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Assessing Forest Sustainability in the Tropical Islands of the United States

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Cover: The rock islands of the Palau archipelago. Photo by LuxTonnerre.

Abstract

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This report is a companion report to the *National Report on Sustainable Forests*, except that the analysis in this case is specifically applied to tropical forests found on U.S. islands and U.S.-affiliated island jurisdictions in the Caribbean Sea and Pacific Ocean. Like its national counterpart, the report uses the Montréal Process Criteria and Indicators for Sustainable Forest Management (MP C&I) to provide a comprehensive picture of forest conditions. Each of the seven criteria in the MP C&I is given a separate chapter, and the resulting analysis includes consideration of ecological, social, economic, and institutional dimensions of forest sustainability.

Our key findings mirror those of the 2010 national report: tropical forests on the U.S. islands are not experiencing broad-scale deforestation, and forest area is stable in most jurisdictions. However, these forests are facing multiple threats from environmental and anthropogenic stressors. With 760 plant and animal species across all the islands identified as at risk of extinction by the International Union for the Conservation of Nature, the threat of native biodiversity loss from extinction and extirpation, particularly in the Pacific, is the biggest warning flag regarding forest sustainability. In the Caribbean, where islands are relatively closer to each other and to the mainland than islands in the Pacific, and where past agricultural practices resulted in broad-scale disruption of native forest ecosystems, new assemblages of forest species are evolving, some including native and nonnative species, though most are still in relatively young age classes. On the social and economic front, commodity wood production plays a minimal to nonexistent role in island economies, but forests provide numerous benefits to island peoples, the importance of which are often enhanced by the limited space and close local social-ecological interactions reinforced by island geography and by long-established patterns of use on the part of local residents. Institutionally, many of the islands face considerable challenges resulting from a lack of economies of scale and sufficient resources for effective forest management.

Keywords: Tropical forests, U.S.-affiliated islands, forest sustainability, criteria and indicators, nonnative species.

Acknowledgments

This comprehensive synthesis of information about forests on the U.S. tropical islands and affiliated jurisdictions relies on a great deal of substantive work by experts who focused on particular regions and specific areas within the broad discipline of forestry. Much of this effort is reflected by the references accompanying each chapter, but considerable work was devoted to the project that could not be presented in published form, without which this report would not have been possible.

The project began with the compilation of individual indicator reports for each of the nine island jurisdictions that were covered. This was a major undertaking; although publishing each of these indicator reports was not feasible, they helped lay the foundation for the entire project. Karen Bennett (formerly with the U.S. Forest Service's Institute of Pacific Islands Forestry, or IPIF) led this effort in the Pacific and was later succeeded by Kathleen Friday (IPIF/Pacific Southwest Region State and Private Forestry). From the U.S. Forest Service's International Institute of Tropical Forestry (IITF), Kathleen McGinley (Research and Development) and Constance Carpenter (State and Private Forestry) worked on these island-specific reports for the Caribbean. Leo Zhangfeng-Liu and Lisa Fischer (contractor for and formerly with Pacific Southwest Region State and Private Forestry, respectively), Thomas Brandeis (U.S. Forest Service Southern Research Station), and Eileen Helmer (IITF research ecologist) added essential pieces to the puzzle.

More generally, we have made repeated use of certain key data sources and key information contacts, particularly in regard to forest inventory information provided by the Forest Inventory and Analysis program. In addition to Thomas Brandeis, Joseph Donnegan and Olaf Kuegler (both at the U.S. Forest Service Pacific Northwest Research Station) deserve special thanks here.

We thank our numerous reviewers for the time and focused attention they gave to this report in its preparation. More than 20 people provided review comments on specific chapters or on the document as a whole. In many cases, these comments were quite extensive, and all resulted in important improvements to the report.

Special thanks also go to Olga Ramos (IITF, GIS and Remote Sensing Lab), who provided many of the maps used in the publication, and Keith Routman (U.S. Forest Service Pacific Northwest Research Station) for his substantial work in editing and designing this document.

The Statewide Assessments and Resource Strategies (SWARS—subsequently called Forest Action Plans) provided essential background for many of the sustainability criteria addressed in this report, particularly the more qualitative assessments presented for Criterion 6 (social and economic conditions) and Criterion 7 (institutional framework). We cannot acknowledge by name each of the many island forestry staff and contractors who contributed to the SWARS, but their major contribution to this report and sustainable forest management in general is recognized.

Preface

In September 2017, two major hurricanes passed through the Caribbean, causing catastrophic damage to communities, infrastructure, and ecosystems across Puerto Rico, the U.S. Virgin Islands, and many other island jurisdictions throughout the region. Hurricane Irma was a category 5 storm when it passed directly over the U.S. Virgin Islands on September 6, 2017, causing flooding, landslides, and extensive structural damage, particularly on the island of St. Thomas. The outer bands of Hurricane Irma also grazed Puerto Rico, affecting natural and built infrastructure and leaving more than 1 million inhabitants (30 percent of the population) without power. Two weeks later, on September 20, 2017, Hurricane Maria, a second category 5 storm, made landfall on the southeast coast of Puerto Rico, traversing the island in its entirety, as its northern eyewall crossed over St. Croix in the U.S. Virgin Islands. Hurricane Maria, the strongest storm to make landfall in Puerto Rico since Hurricane San Felipe II in 1928, produced widespread storm surges, flash floods, and landslides, and it resulted in unprecedented losses to infrastructure, crops, livestock, and natural vegetation across the islands.

As this report goes to press, more than 50 deaths in Puerto Rico and the U.S. Virgin Islands have been attributed to Hurricanes Irma and Maria, and the costs of recovery are estimated in the tens of billions of dollars. Many of the residents of these islands remain without power and with only limited access to basic necessities and public services. Large expanses, once green, now appear brown in satellite imagery, reflecting the changes in vegetation after the hurricanes. Nevertheless, as noted throughout this report and specifically in the chapter covering Criterion 3 (forest disturbance), hurricanes and storms are part of the cycle of island life. In the case of forests, they influence their structure, function, diversity, and composition. Many native island species have evolved to withstand strong storms and hurricanes and to recover rapidly after they have passed. As Dr. Ariel Lugo, director of the USDA Forest Service International Institute of Tropical Forestry in Puerto Rico, observed soon after the event, within 2 weeks of Hurricane Maria defoliated trees already had begun to sprout new leaves, demonstrating the resilience of island species. Similarly, Puerto Ricans and Virgin Islanders have shown great strength and determination as they begin to recover and rebuild.

Future research on forest responses to Hurricanes Irma and Maria will expand existing long-term datasets and knowledge on forest recovery, and will shed new light on forest trajectories in the aftermath of back-to-back major storms. New research also should address how people respond to and recover from major storms and how such storms influence their perspectives on, activities in, uses of, and preferences for forests in natural to urban settings. Future assessments of tropical forest sustainability in Puerto Rico and the U.S. Virgin Islands should continue to examine a broad range of ecological, economic, and social elements and trends. We are confident that such assessments will only further document the enduring resilience of the people, cultures, and forests of these islands.

Executive Summary

The tropical forests found on U.S.-affiliated islands in the Caribbean Sea and Pacific Ocean are unique and varied, as are the peoples who inhabit them. Comprising just 0.2 percent of total U.S. land area, the islands span two hemispheres and possess a disproportionately large number of endemic species and distinctive ecosystem types. Moreover, each island has a unique history of human habitation and cultural development. The current status and future sustainability of the forests on these islands are the focus of this report.

The U.S. Forest Service's *National Report on Sustainable Forests*, the next edition of which is slated for publication in 2018, assesses forest sustainability for the U.S. mainland using the Montréal Process Criteria and Indicators for Sustainable Forest Management (MP C&I). With 54 indicators arranged under 7 criteria, the MP C&I constitutes an explicit and comprehensive information framework for assessing sustainability across ecological, social, and economic dimensions. This report extends this application to forests found on the U.S.-affiliated islands, treating each criterion in a separate chapter.

Although the MP C&I provides a framework for information display and analysis, the actual assessment of sustainability is here addressed synthetically through summarization, first in criterion summaries for each criteria, and then in a compilation of key findings in a summary chapter.

Key Findings

Are island tropical forests sustainable? This is a complex question with no easy "yes" or "no" answers and subject to varying interpretations. Readers are encouraged to reach their own conclusions based on the information presented in this report. In regard to the overarching question of forest sustainability, the report identifies three major findings:

- **Forest area throughout the islands is relatively stable** (and has in fact increased substantially in the Caribbean over the past 75 years). This fact indicates sustainability from the crucial but very limited standpoint of maintaining forest extent.
- **Native biodiversity in the Pacific Islands continues to be threatened** by various factors, notably the ongoing introduction of nonnative and invasive species, resulting in the endangerment and extinction of endemic species—a significantly negative indication for forest sustainability.
- **Novel assemblages of introduced and native tree species are maturing over large areas of the Caribbean**, indicating the dynamic nature of forest ecosystems. These forests may support ecosystem system functions and biodiversity at levels comparable to native forests. However, their overall implications for sustainability are not yet fully understood and depend on both sustainability definitions and the future trajectory of these novel ecosystems.

Additional Major Findings

- **Approximately 3 million ac of tropical forests exist in the island jurisdictions considered in this report**, ranging from nearly 1.5 million ac in the Hawaiian Islands to fewer than 24,000 ac in the Marshall Islands. Much of this forest land, particularly in Hawaii and the Caribbean, is composed of relatively young stands established on agricultural lands abandoned in the past century (see Criterion 1 in Part II).
- **The number of extinctions and endangered species listings are the biggest warning flags regarding forest sustainability.** Some 760 plant and animal species across all the islands considered in this report are identified as at risk of extinction by the International Union for the Conservation of Nature. Hawaii stands out as particularly critical owing to its high number and rate of endemics and its number of endangered species (see Criteria 1 and 3 in Part II).
- **The history of human settlement and subsequent patterns of land use strongly influence current forest composition and structure throughout the islands.** Forest cover was virtually eliminated in Puerto Rico and the U.S. Virgin Islands (USVI) in the colonial period. Current forests in that region consist largely of trees in smaller size and younger age classes. The same is true for some but not all areas of Hawaii. U.S.-affiliated Pacific islands have experienced long histories of human occupation, with the introduction of various nonnative species and the integration of forests

and agriculture in agroforestry systems, with resulting influences on forest structure and composition (see Criteria 1 and 2 in Part II).

- **Climate change threatens entire islands and ecosystems.** This report is focused on the assessment of **current** conditions, and the projected **future** impacts of climate change are generally beyond its scope. However, any assessment of the future sustainability of island forests must take into account the extreme susceptibility of tropical islands to sea-level rise, storm activity, and other impacts associated with climate change, especially atoll islands that are only a few feet above sea level. Moreover, most of the islands already feel the effects of the changing climate, particularly in terms of increasing variability and extremes in weather patterns.

- **Commercial forestry is relatively limited; nevertheless, linkages between people and forests are very strong.** Throughout the islands, forests provide agroforestry products, subsistence foods, medicinal compounds, wood for local crafts and construction, and other materials for cultural purposes and daily use. This reliance is compounded by the fact that, with the exception of Hawaii, per-capita incomes are less than half the U.S. average, and subsistence activities are concomitantly more important. Furthermore, the proximity and interaction of ecosystem components in island geographies enhances the importance of forests in the provision of ecosystem services such as drinking water, or sedimentation reduction in coastal waters (see Criteria 2 and 6 in Part II).

- **Institutional capacity for forest management is relatively limited, but islands partially compensate for this through regional collaboration and leveraging of available federal programs.** The island jurisdictions covered by this report generally lack the resources and economies of scale to support the sorts of institutions that underlie forest management in the continental United States. In response, many of the islands engage in regional collaboration and exchange (in higher education, for example), and have instituted cross-boundary partnerships that incorporate nongovernmental organizations, citizen groups, local and federal governments, and private sector representatives (see Criterion 7 in Part II).

- **Data that are both consistent over time and comparable across island jurisdictions are relatively rare, but the situation is improving.** The U.S. Forest Service Forest Inventory and Analysis (FIA) program has periodically measured forests in Puerto Rico since the mid 1980s and in the USVI since the mid 1990s. FIA activities also have more recently expanded to include tropical islands in the Pacific, and results will soon be available for the second measurement of some of the last islands to be included. U.S. Census and related socioeconomic data are not always directly comparable across different jurisdictions, especially for the U.S.-affiliated nations (Republic of the Marshall Islands, Federated States of Micronesia, and Republic of Palau), and various other datasets used for the mainland United States in the national report are not available for the tropical islands treated in this report (see chapter 2 in Part I).

Policy Recommendations

The report's policy recommendations focus on information consolidation and fostering collaboration through the ongoing support of regional and federal bodies. Specific recommendations include the following:

- **Pursue consolidation in data development and reporting.** Comparability across time and space is hampered by a lack of repeated sampling. Ongoing improvements of forest inventory data, in particular, will help ameliorate the lack of consistent information on forests, but many important information gaps will remain. Specific recommendations related to data development and reporting are included at the end of chapter 2.

- **Foster public participation and sensitivity to cultural differences as an essential component of forest planning and management activities**. Cultural relationships to the land differ considerably across stakeholder groups, as do styles of communication and political engagement. Public participation strategies and decisionmaking processes need to take these differences into account.

- **Focus management and data acquisition activities on forest conditions and outputs that are most valued by island residents.** Island inhabitants rely on forests for a broad range of services and outputs, few of which enter into formal markets or are subject to quantified measurement. To the extent possible, forest reporting and planning exercises need to explicitly identify these outputs and their relative importance, then use this information to tailor biological inventories, socioeconomic data collection, and management actions accordingly.

- **Support ongoing collaboration between island entities through durable federal and regional programs**. The value of federal programs and regional collaborations for small islands lacking capacity and economies of scale may not be fully understood in national venues, but these activities are critical to sustaining forest management activities on the islands.

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters
Feet (ft)	0.305	Meters
Miles (mi)	1.609	Kilometers
Acres (ac)	0.405	Hectares
Square miles (mi^2)	2.59	Square kilometers
Cubic feet (ft^3)	0.283	Cubic meters
Tons	0.9071	Tonnes


City of Charlotte Amalie, capital of the U.S. Virgin Islands.

Part I.

Introduction and Summary

Nick Hall, courtesy of The Nature Conservancy

Aerial view of Kosrae, Federated States of Micronesia. The sunlit trees at center are the Yela Valley freshwater swamp forest; a Forest Legacy conservation easement here protects the largest remaining stand of ka (*Terminalia carolinensis*) in the world.

Chapter 1

Introduction

Guy C. Robertson and Kathleen A. McGinley

The purpose of this report is threefold: (1) most importantly, to present a comprehensive description of the current state of tropical forest ecosystems on islands in and affiliated with the United States; (2) to construct a well-organized compendium of information as a general reference for multiple purposes; and (3) to provide our own sustainability assessment as a contribution to the broader discussion about the crucial question of forest sustainability in the U.S. tropical islands.

This report is a companion report to the *National Report on Sustainable Forests*, a periodic Forest Service publication that addresses the sustainability of temperate forests of the United States (USDA FS 2011). As in the national report, this effort relies on the Montréal Process Criteria and Indicators for Sustainable Forest Management (MP C&I) as a basis for gathering and organizing information (Montréal Process 2015). In terms of geographical and topical scope, this effort is the first of its kind. It is designed to provide a first approximation of a sustainability assessment of U.S. tropical forests using the MP C&I, and to serve as a baseline for periodic assessments of these forests in the future.

Broadly defined, forest sustainability refers to the ability of forest ecosystems to maintain desired characteristics and provide desired outputs into the future. The identification and definition of these desired characteristics, however, has proven to be a moving target, especially when applied to systems as complex and dynamic as forests. As our understanding of forests has grown, we have increasingly come to recognize the many different ways in which we rely on and benefit from these ecosystems, and we have experienced a commensurate increase in the need for information to manage them effectively. Forest assessment and planning documents now typically include information on, for example, the plants and animals comprising a given ecosystem; physical characteristics, such as soil condition and local climate; social and economic aspects of nearby communities; timber and nontimber forest products; opinion surveys; recreation activity; atmospheric carbon balances; and a host of other elements deemed important by different organizations and individuals interested in forests and their management. Organizing and presenting this vast amount of information, let alone using it to inform decisions, is a major undertaking.

The tropical forests considered in this report differ considerably from their temperate counterparts found on the U.S. mainland, both for their ecological components and for the social and economic systems in which they are embedded. The Montréal Process indicators, however, are flexible enough to be generally applicable to tropical U.S. forests, and they are used here to report on biophysical characteristics such as forest extent and composition, on biological and physical disturbance processes, on the unique social and economic conditions prevalent on the islands, and on the institutions through which people seek to use and protect their forest resources.

A major challenge in compiling this report has been analyzing information from disparate island jurisdictions separated by vast distances and exhibiting different conditions and histories. This challenge extends to data acquisition and consolidation, and the central policy recommendations of the report focus on improving data development and consistency. One of the first steps in this process is to identify currently available data sources, and the report explicitly addresses the "meta-questions" surrounding data generation and use.

The Islands

Nine specific island jurisdictions are treated in this report. Hawaii is the only state. The other jurisdictions are affiliated with the United States in various ways. From east to west, they are:

- U.S. Territory of the Virgin Islands (USVI)
- Commonwealth of Puerto Rico
- State of Hawaii
- Territory of American Samoa
- Republic of the Marshall Islands
- Federated States of Micronesia (FSM)
- Commonwealth of the Northern Mariana Islands
- Territory of Guam
- Republic of Palau

These islands represent some of the most distinctive ecological and social systems to be found in the United States. The ecological richness and number of endemic species in Hawaii, for example, are world famous. The agroforestry practices of native cultures in the South Pacific exemplify a long and unique history of close interaction between humans and nature. And the history of European colonization in the Caribbean, with its introduction of new land use patterns and biological agents, profoundly shapes current ecological conditions in the region in very specific ways.

Given the wide dispersal of the islands across two hemispheres, and their unique histories and ecologies, it is an open question as to whether the inclusion of all the islands in a single report is justified. Indeed, this question challenged the authors of this report, and will likely challenge readers as well. Still, a number of key characteristics are shared to a greater or lesser degree by all the islands. In contrast to the vast majority of the mainland United States where a temperate climate is the norm, these islands all possess tropical forests characterized by high and relatively stable temperatures. Also, they are all subject to the various influences of island geography, including relative isolation, restricted home ranges for native plants and animals, the biological abundance of nonnative species, and socioeconomic characteristics that set them well apart from mainland U.S. culture (see MacArthur and Wilson [1967] and Whittaker and Fernández-Palacios [2017] for indepth discussions of island biogeography). An important question for this study is whether, by assessing them side by side, we can identify similarities across the islands as well as contrasts between them.

In tables or similar listings, the island jurisdictions are presented in this report in order from east to west unless otherwise indicated by the information or topics being considered. This allows for grouping along the major geographic breakpoints: the Caribbean, Hawaii, and the U.S.-affiliated Pacific. We have generally maintained similar groupings in our discussion and analysis sections, but this was not always possible.

The tropical Pacific islands are generally divided into three geographic/cultural regions called Melanesia, Polynesia (which includes the Hawaiian and Samoan archipelagoes), and Micronesia (which includes the Marshall Islands, Mariana Islands, and Caroline Islands). Note that political jurisdictions do not always align with geographic designations. The Samoan archipelago includes independent Samoa, which is not affiliated with the United States; likewise, the Virgin Islands archipelago includes the British Virgin Islands, which are east of the USVI. The Mariana chain includes Guam (the southernmost island) and the Commonwealth of the Northern Mariana Islands. The Caroline Islands include Palau and the FSM. Basic characteristics of the nine jurisdictions are shown in table 1-1, and the island locations are shown in figure 1-1.

Table 1-1. Characteristics of island jurisdictions considered in this report

Island jurisdictions	Total area	Political status	Islands: Permanently inhabited	Islands: Other	Population (2010)
	Acres (hectares)				
Caribbean:					
U.S. Virgin Islands	85,760 (34 706)	Territory	4	50 islands and cays	106,405
Puerto Rico	2,199,901 (890 270)	Commonwealth	3	3+	3,725,789
Pacific:					
Hawaii	4,127,337 (1 670 277)	State	7	Kahoolawe + 9 northwestern islands/atolls + 130 small islands	1,360,301
American Samoa	49,280 (19 943)	Territory	5 islands + Swain's Atoll	Rose Atoll	55,519
Guam	135,680 (54 908)	Territory	1		159,358
Republic of the Marshall Islands	44,800 (18 130)	Nation	20 atolls + 4 islands	9 atolls + Jemo Island	67,182
Federated States of Micronesia	149,804 (60 624)	Nation with four states	Up to 77 inhabited islands	542 islands and atolls	102,843
Commonwealth of the Northern Mariana Islands	113,280 (45 843)	Commonwealth	3	12 northern islands	53,883
Republic of Palau	114,560 (46 361)	Nation with 16 states	7 islands + Kayangel Atoll	250, including "Rock Islands"	20,956

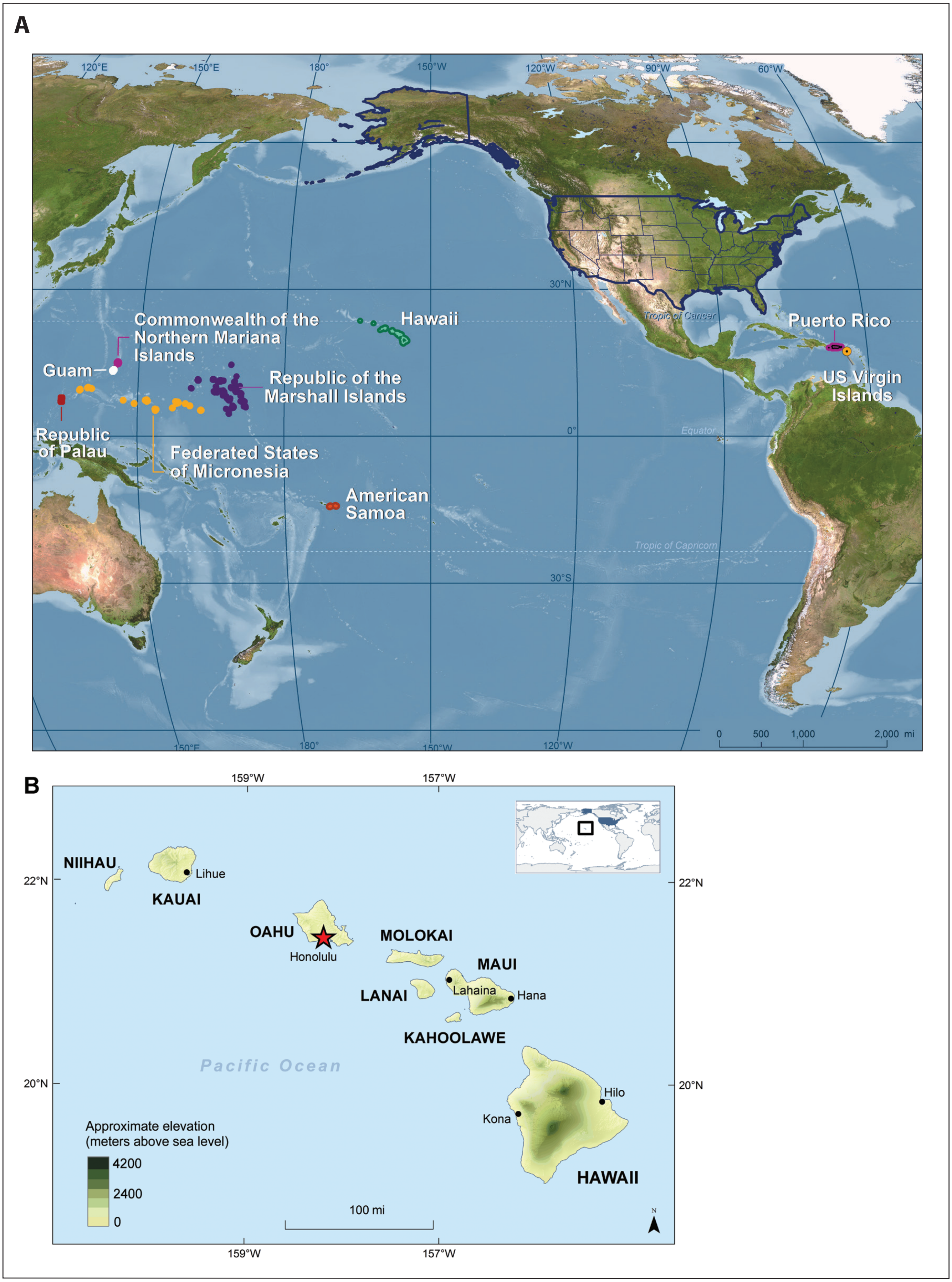

Figure 1-1. Island jurisdictions considered in this report: (A) all, (B) Hawaii, (C) Pacific Islands, and (D) Puerto Rico and the U.S. Virgin Islands.

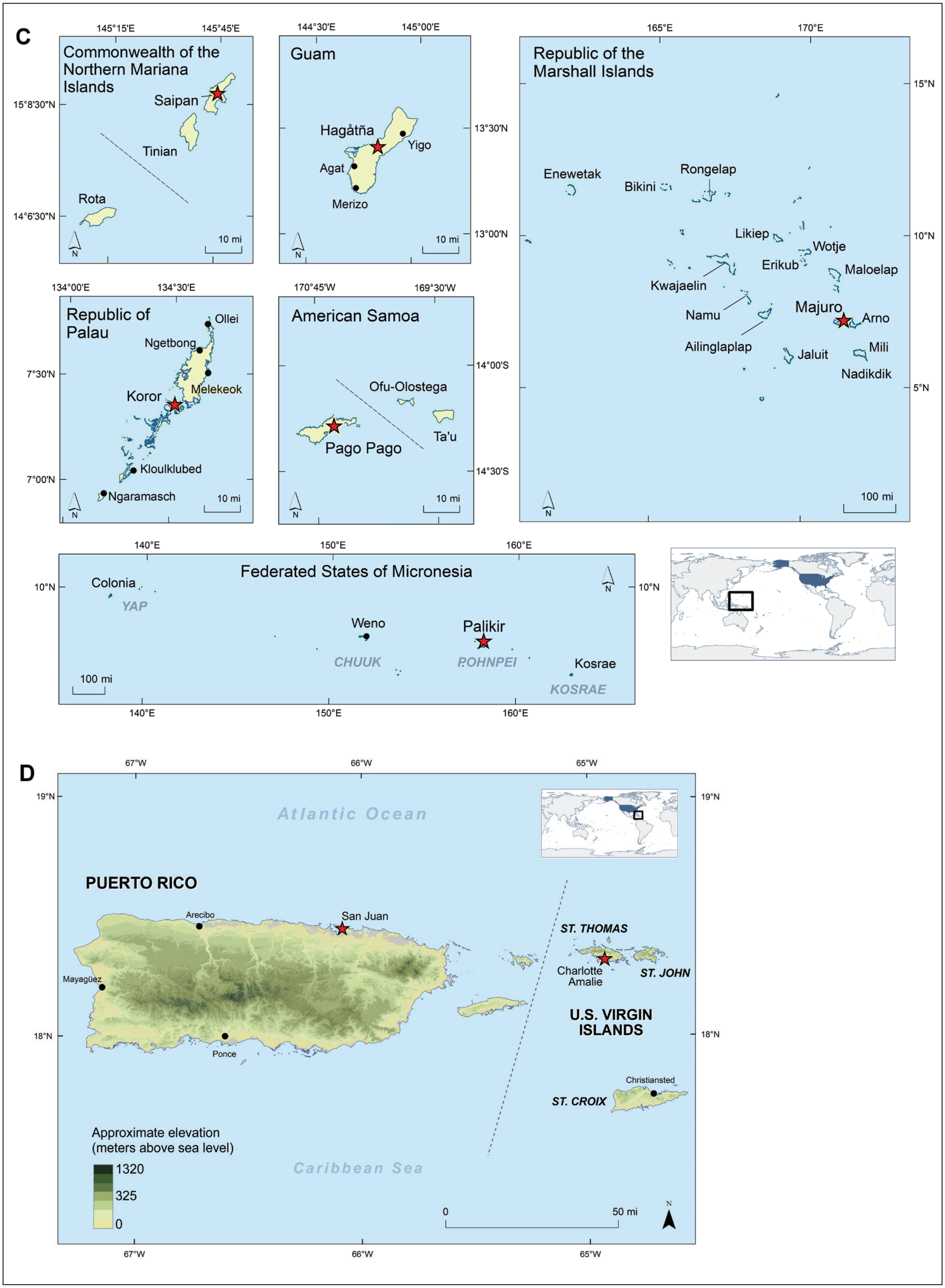

Figure 1-1. Continued.

The wide dispersion of island jurisdictions, particularly in the Pacific, is immediately apparent in figure 1-1. Another geographic characteristic worth noting is that spatial arrangement differs considerably across jurisdictions, with Puerto Rico at one extreme, possessing a relatively large contiguous land mass on the main island, and Micronesia at the other, with a small amount of total area distributed across literally hundreds of islands and atolls spanning a considerable longitudinal arc. This geographic heterogeneity is mirrored in the different political characteristics of the jurisdictions (ranging from U.S. statehood to freely associated nations), which in turn result in different data reporting conventions and different forest management arrangements. Demographics likewise range from large and highly concentrated urban populations in Puerto Rico and Hawaii (in Honolulu at least), to small and dispersed rural or semi-rural settlements in the U.S.-affiliated Pacific. Social and economic conditions also differ considerably across the islands.

