses) are most threatened by conversion to buildings and urban areas (Chakroff 2010). Even on St. John, where 65 percent of the island is a national park that protects the island's interior high-elevation semi-evergreen and deciduous forests, unprotected low-elevation dry forests are endangered and highly susceptible to development pressures. On St. Thomas, where such protections are not in place, development pressure is seen island-wide (Kennaway et al. 2008). With the loss or degradation of forests comes the loss of ecosystem services such as clean water; consequently, drinking water quality is among the foremost concerns in the U.S. Virgin Islands (Chakroff 2010).

- **Urban forest sustainability**

  Forty-eight percent of the forests of St. Croix and 60 percent of St. Thomas forests are classified as urban or community forest (Chakroff 2010). These forests contribute innumerable services to the people of the Virgin Islands, including health benefits,

St. Thomas, U.S. Virgin Islands. Photo by Keith Binns, istockphoto.com.

Urban trees and forests are a vital part of USVI’s natural landscape. Photo by Julie Hewitt, istockphoto.com.

shade and cooling, clean air, cultural and economic values, and recreation opportunities (Chakroff 2010). Urban forests are being fragmented and impaired, especially near roads, in part because of their accessibility and in part from lack of adequate oversight, management, and maintenance (Chakroff 2010, Kenneway et al. 2008). In addition, urban and rural trees are subject to tropical storms and hurricanes, which not only damage the trees but also create hazards to vehicles, homes, and people (Chakroff 2010).

- **Degradation of coastal forest ecosystems**

  Coastal areas with desirable views and ocean access are a prime target for development activities; such activities can be particularly damaging to coastal forests and the coral reefs that rely on forest’s to reduce and filter sediment from runoff and to stabilize shorelines (Chakroff 2010). Upland and coastal development is increasing the amount and magnitude of runoff from buildings and roads, thus threatening USVI coral reefs (Brandeis and Oswalt 2007, Chakroff 2010, Gray et al. 2008). Degraded and diminished coral reefs affect not only wildlife and fish but also the island’s tourism-based economy (Chakroff 2010).

Organic sediment is particularly harmful to coral reefs, such as those found in Trunk Bay, pictured here. In one 2007 rainy season the rate of organic deposits was 28 times higher for a coral reef below a developed USVI watershed than it was for a reef below an undeveloped watershed (Gray et al. 2008). Photo by Daniel W. Clark.

Development Projections

About 12 percent (~5,400 acres) of USVI's private forest land is projected to undergo a substantial increase in housing density from 2000 to 2030, such that the category will shift from very rural (rural I) to less rural (rural II) or to urban-exurban (Fig. 6). Substantial housing increases are projected to occur in localized areas across the Virgin Islands, most notably in much of the remaining rural private forest across inland areas of northern St. Thomas. Increases are also expected in smaller patches of St. Thomas' coastal forests, including those located on Neltjeberg Bay on the northeastern area of the island, as well as forests along Bovani Bay and the northeastern tip of Western Island. Projected change for St. John is minimal.

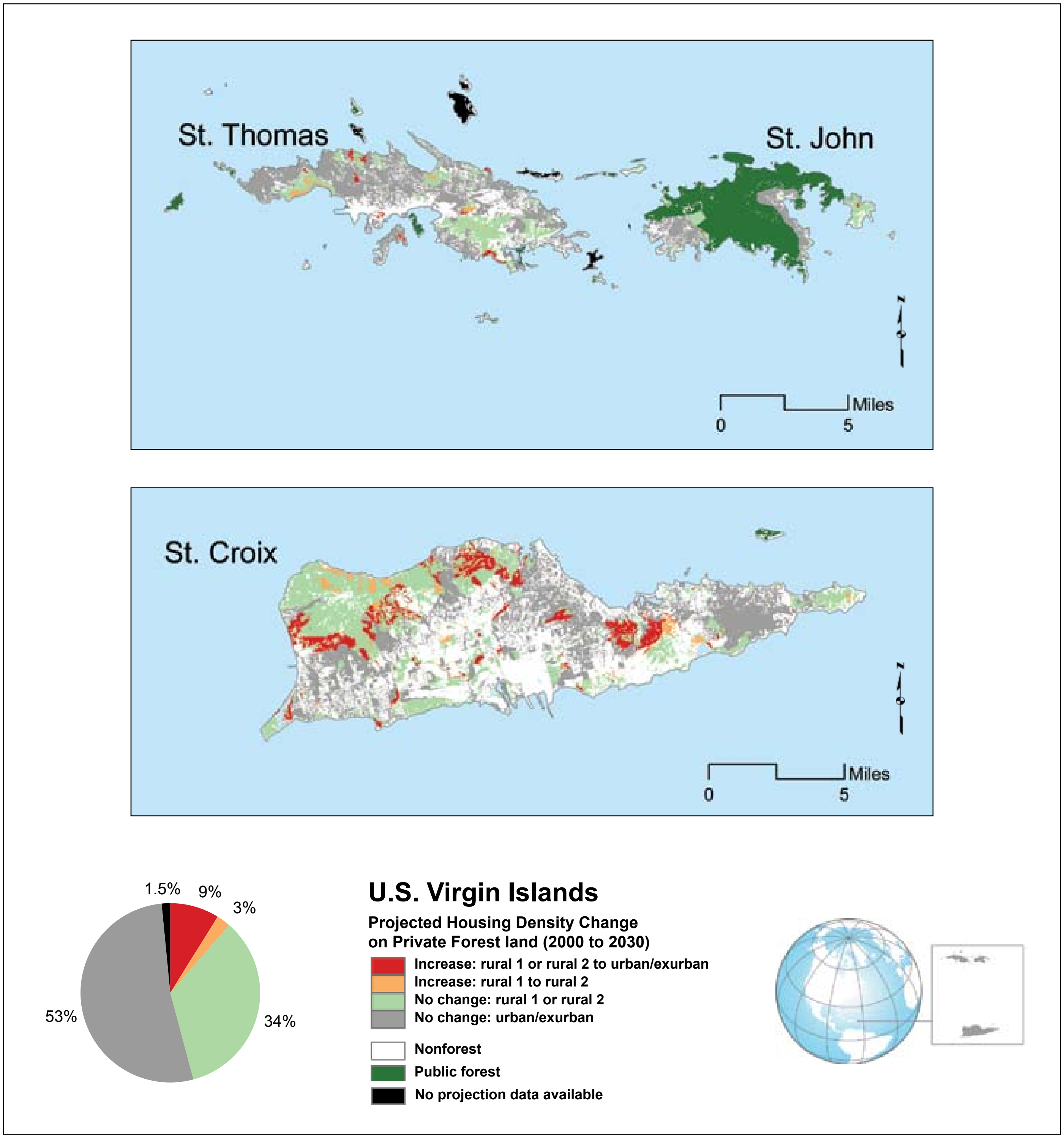


Figure 6.—Maps show projected housing density change on private forest land in U.S. Virgin Islands between 2000 and 2030 along with public forest and nonforest areas. Pie chart reflects the percentage of private forest land area in each of the mapped change classes.