The Montréal Process Criteria and Indicators

The Montréal Process Criteria and Indicators for Sustainable Forest Management (MP C&I) are the framework by which data are organized in this report. Other C&I frameworks would likely serve as well, but the MP C&I do have several advantages in this application: (1) they are firmly established; (2) they are comprehensive in scope and allow for flexible application; and (3) they are consistent with U.S. forest sustainability reporting at the national level. The MP C&I were first instituted in the 1990s as a response to growing concerns about the sustainability of the world's temperate and boreal forests (Montréal Process 2015). Twelve countries, including the United States, voluntarily participate in the Montréal Process through the application of the MP C&I to assess their respective forest resources and through periodic meetings to review and adjust the C&I and coordinate reporting activities. The process for C&I formulation and adjustment is based on the consensus of participating countries, and the result is a comprehensive list of forest ecosystem characteristics, and related socioeconomic characteristics, deemed important by member countries and applied in a flexible fashion in accordance with the resource conditions and reporting preferences of each. Other C&I that are specifically tailored to tropical forests exist, notably those produced by the International Tropical Timber Organization (ITTO 2005), but the vast majority of MP indicators are equally applicable to temperate and tropical forests. The use of the MP C&I in this report has the added benefit of allowing more direct comparison with the *National Report on Sustainable Forests*.

The current version of the MP C&I contains 54 indicators arranged under 7 criteria (table 1-2). The first five criteria address the biophysical characteristics of forests and rely heavily on data generated by forest inventory

Table 1-2. Montréal Process Criteria and Indicators criterion summary

Criterion name	Description
1. Conservation of biological diversity	Nine indicators describing the biophysical characteristics of forests, including forest extent, composition, diversity of flora and fauna. Conservation efforts also covered.
2. Maintenance of productive capacity of forest ecosystems	Five indicators describing forest productive capacity, area of planted forests, and current production levels of forest outputs (timber and nontimber).
3. Maintenance of forest ecosystem health and vitality	Two indicators describing (1) biotic forest disturbance processes (e.g., insects and diseases), and (2) abiotic disturbance processes (e.g., fire and drought).
4. Conservation and maintenance of soil and water resources	Five indicators describing forest soils and water conditions along with efforts to conserve them.
5. Maintenance of forest contribution to global carbon cycles	Three indicators describing (1) forest carbon pools, (2) carbon pools in long-lived forest products, and (3) avoided carbon emissions from using wood to produce energy.
6. Maintenance and enhancement of long-term multiple socioeconomic benefits to meet the needs of societies	Twenty indicators describing (1) the production and consumption of forest products, (2) investments in the forest sector and related human capital, (3) forest employment and community conditions, (5) forest-based recreation and tourism activity, and (5) cultural and spiritual values associated with forests.
7. Legal, institutional, and economic framework for forest conservation and sustainable management	Ten indicators describing legal and institutional arrangements for forest planning and management, public participation mechanisms, economic incentives, and monitoring efforts.

and monitoring activities. The sixth criterion contains 20 indicators and is essentially a catch-all criterion for social and economic aspects of forests and their related human systems. Criterion 6 relies primarily on social and economic statistics generated outside of the forest sector. Criterion 7, the last criterion, addresses policy and institutional arrangements for forest planning, management, and monitoring, and the indicators in this criterion are treated mainly through qualitative description.

Taken together, the seven criteria and 54 indicators of the MP C&I can be viewed as an attempt to provide a detailed definition of forest sustainability. More to the point, they provide a useful framework for organizing the various pieces of information necessary to assess forest sustainability. Exactly what to do with this information once it is gathered and presented, however, remains an essential question. Various systematic modelling approaches to sustainability assessment using C&I have been attempted over the years (see Singh et al. 2009 for a useful survey of this work), but generally these efforts are most successful when applied to relatively narrow sustainability problems. Comprehensive assessments of forest sustainability across ecological, social, and economic dimensions are less amenable to this sort of technique. Similarly to the national report, we take a more qualitative approach, presenting available data for the indicators, then summarizing those data and identifying key findings with the aim of informing broader public discussions of sustainability rather than producing a definitive or quantitative determination of whether forests are sustainable.

The MP C&I present a daunting set of data requirements, but many of the indicators are best viewed as data placeholders to remind us of the information still needed to provide a complete assessment of forest ecosystems and their sustainability. Fully populating the MP C&I with quantitative and definitive information is a practical impossibility. This is true for the national report, and, given the relative scarcity of information available for the U.S. tropical islands, it is even more so for this report. For certain indicators, particularly those that rely on forest inventory data, we have good information. In other areas, such as indicators related to forest health or socioeconomic conditions, our information is mostly anecdotal or absent. Though this situation is far from satisfactory, the indicators in this latter category serve a useful purpose in reminding us of important gaps in our data **and** our understanding.

Roadmap to the Report

This report is divided into two main parts. In Part I, this introductory chapter is followed by a chapter describing the data used to produce the report. Designed primarily for analysts, this “data chapter” identifies major data sources, their periodicity, and their application to tropical islands. Part I concludes with a chapter summarizing key findings and major policy recommendations based on the C&I information provided in Part II as well as the data reporting arrangements identified in the data chapter.

Part II comprises the bulk of the report and contains seven chapters addressing each of the seven criteria of the MP C&I. The first four chapters of Part II generally follow the MP framework, addressing each indicator in turn (at least in those instances in which adequate data are available). Owing to a lack of data or applicability in the island context, criteria 5 (carbon), 6 (social and economic aspects), and 7 (institutional framework) are addressed in a more abbreviated fashion. In these chapters, we simply try to present useful information addressing the criteria but generally bypass the MP indicator framework.

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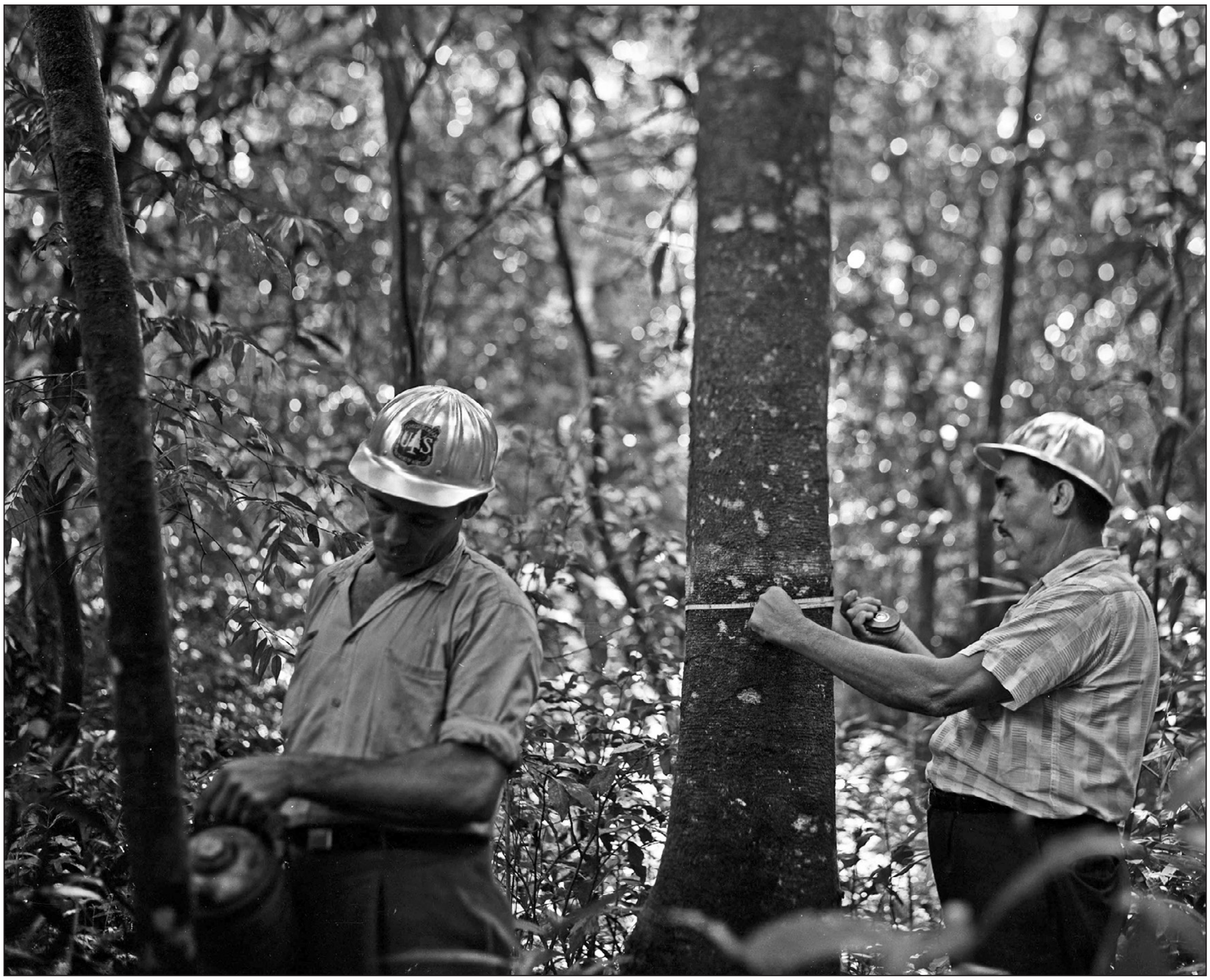
USDA Forest Service



A tropical rain forest timber stand improvement operation (circa 1960) on the El Yunque National Forest, Puerto Rico, in which undesirable trees were poisoned or marked for removal, desirable trees were marked to retain for the future crop; and records were kept of tree growth to learn the effect of improvement methods.

Chapter 2

Description of Available Data

Guy C. Robertson and Kathleen S. Friday

Introduction

Information provides the foundation for assessment. Forest sustainability assessments must treat a broad range of indicators across ecological, social, and economic domains, often with relatively few resources to devote to primary data collection. As a result, these assessments must rely on various established data streams to populate their respective indicators with useful information. This was certainly the case for the mainland assessment provided in the *National Report on Sustainable Forests—2010* (USDA FS 2011b), and it is also true for this report. An assessment of available data and reporting mechanisms speaks to our ability to understand, manage, and conserve island forests, so it is an important sustainability measure in its own right. Moreover, sustainability assessments such as this report usually do not exist in isolation; there are various other reporting mechanisms and requirements in which the island entities considered in this report are engaged. To make the best use of the scarce resources at hand and enhance the value of all reporting efforts, it is important to clearly identify key data sources and coordinate reporting activities so that these activities support each other while avoiding costly duplication of efforts.

The objective of this chapter is to identify (1) the key data sources that help inform sustainable forest management in the U.S. tropics and (2) the key reporting activities that the tropical islands are conducting. These resources are listed in tables 2-1 and 2-2 and are further described in subsequent sections of this chapter.

Primary Data Sources

As is true in forest reporting on the U.S. mainland, forest inventory data forms the backbone of forest sustainability reporting for the tropical islands, particularly in regard to biophysical characteristics of forest ecosystems. In the continental United States, the Forest Service's Forest Inventory and Analysis (FIA) program provides much of this information, and the FIA has begun expanding its activities to cover the U.S. tropics. Additional data collection efforts provide information on forest species, forest health issues (e.g., forest pests, invasive species, and forest disturbance events), and the extent and nature of forest cover. In the socioeconomic domain, major reporting mechanisms such as the U.S. Census and the products of other U.S. Department of Commerce bureaus provide data that extend well beyond the purview of the U.S. Forest Service or local forest agencies but that are nonetheless essential to understanding the social and economic dimensions of forest sustainability. Various other sources provide statistics on economic, environmental, and social conditions.

Although coverage from the main statistical sources identified in table 2-1 is generally uniform for the continental United States, the same cannot be said for the tropical islands. Much of this owes to their differing status, ranging from statehood (i.e., Hawaii) to free association (e.g., Federated States of Micronesia), meaning that even such standard statistical efforts as the U.S. Census are not evenly applied. Likewise, their distant locations and island topography (Palau, for example, has more than 300 small islands) make ecosystem sampling such as is undertaken by FIA an expensive and technically challenging proposition. Coverage in regard to land use and characteristics is spotty and difficult to analyze in a consistent fashion, although, for FIA at least, the situation has been improving.

Forest Service Inventory and Analysis Program

The FIA program has been in operation for more than 80 years and constitutes the principal source of information on U.S. forests and the trees that comprise them. It was a primary resource for the *National Report on Sustainable Forests*, without which that report would not have been possible. FIA relies on on-the-ground sampling of forest plots to develop statistical reports on forest conditions. The inventory is applied on a uniform basis to all forested areas in the United States and its territories to develop statistical measures that are consistent across time and space and can be assessed at multiple spatial scales, including U.S. counties. The information provided from base sample plots (so-called "phase 2 plots") includes forest area, ownership, tree species counts, wood volumes, forest growth and removals, tree diameter class (size), tree mortality, and forest carbon mass and biomass. Although the inventory is primarily focused on

Table 2-1. Data sources for assessing tropical forest sustainability in U.S. territories

Program	Agency	Description
Forest Inventory and Analysis (FIA)	U.S. Forest Service	FIA conducts plot-based sampling of forest cover, species composition, and other characteristics. In the Caribbean, this work is jointly funded and conducted with the International Institute of Tropical Forestry. Plots are revisited on a periodic basis with the aim of providing a statistically consistent representation of forest extent and conditions for a given geographical area. The ability to address smaller spatial scales is limited by sampling intensity.
Vegetation surveys and mapping	U.S. Forest Service	In the 1980s, the Pacific Southwest Research Station mapped vegetation types using aerial photography for nearly all high islands of the U.S.-affiliated Pacific, with the notable exceptions of Hawaii and Guam. In the 2000s, the Pacific Southwest Region State and Private Forestry program began to assist Pacific state foresters with vegetation type maps on a regular basis.
U.S. endangered species listings	U.S. Fish and Wildlife Service	Provides the names, numbers, and descriptions of all federally listed threatened and endangered animal and plant species, including those found in politically affiliated jurisdictions. Additional information on conservation needs and efforts also is made available.
IUCN Red List of Threatened Species	International Union for the Conservation of Nature (IUCN)	Provides the names, conservation status, and descriptions of globally threatened animal and plant species as determined and periodically reviewed by experts based on globally agreed assessment criteria.
Global Invasive Species Database (GISD)	Invasive Species Specialist Group (ISSG), organized by the IUCN Species Survival Commission	The ISSG is a global network of scientific and policy experts focused on invasive species. It manages the GISD as an online resource of information on invasive species, their ecology, spread, management, and effects.
U.S. Census	U.S. Census Bureau	Provides total population and assorted demographic and economic statistics based on the decadal U.S. Census. Additional demographic and economic statistics information are provided through community sampling efforts.
Various economic statistics collected by U.S. federal agencies	Bureau of Labor Statistics, Bureau of Economic Analysis, etc.	Assorted statistics on employment, production, and trade.
Various local and regional data reporting activities	State-level agencies or equivalent	Tourism visitation rates. Assorted economic, social, and environmental statistics.

forestry measures for growth and volume, augmented sampling of a subset of the base plots ("phase 3 plots") has expanded the survey's reach into categories that track forest health conditions and related characteristics (for information regarding FIA sampling procedures, see Bechtold and Patterson 2005). In the past, FIA provided periodic inventories that described conditions as sampled for a given state in a given year or pair of years, then moved on to the next state. In the past decade, FIA has switched to an annualized inventory for U.S. states, using continuous sampling across all states except Hawaii. U.S. jurisdictions in the Pacific remain on a periodic inventory, however, while those in the Caribbean are sampled continuously but reported periodically.

FIA activity and status for the tropical islands are shown in table 2-3. Inventories have been completed within the past decade for all the islands, and subsequent inventories for all are scheduled over the next 5 years (note that the "Year of Inventory" columns in the table denote the year in which the inventory activities are locked down for statistical purposes, not the year in which the data are compiled, analyzed, and presented). Reports have been published for the first set of completed inventories, and current data are available through the FIA website referenced above. As on the mainland, phase 3 plots in the Pacific are sampled on an "ala carte" basis determined in part by FIA client needs; islands are allowed to choose certain of the variables to be measured. This allows

Table 2-2. Forest reporting activities engaged in by U.S. tropical islands

Program	Agency	Description
Global Forest Resource Assessment (GFRA)	U.N. Food and Agriculture Organization	Compiles forest statistics for countries around the globe. Relies on submissions by individual countries and does not generate its own statistics.
Statewide Assessments and Resource Strategies (SWARS), subsequently called Forest Action Plans	State or comparable level	The Cooperative Forestry Assistance Act, as enacted in the 2008 Farm Bill, required each state to develop SWARS reports by 2010. The assessments of forest resources provided analyses of forest conditions and trends, and delineated priority forest landscape areas for investing Forest Service State and Private Forestry funds and other resources.
National Forest Health Monitoring	U.S. Forest Service	Annual Forest Health Highlights summarize forest health conditions, and are published at regular intervals (generally annually) for the Pacific Islands.

Table 2-3. Forest Inventory and Analysis inventory status in tropical islands

Jurisdiction	Year(s) of completed inventory	Year of last published report	Year(s) of next inventory	Total Phase 2 plots	Total Phase 3 plots	Online data
Caribbean:						
Puerto Rico	1980, 1985 (partial update), 1990, 2003, 2009	2013	Periodic, 2014	373	61	Yes
U.S. Virgin Islands	2004, 2009	2013	2014	73	40	Yes
Pacific:						
Hawaii	Periodic, 2010–2015	Not yet published	Periodic, 2017–2020	Planned: 500	—	No
American Samoa	2001, 2012	2004	2022	21	—	Yes
Republic of the Marshall Islands	2008	2011	2018	44	—	Yes
Federated States of Micronesia	2005–2006	2011	2016	73	—	Yes
Commonwealth of the Northern Mariana Islands	2004, 2015	2011	2025	35	—	Yes
Guam	2002, 2013	2004	2023	46	—	Yes
Republic of Palau	2003, 2014	2007	2024	54	—	Yes

— = not available.
Source: USDA FS (2011b: table 10), updated by authors.

for the flexible inclusion of some variables (understory vegetation and tree crowns in the case of the Pacific islands) and the omission of others (soils, lichens, ozone, and down woody debris). Local entities have the option of further increasing the number of phase 3 plots through cost-sharing agreements with the Forest Service.

For forest inventory activities, however, the geography of the islands presents several challenges that are not easily overcome. From a statistical standpoint, the heterogeneity of many of these places, with their numerous islands of varying sizes and conditions, means that statistical averages derived from the inventory will be subject to wide error bounds and may not be all that representative of actual conditions on the ground (although this problem will be much more important in some places than in others). And, from a practical standpoint, the island topography and remote location of many places, especially in the Pacific, make the establishment and repeated sampling of plots a difficult and costly endeavor. This is compounded by the fact that actual forest areas being sampled are quite small, so significant resources must be expended to inventory a relatively small amount of forest. These issues all point to the fact that islands constitute a very different operating environment than the continental land mass for which FIA, and similar land inventories, was designed. That said, FIA still stands as a valuable data source for understanding tropical forests in the islands, and discussions are underway as to how this source may be augmented or adjusted to better fit local needs.

Other Sources of Ecological Data

Various other sources provide information on ecological conditions of forests in the tropical islands. Some of these are specific to individual territories, but the sources listed here apply to all islands included in this report or regional aggregations thereof (i.e., islands in the Pacific or the Caribbean). In many cases, the challenges related to island topography and remoteness listed for FIA above also apply.

U.S. Forest Service Pacific Southwest Region "Pacific Imagery Consortium Vegetation Mapping and Monitoring" (PICVM). Using satellite imagery as its primary data source, this project provides vegetation maps for Hawaii and the Pacific Islands territories (table 2-4). Vegetation type classification is not necessarily consistent with earlier maps or between islands. Maps, analysis, and background information are available from the Forest Service's Pacific Southwest Region State and Private Forestry unit at https://www.fs.usda.gov/detailfull/r5/forest-grasslandhealth/?cid=fsbdev3_046690&width=full).

U.S. Forest Service Forest Health Highlights. The Forest Service's national Forest Health Monitoring (FHM) program is designed to determine the status, changes, and trends in indicators of forest condition on an annual basis. FHM uses data from ground plots and surveys, aerial surveys, and other biotic and abiotic data sources and develops analytical approaches to address forest health issues that affect the sustainability of forest ecosystems. FHM's *Forest Health Highlights* reports are usually released annually for Hawaii and the U.S.-affiliated Pacific islands collectively, and the Forest Service plans to release reports for the Caribbean islands in the future. Current and historical highlights may be found at http://www.fs.fed.us/foresthealth/fhm/fhh/fhmusamap.shtml.

U.S. Fish and Wildlife Service Threatened and Endangered Species Listings. The listing process uses a candidate assessment approach to identify threatened and endangered (T&E) species and assign them conservation priorities and associated legal protections. The assessment process is targeted to individual species and relies on multiple information sources (state agencies, university

Table 2-4. Vegetation type mapping status in tropical islands

Jurisdiction	Year(s) of imagery	Report/publication	Vegetation data package
Caribbean:			
U.S. Virgin Islands	Circa 2000	Kennaway et al. 2008	http://data.fs.usda.gov/geodata/rastergateway/caribbean/index.php
Puerto Rico	Circa 1991, 2000, 2003	Gould et al. 2008, Kennaway et al. 2007	http://data.fs.usda.gov/geodata/rastergateway/caribbean/index.php
Pacific:			
Hawaii			
American Samoa	1984	Cole et al. 1988	FIA
Republic of the Marshall Islands	2008		PICVM
	2003–2004	Liu and Fischer 2007	PICVM
	2010–2011		PICVM
Federated States of Micronesia	1975-1976	Falanruw et al. 1987, MacLean et al. 1986, Whitesell et al. 1986	FIA
	2006–2010		PICVM
Commonwealth of the Northern Mariana Islands	1976	Falanruw et al. 1989	FIA
	2006	Liu and Fischer 2006	PICVM
Guam	2005–2006		PICVM
	2011–2014	Liu and Fischer 2014	PICVM
Republic of Palau	1976	Cole et al. 1987	FIA
	2005–2006		PICVM

PICVM = Pacific Imagery Consortium Vegetation Mapping and Monitoring.
Forest Inventory and Analysis (FIA) digitized maps from the 1980s.

studies, etc.). NatureServe (http://www.natureserve.org) is a primary data source providing ongoing tracking of T&E species, but its extension to the tropics beyond Hawaii is limited to Latin America and the Caribbean through its sister database "InfoNatura" (http://infonatura.natureserve.org/). Note that these data sources focus on species as the unit of analysis and not on geographic units (in contrast to FIA or the U.S. Census).

IUCN Red List of Threatened Species. The International Union for the Conservation of Nature (IUCN) maintains threatened species listings similar to those kept by the U.S. Fish and Wildlife Service, but compiled at the international level and involving somewhat different criteria for listing. Groups responsible for the nomination and review of listings include BirdLife International, the World Conservation Monitoring Centre, and the IUCN Species Survival Commission, among many others. Here again, species are the unit of analysis and not geographic units.

Global Invasive Species Database (GISD). Managed by the IUCN, the GISD tracks invasive species by geographic area. The database is searchable by location and can be found at http://www.issg.org. The purpose of the GISD is to share descriptive information on identified species where available rather than to quantify the occurrence of invasive species for geographic localities. So the number of species listed in the GSID serves as a general indicator but not as a statistical sample of invasive species activity.

Sources for Socioeconomic Information

Socioeconomic information for the tropical islands is generally available through standard government reporting activities, such as those of the Census Bureau (CB) and other branches of the U.S. Department of Commerce. However, because the territories differ in their legal status, coverage is not uniform across all the islands, and time series are less well developed than for U.S. states. Additionally, many of the trade statistics produced for the national report are reported at the national or customs district level and cannot be replicated for individual island territories. In many cases, reporting of socioeconomic data for island territories (excluding Puerto Rico and Hawaii) appears to be ad hoc, and measures are not included in the standard statistical tables presented for U.S. states. The U.S. Department of the Interior's Office of Insular Affairs provides an excellent compilation of statistics for territories and freely associated states (once again excluding Puerto Rico and Hawaii) at http://www.doi.gov/oia/.

U.S. Department of Commerce Census Bureau. Performs a decadal census for U.S. states and territories. The 2010 census includes Puerto Rico and Hawaii. More limited coverage is provided on a different schedule for American Samoa, the Northern Marianas, Guam, and the U.S. Virgin Islands. Besides demographic statistics, the CB provides many economic indicators, including regional income measures. The freely associated states (Federated States of Micronesia, Republic of the Marshall Islands, and Republic of Palau) are omitted from regular U.S. Census reporting and rely on local efforts to produce demographic information.

U.S. Department of Commerce Bureau of Economic Analysis (BEA). The BEA estimates gross domestic product statistics for states and U.S. territories (but not for freely associated states).

Regional Studies and Data Reporting Activities

The tropical islands engage in several periodic data reporting activities and have commissioned numerous one-time reports addressing various forest-related issues. These range from repeated estimates of tourism visitation rates to special studies on topics such as subsistence use or the effects of nonnative species. The information and analysis produced are often quite detailed, being focused on specific areas of interest, but are rarely consistent with data presented for other areas or at other times for the same area. Consequently, these studies represent an important resource for understanding conditions in particular locations, but they present challenges when trying to compile results for broader regions (e.g., the Pacific or Caribbean) or timespans.

Statistical Compilations and Related Reports

Whether addressing environmental conditions or socioeconomic conditions, many special studies and periodic reports will overlap with forest sustainability reporting. Two reports, the Global Forest Resources Assessment (GFRA) and the Statewide Assessment and Resource Strategies (SWARS), stand out as particularly important because they explicitly cover forests and their management, are (or will be) published on a periodic basis, and are produced by all the geographic units considered in this report. The significance of these two reports extends beyond merely providing a consistent data source for sustainability reporting. Given their respective scopes, the overlap between them, and the need to produce them repeatedly, they present an opportunity to efficiently consolidate and expand reporting activity through integration, a topic that is addressed more fully in the policy recommendations below.

The FAO GFRA

Every 5 years, the United Nations Food and Agriculture Organization (FAO) compiles forest statistics from all the countries in the world to produce the GFRA, a census of forest conditions and extent. The most recent edition was produced in 2016 (FAO 2016). Besides the main report, the GFRA includes country-specific reports, each composed of brief descriptions of forest conditions in the given country, followed by data tables and notes as to definitions, data sources, and the derivation of each table (see table 2-5 for a listing of GFRA tables and their coverage among the island jurisdictions considered here).

The 17 tables stipulated for use in the GFRA country reports cover a range of topics broadly commensurate with those covered by the Montréal Process Criteria and Indicators (MP C&I), but most countries do not report out on every table. Eight of the nine island entities covered in this report provided data for GFRA (Hawaii was incorporated in the U.S. country report), relying almost exclusively on FIA data to populate the tables. As a result, the information available in their specific country reports is weighted to the type of data provided by forest inventories and the FIA in particular, and the reports are generally weak in their social, economic, and institutional areas. Although GFRA country reports for U.S. territories serve mainly as a window to already available FIA data, they do have the virtue of packaging these data in a consistent, easily accessible, and fully documented fashion on a regular basis. Moreover, the 17 GFRA country tables provide a ready framework for expanding quantitative reporting on forest conditions. (See http://www.fao.org/forestry/fra/en/ for the GFRA main report, country reports, and associated information.)

Statewide Assessment and Resource Strategies

As stipulated in the 2008 Farm Bill (P.L. 110-246), all U.S. states and territories were required to produce a SWARS report by 2010 to qualify for assistance through the U.S. Forest Service's State and Private Forestry division. These assessments and strategies, subsequently

Table 2-5. Summary of data tables provided in FAO 2010 Global Forest Resource Assessment (GFRA) country reports

GFRA table number and title	Tables included in country reports[a]							
	PR	USVI	AS	RMI	FSM	CNMI	GU	RP
T1. Extent of forest and other wooded land	X	X	X	X	X	X	X	X
T2. Forest ownership and management rights								X
T3. Forest designation and management		X	X	X	X	X	X	X
T4. Forest characteristics	X	X		X	X	X		X
T5. Forest establishment and reforestation								
T6. Growing stock	X	X	X	X	X	X	X	X
T7. Biomass stock	X	X	X	X	X	X	X	X
T8. Carbon stock	X	X	X	X	X	X	X	X
T9. Forest fires								
T10. Other disturbances affecting forest health and vitality			X	X	X	X	X	X
T11. Wood removals and value of removals								
T12. Nonwood forest products removals and value of removals								
T13. Employment								
T14. Policy and legal framework								X
T15. Institutional framework								
T16. Education and research								
T17. Public revenue collection and expenditure								

[a] Data for Hawaii are subsumed in the U.S. GFRA country report.

FAO = United Nations Food and Agriculture Organization; PR = Puerto Rico; USVI = U.S. Virgin Islands; AS = American Samoa; RMI = Republic of the Marshall Islands; FSM = Federated States of Micronesia; CNMI = Commonwealth of the Northern Mariana Islands; GU = Guam; RP = Republic of Palau.

Source: FAO 2010.

called “forest action plans” by the Forest Service and the National Association of State Foresters, can be found at http://www.forestactionplans.org/.

All the island entities considered in this report have completed assessment reports, each of which represents a considerable accomplishment and a valuable information resource. Updates will be required by 2020.

In contrast to the FAO GFRA data tables, the statewide assessments allow for an open-ended approach, with format and issues to be chosen by each state or territory respectively. The resulting reports often total well over 100 pages and include a wealth of information not only on forest conditions, but on the local economy, social conditions, and the principal concerns and desires of local residents regarding their forests. Although difficult to compare over time or space, the resulting narratives provide a depth of understanding of local forests and people that is wholly lacking in the FAO GFRA tables and impossible to convey in a summary study such as this report.

Conclusions and Recommendations

Much of the information required for comprehensive forest sustainability reporting is hard to find and compile even for the continental United States, a region that possesses some of the best environmental and social statistics and analyses in the world. By and large, U.S. tropical islands possess nowhere near the same information infrastructure, and this lack is further compounded by their island geographies, where heterogeneity makes comparison difficult and isolation makes measurement expensive. Noted data gaps include basic forestry information such as the distribution of species, and even forest types, as well as the prevalence of nonnative species (a pressing problem in the Pacific Islands) or the distribution of rare flora and fauna. On the social front, much of our understanding of the relationships between people and forests is based on anecdotal information, where it exists at all, and in regard to institutions we have yet to devise adequate measures, much less populate them with relevant data, even though we know that institutions are crucial to securing sustainable forest management.

These gaps and weaknesses notwithstanding, there are several promising developments in terms of forest sustainability reporting in the U.S. tropics. The FIA program is institutionalizing its activities throughout the islands, augmented by new remote-sensing-based mapping techniques. Repeated sampling through FIA will increasingly allow us to track changes in forest area and composition, an essential element in forest sustainability reporting. Lists of threatened species and invasive pests and weeds are being compiled and consolidated under the auspices of federal agencies and the IUCN. Socioeconomic statistics are being gathered by the CB and BEA, and one can hope that these will improve in the future. And finally, the need for information describing forest ecosystems and their social dimensions is increasingly recognized, as indicated by the content of the FAO GFRA tables and the statewide assessments.

The information that does exist, however, is often fragmented and difficult to access. A central objective of this report (and of the MP C&I, for that matter) is to bring this information together and present it in an easily digestible format. The two other comprehensive reporting functions identified in this section, the FAO GFRA and statewide assessments, serve a similar purpose, and it makes sense to consolidate these reporting activities by using the GFRA tables as the database, the statewide assessments for expanded narratives and priority setting, and regional sustainability reporting for summarizing across island entities. Specific recommendations for such a consolidation could include:

- Identify currently unaddressed FAO GFRA table elements as candidates for future data acquisition or development, particularly from among those addressing social and economic aspects.
- Consider a very limited number of additional variables to be included alongside the FAO GFRA data elements—enumeration of known invasive or T&E species, for example.
- Assist the island jurisdictions by providing standardized, peer-reviewed information to incorporate into their statewide assessments, and by using FAO GFRA tables as a primary database and (perhaps) Montréal Process criteria to establish a standard outline. Include basic demographic and socioeconomic data, and explicitly list local priorities and hot-button issues.
- Build regional sustainability reports (Pacific, Caribbean, or combined) from consolidated data in the FAO GFRA. Provide comparison and analysis of local priorities and issues identified in the statewide assessments.

Whatever the actual steps, consolidating these reporting processes makes good sense. Such a consolidation could substantially enhance the utility of the information presented for each island entity while substantially reducing the associated cost. It will also greatly facilitate cross-boundary sustainability assessments such as this report.

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USDA Forest Service Forest Inventory and Analysis (FIA)

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Chapter 3

Tropical Sustainability Key Findings and Recommendations

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Introduction

Comprehensive forest sustainability assessments are designed to evaluate the most important conditions and characteristics of forests as they relate to the ecological, social, and economic dimensions of sustainability. This type of assessment entails the consideration of a great deal of information. The Montréal Process Criteria and Indicators (MP C&I) framework provides an internationally agreed framework that greatly facilitates the organization and analysis of such information. However, the MP C&I do not by themselves provide an assessment of forest sustainability. Various methods have been suggested for developing rigorous and often quantified sustainability assessments (see Singh et al. 2009 for a useful survey of this work). The Montréal Process and its related reporting effort in the United States (USDA FS 2011), on the other hand, stress the importance of broad public discussions based on the best available scientific information in the assessment of forest sustainability. The resulting reports, including this one on U.S. and U.S.-affiliated tropical islands, are designed to inform dialogue and decisions as opposed to providing clear-cut determinations of sustainability.

Summarizing of key findings plays an important part in this process. This report provides several summary levels: (1) each chapter devoted to specific Montréal Process criteria includes a criterion summary near the beginning; (2) key findings are gleaned from the criterion reports as a whole and are listed in the current chapter along with policy recommendations; and (3) these findings are further outlined in a brief executive summary included at the beginning of this report. Readers should be aware that the key findings included here are solely the choice of the authors based on their experience in producing the C&I chapters and their consideration of the various comments received in the process of producing and reviewing this report. Readers are further encouraged to consider the information presented here and elsewhere to reach their own conclusions about forest sustainability in the U.S. tropical islands.

Are Forests in the U.S. Tropical Islands Sustainable?

Producing a simple yes or no answer to this question is a practical impossibility given the complexity of forest ecosystems and the subjective nature of sustainability definitions. However, we can highlight the following major points, which have direct bearing on the overall question of sustainability (additional key findings are presented in the following section):

- **Forest area throughout the islands is relatively stable** (and has in fact increased substantially in the Caribbean over the past 75 years). This fact indicates sustainability from the very limited standpoint of maintaining forest extent.
- **Native biodiversity in the Pacific Islands continues to be threatened** by various factors, notably the ongoing introduction of nonnative and invasive species, resulting in the endangerment and extinction of endemic species—a strong negative indication for forest sustainability.
- **Novel assemblages of nonnative and native tree species are maturing over large areas of the Caribbean,** indicating the dynamic nature of forest ecosystems. These forests may support ecosystem functions and biodiversity at levels comparable to native forests. However, their overall implications for sustainability are not yet fully understood and depend on both sustainability definitions and the future trajectory of these novel ecosystems.

Forest Area

Time-series data adequate to precisely measure changes in forest area are unavailable for most of the tropical jurisdictions considered in this report. However, available monitoring data, combined with piecemeal observations, suggest that forest land is relatively stable in many jurisdictions, with minor losses occurring in some areas—primarily as a result of human development pressure—and gains in other areas. There is no evidence of recent broad-scale loss of forest cover from either resource extraction or extensive conversion to agriculture. In fact, many islands have experienced forest recovery following the abandonment of agricultural lands that were converted from forests in the early 1900s. This recovery is especially pronounced in the Caribbean, where both Puerto Rico and the U.S. Virgin Islands (USVI) were once largely deforested and now exhibit more than 50-percent forest cover. As a result, from the critical standpoint of forest area, the tropical forests considered here demonstrate a fundamental measure of sustainability, though both the lack of adequate time-series data and anecdotal evidence of loss to development are cause for concern, especially where these issues continue unabated. The relative stability of forest area in the U.S. tropics mirrors developments in the temperate forests of the continental United States, where total forest area has been stable to slightly increasing for much of the past century (USDA FS 2011). Similar trends are documented in recent decades for the Northern Hemisphere at large (United Nations 2015). The maintenance of total forest area alone, however, is by no means sufficient to ensure overall forest sustainability. National or regional statistics may mask important changes at local levels or for specific forest types. Likewise, forest health, integrity (i.e., a lack of fragmentation), inherent biodiversity, and the provision of ecosystem services are crucial measures for tropical and temperate forests. Although the data describing these elements for U.S. tropical forests are less conclusive than those describing overall forest area, several areas for concern are indicated.

Invasive Species in the Pacific

In the Pacific, where many of the islands have high numbers of endemic species and are subject to the ongoing influence of invasive species, forest health and the conservation of native biodiversity are threatened. Invasive species (plants, vertebrates, invertebrates, or diseases) may precipitate the loss of endemic species through predation and competition, or they can radically alter the structure and function of island forests, thus changing fire regimes and the provision of ecosystem services and products. The contribution of invasive species to the loss of biodiversity through the extinction of endemic species is a well-documented phenomenon in Hawaii (see Criterion 1 in Part II), and it is occurring to a lesser degree in other areas. Although many of these changes are not necessarily a threat to the sustainability of forests when measured in terms of area, they may threaten the sustainability of essential forest components and characteristics—and they can present unique challenges to forest managers. Ecosystem services, including the provision of fresh water, may also be threatened.

Novel Forests in the Caribbean

In the Caribbean, the proximity of islands to each other, and to the mainland, allowed for greater mixing of species throughout the region's ecological history, resulting in comparatively fewer endemic species and lower susceptibility to invasive species than in the Pacific. Also, the marked recovery of forests over the past century has resulted in novel assemblages of native and introduced tree species, most of which are in relatively young age classes. As these "novel forests" age, a crucial question is how the evolving forest structures and species mixes will influence forest conditions and thereby the values and services associated with forest sustainability. Evidence suggests that these forests have become increasingly naturalized, with introduced species persisting alongside their native counterparts, oftentimes contributing to biodiversity and the provision of ecosystem services (Lugo 2013). Similar processes are no doubt occurring in the Pacific (and elsewhere), but the extensive deforestation and recovery in Puerto Rico and the U.S. Virgin Islands means that they are especially pronounced in these islands.

Key Findings

- **Island ecology and geography affect all aspects of forest sustainability for the places considered in this report.** Small land masses separated by large expanses of open ocean result in widely differing ecological, social, and economic conditions across the island jurisdictions considered in this report. Although these influences affect all of the islands, they are generally more pronounced on Pacific islands owing to their greater isolation.
- **Approximately 3 million ac of tropical forests exist in the U.S. and U.S.-affiliated islands**, ranging from nearly 1.5 million ac in the Hawaiian Islands to less than 24,000 ac in the Marshall Islands. Much of this forest land, particularly in Hawaii and the Caribbean, is composed of relatively young stands established on agricultural lands abandoned in the past century. The percentage of land in forest ranges from 90 percent in American Samoa to 36 percent in Hawaii (presettlement percentages can be assumed to approach 100 percent except in Hawaii, where high elevations and volcanic landscapes preclude forest cover) (see fig. 3.1 and Criterion 1 in Part II).
- **Total acreage of forest land appears to be relatively stable**, but this fact masks local and regional shifts in forest area and type. Losses of forest land to development are generally much less than losses of forests to agricultural development in the past century and before. In some islands, notably Puerto Rico, forest colonization of abandoned lands compensates for loss to development. In the Caribbean, forest area is significantly higher than it was 75 years ago, but development pressure may lead to locally significant fragmentation and loss of forest lands (Criterion 1 in Part II).

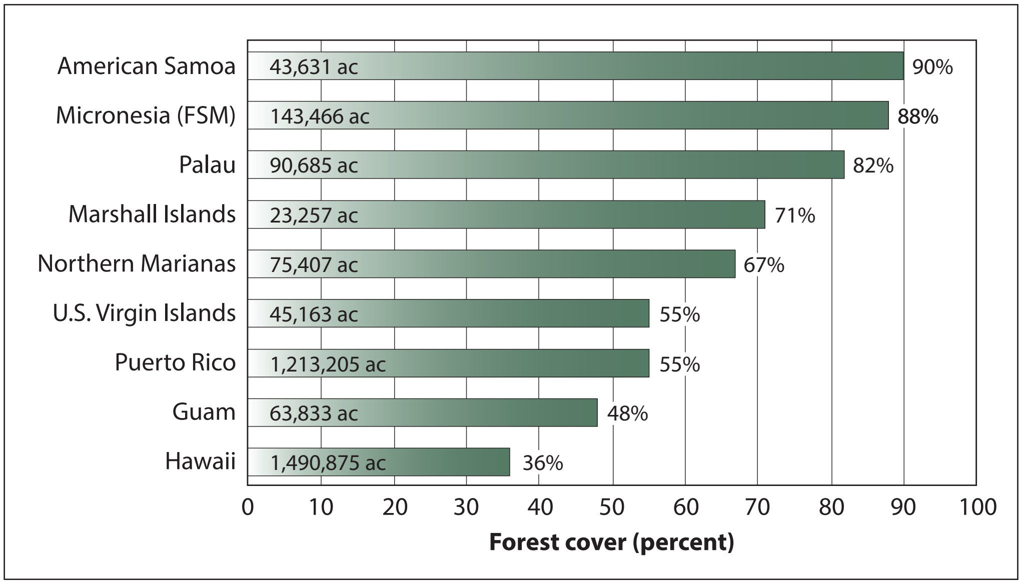

Figure 3-1. Forest area and percentage of forest cover by island jurisdiction. FSM = Federated States of Micronesia. Source: for Hawaii, Gon et al. (2006); for all others, U.S. Forest Service Forest Inventory and Analysis.

- **The history of human settlement and subsequent patterns of land use strongly influence current forest composition and structure throughout the islands.** Forest cover was virtually eliminated in Puerto Rico and the USVI to provide land for plantation agriculture in the colonial period. Current forests in that region exist largely as the result of natural regeneration and afforestation on once denuded lands, and current forest structure reflects this in its preponderance of trees in smaller size and younger age classes. Forests are seen as contributing to land rehabilitation in these instances. The same is true for some but not all areas of Hawaii. U.S.-affiliated Pacific islands have experienced long histories of human occupation with the integration of forest and agriculture in agroforestry systems in suitable areas. The overall result is that many of the forests found throughout the islands are composed of novel structures and species configurations. This results in both increasing wood volumes on forested lands as younger stands grow, and relatively high degrees of dynamism as stands age and tree species compete (see Criteria 1 and 2 in Part II).

- **The number of extinctions and endangered species listings are the biggest warning flag regarding forest sustainability in the entire report.** Pacific islands possess a high number and rate of occurrence of endemic species, which are often characterized by limited population numbers and geographic ranges, and which are thus subject to species extinctions and extirpations in the presence of increasing anthropogenic pressures. Some 760 plant and animal species across all the islands considered in this report are identified as at risk of extinction by the International Union for the Conservation of Nature (IUCN), and nearly 500 plant and animal species have been listed as endangered or threatened with extinction in the Northern Marianas, Guam, Hawaii, Puerto Rico, and the U.S. Virgin Islands by the U.S. Fish and Wildlife Service (freely associated states are not included in these listings). Hawaii stands out as particularly important owing to its number of endemics and endangered species. When viewed on a per-acre basis, these rates of endangerment are orders of magnitude higher than those encountered in the continental United States. Invasive species are often a major factor leading to extinctions; Hawaii, as an extreme example, faces the challenge of prioritization and triage involving hundreds of invasive species and hundreds of endangered species (see Criteria 1 and 3 in Part II).

- **Climate change threatens entire islands and ecosystems.** This report is focused on the assessment of *current* conditions, and the projected *future* impacts of climate change are generally beyond its scope. However, forests on the tropical islands are particularly susceptible to anticipated changes in sea levels, precipitation and temperature patterns, and tropical storm activity, and they already are feeling the effects of a changing climate, particularly in terms of increasing variability and extremes in weather patterns. In many of the smaller islands in the Pacific, where elevations are often low, the ratio of coastal to interior areas high, and opportunities for local migration of forest species and people constrained, the threats posed by global climate change are severe. They include the potential destruction of coastal mangrove forests and the intrusion of salt water into ground water.

- **Commercial forestry is relatively limited, but linkages between people and forests are very strong.** Owing to the importance of traditional lifestyles for many island inhabitants, local residents rely on their forest resources in ways that are perhaps underappreciated by urban residents living elsewhere. Throughout the islands, forests provide subsistence foods, medicinal compounds, wood for local crafts and for construction, and other materials for cultural purposes and daily use. This reliance is increased by the fact that, with the exception of Hawaii, per-capita incomes are less than half the U.S. average, and subsistence activities are concomitantly more important. Moreover, island geography reinforces the linkage between forest conditions and other critical resources and services (e.g., drinking water, or sedimentation in coastal waters), and agroforestry, both for subsistence and commercial use, is a common practice on many islands (see Criteria 2 and 6 in Part II).

- **Forests are essential to the supply, quantity, and quality of island water resources, but are affected by human uses to varying degrees.** The conversion of forest lands to other uses has significantly affected water availability and quality on most of the inhabited islands. In many cases, nonforest land uses, such as agriculture and livestock grazing, as well as industrial, urban, and tourism development, have led to overuse of existing water supplies, sedimentation of waterways and bodies, including reservoirs, and contamination of surface and ground waters. Forest-based provision of water resources and services is affected by various disturbances, including feral ungulates, fire, nonnative invasive plant species, unsustainable water withdrawals and diversions, and climate change, indicating the need to consider water and forests together in the pursuit of sustainable forest management (see Criterion 4 in Part II).

- **Institutional capacity for forest management is relatively limited, but islands partially compensate for this through regional collaboration and leveraging available federal programs.** With the partial exception of Hawaii and Puerto Rico, the island jurisdictions covered by this report lack the resources and economies of scale to support the sorts of institutions that underlie forest management in the continental United States. In response, many of the islands engage in regional collaboration and exchange (in higher education, for example), and have instituted cross-boundary partnerships incorporating nongovernmental organizations, citizens groups, local and federal governments, and private sector representatives. Additionally, they have actively sought assistance from federal agencies to enhance their forest monitoring and management capacity. Continued support from federal programs and regional collaborations are an essential enabling condition for forest management (see Criterion 7 in Part II).

- **Forest regulations, standards, and guidelines are generally in place throughout the islands, but enforcement is uneven.** This is likely the result of low institutional capacity and limited commercial use of forests. At the same time, islands also possess differing customs and land tenure arrangements that affect forest practices in nonregulatory ways (see Criteria 4 and 7 in Part II).

- **Land tenure in the U.S.-affiliated Pacific jurisdictions often combines traditional resource allocation arrangements with Western concepts of land ownership and control.** This includes communal decisionmaking processes and restrictions on the sale of lands to external entities. The combination of traditional and Western land-tenure arrangements has not always been smooth, and this fact points to the importance of cultural sensitivity when pursuing forest management in the islands (see Criterion 7 in Part II).

- **Data that are both consistent over time and comparable across island jurisdictions are relatively rare.** The *National Report on Sustainable Forests* (USDA FS 2011) relied on well-established data series from the Forest Service's Forest Inventory and Analysis unit (FIA), the U.S. Census and similar long-standing reporting activities, to assess forest sustainability for the continental United States. FIA has periodically measured forests in Puerto Rico since the mid-1980s and in the USVI since the mid-1990s, moving to cyclical measurements in 2014. FIA activities also have more recently expanded to include the tropical islands in the Pacific, and results will soon be available for the second measurement of the most recent islands to be included. U.S. Census and related socioeconomic information are not always directly comparable across different jurisdictions, especially for the freely associated states (Republic of the Marshall Islands, Federated States of Micronesia, and Republic of Palau), and various other data sets used in the national report are not available (see chapter 2 in Part I).

Policy Recommendations

To ensure forest sustainability in coming decades, *The National Report on Sustainable Forests—2010* emphasizes the need for flexible and adaptive forest management actions informed by sound data and open public discussion. This general recommendation is equally relevant for forest management on U.S. and U.S.-affiliated tropical islands, and it is encouraging to see that efforts to strengthen data acquisition and public dialogue are well underway in the islands. Given the heterogeneity of ecological, social, and economic conditions across the islands, it is hard to discern more specific policy recommendations that can be applied to all. We can nonetheless propose the following general observations to help guide management and policy formation in the future.

- **Pursue consolidation in data development and reporting.** Comparability across time and space is hampered by a lack of repeated sampling. Ongoing improvements in forest inventory data, in particular, will help ameliorate the lack of consistent information on forests, particularly in the Pacific. The islands produce a number of similar information reports on forests (e.g., the state-level Forest Action Plans, and submissions to the UN Food and Agriculture Organization's *Global Forest Resource Assessment*) as well as reports specific to individual jurisdictions and issues. Consolidation and standardization of these reporting activities will benefit both information consumers (by providing greater comparability and transparency) and producers (through reporting efficiencies and avoiding duplicate efforts). Specific recommendations related to data development and reporting are included at the end of chapter 2.
- **Foster public participation and sensitivity to cultural differences as an essential component of forest planning and management activities**. Most residents have a direct and material interest in forest conditions, outputs, and ecosystem services. Although many stakeholders may not exhibit the same degree of organization as those encountered on the mainland owing to lack of resources and economies of scale, they nonetheless have a substantial interest in management decisions and outcomes. Cultural relationships to the land will also differ, as will modes of engagement in decision processes. It is important that these stakeholders and their perspectives be adequately integrated in planning processes and management activities. This point highlights the need for investments in culturally aware capacity building to fully engage local stakeholders in adaptive forest management and planning processes.
- **Focus management and data acquisition activities on forest conditions and outputs that are most valued by island residents.** Island inhabitants rely on forests for a broad range of services and outputs, few of which enter into formal markets or are subject to quantified measurement. To the extent possible, forest reporting and planning exercises need to explicitly identify these outputs and their relative importance, then use this information to tailor biological inventories, socioeconomic data collection, and management actions accordingly.
- **Support ongoing collaboration between island entities through durable federal and regional programs**. Extension of FIA inventory sampling to all the islands provides not just data but also a chance for islands to share information and experiences. Regional efforts like the Micronesia Challenge (see Criterion 7 in Part II) strengthen communication and collaborative management strategies between forest professionals and citizens. The value of these programs, and others like them, for small islands lacking capacity and economies of scale should not be underestimated, and they should be maintained.

These policy recommendations call for more data collection and more consultative processes that cannot be undertaken without the active participation of island forest managers who already are handling a range of responsibilities typical of larger institutions on the U.S. mainland. As a result, following these recommendations will require additional assistance in the form of research and technology transfer and the simple provision of additional outside funding. Assistance providers need to be aware of the specific ecological, cultural, and political conditions specific to each island, and to work in close collaboration with local experts and leaders.

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Part II.

Criterion and Indicator Reports

An ‘i’iwi (scarlet honeycreeper, *Vestiaria coccinea*) perches in an ‘ōhi’a (*Metrosideros polymorpha*) blossom in Hawaii. The ‘i’iwi is proposed for “threatened” status and ‘ōhi’a is being attacked by a new fungal disease, *Ceratocystis fimbriata*.

Criterion 1

Conservation of Biological Diversity

Kathleen A. McGinley and Constance A. Carpenter

Introduction

Tropical forests are among the most diverse ecosystems on Earth, hosting about two-thirds of the planet's terrestrial biodiversity and providing benefits from local to global levels through the provision of goods and services (see, for example, Gardner et al. 2009). Biological diversity encompasses the range of physical environments and biotic communities (i.e., ecosystem diversity); groups of interbreeding natural populations (i.e., species diversity); and variation in the genetic makeup of plants, animals, and microorganisms (i.e., genetic diversity) over a specified area. Biological diversity is an important factor in ecosystem, species, and genetic response to natural and human disturbances and to the maintenance and recovery of essential ecological processes.

Forest composition, structure, and inherent biodiversity change through succession and in response to disturbances. Tropical islands with high rates of natural or anthropogenic disturbances typically host forests in an ongoing state of recovery (see, for example, Chazdon 2003, Foster et al. 1997, Waide and Lugo 1992). Recurring effects from tropical storms and hurricanes, cyclones, typhoons, and other natural disturbances produce patches of forest regeneration, maturity, and senescence as disturbance and recovery overlap in time and space (Chazdon 2003). Forest succession that follows anthropogenic disturbances also may result in novel combinations of species, as natural processes lead to the remixing or reassembling of native and nonnative plant and animal species into novel communities that are adapted to anthropogenic environmental conditions (Lugo 2009). Nevertheless, the naturalization of nonnative species in island ecosystems affects successional dynamics in ways that are neither completely understood nor identical for all islands.

Under Criterion 1, we examine inherent biological diversity of tropical island forests, along with related forest conditions and conservation efforts. Systems of reserved lands are promoted to ensure that representative examples of all ecosystem types are preserved in perpetuity. Protection of a representative array of natural habitats and intact ecosystems is intended to safeguard examples of most species and their genetic diversity. Species that fall through this coarse filter can be targeted by finer filters, such as protecting lands necessary to the conservation of a particular species and species-specific in situ and ex situ conservation measures.

Criterion Summary

Tropical and subtropical forests cover more than 3 million ac of the U.S. and U.S.-affiliated tropical islands, ranging from nearly 1.5 million ac in Hawaii to fewer than 25,000 ac in the Republic of the Marshall Islands. Most of these island jurisdictions experienced significant conversion of forests to nonforest land uses in the past, but nearly all are predominantly forested today (except for Hawaii and Guam, which have 36 and 48 percent forest cover, respectively). Although much of the islands' forest lands historically were converted to agricultural and urban uses, or to grasslands and badlands, forest area is stable on most islands, except a few areas that continue to lose forests to agriculture or to urban and suburban development (e.g., the U.S. Virgin Islands [USVI]). Reflecting these land use histories and natural island processes, most forests are in early to middle stages of succession, dominated by the smaller diameter trees indicative of younger aged forests. Significant areas of native forest have been replaced or altered by human activity, resulting in managed or novel forest ecosystems throughout much of the Pacific and Caribbean.

Given that the islands were predominantly, if not entirely, forested prior to major human occupation, the change from forest to other land uses in effect represents a breaking up of once continuous forests. Islands with more land in nonforest land uses may have more fragmented landscapes, though some islands have maintained contiguous forest in certain regions or habitats (e.g., upland forests in Hawaii), while primarily converting forests to nonforest uses in others (e.g., lowland and coastal terrain in Hawaii). Other than Hawaii, which has the highest percentage of land in nonforest uses (64 percent), islands in the Pacific tend to have the least percentage of nonforest land use (<35 percent). Nonetheless, it is difficult to determine the degree of forest fragmentation for most of the islands.

The majority of forested land across the islands is privately owned, except in Hawaii, Guam, and Palau, where more than half of forest area falls under public ownership. Throughout the islands, there is a wide range in the area and percentage of forests that are formally or legally protected. In addition to formal forest protection, traditional governance structures have resulted in widespread community forest management and protection, particularly in the Pacific region. In many cases, traditional and community forest management have sustained a largely forested landscape that typically encompasses a combination of native forest, secondary forest, and traditional agroforest, as well as spiritually significant forest areas that are strictly protected.

Although the islands are rich in plant and animal species per unit area, they do not host the levels of diversity found in mainland tropical areas, owing in part to their size and relative isolation. Nevertheless, many of the islands have high levels of endemism (i.e., species native to a specific island, group of islands, or other geographic area), which correlates with their isolation, climate, and heterogeneity of habitats. For example, Hawaii has exceptionally high levels of endemic species, including more than 99 percent of its identified terrestrial insects, spiders, and land snails; 90 percent of its plants; and more than 80 percent of its breeding birds.

Some 760 terrestrial plant and animal species across the islands are considered by the International Union for the Conservation of Nature (IUCN) to be at risk of extinction, and nearly 500 forest-associated plant and animal species have been listed by the U.S. Fish and Wildlife Service as endangered or threatened with extinction in the Northern Marianas, Guam, Hawaii, Puerto Rico, and USVI. Many of these at-risk plants and animals are endemic species, such that their extirpation would mean extinction of the global population and a permanent loss to world species richness. Extinction rates for island species are generally much higher than continental rates, in part because island species tend to have small populations, restricted genetic diversity, and narrow geographic ranges, making them more susceptible to the effects of natural and anthropogenic disturbances. A wide array of onsite and offsite efforts to protect at-risk forest species and native biodiversity in general has been established throughout the islands. These efforts have resulted in some notable successes, but the threat of species extinctions continues.

Montréal Process Criterion Indicators

Criterion 1 of the MP C&I focuses on the biological diversity of forest systems and contains nine indicators related to ecosystems, species, and genetic diversity (listed below). There are fairly good data related to forest ecosystem diversity for many of the jurisdictions in this report, and some good data on forest species diversity for a few jurisdictions, but very limited data for genetic diversity for any of the jurisdictions. Given the limited amount of data related to forest genetic diversity and its conservation, the associated indicators were combined in this report. The nine MP C&I indicators for Criterion 1 are as follows:

- **1.01:** Area and percentage of forest by forest ecosystem type, successional stage, age class, and forest ownership or tenure.
- **1.02:** Area and percentage of forest in protected areas by forest ecosystem type, and by age class or successional stage.
- **1.03:** Fragmentation of forests.
- **1.04:** Number of native forest-associated species.
- **1.05:** Number and status of native forest-associated species at risk, as determined by legislation or scientific assessment.
- **1.06:** Status of onsite and offsite efforts focused on conservation of species diversity
- **1.07:** Number and geographic distribution of forest-associated species at risk of losing genetic variation and locally adapted genotypes.
- **1.08:** Population levels of selected representative forest-associated species to describe genetic diversity.
- **1.09:** Status of onsite and offsite efforts focused on conservation of genetic diversity.

Indicator 1.01
Forest Area and Percent By Forest Ecosystem Type, Successional Stage, and Forest Ownership or Tenure

Total Forest Area

The vast majority of the U.S. and U.S.-affiliated tropical islands included in this report were originally completely or nearly completely forested and, with the exception of Hawaii and Guam, are predominantly forested today (fig. C1-1). Overall, the islands show a large variation in both total forest area and percentage cover, with no discernable correlation between these two measures. Although Hawaii has the least percentage of forest cover, it has the greatest total area of forest at nearly 1.5 million ac. At the other end of the spectrum, American Samoa has the highest percentage of forest cover but a comparatively small total forest area. At 23,252 ac, forest area in the Marshall Islands is approximately 1/50th that of Hawaii.