Caribbean Landscape Conservation Cooperative (CLCC): Science and Technology for Conservation Planning and Action

The U.S. Forest Service's International Institute for Tropical Forestry (IITF) has worked with other Federal and local agencies to establish the Caribbean Landscape Conservation Cooperative (CLCC), bringing the U.S. Virgin Islands and Puerto Rico into a national network of 22 landscape conservation cooperatives. The CLCC mission is "providing science and technology for conservation planning and action—addressing the need to restore and sustain natural resources in Caribbean land and seascapes."

Landscape conservation cooperatives involve applied conservation science partnerships among State and Federal agencies, regional organizations, tribes, nongovernmental organizations, universities, and other entities within a geographic area. They are designed to provide science to inform resource management decisions in an integrated fashion across landscapes—at a broader scale than any individual partner's responsibility. Landscape conservation cooperatives consider landscape-scale stressors including climate change, habitat fragmentation, urban sprawl, invasive species, and water availability in order to assess the conservation status of species and habitats and provide a vision for sustainable landscapes under future scenarios.

The CLCC emphasizes the connectivity of USVI and Puerto Rico with the greater Caribbean and the continental regions through shared species, habitats, and conservation opportunities and goals. The CLCC aims to provide a regional context for conservation planning and management at different scales—from decisions on site management to understanding the implications of management actions regionally, nationally, and globally.

—Source: U.S. Forest Service 2012

The International Institute of Tropical Forestry (IITF). Photo by Maya Quinones, U.S. Forest Service. The map shows the extent of the Caribbean Landscape Conservation Cooperative in 2011. Colors represent developed land (black), forested land (green), shrubland (brown), and grassland (light tan). Source: U.S. Forest Service 2012.

SUMMARY AND CONCLUSIONS

Hawaii, Puerto Rico, and other Pacific and Caribbean islands encompass diverse and invaluable tropical and subtropical forest resources that are confronted by housing pressures similar to those faced by mainland forests. Unlike the mainland, however, islands face additional challenges due to their small size, relative isolation, and unique plant and animal life. Island forests are highly susceptible to storms and climate change, and exceptionally vulnerable to the introduction of nonnative species (U.S. Forest Service 2007). Many have high demands for recreation, tourism, and agroforestry or forest product businesses but some have limited resources for forest management or development of sustainable forest products (U.S. Forest Service 2007). Private forests across these islands have been affected by past and present land use choices and are increasingly vulnerable to impacts from future development.

In localized areas of every island complex covered by this report, from 3 to 25 percent of private forest land could experience a substantial increase in housing density between 2000 and 2030. Such projections—based on long-term growth trends and patterns, road densities, and locations of urban areas—assume that removal, fragmentation, or degradation of private forests on the islands is likely to continue despite the fact that, with the exception of Hawaii, human populations on the islands have declined somewhat in the past decade (Census Bureau 2011a-e).

As seen in the case studies sampled here, much is being done throughout America's Pacific and Caribbean islands to prevent, reduce, or reverse the impacts of development on island forests. Creative and comprehensive approaches have included biological control of invasive species in Hawaii, restoration of native ecosystems through nurseries and training in American Samoa, and technical assistance for private landowners in Puerto Rico. Other positive steps include successful education and outreach in Guam, mitigation banking that protects endangered and endemic species in the Commonwealth of the Northern Mariana Islands, and a landscape-scale conservation collaborative in the U.S. Virgin Islands and Puerto Rico. The U.S. Forest Service's Forest Stewardship, Forest Legacy, and Urban Forestry programs also have helped focus substantial effort on preservation and restoration of native forests on the islands.

But the stakes are high and the work is nowhere near complete. Although in some places such as Puerto Rico, forest cover has increased substantially in recent decades, in other places such as Guam, accelerated loss of forest is expected to accompany an abrupt rise in population and development in the near future. Forests throughout the islands remain exposed to threats from invasive species of plants and animals, in part due to housing development.

As in other Forests on the Edge reports, the development projections reported here serve not to pinpoint specific locations where housing development will occur but rather to suggest areas where development and related impacts can be expected at a broader scale. Some places identified here might have constraints or conditions that could preclude actual development—such as extremely steep slopes, or economic or social constraints—that our models were not able to consider fully.

It is critical that resource managers, developers, community leaders, and landowners consider the unique and sensitive ecologies of island forests when planning for future development. This is especially important in light of the added stressors that climate change will bring. Careful planning will help sustain and protect native species, water, and forest ecosystems—along with the people and cultures that depend on them.

The endangered halapepe (*Pleomele hawaiiensis*) in flower, Puuwaawaa, Hawaii Island, Hawaii. Photo by J.B. Friday.

ACKNOWLEDGMENTS

We are grateful for the assistance of many individuals who helped guide, clarify, and improve the accuracy of this report, which covers areas that are not well-represented in the scientific literature in terms of current and consistent data on forests and development. We are particularly grateful to Lisa G. Mahal, University of Nevada/Las Vegas; Ronald E. McRoberts and Mark D. Nelson, U.S. Forest Service, Northern Research Station, for data and analysis in early stages; and Marge Victor, Oregon State University, for early drafts and research. We updated, expanded, and edited their prior contributions to produce this report.

Extensive contributions and detailed technical reviews were provided by Susan Cordell, U.S. Forest Service, Institute of Pacific Islands Forestry; James B. Friday, University of Hawaii at Manoa, Komohana Research and Extension Center; and Eileen Helmer and Ariel Lugo, U.S. Forest Service, International Institute of Tropical Forestry. As with all Forests on the Edge reports, we continue to be grateful to David Theobald, senior scientist with Conservation Science Partners, Fort Collins, CO, for his insightful analyses and data on population and housing density.