Historically, most islands underwent some (and often a significant degree of) conversion of forest to agricultural

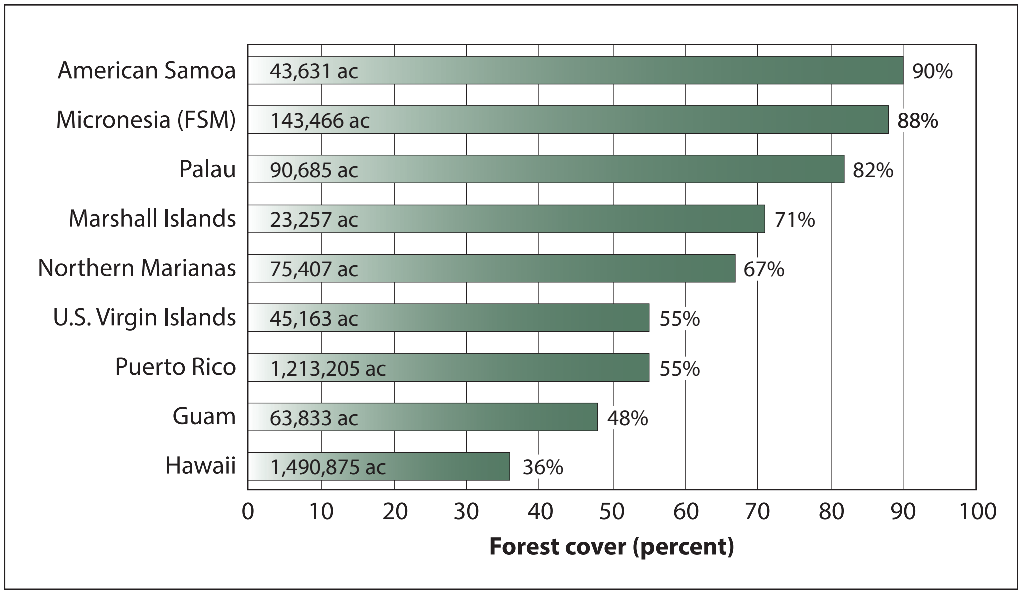

Figure C1-1. Forest cover as a percentage of total land area for the U.S. and U.S.-affiliated tropical islands (2001–2009). Source: for Hawaii, Gon et al. (2006); for all others, U.S. Forest Service Forest Inventory and Analysis (FIA). Note: FIA classifies "forest" as areas having "at least 10 percent tree cover," and may include agroforests and mangrove forests. For Hawaii, Gon et al. (2006) used the National Vegetation Classification System, classifying "native" forest as areas at least 25 percent vegetated, whereby native "open forest" is 25 to 60 percent vegetated and native "closed forest" is >60 percent vegetated. Nonnative "forest" vegetation types are at least 15 percent vegetated.

and grazing lands, or to grasslands and badlands, typically tied to periods of initial settlement and the introduction of fire, or resulting from colonization and population growth. Military occupation and associated deforestation and other ecosystem disturbances (including atmospheric nuclear testing) before, during, and after World War II occurred on several islands in the Pacific. Conversely, relatively few isolated islands (e.g., some atoll islets and rock islands of Palau) and those with forests on steep, rugged terrain or very wet climates (e.g., Tutuila in American Samoa and central mountains of high islands in eastern Micronesia) experienced very little historical forest loss and conversion, particularly when compared to other more accessible islands and those with more gently sloped terrain (e.g., Hawaii, Puerto Rico).

Over time, many deforested and converted lands were abandoned and reestablished as forests through natural regeneration, active planting, or both. These "forest transitions" typically are associated with shifts in socio-economic dynamics, including changes that result from globalization, industrialization, and urbanization, as well as from the direct effects of environmental legislation and conservation efforts (Aide and Grau 2004, Meyfroidt and Lambin 2011, Rudel et al. 2000). Today, most islands maintain at least some agricultural areas where forests once grew, and most continue to convert some forest area to development for residential, business, military, industrial, and tourism purposes. In the Caribbean, forests have recuperated significantly since the height of agricultural production in the early 20th century, yet some forest conversion persists, particularly for urban and tourism development (e.g., St. Croix) (Brandeis and Turner 2013a, 2013b). In Puerto Rico, in particular, more than 90 percent of the nearly continuous original forests had been cleared for agriculture by the early 1900s. However, through the reversion and replanting of abandoned agricultural lands, forests have since rebounded to cover more than half of Puerto Rico. To date, forest recovery in Puerto Rico has outpaced any forest conversion to development or other uses, forestalling any new net loss of forests for now (Brandeis and Turner 2013a).

Hawaii, once nearly completely covered by forests, is now about 36-percent forested owing in part to sustained agricultural production and development in areas once forested. In the Pacific, there is a broad range in forest distribution and dynamics. In Palau, for example, forests have been maturing and increasing on Babeldaob (at least until 2003), while forests were being lost to urban development and conversion to nonforest vegetation on Peleliu, Koror, and Angaur (Donnegan et al. 2007). In American Samoa, total forest area declined by at least 1.3 percent from 1988 to 2001. During the same period, mangrove forests were reduced by about 18 percent by development and urbanization (Donnegan et al. 2004a). In the Northern

Marianas, trends detected from photointerpretation and mapping suggest "conversions of forest and nonforest vegetation to urban land, especially on Saipan where urban land more than tripled" between 1989 and 2005 (Donnegan et al. 2011a).

Forests by Ecosystem Type (Holdridge Life Zone)

Vegetative community classes have not been fully developed for all of the islands, and those that do exist have not been standardized across the islands or similar life zones. Therefore, we examine island forests according to the Holdridge Life Zones system, which can be used as a proxy for ecosystem or community type. The Holdridge Life Zones system empirically defines the conditions for vegetation growth based on bioclimatic information (i.e., biotemperature, precipitation, and evapotranspiration (Holdridge 1967) (fig. C1-2). Its application facilitates global comparisons of ecological information, particularly across the tropics (Halasz 2007).

Life zone maps developed by Ewel and Whitmore (1973) for the Caribbean and by Tosi et al. (2002) for the Pacific (except the Marshall Islands) indicate the potential for a given area to support characteristic vegetative communities. Much of the Pacific and the entire Caribbean region geographically fall within the tropics, delineated by the Tropic of Cancer to the north and Tropic of Capricorn to the south. However, when bioclimatic variables are considered within the Holdridge Life Zones system (e.g., relatively uniform and high biotemperatures), more than 90 percent of the total land base of these islands is classified as subtropical. Based on their Holdridge classification, the vast majority of these islands are assumed to have been predominately to entirely forested prior to human settlement (Ewel and Whitmore 1973, Tosi et al. 2002). Hawaii is the most diverse jurisdiction with 27 life zones; at the other end of the spectrum, the USVI comprise two life zones.

Brandeis and Turner (2013a, 2013b) and Bennett and Liu (n.d.) used geographic information system analysis, overlaying life zone maps with vegetation maps, to determine current acreages of land cover and use types per life zone (fig. C1-3; table C1-1). Today, the most abundant forested life zone across all the islands is subtropical moist forest, three-fourths of which occurs in Puerto Rico given its

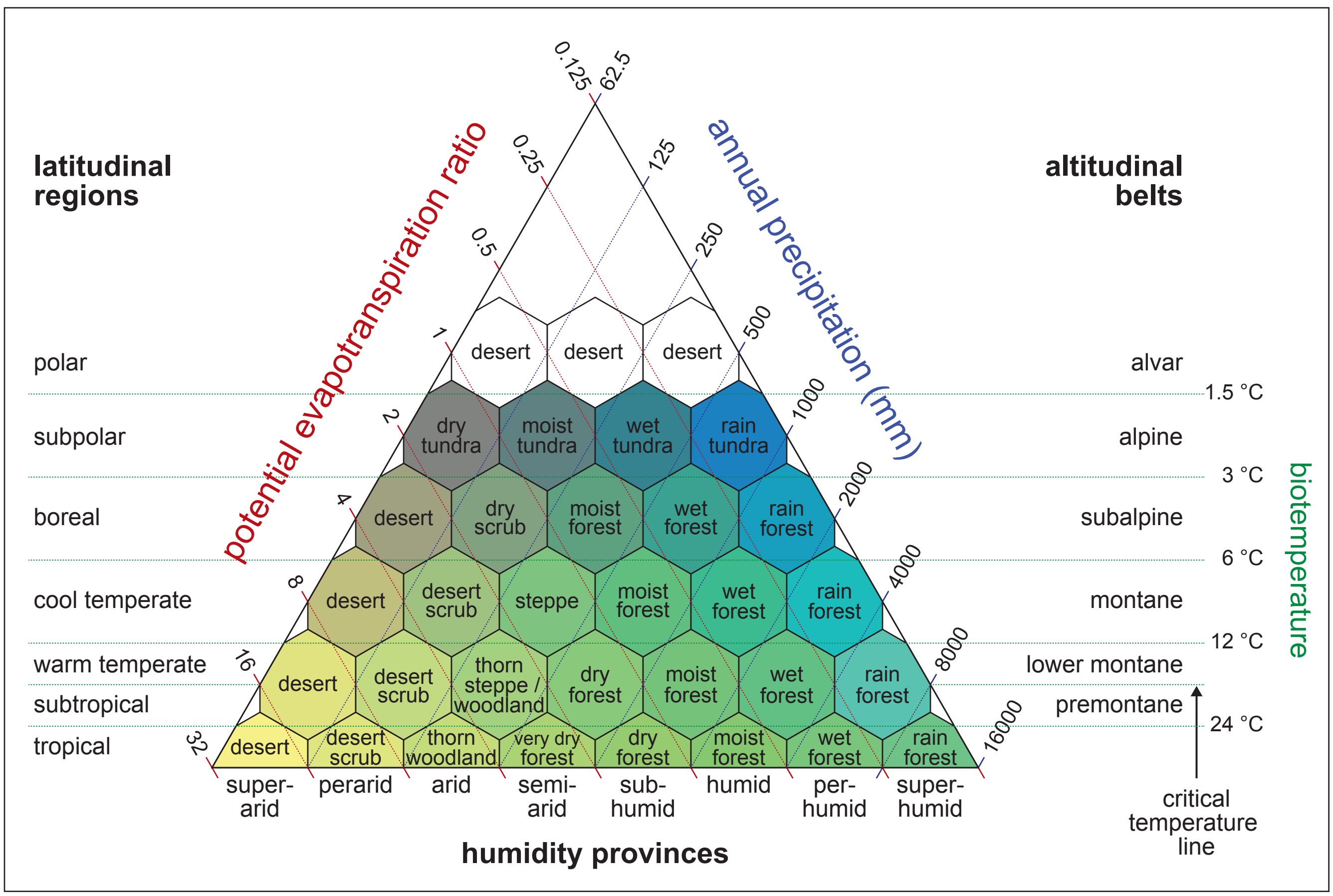

Figure C1-2. Holdridge Life Zone classification system. Source: Holdridge (1967), cited by Halasz (2007).

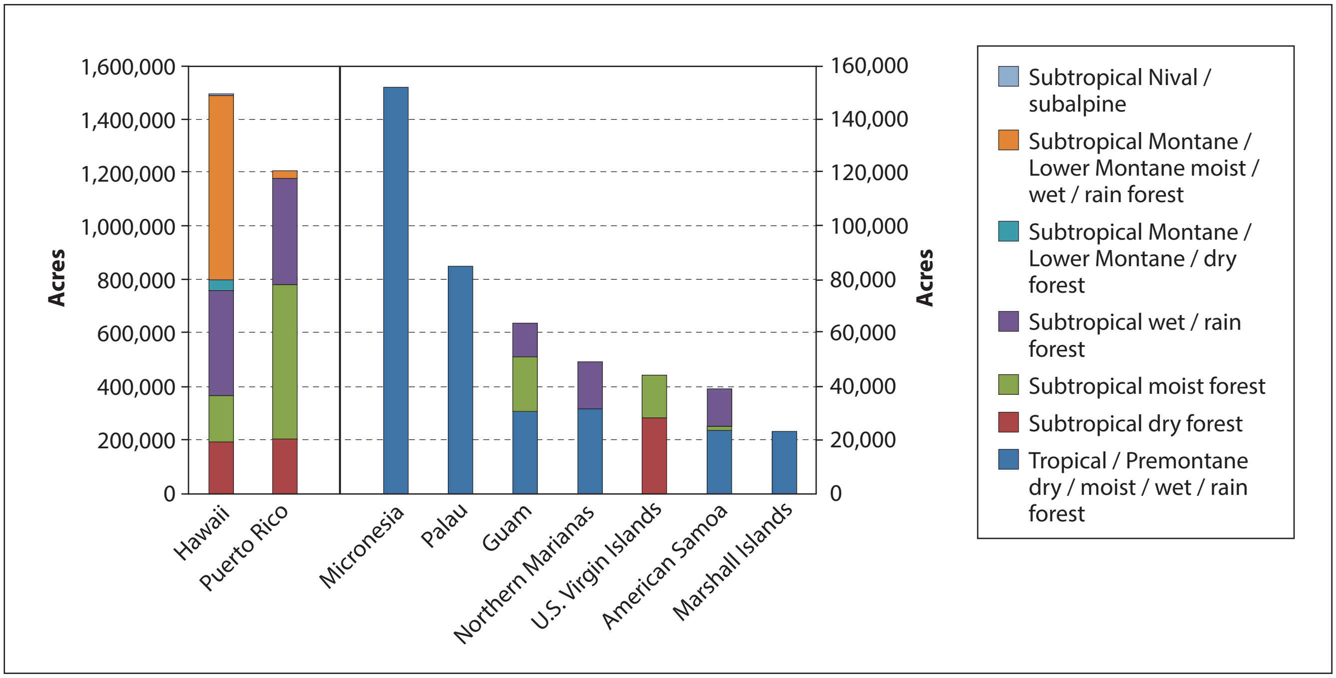

Figure C1-3. Forested acreage of Holdridge Forest Life Zones in the U.S. and U.S.-affiliated tropical islands (2001–2009). Source: Bennett and Liu (N.d.); Brandeis and Turner 2013a, 2013b.

Table C1-1. Forest area per Holdridge forest life zone group in the U.S. and U.S.-affiliated tropical islands, 2003–2013

	Total forest land area	Tropical/ premontane dry/ moist/ wet/rain forest	Sub-tropical dry forest	Sub-tropical moist forest	Sub-tropical wet/rain forest	Subtropical montane/ lower montane dry forest	Subtropical montane/ lower montane moist/wet/ rain forest	Subtropical nival/ subalpine
	Acres							
Caribbean:								
U.S. Virgin Islands	45,163		28,896	16,266				
Puerto Rico	1,213,205		199,691	578,801	398,145		21,670	
Pacific:								
Hawaii	1,489,251		186,894	172,522	391,890	44,495	691,592	1,858
American Samoa	40,265	24,796		697	14,772			
RMI	24,329	24,329						
FSM	151,834	151,834						
CNMI	49,885	32,964			16,921			
Guam	64,555	31,882		20,055	12,618			
Palau	85,702	85,702						
Total	3,218,897	351,507	380,915	864,581	835,275	44,495	720,587	1,858

RMI = Republic of the Marshall Islands; FSM = Federated States of Micronesia; CNMI = Commonwealth of the Northern Mariana Islands. Source: Bennett and Liu (N.d); Brandeis and Turner 2013a, 2013b.

relatively large area of forest. Subtropical wet forest is also abundant. Almost a quarter of the total forest area occurs in mountainous terrain (i.e., montane), most of which is found in Hawaii. The Pacific Islands are small, but collectively they contain seven tropical and four subtropical forested life zones ranging from dry forest to rain forest as well as some pre-montane forested life zones (note: some life zones have been combined in fig. C1-3 and table C1-1).

Native and Novel Forests

"Native forests" are naturally established ecosystems composed primarily of indigenous species, many of which have evolved together over thousands to millions of years (Friday et al. 2008, Kagawa et al. 2009, Parrotta et al. 1997). "Novel forests" are those that have emerged naturally, in response to new environmental conditions created by human activity that result in the remixing or reassembling of indigenous and introduced or nonnative species into novel or new communities (Lugo 2009). Novel forests typically exhibit ecosystem functions such as soil protection, nutrient cycling, and wildlife habitat similar to (and in some cases exceeding) those functions exhibited by native forests (Lugo 2009). Yet, while nonnative-dominated novel forests in Puerto Rico have been shown to "provide suitable regeneration sites for native species and promote native species abundance," in Hawaii native trees and plants "are largely unable to colonize" novel forests once they are established, owing in part to the "wide diversity of growth strategies among the exotic species on Hawaii [which] may limit the opportunities for native plants to colonize exotic-dominated forests" (Mascaro et al. 2008). Overall, the islands in this report do maintain some forest communities composed mainly of native species, but increasingly they host forests that include a mix of native and nonnative species. Forest communities that recolonize abandoned agricultural lands are generally a mixture of native and nonnative species, of which the latter may have been purposefully or inadvertently brought to the islands. They are different from planted forests or plantations, and from agroforests, which intentionally integrate trees and shrubs with crop and animal farming systems.

In the Caribbean, very little native forest remains on the inhabited islands of Puerto Rico and the USVI because these were nearly completely deforested for agricultural uses during the late 18th and early 19th centuries. In Puerto Rico, remnants of native forest can be found in the peaks of the highest mountains and along some steep slopes, as well as on the less populated and uninhabited smaller islands and cays off the coast of the main island. Native and nonnative tree species are found in the vast majority of the forested areas of Puerto Rico, regenerating naturally in established, maturing forests, as well as on recently abandoned agricultural land. For example, the African tuliptree (*Spathodea campanulata*), an introduced tree species, represents more basal area and frequency in number than any other tree species on the island (Brandeis and Turner 2013a, Brandeis et al. 2007a). Moreover, it also is important in the understory of most forests, indicating its capacity to regenerate (Brandeis and Turner 2013a). Nonetheless, three native tree species, American muskwood (*Guarea guidonia*), gumbo limbo (*Bursera simaruba)*, and pumpwood (*Cecropia schreberiana*), were the next three most commonly found tree species on the island, indicating that native trees are regenerating successfully across the island, despite significant effects from human activities throughout much of the landscape (Brandeis and Turner 2013a, Brandeis et al. 2007a).

Although Hawaii has lost a significant amount of its original forest cover, 22 percent of the total area is classified as native forest (Gon et al. 2006). As inferred from life zone mapping, 77 percent of the state's original, native forest cover has been lost. Yet, 61 percent of remaining forest land in Hawaii is considered to be native forest cover (Gon et al. 2006) (fig. C1-4). Polynesian settlement in the Hawaiian Islands in the 4th and 5th centuries CE altered coastal, dry, and some mid-elevation forest types through agriculture and the use of fire (Graves and Addeson 1995). After European contact in the late 1700s, the expansion of agriculture and the introduction of cattle, later followed by urban land uses, accelerated forest loss, particularly in lower elevations (Graves and Addeson 1995). Today, there is very little native vegetation below 2,000 ft elevation in Hawaii. Native forest types exhibiting significant reduction in range include the subalpine forest (2 percent forested), montane dry forests (11 percent forested) and the subtropical (lowland) dry forest communities (17 percent forested) (Bennett and Liu, n.d.). In particular, the mesic montane forest type has been all but lost to the effects from timber logging (e.g., *Acacia koa*), sugar plantations, cattle ranching, and spread of invasive grasses that can lead to increased susceptibility to and severity of wildfire (Denslow et al. 2006, Gon and Olson 1999).

Human settlements have influenced Hawaiian and other Pacific islands' forest composition and structure for a thousand years or more. Throughout the region, plants used historically for medicine and food are found in now-remote areas, which were inhabited, harvested, and modified by earlier, denser human populations, prior to the introduction of Western diseases and the modern concentration of populations in developed

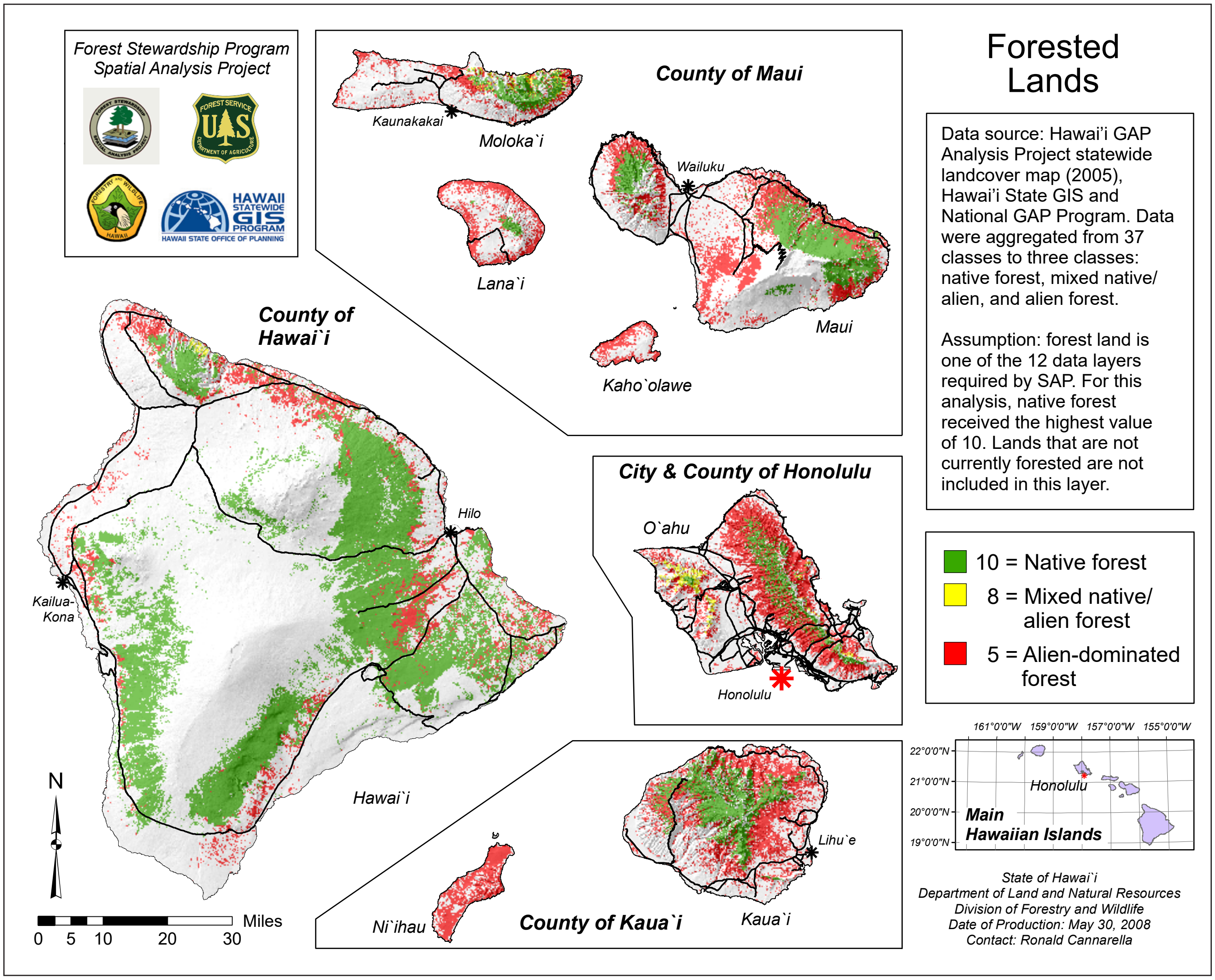

Figure C1-4. Forested lands in the main Hawaiian Islands (Conry et al. 2008). GIS = geographic information system; GAP = Gap Analysis Program; SAP = Spatial Analysis Project.

areas (Donnegan et al. 2011b). For example, paleo-environmental evidence from Palau suggests that, some 2,500 years ago, forests were modified and converted to agricultural uses that often incorporated terracing practices (Athens and Ward 2002). More recent human disturbances throughout the region, including agricultural practices and forest clearing associated with military and mining activities, have resulted in the expansion of novel forest ecosystems as the activities are abandoned and forests regenerate with new combinations of native and nonnative species. In particular, the Pacific Campaign of World War II had significant impacts on the vegetation of many of these islands. Throughout Micronesia, lowland forest vegetation has been "heavily modified over thousands of years of human activity, including agroforestry and tree gardening" (Raynor and Fownes 1991). Today, most Micronesian and American Samoan forests are "a mixture of native and nonnative species, primarily of smaller tree size classes." Some native forests are still found in the intertidal zone (mangroves), limestone regions (especially the uninhabited rock islands of Palau and military bases of Guam), along steep slopes and ravines, and on the central high slopes in Pohnpei, Kosrae, the American Samoan high islands, and Babeldaob (Palau). Native forests have largely been replaced by agroforestry systems—especially coconut plantations in the Marshalls and other atolls in the region, except for some of the undisturbed islets where native mixed-broadleaf forest remains largely undisturbed by humans (Donnegan et al. 2004a, 2004b; 2007; 2011a, 2011b, 2011c). Additionally, in Guam, much of the forest is affected by the high number and density of nonnative *Leucaena leucocephala* shrubs, which spread extensively following widespread forest clearing during World War II (Donnegan et al. 2004b).

Forest Successional Stage and Age

Measures of forest successional stage or age are important for understanding variations in their structure and composition over time and across the landscape, but such measures are difficult to come by in general, and in the tropics in particular, partly because the number of tree rings in tropical trees does not correspond to age in years, but to variable time periods related to available moisture. Where available, forest age can be estimated by analyzing multitemporal satellite images, aerial photographs, or other measures, yet these are scarce for most tropical islands. Kennaway and Helmer (2007) mapped land use in Puerto Rico from 1951 through 2000, demonstrating that, by 2000, only 21 percent of the total forest area was more than 50 years old. Twenty-seven percent was aged 23 to 49 years, 31 percent was aged 10 to 22 years, and 21 percent of the total forest area was less than 10 years old.

Forest stands that are classified according to the predominant diameter class of live trees can be used as an approximate indicator of forest successional stage, specifically when combined with information related to land use history and forest life zone, type, species composition, and stocking. Forest size-class data are available from the Forest Service's Forest Inventory and Analysis (FIA) program for most of the jurisdictions (except Hawaii). In general, these data reflect known forest types and land use histories of the islands, with the majority of forest stands dominated by trees less than 11 inches diameter at breast height (dbh), indicating mostly young- and intermediate-aged forests of early and mid-successional types (fig. C1-5).

Forests in the Marshall Islands represent the highest proportion of trees categorized as "large diameter" (60 percent: ≥ 11 inches dbh) (fig. C1-5). American Samoa and the Federated States of Micronesia (FSM) also have a significant portion of trees in the large stand class (≥ 11 inches dbh: 36 percent and 31 percent, respectively). The dominance of comparatively large trees on these islands is mostly attributed to the presence of coconut trees in plantations and agroforests (Donnegan et al. 2004a, 2007, 2011b). While individual native and nonnative trees greater than 21 inches dbh are found throughout most forest stands across all jurisdictions, and those trees may in fact dominate the canopy, only the FSM exhibits any forest area (1.7 percent) dominated in number by trees this large. At the other end of the spectrum, the USVI exhibit the highest proportion of forested area dominated by small-diameter trees (85 percent: 1 to 4.9 inches dbh), reflecting not only the relatively early stage of succession of most forests, but also the predominance of subtropical dry forest, which typically consists of slower growing, smaller sized trees (Brandeis et al. 2007b). In Guam and the Northern Marianas, forests tend to be dominated by smaller trees, owing to frequent disturbance by typhoons, and more recently, to human-induced land use effects and change (Donnegan et al. 2004b, 2011a). Finally, in Puerto Rico, most forests are considered to be relatively young and are dominated by smaller stand classes in which regeneration is abundant. These forests are growing, "with a slight tendency toward increasingly larger diameter stands" (Brandeis and Turner 2013a).

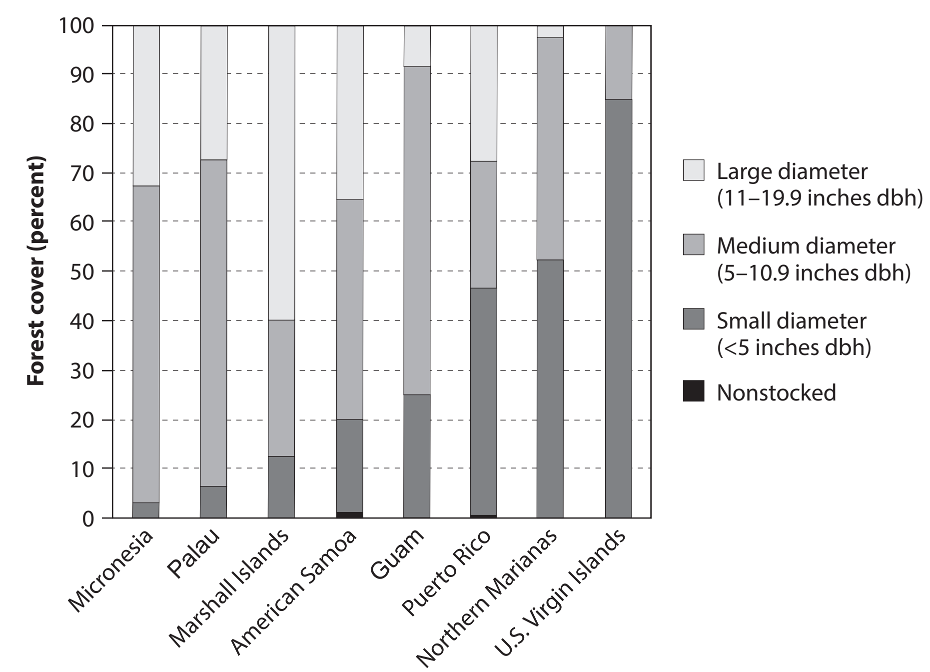

Figure C1-5. Forest area dominated (>50 percent) by nonstocked, small-, medium-, and large-diameter stand classes. Source: U.S. Forest Service Forest Inventory and Analysis (data for Hawaii were not available at the time this report was published); dbh = diameter at breast height.

The distribution of forest stand-size classes throughout the islands reflects natural and anthropogenic processes, with significant expanses of native forests having been replaced or altered by active and abandoned agroforests in the Pacific (Donnegan et al. 2004a, 2004b; 2007; 2011a, 2011b, 2011c) and by secondary forests in the Caribbean (Brandeis and Turner 2013a, 2013b). For example, coconut plantations and mixed coconut forests are widespread in American Samoa and the Marshalls (Donnegan et al. 2004a, 2011c). In the FSM, forests are "generally dense with larger trees, reflected in high basal area and wood volume on a per-acre basis." In addition, ancient and ongoing "tree gardening" has resulted in "an abundance of fruit and nut trees interspersed with other canopy trees" (Donnegan et al. 2011b). And, in Puerto Rico and the USVI, as in Palau, the conversion of forest to agriculture in the early to mid-20th century largely has given way to agricultural abandonment and the reversion of converted lands to grassland and eventually to secondary forest across a large part of the landscape (Brandeis and Turner 2013a, 2013b, Donnegan et al. 2007).

Forest Ownership

Forests are mostly privately or communally owned in all jurisdictions except Hawaii, Guam, and Palau, where more than half of the total forest area falls under public (i.e., governmental) ownership (53 percent, 56 percent, and at least 70 percent, respectively) (table C1-2). Although the national governments of Micronesia and Palau do not own forest land, state and local governments within those nations do own a range of forest area, including 70 percent or more in Palau. Land ownership and tenure is complex in many of the islands, particularly in the Pacific, and is discussed in greater detail under Criterion 7.

Table C1-2. Percentage of forest area by ownership type and jurisdiction, circa 2010

	Total forest area		
	Private	Local jurisdiction (national/state/municipal)	Federal (United States)
		Percent	
U.S. Virgin Islands	83	0	17
Puerto Rico	85	11	4
Hawaii	47	44	9
American Samoa	96 (or more) (includes "communal")	4 (or less)	0 (13 percent is leased to the National Park Service)
Marshall Islands	100	0	0 (most of Kwajelein Atoll is leased to the U.S. military)
Micronesia:			
Chuuk and Yap	About 100	About 0	0
Pohnpei	About 64	About 35	0
Kosrae	27	16 (an additional 58 percent is constitutionally designated for release to private ownership)	0
Northern Marianas	N/A	About 50	N/A (parts of Tinian are leased to the U.S. military)
Guam	51	19	29
Palau	30 (or less)	70 (or more)	0

Sources: American Samoa Community College 2010; Biza 2012; Brandeis and Turner 2013a, 2013b; Commonwealth of the Northern Mariana Islands 2010; Donnegan et al. 2011a; Gon et al. 2006; Guam 2010; Republic of the Marshall Islands 2010; Republic of Palau 2010.

N/A = not available.

Indicator 1.02
Forest in Protected Areas

Throughout the islands, there is a wide range in the area and percentage of forests that are formally protected through parks, reserves, protected areas, and other official measures. Formally protected forests are found on public, private, and communal lands. In addition to formally protected areas, most islands exhibit several other forms of forest protection through traditional practices, collaborative arrangements, and private measures. However, statistics on forest protection are not available or comparative for all jurisdictions.

The USVI, Puerto Rico, and Hawaii have been assessed through the National Gap Analysis Program, which provides information on the status and conservation of plants and animals across the landscape, including the assessment of the status of land stewardship in terms of protected area location and conservation measures (table C1-3). Hawaii has the greatest total extent of formally protected forest (227,314 ac), followed by Puerto Rico (134,699 ac), while the USVI had the highest proportion of forest formally protected (14.7 percent) (Gap Status 1 + 2) (Gon et al. 2006, Gould et al. 2007, 2013).

Table C1-3. Area and percentage of forests in protected areas (Gap Status 1 + 2), 2003–2013

Jurisdiction	Area	Total forest
	Acres	*Percent*
U.S. Virgin Islands	8,575	14.7
Puerto Rico	134,699	11.6
Hawaii	227,314	13.1

Source: Gon et al. 2006; Gould et al. 2007, 2013.

Among the islands in the USVI, nearly three quarters of forests on St. John are formally protected; 65 percent of this area is within Virgin Islands National Park. However, less than 5 percent of the forests on St. Thomas and St. Croix are found in protected areas (Gould et al. 2013). In Puerto Rico, 11.6 percent of forests (at least 25-percent tree cover) are formally protected (Gap Status 1 + 2) (Gould et al. 2007). Forested areas with a priority on biodiversity conservation (Gap Status 1) include two management areas in the El Yunque National Forest: the Baño del Oro and El Toro Wilderness Areas. Flooded forests (i.e., mangrove and *Pterocarpus* swamp forests) in Puerto Rico had the greatest proportion of their total area under protection (46 percent: Gap Status 1 + 2), followed by dry (26.9 percent protected) and wet (15.4 percent protected) forest types. Conversely, moist woody forest vegetation had less than 4 percent of its range protected (3.9 percent protected) (Gould et al. 2007).

In Hawaii, 13.1 percent of forests are protected (Gap Status 1 + 2) (Gon et al. 2006). Forest types with the greatest percentage of their range protected (Gap Status 1 + 2) are the koa forest (93 percent), olopua-lama forest (93 percent), and closed ohia forest (32 percent). Conversely, closed hala and *Pouteria* forest cover types have none of their range formally protected. Using a broader definition of "protected forest area" to include forests where conversion to other land uses is prohibited, but where resource extraction and other potentially intense uses are permitted (e.g., Gap Status 3), indicates that Hawaii has nearly 43 percent of its total forest area under some formal protection or management, followed by 16.8 percent in the USVI and 11.7 percent in Puerto Rico (Gap Status 1 + 2 + 3) (Gon et al. 2006; Gould et al. 2007, 2013) (table C1-4).

In 2006, Palau, Micronesia, the Marshalls, Guam, and the Northern Marianas established the Micronesia Challenge—a regional effort to achieve "effective conservation" of 20 percent of terrestrial areas and 30 percent of marine areas by 2020 (PCS and TNC 2011). As of 2011, between 9 and 23 percent of each jurisdiction, including forested areas, were considered to be within a "protected/managed area" and contributing to the Challenge's goals. Although these statistics are not entirely indicative of a

Table C1-4. Forest area under protection or management and prohibition of conversion to other land uses, 2003–2013

Jurisdiction	Total forest area protected/managed
	Percent
U.S. Virgin Islands[a]	16.8
Puerto Rico[a]	11.7
Hawaii[a]	42.8
American Samoa[b]	20–22
Marshall Islands[b]	Data not available (16 percent of all lands)
Micronesia[b]	15-17
Northern Marianas[b]	9–13
Guam[b]	23–48
Palau[b]	20–24

Source: Gon et al. 2006; Gould et al. 2007, 2013; PCS and TNC 2011.
[a] Gap Status: 1, 2, and 3.
[b] Micronesia Challenge: "protected/managed."

strong measure of legal protection of these areas, they do offer a category of protection that is regionally consistent and encompasses international agreement to progress toward formal protection (PCS and TNC 2011).

Indicator 1.03
Fragmentation of Forests

The fragmentation of forested land can occur as a result of anthropogenic or natural processes. It can lead to species isolation and loss, habitat degradation, and a reduction in the capacity of the forest to sustain the natural processes necessary for maintaining ecosystem health. Throughout the islands, forest fragmentation largely results from human-induced conversion of forests to agriculture, and, more recently, to urban uses. Additional fragmentation results from the reversion of forest patches on historically pastured or farmed land. In Hawaii, in particular, natural fragmentation of forests has been occurring for some 400,000 years or more from volcanic activity (Flaspohler et al. 2010). During these events, lava flows into once continuous forests, leaving behind forest fragments of varying sizes (Flaspohler et al. 2010). These forested areas or fragments, known as *kipuka*, have different soils, vegetation, and microclimates than the surrounding land matrix because they were spared when the lave flowed around them and are found in different stages of succession than their neighbors (Flaspohler et al. 2010).

Direct measures of forest fragmentation are hard to obtain for most of the islands. In Puerto Rico, while forest is the dominant land cover across the landscape (55 percent), forest fragmentation is extensive (Helmer 2004, Helmer and Ruefenacht 2005). Specifically, by about 2000, 96 percent of all forest fragments in Puerto Rico were less than 10 ha (24.7 ac) in size, and nearly three fourths of all fragments were smaller than 1 ha (2.47 ac) (fig. C1-6). Conversely, only one forest fragment measured greater than 100 000 ha and only one other fragment was between 10 000 and 100 000 ha in size (Helmer and Ruzycki 2008, Kennaway and Helmer 2007, Kennaway et al. 2008). Nevertheless, forested landscapes and the state of forest fragmentation are dynamic. For example, Lugo (2002) documented a decrease in the number and size of agriculture and pasture land cover fragments and an increase

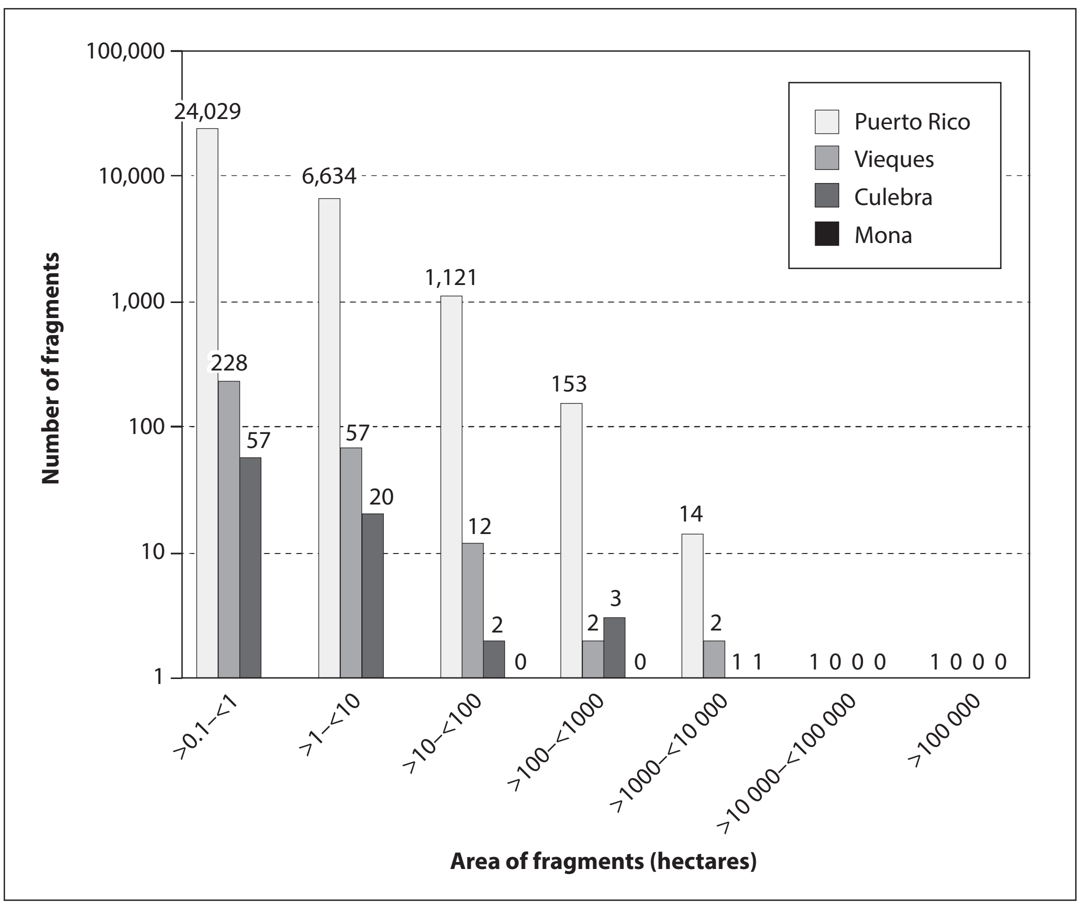

Figure C1-6. Frequency of forest patches in Puerto Rico in 2000. Produced by E.H. Helmer, 2010 from Helmer and Ruzycki, 2008; Kennaway and Helmer, 2007; Kennaway, et al. 2008.

in urban and forest fragments between 1977 and 1995 in northeastern Puerto Rico in a study of landscape-level land cover trends for six major land cover types—agriculture and pasture, closed forest, open forest, wetlands, open water, and urban. The results indicated a reduction in the fragmentation of the landscape during this period as forest and urban area increased, forming more and larger fragments, primarily regenerating or building over former fragments of agriculture and pasture.

In Hawaii, most forest area is found in large patches (≥1,000 ac), with nearly all native forest occurring in patches greater than 1,000 ac (Conry et al. 2008) (fig. C1-7). Most large forest patches are formally protected, while smaller forest patches occur primarily as scattered remnants, and some secondary forests in areas have been converted from forest to nonforest by urban development, agriculture, fire, and grazing (Gon et al. 2006).

Because all the islands considered in this report were predominantly, if not entirely, forested historically, change from forest to other land uses in effect represents a breaking up of once continuous forests. Today, Hawaii exhibits the highest percentage of land in nonforest uses (64 percent), followed by Guam (52 percent). The FSM and American Samoa have the lowest percentage of land in nonforest uses (12 percent and 17 percent, respectively) (fig. C1-8).

Islands with higher proportions of land in nonforest land uses potentially have more fragmented landscapes, though some islands have maintained contiguous forest in certain regions or habitats (e.g., upland forests in Hawaii), while primarily converting forests to nonforest uses in others (e.g., lowland and coastal terrain in Hawaii). For example, the trajectory of forest land use and cover in Hawaii differs from Puerto Rico in that much of the lands

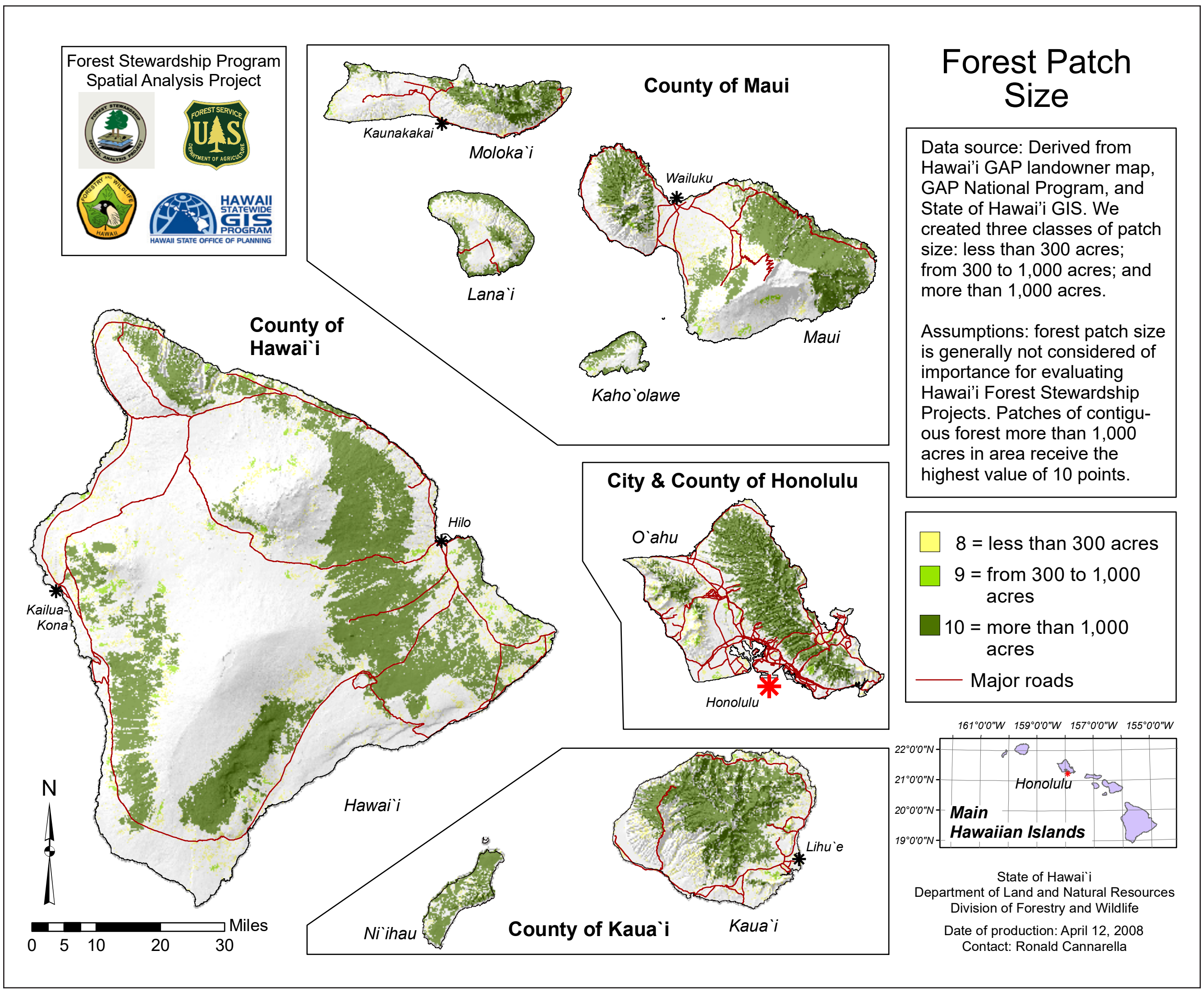

Figure C1-7. Forest patch size in the main Hawaiian Islands (Conry et al. 2008). GIS = geographic information system; GAP = Gap Analysis Program.

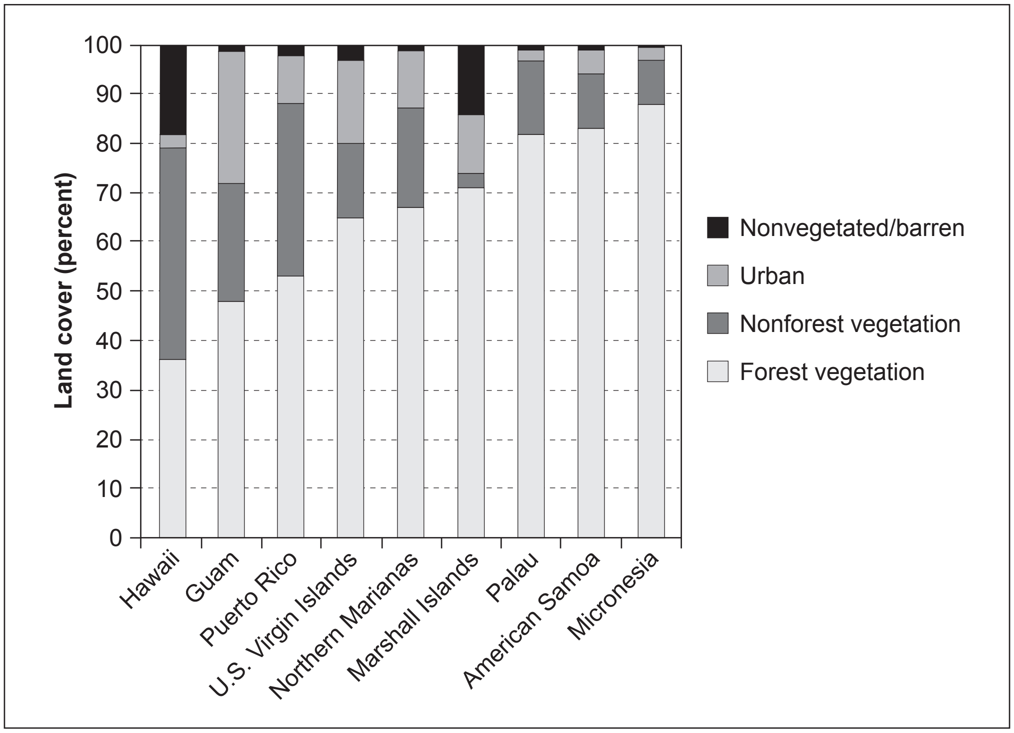

Figure C1-8. Distribution of land cover by jurisdiction. Source: for Hawaii, Gon et al. 2006; for all others, U.S. Forest Service Forest Inventory and Analysis.

in Hawaii that were converted historically from forest to agriculture continue to be farmed and grazed today, while a significant portion of converted agriculture and grazing lands in Puerto Rico have been abandoned and are in the process of secondary succession, in part accounting for the higher proportion of small forest fragments.

Indicator 1.04
Species Diversity

Identifying and monitoring forest-associated species is important to understanding forest diversity across the islands, and tracking changes in species numbers is crucial for understanding critical components of forest health and productivity. Data on the number and richness of forest species are difficult to find for most of the islands, excepting Hawaii, Puerto Rico, and the USVI. Although the islands do not demonstrate high rates of species richness, in comparison to mainland tropical areas, for example, many do demonstrate high levels of endemism, which correlates with their isolation, climate, and heterogeneity of habitats. Hawaii, in particular, has exceptionally high numbers of endemic species. Conversely, given their proximity to other islands in the Caribbean and the American mainland, Puerto Rico and the USVI demonstrate comparatively lower levels of species endemism.

In Hawaii, more than 23,000 species have been documented, including more than 7,000 endemic forest-associated species (table C1-5). Endemism is very high among most Hawaiian taxa, at more than 99 percent of terrestrial insects, spiders, and land snails; 90 percent of plants; and more than 80 percent of breeding birds (Mitchell et al. 2005). Also endemic to Hawaii, the Hawaiian hoary bat (*Lasiurus cinereus semotus*) is the only native terrestrial mammal. Hawaii has one native terrestrial reptile, the Hawaiian blind snake (*Ramphotyphlops braminus*), but no native amphibians.

More than 10,000 terrestrial plant and animal species have been documented in Puerto Rico and the USVI. Naturalized nonnative plant and animal species comprise a significant portion of these islands' biota. About half the forest-associated mammals are bats, while the other half are nonnative species such as the introduced Indian mongoose (*Herpestes auropuctatus*) and feral pigs, cats, and dogs. Forest-associated amphibian species in Puerto Rico exhibit high levels of endemism. The relatively large number of documented bird species in these islands is attributed to their importance as wintering and breeding grounds for migratory bird species, many of which depend on forests for habitat and food (Gould et al. 2007, Joglar 2005).

Table C1-5. Number of documented species and native-forest-associated species for major taxonomic groups in the U.S. Virgin Islands, Puerto Rico, and Hawaii (endemism [E] noted in parentheses)

	U.S. Virgin Islands			Puerto Rico			Hawaii		
	Documented	Forest-associated	Forest-associated endemic	Documented	Forest- associated	Forest-associated endemic	Documented	(Native) Forest-associated	Forest- associated endemic
Mammals—terrestrial	38	16	0	45	13	0	20	1	1
Birds	232	99	1	320	154	19	274	37	33
Fish—freshwater	7 (0 E)	N/A	N/A	37 (7 E)	N/A	N/A	45	5	5
Amphibians	8	8	1	24	15	12	4	0	0
Reptiles	22	18	3	55 (44 E)	N/A	N/A	18	1	1
Insects	1,769 (6 E)	N/A	N/A	5,373 (1,518 E)	N/A	N/A	7,902	~5,000	>99%
Plants—vascular	~900	N/A	N/A	3,126 (240 E)	N/A	N/A	2,597	1,233	981

Source: Acevedo-Rodriguez 1996, Eldredge and Miller 1995, Gould et al. 2008, Infonatura 2007, Joglar 2005, Liogier and Martorell 1998, Mitchell et al. 2005, Pyle 2002, Riegl and Dodge 2008, Suárez Zapata 2014, Weaver 2006.

N/A = not available.

Indicators 1.05 and 1.06
Species at Risk of Extinction and Related Conservation Efforts

Identifying forest-associated species that are at risk of extinction and developing efforts to protect and conserve them are important factors in understanding and protecting forest diversity, health, and vitality. The International Union for the Conservation of Nature (IUCN) documents and lists globally extinct and threatened species in its Red List database (http://www.iucnredlist.org). The IUCN Red List is based on standard criteria with quantitative thresholds for population and range size, structure, and trends that are used to assign species to categories of extinction risk, ranging from "Least Concern" to "Critically Endangered," as well as "Extinct in the Wild" and "Extinct" (IUCN Standards and Petitions Subcommittee 2013).

Individual species are the primary unit of analysis for IUCN Red List data, such that candidate species are first identified and then assessed in terms of their population numbers, geographic range, habitat availability, and other factors. The juxtaposition of the IUCN species-specific process with the location-specific analysis used in this report is not simple or direct (IUCN 2003). Specifically, the IUCN data cited here do not track local extirpations of listed species and may not reflect all occurrences of all extinct and at-risk species. Nevertheless, the IUCN Red List is an important and widely cited global database on at-risk species, and it is unique in its provision of information for all island jurisdictions included in this report.

Because the islands included in this report were originally predominately to entirely forested in accordance with predicted forest distribution arising from the Holdridge Life Zones classification system (see fig. C1-2) (Ewel and Whitmore 1973, Tosi et al. 2002), we report the total number of native terrestrial species listed by the IUCN in categories of extinction and at-risk of extinction (extinct in the wild, critically endangered, endangered, vulnerable, near threatened) (table C1-6). The IUCN lists 473 terrestrial animal and 409 terrestrial plant species at risk of extinction or already extinct across the United States and U.S.-affiliated islands included in this report, not including taxa known to have become extinct prior to 1500 CE nor "undescribed species assessed as data deficient" (IUCN 2015). Greater numbers of listed species are generally associated with larger land areas. Of the islands considered herein, Hawaii encompasses the greatest numbers of species listed as extinct (89 percent of total) and at-risk of extinction (49 percent of total) by the IUCN. Additionally, Hawaii accounts for 69 percent

Table C1-6. Number of Terrestrial IUCN Red List species native to U.S. and U.S.-affiliated tropical islands per at-risk category

	IUCN categories						Kingdom	
	Extinct[a]	Extinct in wild	Critically endangered	Endangered	Vulnerable	Near threatened	Animalia	Plantae
U.S. Virgin Islands	2	0	10	11	5	7	22	13
Puerto Rico	4	0	35	33	28	18	55	63
Hawaii	109	7	204	87	62	16	175	310
American Samoa	1	0	2	9	10	5	24	3
Marshall Islands	0	0	0	3	4	8	15	0
Micronesia	2	0	6	12	11	17	43	5
Northern Marianas	0	0	9	11	9	8	32	5
Guam	3	2	8	13	9	11	42	4
Palau	1	0	27	16	8	19	65	6
United States[b]	157	10	263	200	298	202	675	458

[a] Known extinctions of documented species since 1500. Known species that are missing and can no longer be found but which cannot be confirmed as extinct are flagged as "possibly extinct" within the "critically endangered" category.

[b] For reference; includes Hawaii.

Source: International Union for Conservation of Nature (IUCN) *2015 Red List of Threatened Species* online database (http://www.iucnredlist.org/).

of the species listed as extinct and 39 percent of the listed at-risk species of the entire United States. Animal species listings outnumber listed plant species, except in Hawaii and Puerto Rico. In the Pacific Islands, birds dominate the IUCN lists of species, with the exception of Palau, where a majority of the listed species are gastropods (snails and slugs). In the Caribbean, the number of IUCN-listed bird species is relatively balanced by listed amphibians and reptiles.

Island extinction rates are generally higher than continental rates in the same latitudinal belt, in part because island species typically have small populations, restricted genetic diversity, and narrow geographic ranges, making them more susceptible to impacts from natural and anthropogenic disturbances (MacArthur and Wilson 1967, Vitousek 1988). Notably, Hawaii represents less than 1 percent of the total area of the United States, but possesses a majority of its documented plant and animal extinctions. Prehistorically, innumerable native Hawaiian species went extinct under natural conditions, but extinctions have accelerated since initial human contact from 800 to 1,600 years ago. For example, nearly 10 percent of recorded Hawaiian plants are presumed to be extinct. In addition, sixteen named forest bird species have gone extinct in historical times, another two forest bird species are presumed extinct (i.e., *Hemignathus ellisianus procerus* = *H. procerus* (other *H. ellisianus* subspecies also considered extinct); *Pareromyza flammea*) and seven more birds are likely extinct (i.e., *Hemignathus lucidus, Melamprosops phaeosoma, Moho braccatus, Myadestes lanaiensis, M. myadestinus, Paroreomyza maculate, Psittirostra psittacea*, not including *Corvus hawaiiensis*) (Eldredge and Miller 1995, Pyle and Pyle 2009). These extinctions are driven by a complex array of factors, including historical hunting by native islanders and European colonizers, predation by introduced species, introduced diseases, and habitat loss and fragmentation, all of which are exacerbated by limited genetic diversity, particularly as endemic populations decreased in size and range (Groombridge 2008). On small islands with native fauna that have evolved largely without predators, extinctions may be driven by the introduction of a single species. For example, the introduced brown tree snake *(Boiga irregularis)* is considered to be responsible for the extirpation of nine of Guam's 11 native forest-dwelling birds (Fritts and Rodda 1998).

In the Caribbean islands, the number of known extinctions since human contact is relatively low, in spite of significant changes in land use over the past century or so. Specifically, human activity reduced the area of native forest in Puerto Rico to less than 5 percent by the 1940s, but given the use of shade trees in the coffee region and the growth of secondary forest patches throughout the island, forest cover never fell below 10 to 15 percent, contributing significantly to the protection of fauna and flora species (Lugo 1988). For example, for the first 500 years of colonization in Puerto Rico, Brash (1984) documented the extirpation of seven known bird species (12 percent of originally documented bird fauna), including four endemic species, while during the same period the total population of species increased because of the naturalization of nonnative species. By the 1980s, there were more breeding birds species present on the island (97 species) than in pre-Colombian times (60 species) (Brash 1984). Nonetheless, a small but increasing number of bird species in Puerto Rico and the USVI are threatened by habitat destruction, degradation, and fragmentation; predation by introduced and other species; and increasing susceptibility to parasitism and disease (IUCN 2008, Joglar 2005, Lugo et al. 2012).

The threat of extinction is more severe for several Caribbean species of amphibians and reptiles, such as the golden coqui (*Eleutherodactylus jasperi*), a species of frog endemic to Puerto Rico that is the only known live-bearing species from the Leptodactylidae family. It was last seen in 1981 (Hedges and Joglar 2004) and is listed as critically endangered by the IUCN (2013) and as threatened under the U.S. Endangered Species Act (ESA) (USFWS 2008). Similarly, the Virgin Islands coqui (*Eleutherodactylus schwartzi)* is thought to be extirpated from the Virgin Islands, surviving only on the British Virgin Islands of Tortola and Virgin Gorda (Kaufman and Mallory 1993). The St. Croix racer (*Alsophis sanctaecrucis),* a snake endemic to the USVI, was last seen in the early 1900s, and is now considered extinct (Kaufman and Mallory 1993). Many forest-associated amphibian and reptile populations in these islands have been negatively affected by habitat destruction, forest fragmentation, limited distribution, high habitat specialization, slow reproduction, introduced predators, and infectious disease—many of which are being exacerbated by changes in climate (Burrowes et al. 2004, IUCN 2008).