The following specialists reviewed and provided instrumental content or clarification: Russell Benford, Commonwealth of the Northern Mariana Islands, Division of Fish and Wildlife; Ron Cannarella, Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife Planning and Information Services; Joe Donnegan, Forest Service, Forest Inventory and Analysis program; Lisa Fischer and Zhanfeng Liu, Forest Service, Pacific Southwest Region, Remote Sensing Lab; Magaly Figueroa, Forest Service, International Institute for Tropical Forestry, State and Private Forestry; Kathleen Friday, Forest Service, Pacific Southwest Region, State and Private Forestry; Diane Haase, Forest Service, Pacific Northwest Region, Cooperative Programs; John (Bart) Lawrence, USDA Natural Resources Conservation Service, Pacific Islands Area, Guam; Sheri Mann, Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife; and Ana Tunabuna-Buli, Land Resources Division of the Secretariat of the Pacific Community. Carly Wyman and Jennifer Geraci, Forest Service, Publishing Arts, helped research and write case studies.

LITERATURE CITED

Abbott, T.; Pangelinan, A.; DeCruz, T. 2002. **Management plan for nightingale reed-warblers in the Saipan upland mitigation bank.** Saipan: Commonwealth of the Northern Mariana Islands, Department of Land and Natural Resources, Division of Fish and Wildlife. http://coastalzone.com/pubabs/SUMBA_mp.doc. (25 August 2014).

Alig, R. 2007. **A United States view on changes in land use and land values affecting sustainable forest management.** Journal of Sustainable Forestry. 24(2/3): 209-227.

American Samoa Community College. 2010. **American Samoa forest assessment and resource strategy, 2011-2015.** Pago Pago, American Samoa: American Somoa Community College. http://www.wflccenter.org/islandforestry/americansamoa.pdf. (8 June 2011).

Brandeis, T.J.; Oswalt, S.N. 2007. **The status of U.S. Virgin Islands' forests, 2004.** Resour. Bull. SRS-122. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 61 p.

Brandeis, T.J.; Helmer, E.H.; Oswalt, S.N. 2003. **The status of Puerto Rico's forests, 2003.** SRS-119. Asheville, NC: U.S. Department of Agriculture, Southern Research Station. 93 p.

Bruegmann, M.M. 1996. **Hawaii's dry forests.** Endangered Species Bulletin. 21: 26-27.

Cabin, R.J.; Weller, S.G.; Lorence, D.H.; Flynn, T.W.; Sakai, A.K.; Sandquist, D.; Hadway, L.J. 2000. **Effects of a long-term ungulate exclusion and recent alien species control on the preservation and restoration of a Hawaiian tropical dry forest.** Conservation Biology. 14: 439-453.

Metrics Table

When you know:	Multiply by:	To find:
Acres (ac)	0.405	Hectares (ha)
Feet (ft)	0.305	Meters (m)
Inches (in.)	2.540	Centimeters (cm)
Miles (mi)	1.609	Kilometers (km)
Square miles (mi^2)	2.590	Square kilometers (km^2)

Cannarella, R.J. 2010. **Statewide assessment of forest conditions and resource strategy, 2010.** Honolulu, HI: Hawaii Department of Land and Natural Resources. 271 p. http://dlnr.hawaii.gov/forestry/info/fap/. (17 March 2014).

Carpenter, C.; McGinley, K.; Ramos, O.; Bennett, K.; Fischer, L.; Liu, Z. 2007. **Tropical and subtropical forests of US islands and related island republics.** [Place of publication unknown]: Sustainable Forests Roundtable. http://www.sustainableforests.net/docs/2007/0907%20Roundtable%20SF/Carpenter%20Tropical%20&%20Subtropical%20Forests.pdf. [Powerpoint presentation]. (1 February 2012).

Chakroff, M. 2010. **U.S. Virgin Islands forest resources assessment and strategies: A comprehensive analysis of forest-related conditions, trends, threats and opportunities.** Kingshill, VI: Virgin Islands Department of Agriculture, Forestry Division. 107 p.

Commonwealth of the Northern Mariana Islands (CNMI) Forestry. 2010. **Commonwealth of the Northern Mariana Islands (CNMI) statewide assessment and resource strategy, 2010-2015.** 78 p. http://www.wflccenter.org/islandforestry/cnmi.pdf. (10 June 2011).

Cordell, S. [No date]. **The potential for restoration to break the grass/fire cycle in dryland ecosystems in Hawaii (RC-1645).** Alexandria, VA: Strategic Environmental Research and Development Program. 2 p. http://www.serdp.org/content/view/pdf/7987. (8 July 2013).

Craig, P., ed. 2002. **Natural history guide to American Samoa.** Pago Pago, American Samoa: U.S. Department of the Interior, National Park of American Samoa, Department of Marine and Wildlife Resources. 76 p.

Cuddihy, L.W.; Stone, C.P. 1990. **Alteration of native Hawaiian vegetation: effects of humans, their activities and introductions.** Manoa: University of Hawaii, Cooperative National Park Resources Study Unit. 138 p.

Dingeman, R. **State wins against gall wasp.** The Maui News. 2010 March 27. http://www.flemingarboretum.org/State%20wins%20against%20gall%20wasp%20-%20Mauinews.com.pdf. (9 August 2012).

Donnegan, J.A.; Butler, S.L.; Grabowiecki, W.; Hiserote, B.A.; Limtiaco, D. 2004a. **Guam's forest resources, 2002.** Resour. Bull. PNW-RB-243. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 32 p.

Donnegan, J.A.; Butler, S.L.; Kuegler, O.; Hiserote, B.A. 2011. **Commonwealth of the Northern Mariana Islands' forest resources, 2004.** Resour. Bull. PNW-RB-261. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 40 p.

Donnegan, J.A.; Mann, S.S.; Butler, S.L.; Hiserote, B.A. 2004b. **American Samoa's forest resources, 2001.** Resour. Bull. PNW-RB-244. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 32 p.

Ecosystem Marketplace Network (EMN). 2010. **Saipan's upland mitigation bank.** http://www.speciesbanking.com/program/saipans_upland_mitigation_bank. (25 August 2014).

Food, Conservation, and Energy Act of 2008. **Public Law 110-234.** http://www.gpo.gov/fdsys/pkg/PLAW-110publ234/html/PLAW-110publ234.htm. (25 August 2014).