Under the provisions of the ESA, the U.S. Fish and Wildlife Service (USFWS) identifies and lists plant and animal species considered to be at risk of extinction in the United States and affiliated jurisdictions. At-risk forest-associated species have been listed by the USFWS in the USVI, Puerto Rico, Guam, the Marshall Islands, and Hawaii. Although there is some overlap of species listed by the USFWS and the IUCN, neither list is entirely inclusive of the other for any jurisdiction. As of 2010, 503 plant and animal species in Hawaii, Puerto Rico, and the USVI were listed as endangered, threatened, or candidate species for listing by the USFWS (table C1-7). More than three-fourths of these at-risk species are plants. Moreover, many of the species listed by the USFWS are endemics, such that their extinction within the jurisdiction would mean extinction of the global population and a permanent loss of biodiversity.

A wide array of on- and offsite efforts to protect at-risk forest species and their diversity has been established throughout the islands. For example, the USFWS prepares, coordinates, and implements species recovery plans and critical habitat designations for the prevention of the extinction of listed species, in coordination with other federal agencies and partners, as part of its administration and implementation of the ESA. Many such plans and habitats are found throughout the United States and U.S.-affiliated tropical islands. Many at-risk animal and plant species are the subjects of additional, and in some cases, considerable in-situ and ex-situ conservation efforts throughout the islands. These efforts include the protection and restoration of habitat; captive breeding and reintroduction of captive-born species; and research, education, and outreach. For example, numerous at-risk tropical plant species are conserved ex-situ in the Center for Plant Conservation's National Collection of Endangered Plants, including 96 at-risk plant species native to Hawaii,

Table C1-7. Endangered (E), threatened (T), and candidate (C) forest-associated species listed by the U.S. Fish and Wildlife Service in Hawaii, Guam, the Marshall Islands, Puerto Rico, and the U.S. Virgin Islands in 2010

	U.S. Virgin Islands			Puerto Rico			Hawaii			Marshall Islands			Guam		
	E	T	C	E	T	C	E	T	C	E	T	C	E	T	C
Mammals							1				1		1	1	
Birds	2	2	1	8	2	1	24			6			6		
Amphibians				1	3										
Reptiles	2			3	2										
Snails							41	1	3						
Plants	4		4	45	5	4	273	7	46	3			1		1

Source: USFWS 2008.

21 species native to Puerto Rico, and 6 species native to the USVI (CPC 2008). Through participating partner botanical institutions, the center collects and maintains "plants, seeds, cuttings, and other plant material."

The Puerto Rican parrot (*Amazona vittata*)—considered one of the 10 most endangered bird species in the world—represents an example of extensive conservation efforts (Birdlife International 2008a). Once prevalent in Puerto Rico, this species was nearly extirpated by the 1950s having been reduced to about a dozen birds in the wild. The Puerto Rican parrot was federally listed as an endangered species in 1967 under the Endangered Species Preservation Act of 1966 and later protected under the Endangered Species Act of 1973 (USFWS 2008). Significant efforts to preserve the species began in 1968, including experiments with artificial nest sites, control of nest predators and competitors, captive breeding, captive-bred bird reintroductions, and radiotelemetry monitoring of reintroduced species. Today, the USFWS works closely with the Forest Service and the Puerto Rico Department of Natural and Environmental Resources through collaborative efforts to preserve the parrot, including threats management, captive breeding, and release of captive-bred parrots into the wild. As of 2013, there were nearly 400 parrots in captivity and more than 100 being tracked in the wild across the island, up from 225 in captivity and about 40 in the wild in 2008.

Indicators 1.07, 1.08, and 1.09 Genetic Diversity, Its Status, and Related Conservation Efforts

Genetic diversity within and across species is an important factor in forest health and productivity. For most of the islands, the vast majority of forest-associated species at risk of extinction also are at risk of losing genetic variation, particularly given the isolation and remoteness of most of these areas. In particular, species that encompass many subspecies or a wide variety of genotypes are vulnerable to losses in genetic diversity as populations decline. This is a common characteristic of many Hawaiian species that have a broad geographic range within which evolution and adaptive radiation have taken place in local niches (without completely separating into distinct species). These subspecies and genotypes are subject to the same threats as species at risk: habitat loss to development, nonnative species, fire, and loss of pollinators or other symbiotic species, and their decline or loss represents crucial losses in genetic diversity.

Many forest-associated species currently are found on fewer islands or in fewer locations than their original distribution, largely because of land use changes and the associated loss of native forests, which have likely led to the loss of locally adapted genotypes. For some species, information is available concerning historical ranges and current ranges; for others, historical ranges might be extrapolated from climate and soils data as well as palynology. Nonetheless, a comprehensive summary of the percentage of species occupying a given portion of their original range was not available for any of the islands at the time of this study.

As an example, Hawaii's *Acacia koa*, a dominant native forest tree species, displays a great deal of genetic diversity and numerous subspecies. Yet, its range has been substantially reduced by forest conversion and harvesting (fig. C1-9), indicating potential loss in its genetic diversity. Subspecies of *A. koa* are not listed for protection under state or federal law except as local populations are protected in reserves. Similarly, sandalwood (*Santalum* spp.) shows significant genetic diversity within the Hawaiian Islands, including at least six distinct species and several subspecies radiating from two colonization events. Land use changes, invasive nonnative species that modify habitat, and unsustainable harvesting practices have resulted in the reduction in habitat range of sandalwoods in Hawaii, and throughout other parts of the Pacific Basin. One species of Hawaiian sandalwood (*Santalum involutum*) is currently proposed for listing under the ESA as endangered, and one subspecies is already listed as endangered. Conservation efforts are focused on maintaining the genetic diversity of sandalwood and preventing hybridization between species throughout the Pacific, particularly given the high commercial value of several sandalwood species,

Species- and subspecies-specific genetic conservation measures are developed and carried out for several of the at-risk species listed by the USFWS under the ESA, and for many of the threatened animal species listed by the IUCN. Some species, such as the Puerto Rican parrot and the Hawaiian palila (*Loxioides bailleui*) and small Kaua'i thrush (*Myadestes palmeri*), have been the subject of long-term and intensive efforts that include genetic conservation through captive breeding and release into the wild. Some at-risk plant species have also been the subject of genetic conservation efforts, largely through preservation and cultivation in local and international botanical gardens.

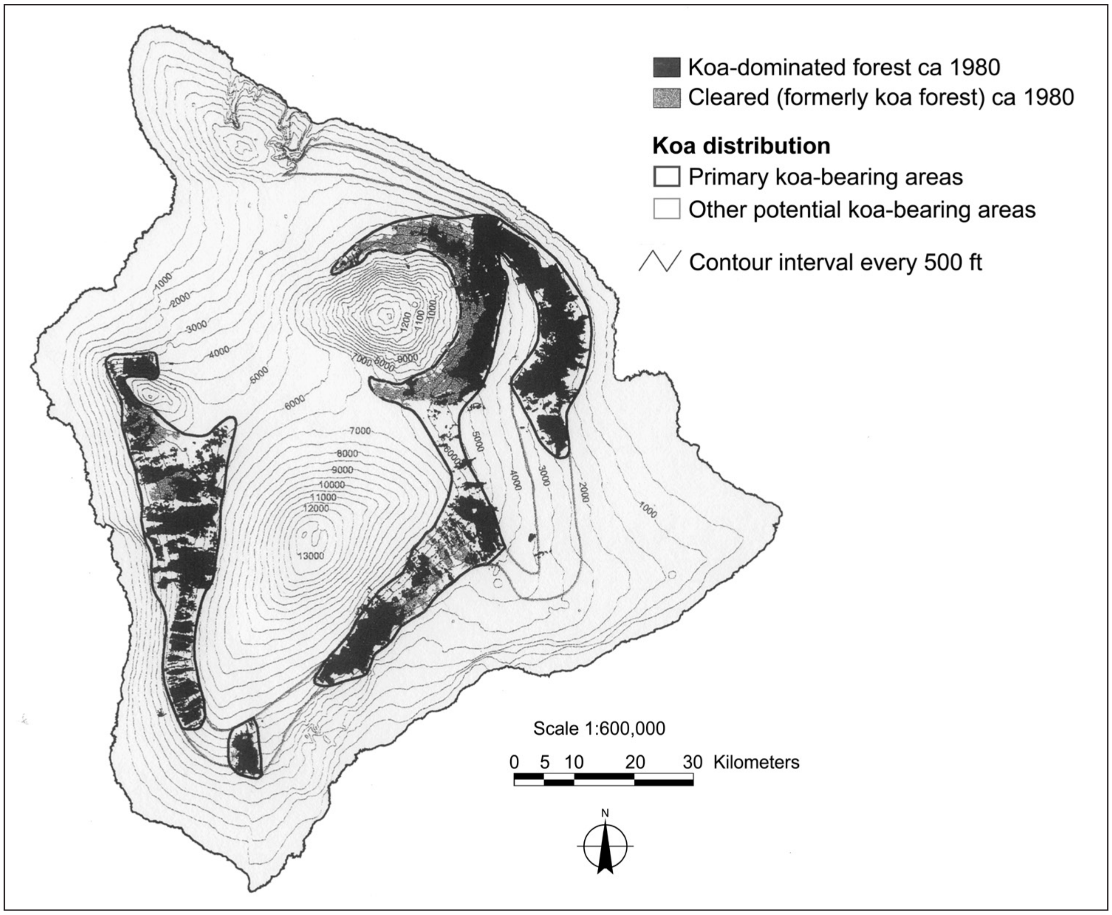

Figure C1-9. Current, former, and potential distribution of *Acacia koa* on Hawai´i Island.

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Native *Acacia koa* is Hawaii's premier native timber tree, traditionally used for voyaging canoe hulls.

Criterion 2

Maintenance of the Productive Capacity of Forest Ecosystems

Kathleen A. McGinley

Introduction

Many tropical island communities depend on forests directly or indirectly for a wide range of extractive and nonextractive goods and services. Some of these goods and services are essential for human survival; others are important to an enhanced quality of life. Tropical island forests harbor a vast diversity of trees, other plants, animals, and other organisms that can be used and harvested regularly as renewable resources. However, if use or harvest levels exceed resource growth and replacement, there is the potential for ecosystem change or even decline. To sustain use and harvests over time, island forests must be sufficiently productive to maintain natural processes and grow raw materials in excess of their use and removal.

Productive capacity of forest ecosystems refers to the ability of forests to produce goods and services for humans. It is a human-derived value and overlaps the economic, social, and environmental realms. Criterion 2 specifically addresses the capacity of forests to produce extractive goods and services, including wood products such as sawlogs, pulpwood, construction materials, and fuelwood, and nontimber forest products (NTFPs) such as medicinal plants, food, forage, and arts and crafts supplies. Tropical island forests also obviously provide environmental services and socioeconomic benefits, which are addressed under other criteria in this report.

Determining sustainable harvest levels requires monitoring and assessment of the forest system in its entirety to determine if changes in the productive capacity of forests may be a signal of unsound forest management practices or other unforeseen agents affecting forest systems. Although efforts to systematically measure and monitor forests under the U.S. Forest Service's Forest Inventory and Analysis (FIA) program have been established on most of these islands, systematic measurement and monitoring of timber and nontimber extractive activities is mostly absent.

Criterion Summary

Most of the islands considered in this report were once nearly completely forested, and all have experienced differing degrees of forest conversion to other land uses. More recently, as agriculture and other land uses have been abandoned, there has been an increasing reversion of converted forest lands to secondary forests. Today, all the island jurisdictions are more than 50-percent forested, with the exception of Hawaii and Guam (35- and 48-percent forested, respectively). However, across the islands, most forests are dominated by relatively small trees (<11 inches diameter at breast height [dbh]), owing to both natural and human-induced disturbance regimes that result in few forest stands with enough big trees for viable, large-scale timber production.

Very little commercial harvest of natural or planted forests occurs on any of the islands, with the exception of Hawaii, where there is an established but small (and growing) timber industry and a discernible area of active forest plantations (4.7 percent of total forest area). Across the islands, forests are perhaps most valued for water and soil conservation, cultural and spiritual values, recreation, and noncommercial forest products such as fuelwood, canoe and construction resources, arts and crafts materials, and wild game. Overall, it appears that forest growth far exceeds forest harvests in most cases, though some select forest resources in Hawaii (e.g., *Acacia koa* and *Santalum* spp. from natural forest stands) and in the Federated States of Micronesia (FSM) (e.g., fuelwood from mangrove forests) are under an increasing threat of overharvesting.

In many cases, the increasing area and growth of secondary forest eventually may represent a potentially significant timber source, though forest protection for water and soil conservation and other nonextractive uses remains a primary objective on most islands. Additionally, agroforestry practices that combine trees and shrubs with agriculture or livestock are fairly common across most of the islands and represent another potential timber source. In Puerto Rico, for example, shade coffee systems that integrate timber species are seeing a resurgence. And, in the Pacific, agroforestry techniques have long been practiced and constitute a traditional land use that can result in more diverse, productive, and profitable land use systems than conventional monocultures.

The Indicators

Criterion 2 of the Montréal Process Criteria and Indicators (MP C&I) contains five indicators, which are focused on forest productivity in relation to actual production levels of timber and NTFPs. Because of ongoing forest inventory activity conducted by the FIA program (see also chapter 1), there is fairly good data coverage for standard forest measures across the islands, but less so for NTFPs. Owing to the extent and quality of this data coverage and the importance of forest inventory information to the other criteria considered in this report, we treat each of the Montréal Process indicators in Criterion 2 separately.

- **2.10:** Area and percentage of forest land and net area of forest land available for wood production.
- **2.11:** Total growing stock and annual increment of both merchantable and nonmerchantable tree species in forests available for wood production.
- **2.12:** Area, percentage, and growing stock of plantations of native and exotic species.
- **2.13:** Annual harvest of wood products by volume and as a percentage of net growth or sustained yield.
- **2.14:** Annual harvest of nonwood forest products.

Indicator 2.10
Forest Land Available For Wood Production

Most of the island jurisdictions have extensive forest cover—all but Hawaii and Guam are more than 50-percent forested. However, other than Hawaii, where there is an established, small timber industry, very little of the total forest area in any jurisdiction is actively managed for timber or other wood products. Additionally, significant areas of forest are formally protected or otherwise unavailable for wood production on many of the islands. Current, direct measures of forest land available for wood production are not available for any of the islands, but indirect measures provide an estimate of potentially productive forest land.

In the Caribbean islands, very little of the available wood volume is harvested, and there is no indication that this situation will change in the foreseeable future. In the U.S. Virgin Islands (USVI), which was 55-percent forested in 2009, forested land is increasing as agricultural activities decrease (Brandeis and Turner 2013b). However, there is competition for these lands from other, nonforest land uses (e.g., development). Few forests are harvested for timber or other wood products, and there is limited, if any, commercial wood production (Brandeis and Oswalt 2007). The actual area of forest land available for wood production in the USVI is unknown, but given the protected status of some forests, the large portion (59 percent) of forest in the subtropical dry forest life zone, which is dominated by slower growing, smaller trees, and other limiting factors, a relatively small portion of the total forest area in the USVI is potentially available for wood production.

In Puerto Rico, recent forest inventories do not measure forest area available for wood production, but forest inventories in 1980 and 1990 did delineate potential areas for commercial wood production on the main island of Puerto Rico based on site productivity and land use. Excluded from these measurements were mountainous regions where excessive slopes or rainfall limit operability, the subtropical dry forest region where rainfall is less than 1000 mm (37.39 inches) per year, areas with unproductive soils, and areas with land uses not compatible with commercial wood production (e.g., protected, urban, critical watersheds) (Birdsey and Weaver 1982, Franco et al. 1997). The commercially designated forest inventory area in 1990 was about 437,000 ac, of which 34 percent was forested (about 148,000 ac). The commercially designated forest area in 1990 was mostly found in the subtropical moist and wet forest life zones, primarily in upland, nonurban areas between the valleys dedicated to agricultural production and higher mountain areas with steep slopes that are primarily reserved for watershed protection and other functions. A minute fraction of this forest area is actively managed for timber today.

Forests cover nearly 1.5 million ac of Hawaii (about 36 percent of its total land area), including more than 70,000 ac of forest plantations, which comprise forests planted for the primary purpose of timber production, as well as forests planted for the primary purpose of watershed protection (Gon et al. 2006, Little and Skolmen 1989, Matsuwaki 2015). Gon et al. (2006) identified 504,607 ac (34 percent of all forest) from 1999–2005 Landsat Thematic Mapper satellite data as being within Hawaii Gap Status 4, which is defined as "an area lacking a mandate to prevent conversion of natural habitat types to anthropogenic habitat types; where intensive use allowed throughout the tract; and includes those tracts for which the existence of such restrictions or sufficient information to establish a higher status is unknown." Thus, the area of forest classified as Hawaii Gap Status 4 by Gon et al. (2006) is expected to be available for wood production provided that accessibility, stand and site conditions, and other factors critical for timber production viability are met. Note that this does not include pasture lands with potential for reforestation. It also does not include the 738,983 ac of mostly forest reserves classified as Hawaii Gap Status 3, which is generally unavailable for timber production, even though it may be subject to artisanal extraction for canoes and other products (i.e., “an area having designated protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad, low-intensity type or localized intense type” (Gon et al. 2006).

In recent forest inventories of the U.S.-affiliated Pacific islands, Donnegan et al. (2004a, 2004b; 2007; 2011a, 2011b, 2011c) measured the potential productivity of forest land based on a topographic relative moisture index (TRMI) that takes into account the potential of a site to retain moisture relative to the soil-based forest type. The majority of forest land in Guam, the Northern Marianas, Palau, and American Samoa was classified as demonstrating relatively high potential for forest productivity in terms of soil moisture retention (74, 58, 58, and 57 percent, respectively). Thirty-six percent of the forest area in the FSM was classified as such. Nevertheless, a significant proportion of the terrain on these islands is steeply sloped, in karstic regions, or encompasses shallow, porous soils that prohibit or significantly limit the potential for commercial timber extraction (i.e., about 50 percent of American Samoa and Palau and at least 25 percent of Guam) (Donnegan et al. 2004a, 2004b; 2007; 2011a, 2011b, 2011c). Moreover, formal protection of forests is increasing throughout these islands, particularly under agreements made through the Micronesia Challenge (PCS and TNC 2011) (also see Criterion 1).

Indicator 2.11
Forest Growing Stock

Forests typically are dominated by younger trees of smaller diameter with a mixture of native and nonnative species across most of the jurisdictions addressed in this report. Much of the wood in these forests currently is not suitable for solid wood products, but may be so in the future depending on stocking, growth rates, and applied management practices.

In the Caribbean islands, forests cover more than half of the landscape, though the majority of these forests are young (<25 years), and a very small portion is dominated by merchantable timber trees. The forests generally are increasing in terms of basal area and volume as they grow into older stands with more medium- and large-diameter trees (Brandeis and Turner 2013a, 2013b).

The vast majority of the trees in Puerto Rico’s forests are small (<5 inches dbh) (table C2-1). Although larger diameter trees make up a relatively small percentage of the total number of trees in the forest, they account for most of the measured merchantable volume. Additionally, as growth continues to exceed mortality and removals in Puerto Rico, growing stock volume also is rising. These high growth rates are due in large part to the rapid growth characteristics of young forest stands (Brandeis and Turner 2013a).

Similarly to Puerto Rico, most of the forests in the USVI are young and follow a pronounced reverse-J diameter distribution (Brandeis and Oswalt 2007, Brandeis and Turner 2013b). Although the average forested acre in the

Table C2-1. Forest stocking data on U.S.-affiliated Caribbean and Pacific islands, 2004–2013

	U.S. Virgin Islands	Puerto Rico	American Samoa	Marshall Islands	Micronesia	Northern Marianas	Guam	Palau
Total number of trees (millions)	85	1,460	18	12	94	90	77	97
Total number of trees per acre	1,882	1,250	413	516	655	1,193	1,206	1,069
Total number of trees ≥5 inches dbh (millions) [percentage of total trees]	3 [0.1]	132 [9]	6 [36]	4 [30]	27 [29]	6 [7]	10 [13]	10 [11]
Average number of trees ≥5 inches dbh per acre	60	109	133	111	168	118	74	95
Total net volume[a] (million ft^3)	15	1,276	66	54	571	35	58	265
Average net volume per acre (ft^3/acre)	176	1,052	1,657	1,624	3,530	687	1,431	3,334

[a] Net volume is the cubic volume of all trees >5 inches in diameter less the cubic volume from damage and rotten defects.

dbh = diameter at breast height.

Source: U.S. Forest Service Forest Inventory and Analysis.

USVI contains more trees than in Puerto Rico (1,882 vs. 1,250 trees/ac; respectively), about 80 percent of the total forested area in the USVI is dominated by trees less than 5 inches dbh. Consequently, a very small percentage of trees are considered growing stock in the USVI, and there is significantly less merchantable growing stock in the USVI than in Puerto Rico (Brandeis and Oswalt 2007, Brandeis and Turner 2013b) (fig. C2-1). Moreover, the potential for large-scale timber production in the USVI is relatively limited given the predominance of forests in dry forest life zones, which maintain slower growth rates and smaller diameter trees (table C2-1).

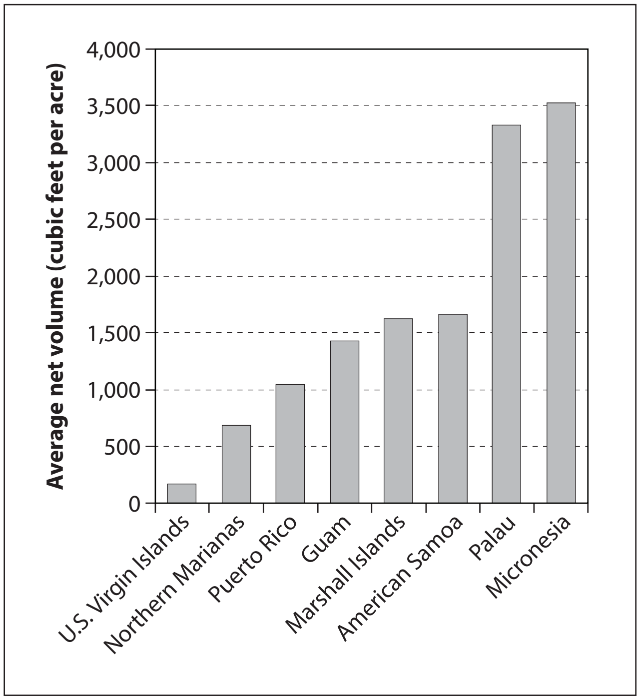

Figure C2-1. Average net volume in cubic feet per acre of live trees ≥1 inch diameter at breast height on forest land.

Forests dominate much of the landscape in the Pacific, with Guam and Hawaii being the only jurisdictions in this report that are less than 50-percent forested (48 and 36 percent, respectively). Similarly to forests in the Caribbean, most Hawaiian and Pacific Island forests exhibit a reverse-J pattern diameter distribution. As in the Caribbean, these structural characteristics are closely tied to natural disturbance processes, such as fire, typhoons, and tropical storms, and to historical and current land use practices that lead to secondary forest growth (e.g., forest clearing for agriculture or settlement, which, after abandonment, is followed by forest recolonization (Cram et al. 2013; Donnegan et al. 2004a, 2004b, 2007, 2011a, 2011b, 2011c) (table C2-1; fig. C2-1). The secondary forest understory is increasingly dominated by nonnative woody species, which may become invasive and outcompete natives, particularly in Hawaii (Ainsworth and Kauffman 2010, Cordell et al. 2009).

There were no comprehensive forest maps for the islands of Hawaii, nor was there a complete statewide forest inventory available when this report was prepared. Consequently, no estimates of total growing stock or growth rates of all merchantable and nonmerchantable tree species were available for Hawaii. Inventory data and extrapolations from about 24,000 ac of planted forest on state lands in Hawaii in the late 1990s reported an estimated 78.2 million ft^3 of merchantable timber from about a dozen nonnative species, including species of the genera *Eucalyptus*, *Grevillea*, *Melaleuca*, *Acacia*, and *Casuarina* (Constantinides and Canarella 1999, 2001; Constantinides et al. 2000a, 2000b; Little and Skolmen 1989).

Overall, of the islands inventoried, the Marshall Islands exhibit the highest proportion of forested area dominated by the largest trees (60 percent: 11 to 20.9 inches dbh). The forests of the FSM demonstrate the greatest net volume per acre (Donnegan et al. 2004a, 2004b, 2007, 2011a, 2011b, 2011c). The dominance of comparatively larger trees in the Pacific Islands is frequently attributed to the presence of coconut trees (Donnegan et al. 2004a; 2007, 2011b), which often occur at high densities in mature plantations. And, although larger trees (>21 inches dbh) are found in many forest stands, very little of the total forested area of the Pacific Islands is dominated by trees greater than 21 inches dbh. In Guam and the Northern Marianas, forests tend to be dominated by smaller trees, owing to frequent disturbance by typhoons, and more recently to human-induced land use changes. Notably, the most recent forest inventory of Guam found no trees greater than 20 inches dbh (Donnegan et al. 2004b).

Indicator 2.12
Plantations of Native and Exotic Species

Plantations of nonnative (and more recently, native) timber species have been planted on many islands as far back as at least the early 1900s. Today, more than 80,000 ac of planted forest are found on these islands, 86 percent of which are found in Hawaii (table C2-2). Across all jurisdictions, plantations are primarily stocked with nonnative timber species, including *Eucalyptus* spp., *Swietenia* spp., and *Tectona* spp., though there is increasing interest and investment in native species reforestation, particularly

Table C2-2. Forest plantation area and percentage of total forest area,[a] circa 2010

	Planted forest area	Total forest area
	Acres	*Percent*
U.S. Virgin Islands	~270	<1
Puerto Rico	~9,900	<1
Hawaii	70,358	4.7
Guam	~840	1.3
Palau	~100	<1

[a] Only jurisdictions with data are shown here. Source: Francis 1995, Territory of Guam 2010, Matsuwaki 2015, Republic of Palau 2010, Somberg 1976, Weaver and Francis 1988.

for restoration of degraded lands. Data on plantations are available for the Caribbean and three jurisdictions in the Pacific (table C2-2). Although most U.S.-affiliated Pacific islands have some, albeit very limited planted forest area, there were no readily available data on their extent, merchantable volume, or growth rates as of 2010.

Following decades of forest clearing in Puerto Rico, extensive reforestation with nonnative and native species began in earnest in the early 1930s (Weaver 2012). As of 1995, Puerto Rico had about 9,900 ac of planted forests on public and private lands. Planted species include mahogany (*Swietenia* spp.), teak (*Tectona grandis*), eucalyptus (*Eucalyptus* spp.), Caribbean pine (*Pinus caribea*), María (*Calophyllum antillanum*), and mahoe (*Hibiscus elatus*) (Francis 1995). About one third of the total planted acreage was established in the El Yunque National Forest (a.k.a. Luquillo Experimental Forest), where trials with West Indies mahogany (*Swietenia mahagoni*), Honduran mahogany (*Swietenia macrophylla*), and hybrids (*Swietenia macrophylla* × *S. mahagoni*) were conducted (Bauer and Gillespie 1990). Francis (1995) reported a range in average annual volume increments for the major timber species planted on "better than average sites" in Puerto Rico, ranging from 29 to 114 ft^3/ac/year for *Swietenia mahagoni* to 400 to 600 ft^3/ac/year for *Pinus caribea*.

In the USVI, there are about 270 ac of planted forests on St. Croix, composed mostly of teak (*Tectona grandis*), Spanish cedar (*Cedrela odorata*), West Indies mahogany (Swietenia mahagoni), Honduran mahogany (*Swietenia macrophylla*), and hybrids of the latter two species (*Swietenia macrophylla* × *S. mahagoni*) (Somberg 1976, Weaver and Francis 1988). There is no information on annual volume increments for these planted species. St. John and St. Thomas do not have any documented measureable planted forest area.

No new plantations have been established in the Caribbean jurisdictions since those documented in the mid-1990s. Furthermore, there is very little evidence that existing plantations in Puerto Rico or the USVI are actively managed or harvested beyond isolated extractions for personal or artisanal consumption. Likewise, there is no indication that these plantations will be extensively or commercially harvested in the near future.

Forest plantations cover about 70,358 ac in Hawaii, accounting for almost 5 percent of the total forest area (Matsuwaki 2015) (table C2-3). Fifty-seven percent of forest plantations are on private lands, 42 percent on state lands, and about 1 percent on federal and county government lands (Matsuwaki 2015). The Big Island of Hawaii hosts 72 percent of the total planted forest area. The vast majority of planted forests on public lands are stocked with nonnative timber species, including *Eucalyptus* spp., *Grevillea* spp., and *Albizia* spp. Private lands are stocked mostly with native and mixed (native/nonnative) tree species (Constantinides and Canarella 1999, 2001; Constantinides et al. 2000a, 2000b). *Acacia koa* is the principal native tree species used in forest plantations. Although some planted forests in Hawaii are intended for commercial timber harvests, at least half are designated for water and soil conservation, as well as for educational purposes and aesthetic values (Constantinides and Canarella 1999, 2001; Constantinides et al. 2000a, 2000b; Little and Skolmen 1989).

Table C2-3. Planted forest area in Hawaii, 2015

	Federal	State	Private	Total
		Acres		
Kauai	1	3,744	230	3,975
Oahu	0	3,438	5,516	8,954
Molokai	1	1,624	1,188	2,819
Maui	9	2,646	1,490	4,145
Hawaii	188	18,371	31,906	50,465
Total	199	29,823	40330	70,358

Source: Matsuwaki 2015.