Gallucci, F.J. 1987. **Puerto Rico . . . its land, history, culture, and literature.** http://www.yale.edu/ynhti/curriculum/units/1987/1/87.01.04.x.html. (9 June 2011).

Gillespie, T.W. [No date]. **Tropical dry forests of the Pacific: the Marianas Islands.** Los Angeles, CA: University of California Los Angeles. 4 p. http://www.sscnet.ucla.edu/geog/tdfpacific/marianas_islands.html. (25 August 2014).

Gon, S.M., III. 2006. **The Hawai'i GAP analysis project final report.** Honolulu: University of Hawai'i, Research Corporation of the University of Hawai'i. 163 pages.

Gray, S.C.; Gobbi, K.L.; Narwold, P.V. 2008. **Comparison of sedimentation in bays and reefs below developed versus undeveloped watersheds on St. John, US Virgin Islands.** In: Proceedings of the 11th international coral reef symposium; 2008 July 7-11; Ft. Lauderdale, FL: [Publisher unknown]. Volume 1: 351-356. http://www.nova.edu/ncri/11icrs/proceedings/files/m10-13.pdf. (13 June 2011).

Hawaii Department of Agriculture (HDOA). 2008. **HDOA releases biocontrol insect to control gall wasp.** Honolulu, HI: Hawaii Department of Agriculture. [news release]. http://hawaii.gov/hdoa/news/2008-news-releases/news-release-nr08-29-november-25-2008. (19 July 2012).

Helmer, E.H. 2004. **Forest conservation and land development in Puerto Rico.** Landscape Ecology. 19: 29-40.

Helmer, E.H.; Brandeis, T.J.; Lugo, A.E.; Kennaway, T. 2008. **Factors influencing spatial pattern in tropical forest clearance and stand age: implications for carbon storage and species diversity.** Journal of Geophysical Research. 113: G02S04. DOI: 10.1029/2007JG000568.

Helmer, E.H.; Ramos, O.; López, T. Del M.; Quiñones, M.; Diaz, W. 2002. **Mapping the forest type and land cover of Puerto Rico, a component of the Caribbean biodiversity hotspot.** Caribbean Journal of Science. 38(3-4): 165-183.

Helmer, E.H.; Ruefenacht, B. 2005. **Cloud-free satellite image mosaics with regression trees and histogram matching.** Photogrammetric Engineering and Remote Sensing. 71(9): 1079-1089.

Heu, R.A.; Nagamine, W.T.; Suh, T.H.; Tsuda, D.M.; Yalemar, J.A. 2008. **New pest advisory: *Quadrastichus erythrinae* Kim.** Honolulu: Hawaii Department of Agriculture. http://hawaii.gov/hdoa/pi/ppc/npa-1/npa05-03-EGW.pdf. (19 July 2012).

Holdridge, L.R. 1947. **Determination of world plant formations from simple climate data.** Science. 105: 367-368.

Homer, C.; Dewitz, J.; Fry, J.; Coan, M.; Hossain, N.; Larson, C.; Herold, N.; McKerrow, A.; VanDriel, J.N.; Wickham, J. 2007. **Completion of the 2001 National Land Cover Database for the conterminous United States.** Photogrammetric Engineering and Remote Sensing. 73(4): 337-341.

Kennaway, T.; Helmer, E.H. 2007. **The forest types and ages cleared for land development in Puerto Rico.** GIScience and Remote Sensing. 44(4): 356-382.

Kennaway, T.; Helmer, E.H.; Lefsky, M.A.; Brandeis, T.A.; Sherrill, K.R. 2008. **Mapping land cover and estimating forest structure using satellite imagery and coarse resolution lidar in the Virgin Islands.** Journal of Applied Remote Sensing. 2: 023551. DOI: 10.1117/1.3063939.

LaRosa, A.M.; Tunison, T.; Ainsworth, A.; Kauffman, B.; Hughes, R.F. 2008. **Fire and nonnative invasive plants in the Hawaiian Islands bioregion.** In: Zouhar, K.; Smith, J.K.; Sutherland, St.; Brooks, M.L., eds. Wildland fire in ecosystems: fire and nonnative invasive plants. Gen. Tech. Rep. RMRS-GTR-42-vol. 6. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 225-241.

Lim, E.; Taylor, L.A.; Eakins, B.W.; Carignan, K.S.; Grothe, P.R.; Caldwell, R.J.; Friday, D.Z. 2010. **Digital elevation models of Pago Pago, American Samoa: procedures, data sources and analysis.** Technical Memorandum NESDIS NGDC-36. Boulder, CO: U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 26 p.

Liu, Z.; Fischer, L. 2006a. **Commonwealth of the Northern Mariana Islands vegetation mapping using very high spatial resolution imagery: methodology.** McClellan, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, Forest Health Protection. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev3_046396.pdf. (10 September 2012).

Liu, Z.; Fischer, L. 2006b. **Guam vegetation mapping using very high spatial resolution imagery: methodology.** McClellan, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, Forest Health Protection. 17 p.

Liu, Z.; Fischer, L. 2007 (draft). **American Samoa vegetation mapping using very high spatial resolution imagery: methodology.** McClellan, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, Forest Health Protection.

Lugo, A.E.; Helmer, E.H.; Vale, A. 2007. **La conservacion y vulnerabilidad a la urganizacion del karso Puertoriqueno.** Acta Cientifica. 21(1-3): 67-80. Abstract (in English).

Mafnas, J.S. 2010. **Guam statewide forest resource assessment and resource strategy, 2010-2015.** Philomath, OR: Watershed Professionals Network. http://www.wflccenter.org/islandforestry/guam.pdf. (10 June 2011).

Marler, T.E.; Lee, V.; Shaw, C.A. 2007. **Habitat heterogeneity of *Cycas micronesica* seed chemistry in Guam's forest.** Micronesica. 39(2): 297-314.

Marler, T.E.; Moore, A. 2011. **Military threats to terrestrial resources not restricted to wartime: a case study from Guam.** Journal of Environmental Science and Engineering. 5: 1198-1214.

Martinuzzi, S.; Gould, W.A.; Ramos Gonzalez, O.M.; Martinez Robles, A.; Calle Maldonado, P.; Pérez-Buitrago, N.; Fumero Caban, J.J. 2008. **Mapping tropical dry forest habitats integrating Landsat NDVI, Ikonos imagery, and topographic information in the Caribbean Island of Mona.** Revista de Biologia Tropical. 56(2): 625-639.

Puerto Rico, Department of Natural and Environmental Resources. 2011. **Puerto Rico statewide assessment and strategies for forest resources.** San Juan, PR: Puerto Rico Department of Natural and Environmental Resources. 100 p. http://www.stateforesters.org/files/PuertoRico-PR201010221856-001.pdf. (8 August 2012).

Ridgell, C. 2012. **Aim of pig hunting derby is to control wild pig population.** Pacific News Center/ Sorensen Media Group. http://pacificnewscenter.com/index.php?option=com_content&view=article&id=21569:video-pig-hunting-derby-to-control-wild-pig-population&catid=45:guam-news&Itemid=156. (8 August 2012).

Rivera, L.W. ; Aide, L.W. 1998. **Forest recovery in the karst region of Puerto Rico.** Forest Ecology and Management. 108: 63-75.

Rollins, M.G. 2009. **LANDFIRE: A nationally consistent vegetation, wildland fire, and fuel assessment.** International Journal of Wildland Fire. 18: 235-249.

Secretariat of the Pacific Community. 2010. **Natural enemies to fight invasive plant species.** Noumea, New Caledonia: Secretariat of the Pacific Community, Land Resources Division. http://www.spc.int/lrd/index.php?option=com_content&view=article&id=392:natural-enemies-to-fight-invasive-plant-species-&catid=14. (16 July 2012).

Smail, R.A.; Lewis, D.J. 2009. **Forest-land conversion, ecosystem services, and economic issues for policy: A review.** Gen. Tech. Rep. PNW-GTR-797. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 40 p.

Smith, S. 2007. **Quick action and cooperative efforts help save the cycads on Guam.** Unpublished trip report (April 23-26, 2007), U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, Forest Health Protection. Available at the Lassen National Forest, Regional Entomologist staff, 1323 Club Drive, Vallejo, CA 94592.

Smith, W.B.; Miles, P.D.; Perry, C.H.; Pugh, S.A. 2009. **Forest resources of the United States, 2007.** Gen. Tech. Rep. WO-78. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 336 p.

Stein, S.; Alig, R.J.; White, E.M.; Comas, S.J.; Carr, M.; Eley, M.; Elverum, K.; O'Donnell, M.; Theobald, D.M.; Cordell, K.; Haber, J.; Beauvais, T.W. 2007. **National forests on the edge: Development pressures on America's national forests and grasslands.** Gen. Tech. Rep. PNW-GTR-728. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 26 p.

Stein, S.M.; McRoberts, R.E.; Mahal, L.G.; Carr, M.A.; Alig, R.J.; Comas, S.J.; Theobald, M. 2009. **Private forests, public benefits: Housing development and other pressures on private forest contributions.** Gen. Tech. Rep. PNW-GTR-795. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 74 p.

Strieker, G. **Wildlife experts work to save Guam's failing forests.** Cable News Network; 1998 July 15. 2 p.

Terry, I.; Marler, T. 2005. **Paradise lost? Tipping the scales against Guam's *Cycas micronesica*.** The Cycad Newsletter. 28(3-4): 21-23.

Theobald, D. 2005. **Landscape patterns of exurban growth in the USA from 1980 to 2020.** Ecology and Society. 10(1): 32.

United Nations, Secretariat of the Pacific Regional Environment Programme. 2012. **Next steps for developing a site-based conservation programme in the Commonwealth of North Mariana Islands.** http://www.sprep.org/. (5 December 2012).

U.S. Census Bureau. 2001a. **Census 2000 summary file 1 technical documentation.** Washington, DC: U.S. Department of Commerce, Census Bureau.

U.S. Census Bureau. 2001b. **Census 2000 summary file 1.** Washington, DC: U.S. Department of Commerce, Census Bureau.

U.S. Census Bureau. 2001c. **Census 2000 summary file 3.** Washington, DC: U.S. Department of Commerce, Census Bureau.

U.S. Census Bureau. 2011a. **United States census 2010: Census coverage measurement.** Washington, DC: U.S. Department of Commerce, Census Bureau. https://www.census.gov/coverage_measurement/. (25 August 2014).

U.S. Census Bureau. 2011b. **U.S. Census Bureau releases 2010 census population counts for American Samoa.** Washington, DC: U.S. Department of Commerce, Census Bureau. http://www.census.gov/newsroom/releases/archives/2010_census/cb11-cn177.html. (25 August 2014).

U.S. Census Bureau. 2011c. **U.S. Census Bureau releases 2010 census population counts for Guam.** Washington, DC: U.S. Department of Commerce, Census Bureau. https://www.census.gov/newsroom/releases/archives/2010_census/cb11-cn179.html. (25 August 2014).

U.S. Census Bureau. 2011d. **U.S. Census Bureau releases 2010 census population counts for the Northern Mariana Islands.** Washington, DC: U.S. Department of Commerce, Census Bureau. http://www.census.gov/2010census/news/releases/operations/cb11-cn178.html. (25 August 2014).

U.S. Census Bureau. 2011e. **U.S. Census Bureau releases 2010 census population counts for the U.S. Virgin Islands.** Washington, DC: U.S. Department of Commerce, Census Bureau. http://www.census.gov/2010census/news/releases/operations/cb11-cn180.html. (25 August 2014).

U.S. Central Intelligence Agency. 2010. **The world fact book: Northern Marianas Islands.** Washington, DC: U.S. Central Intelligence Agency. https://www.cia.gov/library/publications/the-world-factbook/geos/cq.html. (9 June 2011).

U.S. Central Intelligence Agency. 2011. **The world fact book: Puerto Rico.** Washington, DC: Central Intelligence Agency. https://www.cia.gov/library/publications/the-world-factbook/geos/rq.html. (9 June 2011).

U.S. Forest Service. 2007. **Tropical forests of the United States: applying USDA state and private forestry programs.** Unpublished paper prepared by forestry representatives of the U.S. tropical islands and the Forest Service for use by the State and Private Forestry Program Redesign Committee, May 4, 2007. 9 p. http://www.wflccenter.org/news_pdf/259_pdf.pdf. (7 June 2011).

U.S. Forest Service. 2011. **FHP [Forest Health Program] in Hawaii.** Hilo, HI: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, State and Private Forestry. http://www.fs.fed.us/r5/spf/fhp/hawaii/index.shtml. (6 June 2011).