Ten nonnative timber species planted on state lands in Hawaii were inventoried in the late 1990s (Constantinides and Canarella 1999, 2001; Constantinides et al. 2000a, 2000b). Results demonstrated that there were about 72.8 million ft^3 of merchantable stem volume across nearly 24,000 ac (table C2-4). Planted tree species exhibited a wide range in growth rates (30 to 500 ft^3/ac/yr), with *Eucalyptus* spp. and *Flindersia brayleyana* (Queensland maple) demonstrating the strongest growth and site adaptation across the state (Constantinides and Canarella

Table C2-4. Hawaiian nonnative plantation timber inventory summary data, 1999–2000

Location	Area	Number of stands	Species	Merchantable volume	Mean annual increment
	Acres			*Thousand cubic feet*	*Cubic feet/ year*
Hawaii—Waikea	12,043	228	*Eucalyptus* spp.; *Flindersia brayleyana*; *Toona ciliata*; *Fraxinus uhdei*	16,300	150–500
Hawaii— Kalopa, Waimea, Honuaula, and Kiolakaa-Keaa	1,160	40	*Eucalyptus* spp.; *Cryptomeria japonica*; *Fraxinus uhdei*; *Casuarina eqiusetifolia*	7,400	45–280
Hawaii— Hamakua	6,295	144	*Eucalyptus* spp.; *Flindersia brayleyana*; *Toona ciliata*	37,900	100–500
Subtotal	19,498	412		61,600	45–500
Molokai	2,100	138	*Eucalyptus* spp.; *Pinus elliottii*; *Pinus taeda*	6,900	40–160
Kauai	2,390	178	*Eucalyptus* spp.; *Pinus elliottii*; *Pinus taeda*	4,300	30–300
All	23,988	728		72,800	30–500

Source: Constantinides and Canarella 1999, 2001; Constantinides et al. 2000a, 2000b.

1999, 2001; Constantinides et al. 2000a, 2000b). *Pinus* spp., *Toona ciliata*, *Fraxinus uhdei*, and most of the other nonnative species were not as well adapted to Hawaii's site conditions. Most of the measured stands were either overmature or not actively managed after planting, indicating that reported growth rates may underestimate species growth potential (Constantinides and Canarella 1999, 2001; Constantinides et al. 2000a, 2000b).

Plantation forestry occurs on a very limited basis in the U.S.-affiliated Pacific islands. Guam has about 740 ac of plantations on government-owned land and about 100 ac of planted forests on private land (Territory of Guam 2010). Species and provenance trials with *Eucalyptus* spp. were conducted in the 1970s to select species for establishment in wind-exposed and sheltered sites. More recently, attention has turned to *Acacia* spp. owing to fast growth rates and resistance to fire. Reforestation with *Acacia* spp. is largely for restoration of degraded lands, while plantings of other species are primarily for timber production. *A. auriculiformis* and *A. mangium* are the principal species planted today (Territory of Guam 2010).

In Palau, about 100 ac of mostly mahogany (*Swietenia macrophylla*) have been planted on state and privately owned lands (Republic of Palau 2010). Additionally, line plantings of native and nonnative timber species are increasingly used in agroforestry systems on private lands, as state and private nursery capacity increases to meet the growing demand for timber species (Republic of Palau 2010). Although many of the other U.S.-affiliated Pacific islands do have established plantations, they are very limited in terms of area and lack data on extent, volumes, and growth rates.

Indicator 2.13
Harvest of Wood Products

Across the islands, forests are harvested for artisanal wood products and are important sources of wood for building and canoe materials in Hawaii and the U.S. affiliated Pacific islands. Hawaii is the only jurisdiction with any measurable, albeit limited, commercial timber extraction from forests. Fuelwood from forests is particularly important in many of the Pacific islands. Overall, forests are important sources of noncommercial wood products throughout the islands; although there are no monitoring activities or current data related to this indicator for any jurisdiction, anecdotal evidence suggests that, in the majority of cases, forest growth far outpaces forest harvest. Nonetheless, there is some evidence that harvests of some forest resources in Hawaii and the FSM are reaching or exceeding their available stock (e.g., *Santalum* spp., and fuelwood from mangrove forests, respectively).

Most of the wood products harvested from forests in Puerto Rico and the USVI are for artisanal purposes. Overall, forest growth rates are thought to significantly exceed the artisanal harvest of wood products from forests (Brandeis et al. 2007). However, there was no monitoring or current data on wood products harvests for these islands at the time this report was published.

Forest industry surveys carried out in the Caribbean in the mid-1990s found a limited number of local sawmills (14 private and 2 Commonwealth sawmills in Puerto Rico, 11 small private sawmills in the USVI) that produced an estimated total annual production of 122,000 board feet of milled lumber (about 10,176 ft^3) in Puerto Rico (Kicliter 1997) and about 45,000 board feet (about 3,750 ft^3) in the USVI (Pierce and Hultgren 1997). These sawmills were found to be operating significantly below their productive capacity owing to a highly irregular wood supply (despite extensive forest resources) that was attributed to a lack of interest and capacity in forest management by forest owners (Kicliter 1997, Pierce and Hultgren 1997). Even fewer sawmills are operating in the Caribbean today (Brandeis et al. 2007).

In Hawaii, native and natural forests are harvested for timber and nontimber products. In 2000, the total value of wood products harvested from Hawaii's forests was estimated at $30.7 million (Yanagida et al. 2004). In addition to the harvest of wood products for Hawaii's small commercial timber industry, there is an established craftwood industry developed by local artisans that produce a variety of arts and crafts from native wood species, most notably *Acacia koa*, as well as other native and nonnative species. Koa is highly regarded by artisans for its ecological, cultural, and economic values. Although there was no monitoring of or data on wood products harvests from natural and native forests at the time of this report, some suggest that commercial and artisanal harvests of native koa (*Acacia koa*), ohia (*Metrosideros* spp.), sandalwood (*Santalum* spp.), and hapuu tree ferns (*Cibotium* spp.) (all of which are found in natural forests) "are approaching the limits of available resources," largely because the remaining stock of these species is found mostly on state or federally owned land or in areas zoned for conservation and off-limits to timber harvesting (State of Hawaii 2010). Conversely, inventory data from planted forests available for wood production indicate that most of Hawaii's forest plantations are overmature or undermanaged, leading some to suggest that increased management and harvest is necessary for increasing their productivity, at least from the perspective of maximum timber production (Forest Industry Development Research 2006, State of Hawaii 2010).

In the U.S.-affiliated Pacific islands, wood products from natural and planted forests are harvested mostly on an informal basis, but there are no associated monitoring activities or available data on harvest levels. Wood products are harvested domestically for housing and other building materials, as well as for canoes, furniture, handicrafts, and other wood-based products. Additionally, mangrove forests and other natural and planted forests provide an important source of fuelwood for many island communities. The general assumption across these islands is that most harvests occur far below forest growth rates; however, anecdotal evidence suggests that some island species and forests are not sustainably managed. For example, the State Forest Assessments for the FSM and Palau express concerns that demand for timber of some species may be exceeding growth rates and note the lack of important information on the levels at which forests can be sustainably harvested for wood products (FSM 2010, Republic of Palau 2010). In particular, fuelwood harvests in the mangrove forests of Kosrae and Chuuk appear to be unsustainable, as do harvests of relatively rare large timber trees in the upland forests of Yap, where new sawmill establishment is on the rise despite a lack of information on sustainable timber supplies or regulations for commercial harvesting and processing (FSM 2010).

Indicator 2.14
Harvest of Nonwood Products

Nonwood forest products are important to communities and cultures throughout the islands. They represent nutritional, artisanal, recreational, cultural, and spiritual resources, perhaps most significantly in American Samoa, Micronesia, and Palau, where forests are heavily relied upon for subsistence. Yet, information on the growth and use of nonwood forest products is not systematically collected or analyzed in any jurisdiction, therefore it is impossible to determine if these resources will be available at present rates for future generations.

In the Caribbean, forests are important sources of nonwood forest products to many segments of the population, including artisans, fishermen, shrimpers, and everyday citizens (Francis 2004, Robinson 1997). Harvested products range from medicinal plants, arts and crafts materials, and food and forage to floral and horticultural products, resins, and oils. Forests provide important medicinal resources for the treatment and prevention of illnesses and other medical issues for many Puerto Ricans and Virgin Islanders (Martinez and Martinez 2002, Palada et al. 2005, Taylor 2005). Forest streams and other water bodies in Puerto Rico are highly valued and used by artisanal shrimpers and fishermen (Hein et al. 2008). Harvesting and hunting of other forest-associated fauna are rare in the Caribbean, with the exception of hunting and other means of population control of invasive, nonnative species such as feral pigs and goats (DFW 2001, DiFiore 2001, Fox 2008).

Similarly, Hawaiian forests are important sources of nonwood forest products. They are used for the collection of ferns, honey, other food products, forage, arts and crafts materials, and more (State of Hawaii 2010). In particular, hunting nonnative mammals and birds is a popular activity for many local residents and some tourists. Hunting of some species, such as feral pigs, serve multiple purposes, including recreation and population control, particularly for feral animals that have significant and widespread effects on forest structure and composition.

There are about 916,000 ac of public hunting areas in Hawaii, which in 2010 provided nearly 9,200 hunter trips for game birds and 30,500 trips for game mammals, totaling 39,370 trips (or hunter days) (State of Hawaii 2011). In addition, the number of hunter trips and animal takes are increasing. Hawaii's state game management plan (2012–2016) provides opportunities for recreational hunting of 15 species of nonnative game birds and six species of nonnative game mammals, and aims to direct hunting toward less ecologically sensitive areas, while at the same time providing structured hunter access to more remote/pristine sites.

Forests provide resources for food, shelter, tools, utensils, and transportation throughout the U.S.-affiliated Pacific (Balick et al. 2009, FSM 2010, Republic of Palau 2010). They are commonly used for a variety of medicinal, cultural, and other practices and are considered essential for preserving local livelihoods and traditions (see, for example, Kitalong et al. 2011). However, there are no data on their removal or harvest levels. Native and nonnative plant species are harvested for handicrafts, clothing, oils, medicine, fishing gear, and other products that are integral to traditional life on many of the islands. For example, in Micronesia, it is estimated that as much as 60 percent of the population depends on the forest for subsistence, including timber and nontimber resources for food supplies, wood-fuel, medicinal needs, and other nontimber products and materials (FSM 2010). These resources are "crucial to sustaining the country's rich ethnobiological traditions while improving Micronesians' quality of life" (FSM 2010). Pacific island forests also provide habitat for game animals such as feral pigs. Hunting, preparing, and sharing domesticated and feral pigs are important activities in island culture. Yet some hunting techniques, including the use of fire, negatively affect native forest vegetation, particularly in Guam and Palau. These practices compound the effects of feral pigs and other ruminants on forests, such as the "spread of invasive plants, damage to understory vegetation, and destruction of riparian areas by their feeding and wallowing behavior" (Republic of Palau 2010).

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J.B. Friday

J.B. Friday

Lowland ʻōhiʻa (*Metrosideros polymorpha*) forest in Puna, Hawaii, before (2005) and after (2015) rapid ohia death (*Ceratocystis fimbriata*) infection.

Criterion 3

Maintenance of the Ecosystem Health and Vitality

Kathleen S. Friday

Introduction

The health of an ecosystem depends on the proper functioning and interactions of that ecosystem's characteristic species and natural processes. The native species of a given ecosystem have evolved or persisted within certain environmental conditions; disturbance events and stresses (such as storms and native insects and disease agents) may be characteristic of that ecosystem, with cyclical effects as the ecosystem naturally recovers. Disturbances and stresses resulting from human activities include the introduction of nonnative species, climate change and associated sea-level rise, and land clearance. Forest ecosystems may also be formed of nonnative species, by husbandry (agroforests and plantations) or by colonization by nonnative species so pervasive that to varying degrees they form stable, "novel" (Hobbs et al. 2006) forest ecosystems in conjunction with native species. The health of such ecosystems is defined by the functioning of their biological and physical processes and their ecosystem services, which will depend in large part on interactions between the system's various species, both native and introduced.

A key question is whether disturbances are so great or frequent that forest composition, structure, and function are degraded temporarily or permanently. Disturbances and stresses may interact, compounding their impacts. For example, drought may combine with anthropogenic wildfire and native grasses, or with natural fire and nonnative grasses. In addition, the decline or absence of certain agents and processes that once were part of forest ecosystems may also have an impact on forest health and vitality. For example, reduced numbers or even extinction of pollinators and seed dispersal agents, especially birds and bats in the islands, may directly affect species dependent upon their services; this in turn may affect forest ecosystem structure and function. (See indicators 1.04, 1.05, and 1.06 in Criterion 1 for a discussion of biodiversity in the islands).

To an island landowner or citizen, a "healthy forest" may mean a forest of timber or a food species, productive because it has few insect or diseases. The broad definition of forest health explained above may seem contradictory to this benefits-based approach, because a native forest ecosystem deemed healthy with respect to biodiversity may include native insects and diseases. Conversely, a nonnative plantation, deemed healthy with respect to productivity, may be detrimental to the health of the forested landscape if it is a seed source for a species that invades and transforms native ecosystems nearby. Some (**but not all**) nonnative species, by their introduction, cause or are likely to cause economic or environmental harm or harm to human health, and, as a result, are designated as invasive species (Executive Order No. 13112). Some nonnative species may naturalize (without meeting this definition of invasivity) and form integral components of a "healthy" novel ecosystem. Perspectives regarding the role of nonnative species in forest ecosystems often differ (Lugo 2015), but there are also important areas of agreement. Many island forests have been so affected by invasive pests or fire that ecologists and citizens alike recognize "unhealthy forests" or forests that have degraded until they are no longer even forests, but grasslands. There are also "novel" forests and "traditional" agroforests that are dominated by nonnative species and valued as healthy ecosystems or forms of sustainable agriculture.

Criterion Summary

Abiotic stresses (fire, storms, sea-level change) are strongly influenced by climate, which differs by region as well as locally on islands with strong orographic rainfall patterns. Fire is of great concern in the western Pacific, where it occurs in anthropogenic grasslands and along forest edges, and in dry areas of Hawaii and of southern and western Puerto Rico. Volcanic eruptions affect several islands. Storms differ in frequency (the Marianas are in the typhoon belt) but may profoundly affect any island. Tsunami effects during the 2003–2010 period were limited to American Samoa. Land clearance differs with each island's circumstances. In the Pacific, the effects of climate change may still be largely within the range of natural variation for several decades. Climate-induced sea-level rise is already in evidence, and the atoll island forests in the Pacific will be increasingly overwashed and their people likely displaced; the Republic of the Marshall Islands has no high island refuge.

Islands and regions differ in the degree to which their native ecosystems have been affected by introduced species, especially those species deemed invasive. Hawaiian forests are highly susceptible to species invasions and alteration; their previously isolated native species are not adapted to high levels of competition and herbivory. In addition, much of Hawaii's forest has been historically cleared or grazed, then left open to nonnative plants. Most islands of the Marianas have been heavily affected, owing to centuries of interaction with America and Asia (with attendant species introductions) and disturbance from intensive bombing during World War II. Although introduced plant species are present and widespread in the U.S. Virgin Islands (USVI) and Puerto Rico, their domination of plant communities on those islands is not perceived as a serious concern except where introduced grasses have replaced forests after repeated human-caused fires. American Samoa and the Caroline Islands are intermediate in terms of the effects of introduced species; widespread nonnative agroforests are the result of husbandry (planting) rather than invasion, and native ecosystems persist but are subject to effects from various nonnative species. Succession from monospecific stands of invasive tree species to novel ecosystems including a substantial native component has been documented in the Caribbean (Lugo 2004); by contrast, the restoration of native forest ecosystems in Hawaii has been documented only with intensive management.

The Indicators

Criterion 3 of the Montréal Process Criteria and Indicators (MP C&I) focuses on biotic and abiotic processes and agents; metrics for both indicators are the area and percentage of forest affected beyond "reference conditions." As in the *National Report on Sustainable Forests* (USDA FS 2011), this report presents data for 2003–2010 where available for comparison with reference conditions prior to 2003. The national report, where relevant and possible, compares present-day forests with conditions at the time of European colonization of the continental United States (circa 1630). Especially for the Pacific, where human settlement and European contact occurred much later, reference conditions "before human settlement" (that is, native ecosystems) are relevant to this criterion insofar as that event on each island is marked by the introduction of nonnative species and anthropogenic fire.

The area and percentage of forest affected by biotic agents are not available as single metrics for the islands. Other than Hawaii (Conry et al. 2008, Gon et al. 2006), no jurisdiction has mapped overall "native" versus "nonnative" vegetation; mapped vegetation types such as "secondary vegetation" and "upland forest" are ambiguous with respect to the origins of their flora. The U.S. Forest Service's Forest Inventory and Analysis (FIA) protocols are not designed to detect all occurrences of nonnative species. No jurisdiction has comprehensively or consistently mapped forests affected by insects or disease. Mapping typically is used to track the spread or impacts of pests of particular concern, rather than being more inclusive of all agents and looking at forest ecosystem health. Likewise, the extent, population density, and spread of various introduced vertebrates are studied for the purposes of species-based control, not to look at long-term ecosystem impacts across multiple taxa. The number of invasive or nonnative species found in the islands is a readily available metric that shows both the trend of introductions and the high number of documented invasive species in the islands.

Our discussion of "abiotic" processes includes land clearance. A pattern of small-scale agricultural and agroforestry clearing and disturbance within generally forested areas is a characteristic form of disturbance in tropical islands. Clearance and revegetation may be part of a traditional, productive forest management system that is sustainable even though different in species composition than undisturbed forest. However, if the pace and scale of clearings accelerates, soil resources and species richness may be degraded, and the system may become unsustainable. (By contrast, large-scale permanent conversion of land use from forest to urban or agricultural uses is covered under Indicator 1.01, area of forests.)

For reference, the MP C&I indicators for Criterion 3 are as follows:

- **3.15:** Area and percent of forest affected by biotic processes and agents (e.g., insects, disease, invasive alien species) beyond reference condition.
- **3.16:** Area and percent of forest affected by abiotic agents (e.g., fire, storm, land clearance) beyond reference conditions.

Indicator 3.15
Area and Percent of Forest Affected by Biotic Processes and Agents (e.g., Insects, Disease, Invasive Alien Species) Beyond Reference Condition

Alien (nonnative or "exotic") species, including insects and diseases, have been introduced in large numbers to the islands, accidentally or deliberately, by indigenous people and modern commercial activity. Of these introductions, some are valuable or harmless, while others are predicted or observed to be invasive. The Hawaii Weed Risk Assessment predicts whether a given species will cause economic or environmental harm or harm to human health in any Hawaii ecosystem, via a scoring system that has been validated by field observations of nonnative species that were introduced more than 40 years ago. In Hawaii, "environmental harm" is considered to include "substantial effects on native ecosystems;" however, a nonnative species that naturalizes is not necessarily labeled "invasive" (Daehler et al. 2004). Similarly, Kairo et al. (2003) distinguished between nonnative species in the Caribbean that were merely naturalized (established in the wild) versus those considered to be invasive (reported to be spreading, regarded as a threat to a native species or ecosystem, or causing negative socio-economic impacts). In the extreme case among the islands, Hawaii has had about 10,000 plant species introduced, of which about 1,150 have escaped cultivation and 176 are listed in the Global Invasive Species Database (table C3-1), contributing to extensive loss of native forest, as discussed below.

Insects (Native and Nonnative)

FIA data do not indicate widespread insect damage in most tropical island forests. In the Pacific west of Hawaii, fewer than 5 percent of trees are dead for any reason. The data give no indication that insects are a major cause of the mortality that has occurred. For all Caribbean and Pacific islands with FIA data, the proportion of total live trees damaged for any reason ranges up to 37 percent. Considering live trees with any form of damage, and attributing that damage to insects vs. other factors, insects are primary damage agents in 2 to 16 percent of cases of damage (depending upon the island), and therefore on less than 5 percent of all live trees on most islands. One exception is the Republic of the Marshall Islands, where 18.5 percent of trees were damaged by insects, all by foliar damage to *Scaevola taccada*. Hawaii may also be an exception, but comparable FIA data has not yet been published for Hawaii.

Newly introduced insects do often have severe impacts on certain plant species, including rare or endemic species or valued agroforest species. Guam's native cycad (*Cycas micronesica*) is declining rapidly from infestation of the cycad aulacaspis scale (*Aulacaspis yasumatsui*) and other native and introduced pests. Coconut rhinocerous beetle (*Oryctes rhinoceros*) was first detected in Guam in 2007 and the eradication zone increased to 3,335 ac in 2009; growth of beetle populations has been slowed, and its spread has been limited by sanitation and trapping. (Neither the scale nor beetle had affected Guam at the time of the 2002 FIA survey.) The Erythrina gall wasp, *Quadristichus erythrinae*, first found in Hawaii in 2005, has killed nearly all nonnative *Erythrina variegata* trees on the islands to which it has spread. Mortality of Hawaii's endemic *E. sandwicensis* stands has been as high as 50 percent in some stands. Biocontrol has resulted in recovery and resumed flowering. Biocontrol of the Seychelles scale insect (*Icerya seychellarum*) in the Manu'a islands of American Samoa has enabled significant recovery of breadfruit (*Artocarpus altilis*) trees between 1999 (when damage was "serious") and 2010, when a survey found that scales had been suppressed to "very low" levels. Thirteen species of cacti in the subtropical dry forests of Puerto Rico are threatened by Harrisia cactus mealybug, *Hypogeococcus pungens*, a native of South America. In the Pacific, the effects of these and other insects are reported by Neville (2014) and annually in *Forest Health Highlights* (described in chapter 2).

Some insects do not affect plants directly but disrupt the forested ecosystem and forest economics. Africanized

Table C3-1. Number of documented invasive terrestrial species in the U.S. tropical islands

	Number of invasive species per jurisdiction								
Taxonomic group	Puerto Rico	U.S. Virgin Islands	Hawaii	American Samoa	Marshall Islands	FSM	CNMI	Guam	Palau
Mammals	7	7	15	5	6	7	10	8	6
Birds	6	1	10	2	3	1	1	4	1
Amphibians	3	3	5	1	1	1	1	3	1
Reptiles	4	0	8	2	2	4	5	5	2
Insects, arachnids, centipedes/millipedes	14	12	28	8	6	6	9	12	8
Plants	57	25	176	41	45	62	52	67	52
Snails	0	0	5	2	1	1	2	3	2
Total	91	48	247	61	64	82	80	102	72

FSM = Federated States of Micronesia; CNMI = Commonwealth of the Northern Mariana Islands.
Source: Global Invasive Species Database 2011.

bees threaten the nesting success of the Puerto Rican parrot (*Amazona vittata*). Little fire ants (*Wasmannia auropuntata*) hinder forest and agroforest management activities by stinging people; other invasive ants have facilitated the rapid decline of stands of *Pisonia grandis* trees on some Pacific atolls by protecting damaging scale insects from natural enemies (Krushelnycky et al. 2005).

Disease (Native and Nonnative)

FIA data (Brandeis and Oswalt 2007; Brandeis et al. 2007; Donnegan et al. 2004a, 2004b, 2007, 2011a, 2011b) indicate relatively little overall tree damage caused by diseases in tropical island forests, though it must be noted that FIA methods and reporting differ between the Caribbean and the Pacific, and FIA data has not been published for Hawaii. In the Pacific jurisdictions west of Hawaii, the percentage of live trees with any form of damage ranged from 11 to 37 percent, but only 2 to 19 percent of that damage is primarily attributed to disease; the total percentage of live trees with damage primarily attributed to disease was at a maximum 2.5 percent In Puerto Rico and the USVI, the most common disease was fungal infection and decay (63 percent of all damaged trees); this indicates that fungal infection is a primary damage agent on 8.6 percent of all live trees in Puerto Rico and 2.4 percent in the USVI.

Despite these low overall figures, diseases are significant and of concern for agroforest crop species, e.g., citrus canker in Kosrae, citrus greening (Huanglongbing) in Puerto Rico and the USVI, and *Phellinus noxious* on breadfruit and other species in the Pacific.

In Hawaii, two widespread diseases were of particular concern during 2003–2010. Koa wilt (*Fusarium oxysporum*, affecting *Acacia koa*) is present on all islands at elevations up to 7,000 ft. Widescale dieback has not been observed in natural forests, but high incidence and mortality rates are found in koa plantations below 3,000 ft elevation. An invasive rust (*Puccinia psidii*) was first detected in 2005 and is present on all major islands up to 4,500 ft, attacking a variety of native and introduced Myrtaceae. The geographic range of the rust has been mapped, but acres and percentage of forest affected have not been quantified. The greater reason for concern is the potential for the rust to adapt or for more virulent strains to be introduced, affecting ohia (*Metrosideros polymorpha*), Hawaii's most widespread and ecologically important native tree. Finally, even though this report focuses on 2003–2010, a disease just detected in 2010 (*Ceratocystis fimbriata* wilt of ohia) must be noted because of its rapid spread to 34,000 ac (DLNR 2016) and serious threat of catastrophic loss of ohia forests statewide. It is not yet known whether this is a result of an introduction of an exotic strain of the fungus or whether this constitutes a new host of an existing strain (Keith et al. 2015).

Invasive Alien Species—Plants

Hawaii's native ecosystems, which evolved in relative isolation, have been radically altered by invasive plants. Figure C1-4 (see Criterion 1 above) shows that 14 percent of Hawaii was transformed into alien (nonnative) forest by 2003 (little of which consists of plantations); an additional 25 percent was transformed into alien grasslands and shrublands. In some places, this shift resulted from direct invasion by plants into native forest, such as nonnative Albizia (*Falcataria moluccana*) establishing itself and growing above the relatively open canopy characteristic of native Ohia (*Metrosideros polymorpha*) on young substrates. In other cases, nonnative plants colonize disturbed areas instead of native plants after land use conversion, grazing, or fire (in Hawaii, fire itself is sustained primarily by nonnative grasses). Of the remaining 21 percent mapped as native forest, much is affected by nonnative plant species to some degree and may be in transition to nonnative forest types, as alien shrubs such as strawberry guava (*Psidium cattleianum*) occupy the growing space and hinder native forest regeneration.

Also now dominated by "novel ecosystems" are Guam, Saipan, and Tinian of the Mariana Islands. Many invasive and other nonnative plants have exploited openings in the forest created through disturbance, especially clearing for and subsequent abandonment of intensive agriculture prior to World War II; World War II bombardment; and disturbance for urban development. A prime example is *Leucaena leucocephala*, widely believed to have been direct-seeded in the Mariana Islands after World War II. On Saipan and Tinian, only about 5 percent of the land area is still native forest, and almost two-thirds is *Leucaena* shrubland and "mixed introduced forest" (Falanruw et al. 1989). Guam lacks data, but its self-assessment is that, despite relatively constant forest cover since World War II, the condition of the forest has declined in response to continuous abiotic disturbance pressures and the number of nonnative species being introduced.

Other islands have more intact native forest, with varying susceptibility to invasion. *Falcataria* became an emergent (upper canopy tree) over about 12,000 ac in American Samoa (35 percent of Tutuila) before control efforts beginning in 2001 reclaimed nearly 2,000 ac of native forest. A key question is whether invasive species in the canopy provide a favorable environment for native species regeneration. Abelleira Martínez et al. (2010) indicate that the most common tree in Puerto Rico, the African tulip tree (*Spathodea campanulata* Beauv), an introduced species, speeds restoration of forest structure and native tree regeneration on abandoned agricultural and grazing lands. Introduced plant species in Puerto Rico include 16 invasive tree species identified by the Global Invasive Species Database (2011) out of a total of 123 introduced tree species documented by Francis et al. (2000). Many of these have extended their range in the wild, yet none have been documented to replace native tree species. The database reports 11 invasive plants in the USVI; although widespread, they do not dominate most plant communities (Oswalt et al. 2006). *Leucaena* is one tree listed as invasive in the database that does persist and dominate some plant communities in the Caribbean, with benefits and risks as a species used in management (Wolfe and Van Bloem 2012).

Invasive Vertebrates

The introduction of ungulates or carnivores to isolated islands typically has a profound effect on native island ecosystems that evolved in their absence. Ecosystem structure, function, and species composition may be fundamentally changed as:

- Grazing animals (goats, sheep, mouflon, deer, and feral cattle and horses) browse vegetation, hinder regeneration, and over time may convert forests to rangelands, sometimes occupied by fire-prone grasses.
- Predators (snakes, rats, feral cats, monkeys, and mongooses) prey on native bird eggs and nestlings, with attendant secondary effects on pollination and dispersal.
- Rats, iguanas (López-Torres et al. 2011), and other animals consume seeds, fruits, and flowers of many native plant species.
- Trampling and rooting animals (especially hogs) disturb and scarify soil, leading to erosion or establishment of invasive plants. In general, forests on all but some of the smallest or most isolated islands are affected throughout most of their extent by at least one invasive vertebrate. The entirety of Guam (except a few very small offshore islands) is profoundly affected by the brown tree snake (*Boiga irregularis*), which extirpates forest birds; rats are found in abundance throughout most of Hawaii's forests; feral pigs are abundant in many forested areas of American Samoa; monkeys harm threatened and endangered species in Puerto Rico and cause damage to agriculture and orchards as well (Engeman et al. 2010); and the mongoose is widespread in a wide variety of habitats in Puerto Rico, and so forth.

Indicator 3.16
Area and Percent of Forest Affected by Abiotic Agents (e.g., Fire, Storm, Land Clearance) Beyond Reference Conditions

Fire

Fire occurs naturally on islands with active volcanoes, but fire from lightning strikes is rare, and nearly all fire (apart from active lava flows) is anthropogenic, so its effects are outside of the natural disturbance regime. Repeated fire leads to exposure and erosion of soil and changes in forest structure and species composition.

Since human settlement, fire has greatly affected islands with dry or mesic forests or dry seasons. The current, most notable trend is in Hawaii and Puerto Rico, where the leeward (dry) sides of the islands have experienced an increase in the number and severity of wildfires owing to a combination of increased ignition sources by humans and the spread of nonnative fire-adapted grasses, shrubs, and trees, of which fountain grass (*Pennisetum setaceum*) is the best example. The year 2007 was one of the 10 hottest years on record by that time, which could account for increased fire activity in Puerto Rico and the USVI that year.

Guam and the CNMI have a long history of arson by hunters, and Palau a history of agricultural burning and current-day arson. However, for these islands, consistent published data are unavailable for long-term trends in fire frequency and effects on forests. Grassland fires degrade forest fragments and forest edges and stop forest regrowth. Urban development of grasslands can increase ignitions or reduce fuels. Despite the common occurrence of fire in grasslands that neighbor forests, total forest cover in Guam has been relatively unchanged over the past 50 years.