U.S. Forest Service. 2012. **International Institute of Tropical Forestry 2011 accomplishment report.** San Juan, PR: U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry. 60 p.

U.S. Department of Defense. 2010. **Final environmental impact statement—Guam and CNMI military relocation: Relocating marines from Okinawa, visiting aircraft carrier berthing, and Army Air and Missile Defense Task Force, executive summary.** Washington, DC: U.S. Department of Defense, Department of Navy. 60 p. http://www.guambuildupeis.us/final_documents. (22 June 2012).

U.S. Fish and Wildlife Service. 2012. **Endangered species.** Honolulu, HI: U.S. Department of Interior, Fish and Wildlife Service, Pacific Islands Fish and Wildlife Service. http://www.fws.gov/pacificislands/species.html. (4 December 2012).

U.S. Department of the Interior (USDI); U.S. Department of Agriculture (USDA). 2013. **LANDFIRE data distribution site.** http://www.landfire.gov. (26 February 2013).

U.S. Environmental Protection Agency. 2008. **Commonwealth of the Northern Mariana Islands.** Washington, DC: U.S. Environmental Protection Agency. http://www.epa.gov/region09/islands/cnmi.html. (23 June 2008).

U.S. Environmental Protection Agency. 2012. **Mitigation banking factsheet.** Washington, DC: U.S. Environmental Protection Agency. http://water.epa.gov/lawsregs/guidance/wetlands/mitbanking.cfm. (5 December 2012).

U.S. Geological Survey. 2005. **Hawaiian Islands: USGS Hawaii data clearinghouse.** Washington, DC: U.S. Department of Interior, Geological Survey. http://hawaii.wr.usgs.gov/islands.html. (6 June 2011).

U.S. Virgin Islands (USVI), Department of Agriculture. 2010. **Assessment of need—Forest Legacy Program, U.S. Virgin Islands. Appendix E.** Estate Lower Love, St. Croix, USVI: USVI, Department of Agriculture. 100 p. http://www.geographicconsulting.com/wp-content/uploads/2011/10/Forest-Legacy-Assessment-of-Need-Update-2010-VIDOA.pdf. (8 July 2013).

Wagner, W.L.; Herbst, D.R.; Sohmer, S.H. 1999. **Manual of flowering plants of Hawai'i.** Special Publication 83. Honolulu, HI: Bishop Museum. 1,918 p.

Western Forestry Leadership Coalition (WFLC). 2010. **Threats to western private forests: A framework for conserving and enhancing the benefits from private working forests in the western U.S.** Lakewood, CO: Western Forestry Leadership Coalition. 31 p. www.wflcweb.org. (8 July 2012).

Wilcove, D.S.; Rothstein, D.; Dubow, J.; Phillips, A.; Losos, E. 1998. **Quantifying threats to imperiled species in the United States.** BioScience. 48(8): 607-615.

Zimmerman, N.; Hughes, R.F.; Cordell, S.; Hart, P.; Chang, H.K.; Perez, D.; Like, R.K.; Ostertag, R. 2008. **Patterns of primary succession of native and introduced plants in lowlands wet forests in eastern Hawaii.** Biotropica. 40(3): 277-284.

Found in dry and mesic forests, the Mamane tree (*Sophora chrysophylla*) is seen here growing on aa lava, Mauna Kea, Hawaii Island, Hawaii. Photo by J.B. Friday.

APPENDIX: METHODOLOGY DETAILS

Technical Information Regarding Datasets and Analysis

An overview of the analysis process appeared earlier in this report in the Methods section. The aim of this appendix is to provide sufficient additional detail so that interested parties can replicate or critique the methodology.

Maps appearing in this report were produced by using geographic information system (GIS) software (Esri's ArcMap 10.0), including core functionality as well as the spatial analyst extension. Graphs were produced by exporting attribute data from geospatial datasets and generating summaries using pivot tables in Microsoft Excel 2010.

To assess the potential for increased housing development to impact private forest land, geospatial datasets were constructed that represent: (1) projected housing density changes between 2000 and 2030, (2) land ownership, and (3) land cover. All datasets were converted to raster format at a resolution that matched the available land cover data for each island. Additional detail for each of the data types is provided below.

Projected Housing Density Changes Between 2000 and 2030

Using population and housing density data from the 2000 U.S. Census (U.S. Census Bureau 2001 a-c) as a baseline[16], projections of housing density increases were derived from predicted population changes. A spatially explicit model was used to predict the full urban-to rural spectrum of housing densities (Theobald 2005). The same projection approach was used in previous FOTE reports, and additional discussion and description can be found in those sources (for example, refer to the appendix in the *Private Forests/Public Benefits* report [Stein et al. 2009]).

[16] 2010 housing data for the trust territories were not available at the time of Theobald's (2005) housing density analysis.

The projected housing density dataset contains elements of land use in addition to housing density categories (Table A-1). The land use categories are necessary to identify areas that are likely not developable. Categories in the projected housing density layer were aggregated into the general density categories used in this report, namely rural 1, rural 2, exurban, and urban (Table A-1).

Land Ownership

Ownership data for the islands were gathered from publicly available data sources and were compiled to create a geospatial data layer depicting ownership in five categories: private unprotected, private protected, public, tribal, and private unprotected (undevelopable).

Land Cover

As described in the Methods section, sources of land cover were different for each island (Table A-2). The selection of land cover data source was based on a combination of dataset completeness and local expert opinion on the suitability of each dataset for distinguishing forest from nonforest. Land cover or vegetation categories for each data source were collapsed to a binary forest/nonforest designation (Tables A-3, A-4).

Once the three geospatial datasets were created for each island and converted to a common raster format and resolution, they were combined using a GIS operation (ArcMap spatial analyst combine command). The result of this operation was the attribution of each raster pixel on the island with the information provided in the three datasets.

A simple set of decisions was then applied in order to assign each pixel to a final map category (Fig. A-1). We opted to use a simple, straightforward mapping process to provide maximum transparency of the methodology. For American Samoa's Tutuila island only, we added an elevation threshold to the housing density model such that development was precluded from areas above 328 feet above sea level, based on Digital Elevation Model data (Lim et al. 2010). This modification was in response to local experts who indicated that the northern coast of Tutuila is exceptionally steep and unlikely to be developed because of the rugged terrain.

Table A-1.—Categories in a projected housing density geospatial datasets for subtropical and tropical islands[a], and the corresponding aggregated mapped categories

Housing Density Category	Land use classes included
Rural 1	
	Barren (and <8 units/mi^2) Forestry (and <8 units/mi^2) Grazing (and <8 units/mi^2) Intensive agriculture (cropland and <8 units/mi^2) Residential - (very low-density, 8-16 units/mi^2)
Rural 2	
	Residential - (low-density, 16-32 units/mi^2) Residential - (low-moderate density, 32-64 units/mi^2)
Exurban/urban	
	Residential - (moderate-density, 64-376 units/mi^2) Residential - (moderate-high, 376-1067 units/mi^2) Residential - (high, 1067-6400 units/mi^2) Residential - (very high, >6400 units/mi^2)
Not developable	
	Commercial/industrial Transportation Urban parks/open space Water Built-up public land Wetlands/riparian Protected lands

[a] Hawaii, Guam, American Samoa, Commonwealth of the Northern Mariana Islands, Puerto Rico, and U.S. Virgin Islands.

Table A-2.—Sources of forest land cover definitions for the islands

Island/complex	Dataset description	Resolution	Source
Hawaii	LANDFIRE Existing Vegetation Type	30 m	USDI and USDA (2013)
Guam	Satellite imagery classification by the U.S. Forest Service	15 m	Liu and Fischer (2007)
American Samoa	Satellite imagery classification by the U.S. Forest Service	15 m	Liu and Fischer (2006b)
Commonwealth of the Northern Mariana Islands	Satellite imagery classification by the U.S. Forest Service	15 m	Liu and Fischer (2006a)
Puerto Rico—main island, Vieques, and Culebra	National Land Cover Data (NLCD) database	15 m	Homer et al. (2007), based on Kennaway and Helmer (2007)
Puerto Rico—Mona Island	Landsat, Ikonos imagery	15 m	Martinuzzi et al. (2008)
U.S. Virgin Islands	Satellite imagery and coarse resolution Lidar	15 m	Kennaway et al. (2008)

Table A-3.—Categories in land cover or vegetation geospatial datasets for U.S.-affiliated subtropical and tropical islands in the Pacific Ocean and the corresponding forest/nonforest categories

American Samoa

Forest	Nonforest
Freshwater swamps	Littoral strand
Mangroves	Marshes
Rainforest	Summit scrub
Rhus secondary forest	Montane scrub
	Agriculture
	Urban cultivated
	Secondary scrub
	Sandy beach/bare rocks
	Quarry and landfill
	Urban built-up
	Water

CNMI

Forest	Nonforest
Agroforest	Barren/sandy beach/bare rocks
Agroforest - coconut	Cropland
Casuarina thicket	Other shrub and grass
Leucaena leucocephala (tangantangan)	Savanna complex
Mixed introduced forest	Strand
Native limestone forest	Urban built-up
	Urban vegetation
	Water
	Wetland

Guam

Forest	Nonforest
Acacia plantation	Agriculture field
Casuarina thicket	Badland
Leucaena stand	Barren
Limestone forest	Coconut plantation
Mangrove swamp	Marsh land
Palma brava grove	Other shrub/grass
Ravine forest	Sandy beach/bare rocks
Scrub forest	Savanna complex
	Strand vegetation
	Urban built-up
	Urban cultivated
	Water
	Wetland

Hawaii

Forest	Nonforest
Hawaiian introduced wetland vegetation - tree	Hawaiian introduced wetland vegetation – shrub
Hawaii lowland rainforest	Hawaii wet cliff and ridge crest shrubland
Hawaii montane cloud forest	Hawaii lowland dry shrubland
Hawaii montane rainforest	Hawaii lowland mesic shrubland
Hawaii lowland dry forest	Hawaii montane – subalpine dry shrubland
Hawaii lowland mesic forest	Hawaii alpine dwarf shrubland
Hawaii montane-subalpine dry forest and woodland	Hawaii dry cliff
Hawaii montane-subalpine mesic forest	Hawaii dry coastal strand
Hawaiian introduced dry forest	Hawaii wet – mesic coastal strand
Hawaiian introduced wet-mesic forest	Hawaii subalpine mesic shrubland
Introduced coastal wetland vegetation - tree	Hawaiian introduced deciduous shrubland
Hawaiian managed tree plantation	Hawaiian introduced evergreen shrubland
	Introduced coastal wetland vegetation – shrub
	Open water
	Barren
	Developed – open space
	Developed – low intensity
	Developed – medium intensity
	Developed – high intensity
	No data
	Hawaii bog
	Hawaii lowland dry grassland
	Hawaii lowland mesic grassland
	Hawaii montane – subalpine dry grassland
	Hawaii montane – subalpine mesic grassland
	Hawaiian introduced perennial grassland
	Introduced coastal wetland vegetation – herbaceous
	Agriculture – cultivated crops and irrigated agriculture
	Hawaiian introduced wetland vegetation – herbaceous

Table A-4.—Categories in land cover or vegetation geospatial datasets for U.S.-affiliated subtropical and tropical islands in the Caribbean and the corresponding forest/nonforest categories

U.S. Virgin Islands

Forest	Nonforest
Active sun coffee and mixed woody agriculture	Background/water
Drought deciduous open woodland	High-medium density urban
Drought deciduous dense woodland	Low-medium density urban
Deciduous, evergreen coastal, and mixed forest or shrubland with succulents	Herbaceous agriculture – cultivated lands
Semi-deciduous and drought deciduous forest on alluvium and non-carbonate substrates	Pasture, hay, or inactive agriculture (e.g., abandoned sugar cane)
Semi-deciduous and drought deciduous forest on karst (includes semi-evergreen forest)	Pasture, hay, or other grassy areas (e.g., soccer fields)
Drought deciduous, semi-deciduous, and seasonal evergreen forest on serpentine	Emergent wetlands including seasonally flooded pasture
Seasonal evergreen and semi-deciduous forest on karst	Salt or mud flats
Seasonal evergreen and evergreen forest	Tidally flooded evergreen dwarf-shrubland and forb vegetation
Seasonal evergreen forest with coconut palm	Quarries
Evergreen and seasonal evergreen forest on karst	Coastal sand and rock
Evergreen forest on serpentine	Bare soil (including bulldozed land)
Elfin, sierra palm, transitional, and tall cloud forest	Water – permanent
Mangroves	
Seasonally flooded savannahs and woodlands	
Pterocarpus swamp	

Puerto Rico

Forest	Nonforest
Evergreen forest	Open water
Woody wetlands	Developed – open space
	Developed – low intensity
	Developed – medium intensity
	Developed – high intensity
	Shrub/scrub
	Grassland/herbaceous
	Pasture/hay
	Cultivated crops
	Emergent herbaceous wetlands

Puerto Rico, Mona Island

Forest	Nonforest
Forest	Woodland and shrubland
	Nonforest vegetation
	Barren
	Urban

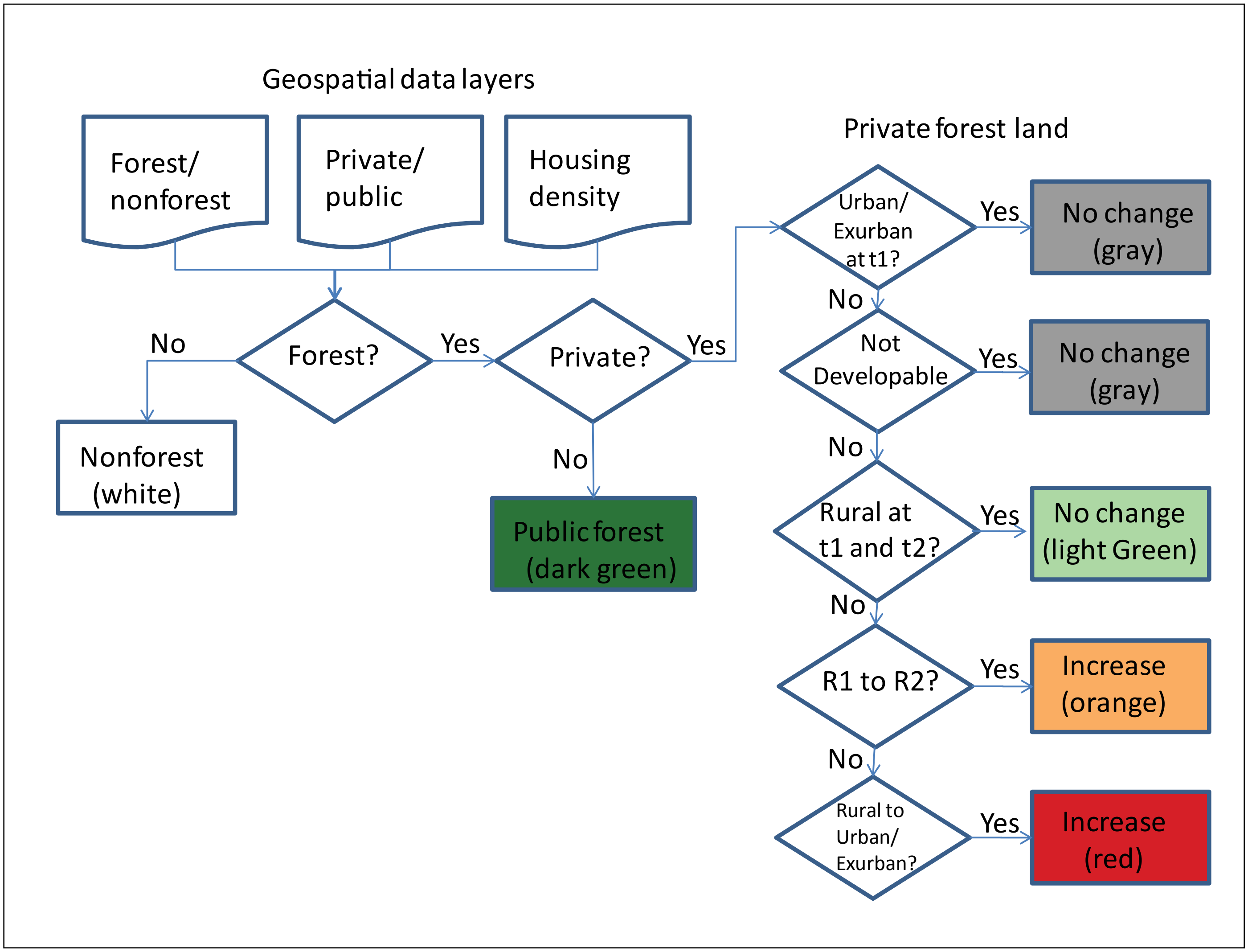


Figure A-1.—Logic applied to three geospatial datasets to determine the impact of projected housing density changes on private forest land. Colors (rectangles) correspond to maps found earlier in the report. For American Samoa's Tutuila Island only, we added an elevation threshold to the housing density model such that development was precluded from areas 328 feet or more above sea level.

Emerald tree skink, also called the green tree skink, (*Lamprolepis smaragdina*). Photo by Daniel W. Clark.

FORESTS ON THE EDGE

Forests on the Edge is a project of the U.S. Forest Service, State and Private Forestry, Cooperative Forestry staff, in conjunction with the Forest Service's Research and Development and National Forest System deputy areas, universities, and other partners. The project aims to increase public understanding of the contributions of and pressures on America's forests, and to create new tools for strategic planning. The first report identified private forested watersheds in the conterminous United States most likely to experience increased housing density. Subsequent reports have provided more in-depth discussion and data on: development pressures on America's national forests and grasslands, impacts of increased housing density and other pressures on private forest benefits, threats to at-risk species, sustaining America's urban trees and forests, and understanding and preparing for wildfire in the wildland-urban interface, among others. Forests on the Edge publications can be viewed or downloaded at the Forest Service Open Space Web site, http://www.fs.fed.us/openspace/fote.

Future Forests on the Edge reports in preparation feature the role of forests in protecting surface drinking water and potential impacts of future development; impacts of increased housing density on forest woody biomass; and impacts of climate change and rising sea levels on island forests.

For further information on Forests on the Edge, contact:

Coordinator, Open Space Initiative
U.S. Forest Service, Cooperative Forestry staff
1400 Independence Avenue, SW, Mailstop 1123
Washington, DC 20250-1123
http://www.fs.fed.us/openspace/fote/

Photos on front cover, from top then left to right: Elysiumm/istockphoto.com; J.B. Friday; EhPoint/istockphoto.com; KeithBinns/istockphoto.com. Back cover: Skibreck, istockphoto.com.