Fire danger throughout Micronesia's wetter islands is associated with drought during El Niño years, for which predictive capacity has improved. Early prediction of the severe 1997–1998 El Niño drought enabled public fire prevention education programs to actually reduce acres burned in Yap.

Volcanic Emissions

Lava inundation affects forests in Hawaii, and volcanic emissions affect forest health over wide areas. Since 2008, increased emissions, including sulfur dioxide, and volcanic fog (vog) and acid rain from Kilauea Volcano in Hawaii, have been sufficient to cause acute injury to plants near Kilauea and chronic injury at greater distances. Ash from the Soufrière Hills volcano on Montserrat fell on Puerto Rican forests in 2001, and ash from Anatahan fell on other Mariana Islands in 2003, affecting forest nutrient fluxes.

Storms

Hurricanes (called typhoons west of the international dateline) and tropical storms, with associated salt spray and ocean surges, are a natural disturbance in island forest ecosystems, though occurring at different intervals in different regions. The Mariana Islands are affected by multiple typhoons annually, and the USVI once every 15 years or so. Major recent hurricanes in Puerto Rico and the USVI include Georges in 1998, Andrew in 1992, and Hugo in 1989. Yap was hit by Sudal in 2004, its strongest typhoon in 50 years, causing extensive forest defoliation and mortality. Kauai was struck by the eye of a category-four hurricane, Iniki, in 1992, the strongest to make landfall in Hawaii's recorded history; forests there still have persistent effects from species invasions into forests damaged by the storm. No major typhoon has struck Pohnpei or Kosrae, in the central Pacific, for over 100 years. Forest plant species and types have evolved within these disturbance regimes and demonstrate considerable resilience to varying levels of recurring effects from storms and hurricanes. In Puerto Rico, the degree of forest damage and associated capacity for forest recovery is also strongly dependent on the history of land use and hurricane damage, such that where there are greater anthropogenic impacts on the forest or surrounding areas, capacity for recovery decreases (Boose et al. 2004).

Heavy sustained rainstorms on the steep slopes and weathered soils of the high Caroline Islands (Kosrae, Chuuk, Pohnpei, Yap, and Palau) and Puerto Rico result in landslides, either related to slope disturbance from infrastructure construction or naturally occurring slumps. These landslides carry away upland forests and agroforests, leaving behind barren slopes; soil and debris are deposited on lower slopes and (on small islands) mangrove forests, producing sediments that can be washed into nearshore marine environments. Typhoon Chata'an thus affected hundreds of acres of forest on the small islands of Chuuk in 2002; scarps remain thinly vegetated today. Landslides have increased over the last decade in Palau (largely resulting from construction of the Compact Road).

Tsunami

American Samoa was struck by a large tsunami in 2009. Coastal forests were uprooted and experienced erosion; effects were more significant where coastal vegetation was already sparse.

Climate Change

Over the next century, climate change is expected to increase base sea levels and temperature steadily.

Sea levels are highly variable in the western Pacific on a daily, seasonal, or decadal basis from storm surges, low pressure events, and currents. In western Micronesia, the rate of mean sea-level (MSL) rise was greater than the global rate between 1993 and 2010 (fig. C3-1). This was because of a multidecadal increase in the strength of the trade winds (La Niña-dominated conditions). These extraordinary rates of increase are not expected to persist over time, because sea levels in the north central and western Pacific fall under El Niño-dominated conditions (Leong et al. 2014). In the meantime, they provided a preview of anticipated high sea levels in the long-term future. The effects of these increased sea levels are amplified by storm surges, eroded coastal vegetation, and hindered restoration of coastal strand forests in the western Pacific.

Changes in the extent of mangrove forests are expected as their seaward fringes are inundated and as mangroves colonize increasingly brackish estuaries; Gilman et al. (2007) predicted a 12-percent decrease in the extent of mangrove forests in the U.S.-affiliated Pacific islands by 2100. The superimposed effect of base sea-level rise will increase the frequency of high-sea-level events that pass given thresholds. For example, sea levels that breach coastal berms contaminate freshwater lenses and freshwater swamps behind the berms; this affects coastal and atoll agroforestry systems. When frequency exceeds recovery periods for such events, ecosystems and societies will be transformed, and atolls with narrow reef flats may become uninhabitable within decades rather than centuries (Storlazzi et al. 2015).

Storms, droughts, and prevailing sea level in the Pacific are driven by El Niño–Southern Oscillation (ENSO) cycles; it is not yet clear how climate change will affect ENSO cycles. The variable effects of ENSO on storms and rainfall are expected to overwhelm incremental climate change in the Pacific for several decades (Australian Bureau of Meteorology and CSIRO 2014). As a matter of perspective, major El Niño events more than a century ago are associated with unusual and devastating

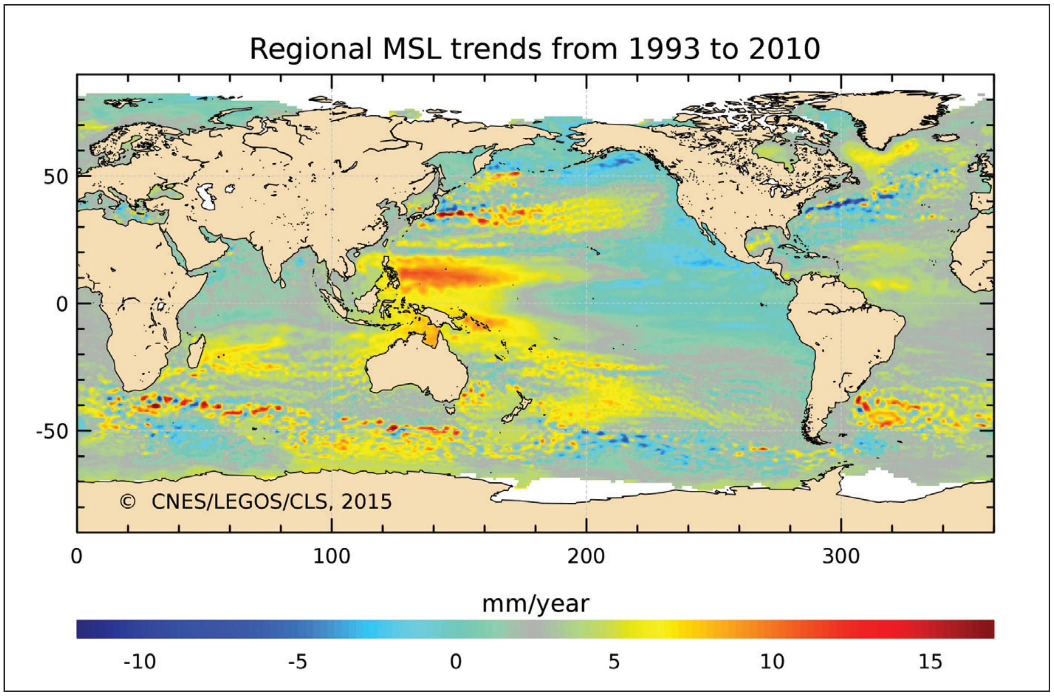

Figure C3-1. Mean sea level rise from 1993 to 2010, ranging from an average of -0.4 inch/year (blue) to 0.6 inch/year (red). Note: Sea-level rise is shown by the source as "mm/year." Multiply 1 millimeter by 0.0394 to find inches. Source: CNES/LEGOS/CLS 2015.

storms in eastern Micronesia at that time (Spennemann and Marschner 1994). Changes in global climate that result in increased temperature or decreased precipitation will affect freshwater stress, as modeled for islands by Karnauskas et al. (2016). Increased freshwater stress or periods of drought would likely increase fire frequency and its adverse effects. Changes in climate that result in warmer waters in the Atlantic Basin for longer periods of time will likely produce increases in the number and strength of hurricanes and storms that affect Puerto Rico.

Mounting evidence indicates specific long-term effects on Hawaii's climate and water: a rapid rise in air temperature, especially at higher elevations; decreased rainfall and streamflows in some areas; and moderate sea-level rise.

Land Clearance and Fill

Total forest cover in Puerto Rico has been steadily increasing through the early 2000s as the economy and land use have shifted away from agriculture, although urbanization is converting some forest land into other uses (Gould et al. 2007). Average forest age is young in fertile areas where agriculture persisted until recently giving way to forest. Overall, land use is a dynamic mosaic with increasingly fragmented forests (Franco et al. 1997). In the USVI, agricultural land uses have likewise given way to fragmented secondary forests, but urbanization has outweighed that trend and total forest cover is decreasing. In Hawaii, native forests are being cleared and fragmented in housing/agricultural subdivisions on the Big Island; native forests are also being degraded by cattle, but some former ranchlands are now being managed to restore native forest. On the other Pacific islands, data are inadequate to quantify net trends, but additional relevant dynamics include the construction of major roads providing access to lands for agroforestry and horticultural use (Palau); migration from outlying islands (Rota in the CNMI, and Tau in American Samoa); migration from atolls to central islands (Yap, Pohnpei); and programs to discourage upland forest clearing (Pohnpei).

Forest loss from land clearing may be reversed when land is left fallow and forest regrows, as has been the case in Puerto Rico, parts of Palau, and other areas. Simple clearing of mangrove forests may or may not result in healthy regeneration, depending upon the substrate, hydrological regime, and other factors. Where mangrove forests are not only cleared but filled to above the high tide mark to create land for urban uses, the area will not revert to mangrove forest unless the fill is removed or washed away (or unless sea level rises above the fill). Mangrove forests are also affected by fill (causeways and roads) that impound or divert water; altered hydrological regimes may result in changes in species composition or conversion to freshwater wetland forest or nonforest estuaries.

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Criterion 4

Conservation and Maintenance of Soil and Water Resources

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Introduction

Healthy and productive forests depend on the maintenance of soil and water resources. Forests also regulate these resources by moderating the flow of water, controlling erosion, and preventing flooding, landslides, and other potentially catastrophic events. If forest soils or waters become diminished or degraded, forest health and other environmental services also may decline. Well-managed forests can help protect important soil and water resources within the forest ecosystem and across the broader landscape.

Tropical soils range from deep, fertile soils occurring in volcanic regions or on nutrient-rich floodplains to shallow soils with limited nutrients that are prone to leaching and erosion. Forests rich in biomass and diversity are found across the range of tropical soil types. These forests exhibit high rates of decomposition and nutrient cycling associated with high temperatures and precipitation, levels of soil phosphorus and nitrogen, and numbers of soil insects and microorganisms. These factors accelerate the decay of plant and other organic materials, releasing nutrients that are quickly (re-)absorbed by living plants through the soil and surface or ground waters. Tropical forests occurring on rich and deep soils often are vulnerable to conversion to other uses, such as agriculture or livestock grazing. Forests occurring on shallow, poor, or unstable soils are susceptible to degradation through erosion or compaction if unsustainably logged or otherwise poorly used or managed.

Forests also are thought to play an important role in water resource quantity, quality, timing, and flows, especially on tropical islands where fresh water supplies often are limited and intricately linked from ridge to reef. These forests are essential for intercepting and storing water and nutrients; protecting soils, floodplains, and streambanks; cleaning and cooling air and water; reducing stormwater runoff; filtering pollutants from air and water; protecting municipal water supplies; reducing flooding; recharging groundwater aquifers; and providing critical habitat for aquatic wildlife. In riparian areas, forests adjacent to bodies of water buffer the movement of pollutants from upslope land use activities and support aquatic health through temperature regulation, additions to the food web, and provision of habitat structure.

Overharvesting, poorly planned and unmaintained roads, unsustainable recreation, and other human activities can degrade soil and water resources and related forest functions. Conversely, the sustainable use and protection of forests can help protect these and other resources and services important to island dynamics and livelihoods. Best forest management practices, riparian zone protection, recreation management, and a wide range of additional measures are designed and implemented to protect forest water and soil resources.

Criterion Summary

Forest soils and their quality and quantity range widely across the tropical islands. In much of the Caribbean and in parts of Hawaii and the Pacific, a significant portion of the total forest area has regenerated on lands previously used for agriculture or livestock grazing; these forests often occupy compacted, eroded, or otherwise degraded soils. As these secondary forests mature, they can contribute greatly to the recuperation, maintenance, and protection of valuable soil resources. Throughout the islands, and particularly in Hawaii and parts of the Pacific, forests are subject to degradation by feral ungulates, such as pigs and goats, which can have significant effects on soil resources through the uprooting of vegetation, exposure of soil and subsoil, and dispersal of nonnative plant species.

Island forests also are essential to the supply, quantity, and quality of water resources within the watershed and in downstream communities. Human water consumption and other activities influence forest water resources and overall forest health throughout the islands. As with soil resources, the conversion of forest lands to other uses has significantly affected water availability and quality on most of the inhabited islands. In many cases, nonforest land uses, such as agriculture and livestock grazing, as well as industrial, urban, and tourism development, have led to overuse of existing water supplies; sedimentation of waterways and bodies, including reservoirs; and contamination of surface and ground waters. Moreover, without further conservation measures and implementation, the hydrological resources and services associated with island forests are likely to be further affected by feral ungulates, fire, nonnative invasive plant species, unsustainable water withdrawals and diversions, and climate change.

Forests are protected to varying degrees for a range of values throughout the island jurisdictions, including the conservation of soil and water resources. However, very little of the protected forest area is designated solely for these purposes. In the Caribbean, the protection of riparian zones is mandated by law. In other areas, specific measures have been taken to protect and conserve the soil and water resources in critical watersheds (e.g., Hawaii, Federated States of Micronesia).

Voluntary best management practices (BMPs) for forest use and conservation that include the protection of soil and water resources are available in Hawaii and Puerto Rico. Additionally, the U.S. Forest Service (USFS) Forest Stewardship Program, which is active in most jurisdictions, promotes long-term forest management that takes into account soil, water, wildlife, and other forest values through technical and financial assistance for forest planning and operations. Nevertheless, there is very limited systematic monitoring of forest use or conservation measures in any jurisdiction.

The Indicators

The Montréal Process Criterion 4 contains five indicators related to the conservation and maintenance of forest soil and water (listed below). However, given the limited amount of available data for most of these indicators, we combined Indicators 18 and 20 for reporting purposes—this strategy has been used in the *National Report on Sustainable Forests* as well (USDA FS 2011). The Montréal Process Criterion 4 indicators are as follows:

- **4.17:** Area and percent of forest whose designation or land management focus is the protection of soil or water resources.
- **4.18:** Proportion of forest management activities that meet best management practices or other relevant legislation to protect soil resources (combined with Indicator 20 below).
- **4.19:** Area and percent of forest land with significant soil degradation.
- **4.20:** Proportion of forest management activities that meet best management practices, or other relevant legislation to protect water-related resources (combined with indicator 18 above).
- **4.21:** Area and percent of water bodies, or stream length, in forest areas with significant change in physical, chemical, or biological properties from reference conditions.

Indicator 4.17
Forest Designated for the Protection of Soil or Water Resources

The formal protection of forests through governmental, nongovernmental, and private measures ranges widely across the islands (see Criterion 1). In addition to formal forest protection, traditional governance structures have resulted in widespread community forest management and protection, particularly in the Pacific islands. Although the protection of soil and water resources is among the primary management goals for most formally protected forest area, very little is solely designated for this purpose. In the Caribbean, riparian zones outside protected areas also must be protected by law. However, monitoring and enforcement are largely nonexistent. In Hawaii and parts of the Pacific, specific measures have been taken to protect and conserve the soil and water resources in critical upland watersheds.

In the U.S. Virgin Islands (USVI), 14.7 percent of forests are formally protected under federal, private, and nongovernmental measures, and an additional 2.1 percent are formally managed or prohibited from conversion to other uses (Gould et al. 2013). Riparian zones are protected through the Virgin Islands Legal Code, which prohibits the cutting of vegetation within 30 ft of the center of a natural water course or body, or 25 ft from the edge, whichever is greater (VI Legal Code (Title 12, Chapter 3, Section 123). Although there are few natural lakes or ponds and no permanent rivers in the USVI, intermittent or ephemeral rivers and streams that fill with water during times of high precipitation "play an important role in … hydrological systems" (Heartsill-Scalley 2012). These riparian zones represent "one of the few remaining areas where canopy forest can be found in the USVI, [yet] despite legal protection, intermittent waterways continue to be degraded through clearing and paving, resulting in erosion and the rapid transportation of significant sediment loading in surface runoff directly to the marine environment" (Gardner 2008).

In Puerto Rico, 11.6 percent of the forested area is formally protected through commonwealth, federal, nongovernmental, and private measures (Gould et al. 2007). The islands' major mountainous forest reserves (i.e., El Yunque National Forest; Carite, Toro Negro, Maricao, and Guilarte Commonwealth Forest Reserves) encompass the headwaters of the primary rivers and streams, which supply much of the water used for domestic, industrial, and agricultural uses (Weaver 2000). Three river segments within El Yunque National Forest, totaling

8.9 mi, have been federally designated as Wild, Scenic, and Recreational Rivers by the U.S. Congress (EYNF 2008). These designations are intended to preserve rivers with outstanding natural, cultural, and recreational values, and their immediate environments, in a free-flowing condition for the benefit and enjoyment of present and future generations (CNFWSRA 2002). Maintaining water quality and natural flow characteristics is a primary management objective in designated river segments. El Yunque National Forest also encompasses the 10,000-ac El Toro Wilderness Area, which permits primitive trail construction and recreation for minimal use and primitive experience, but prohibits road construction or other development; motorized or mechanized use; timber harvesting; water development; manipulative (treatment vs. control) research; mineral activity; and high-use recreation and trails (EYNF 2008).

Riparian zones in Puerto Rico are classified as public domain by the Commonwealth Government (PR Law No. 136 3/6/1976). Buffers of at least 5 m (16.4 ft) must be conserved along waterways and around water bodies and should be protected and managed by the Commonwealth Department of Natural and Environmental Resources (PR Law No. 49). However, implementation of riparian buffer zone legislation is considered weak, and there is limited evidence of its enforcement (see, for example, Heartsill-Scaley and Aide 2003, Lugo et al. 2001).

In Hawaii, 13.1 percent of the total forest area is formally protected through federal, state, nongovernmental, and private initiatives, and another 29.7 percent is formally managed or is prohibited from conversion to other uses (Gon et al. 2006). In 1903, the State Forest Reserve System was established by the Territorial Government of Hawaii, with the active participation of private landowners. Today, these reserves cover 642,000 ac (16 percent of total land area) and are managed to provide a suite of public services, including "the protection and management of forested watersheds for the production of fresh water supply for public uses now and into the future" (State of Hawaii 2009).

Additional measures to protect watersheds, forests, and their soil and water resources include the Hawaii Watershed Protection Board, established by the Hawaii legislature in 2000 to identify critical watershed areas and determine sources of funding to implement watershed protection partnership projects (HAWP 2011). Watershed partnerships are voluntary alliances of public and private landowners committed to the protection of large areas of forested watersheds for enhanced water conservation, quality, and recharge and other ecosystem services and values. These partnerships engage in collaborative management activities such as invasive species control, habitat restoration, reforestation, and on-the-ground protection measures. By 2011, there were nine island-based watershed partnerships that involved more than 60 public and private partners on six islands working collaboratively to protect nearly 1.6 million ac of forested watershed lands (HAWP 2011).

In the U.S.-affiliated Pacific jurisdictions, forest management and protection is on the rise, ranging from 9 to 23 percent or more of total forest area per jurisdiction, as assessed under the Micronesia Challenge (PCS and TNC 2011) (see Criterion 1). For example, in the Federated States of Micronesia (FSM), the state of Pohnpei has legally designated entire upper portions of the island's major watersheds (14,524 ac) for the protection of soil and water resources (FSM 2010). However, a lack of local support and repeated forest clearing for high value cash crops in the area threatens the viability of certain watersheds in this reserve (FSM 2010). Also in Micronesia, the state of Kosrae created the Central Watershed Reserve (17,290 ac) for the protection of soil and water resources. The watershed covers about 67 percent of the total land area of Kosrae, much of which is currently under government control. Within the reserve, 4,940 ac are designated specifically for the protection and production of drinking water. This area encompasses the steepest land, most erodible soils, and uppermost elevations, and thus is intended to "protect much of the most sensitive parts of the watershed" (FSM 2010).

Indicators 4.18 and 4.20
Forest Management Activities That Meet Best Management Practices or Other Relevant Legislation to Protect Soil and Water Resources

Voluntary BMPs for forest use and conservation have been developed by the government only in Puerto Rico and Hawaii. However, there are no known efforts to regularly collect data on BMP implementation or effects. Long-term forest management that takes into account soil, water, wildlife, and other forest values is a primary objective of protected areas in most jurisdictions, and also is promoted through the USFS Forest Stewardship Program, which provides technical and financial assistance to nonindustrial forest landowners through state forest agencies.

In the Caribbean Islands, wood product harvests are not subject to mandatory BMPs for soil or water conservation, and only Puerto Rico promotes and prescribes BMPs for legally mandated riparian protection zones. However, the implementation and impacts of these BMPs are not monitored or measured. Voluntary BMPs are promoted, though not measured, through the Forest Stewardship Program, the Puerto Rico Commonwealth Auxiliary Forests, and other conservation programs. In 2009, there were 104 management plans for forest products and services covering 4,833 ac under the Forest Stewardship Program, and 73 auxiliary forest units covering 7,620 ac in Puerto Rico. In the USVI, 929 ac were enrolled in the Forest Stewardship Program.

Hawaii has a small, active forest products industry that is subject to BMP guidelines related to forest land management planning and operations for private forest landowners to assist them in their compliance with the federal Clean Water Act (CWA). Applicable sections of the CWA protect the nation's waters from the uncontrolled discharge of pollutants (including sand, rock, and other fill materials) and prescribe a permitting process for any activity that may result in pollutant discharges (CFR CWA Section 404). The CWA exempts forestry and other activities from this permitting process, provided that operations are in compliance with 15 mandatory national-level BMPs that are implemented and oftentimes complemented by additional BMPs at the state level.

Hawaii's voluntary BMPs for Maintaining Water Quality address forest roads, preharvest planning, harvesting, silvicultural practices, streamside management zones, fencing, fire management, and reforestation (State of Hawaii 1996). Applications of these guidelines are voluntary and not enforceable, and there were no available quantitative data on their implementation or impacts at the time of this report. Notably, Hawaiian participants in the USFS Forest Stewardship Program "must commit and follow the practices described in their Forest Stewardship Management Plan, which are in compliance with the Department of Forestry and Wildlife Best Management Practices (BMPs) when preparing project sites for planting and harvesting any trees that are planted with program assistance" (State of Hawaii 2009). In 2009, 36 landowners with a total of 19,315 ac of forest land were enrolled in the Forest Stewardship Program in Hawaii (State of Hawaii 2009).

In the U.S.-affiliated Pacific jurisdictions, there are no known official BMPs for forest management, but large-scale forest management operations also are essentially absent throughout much of the region. As in Hawaii and the Caribbean, the Forest Stewardship Program is implemented in the Pacific Island jurisdictions, where funds are used for extension and distribution of seedlings to encourage forest cover for watershed protection, as well as some landscape- and parcel-level planning.

Indicator 4.19
Forest Land With Significant Soil Degradation

There is very little quantitative information on forest soil quality or degradation for any of the island jurisdictions. In general, a significant portion of the total forest area has regenerated on lands previously used for agriculture or livestock grazing. As a result, most secondary forests occur on compacted, eroded, and otherwise degraded soils, where they contribute greatly to the rehabilitation, maintenance, and protection of the islands' soil resources.

The most common threats to forest soil quality across the islands include the introduction and spread of feral ungulates that can uproot forest vegetation and exacerbate erosion, and the spread of nonnative species that can affect forest composition and resilience to wildfire, particularly in the Pacific. Apart from these biological pressures and outright forest conversion, very few of the islands' forests are threatened by unsustainable or large-scale commercial timber harvesting or other intensive, extractive uses. So, it is expected that their continued recuperation, growth, and protection will likely lead to improved forest soil properties and overall forest health.

In Puerto Rico, most of the upper watersheds and forested slopes are associated with relatively well-preserved soil resources, as these areas largely have eluded land cover change or intensive harvesting and other uses owing to their limited access, steep slopes, and more recent conservation policies (Larsen et al. 1999). However, much of the island's forest area (about 80 percent) has only recently (<50 years) regenerated on abandoned agriculture and grazing lands, where such land use often led to soil compaction and degradation (Lugo and Helmer 2004). These secondary or "novel" forests have been found to demonstrate "poor development of the interface between the mineral soil, the humus layer, and the litter layer, [such that the] soil interface is abrupt and lacks the rich organic matter horizon that is typical of mature native forest" (Lugo and Helmer 2004). On average, new forests in wet life zones are associated with lower soil bulk density than mature native wet forests, largely because of higher soil compaction from previous human uses that is typical of secondary forests (Lugo and Helmer 2004). Consequently, most of Puerto Rico's forest soils are poorly developed and, in many cases, degraded, but continued forest growth and recuperation are likely to lead to enhanced soil conditions across the islands.

Although there are no available quantitative data on soil quality for the USVI, the extent of soil degradation from current forest use is considered minimal, because forests are not commercially harvested for timber production, recreation is managed, for the most part, and other forest uses have relatively limited effects on the soil resources. Similarly to Puerto Rico, however, much of the USVI's forested land has regenerated over degraded and compacted soils resulting from previous land uses, such as agriculture and grazing. Moreover, forests in the USVI are increasingly converted to housing, roads, and commercial and industrial development. These land use changes are associated with increased erosion and sediment yields within the watershed and downstream ecosystems, including nearshore coral reefs and other marine communities, which are highly sensitive to fine sediment inputs (MacDonald et al. 1997, Ramos-Scharron and MacDonald 2007).

In Hawaii, a long history of land use conversion, nonnative animal and plant species introductions, and intensive timber harvesting have affected much of the islands' forests and associated soil resources, though no data are available to quantitatively describe the extent of these effects or assess forest soil conditions or trends in general. Presently, feral ungulates (e.g., pigs, goats, sheep, deer, cattle) that tear up, trample, and uproot forest vegetation, often leaving the forest floor overturned or bare, represent a significant threat to forest soils across the Hawaiian Islands (Hess et al. 2006). These activities make the soil more susceptible to erosion and increase the dispersal and germination of fast-growing nonnative species, which in turn can shade out native understory species and ultimately modify the forest habitat (Hess et al. 2006). Some nonnative plants, such as *Miconia calvescens,* have shallow roots that, once established, also reduce the ability of forests on steep slopes to withstand erosion, rockfall, and landslides (State of Hawaii 2010). In response to the devastating effects of feral pigs and other ungulates on native Hawaiian vegetation, numerous public, private, and joint initiatives have been established to implement management techniques that deal specifically with these animals, such as fencing, snaring, and other population controls (Hess et al. 2006), but there are no quantitative data measuring the extent of these activities or their outcomes.

Wildfires and grazing by nonnative ungulates influence Hawaiian forests and soils by removing woody vegetation and ground cover, exposing soil to raindrops, and removing barriers to erosion. Many Hawaiian and other tropical island forests are subject to frequent tropical downpours, and occasional but intense downpours occur even in dry forest areas. These events can quickly cause erosion and landslides in disturbed areas.

In many U.S.-affiliated Pacific Islands, much of the forested area is found on steep slopes (in most cases >50 percent) (Harp et al. 2004). These areas are affected by typhoons and other periods of heavy rain that may result in slopewash and landslides, depending on the land use and severity of the storm. Tropical storms and typhoons develop frequently in Micronesia and affect forests, other natural systems, and human settlements, particularly where sustainable land use planning and practices are not implemented (Harp et al. 2004).

The clearing or conversion of forests to other land uses throughout the Pacific Islands has had a significant effect on soil stability, particularly in upper watersheds and on steep slopes. For example, in Pohnpei, FSM, illegal clearing of forest for the cultivation of sakau along riverbanks in the primary upper watershed is thought to cause significant erosion and sedimentation of lowland areas. Collaborative conservation programs in Pohnpei that integrate alternative income generation with increased monitoring and enforcement have had measurable success in decreasing the number of new forest clearings (e.g., down from more than 600 clearings in 2002 to 5 in 2007) (Conservation Society of Pohnpei 2012).

In Palau, poorly built roads and trails are a major source of sediment to streams and nearshore marine communities (MacKenzie 2015). Additionally, unintentional and unauthorized burns and wildfires increasingly affect forests, particularly with the completion of the Compact Road, which facilitates greater access to once remote areas of Palau.

In Guam, the rough topography of limestone forests in the north has discouraged land use practices that would otherwise have resulted in erosion and other types of soil degradation (Minton 2005). Conversely, in southern Guam, historical deforestation has resulted in a landscape dominated by savanna and badlands devoid of vegetation, with degraded soils. These savannas and badlands are maintained by frequent intentional (e.g., for grazing) and unintentional human-induced burning and feral ungulate grazing, which prevent forest regeneration and degrade the remaining forest by burning in from the edges.

Ultimately, the burning and loss of soil surface cover have resulted in erosion, mass wasting, and increased landslides throughout much of southern Guam (Minton 2005).

Indicator 4.21
Degraded or Diminished Water Bodies or Ways in Forest Areas

Water is one of the most valuable of ecosystem services provided by island forests, but there is very limited comparable quantitative data on the quantity or quality of water resources in forested areas. The extensive area of forested land across the islands contributes significantly to the protection of water resources within and outside forests. The conversion of forest lands to other uses has significantly affected water availability and quality on many of the islands. In most island contexts, nonforest land uses such as agriculture and development (i.e., urban, industrial, tourism) have led to the overuse of existing water supplies, sedimentation of water reservoirs, and contamination of surface and ground waters.

The Clean Water Act (CWA) Section 305(b) requires states and other U.S.-affiliated jurisdictions to assess the quality of waterways, bodies, and other resources and regularly report the findings to the Environmental Protection Agency (EPA). This legislation requires states and other jurisdictions to identify reportable waterways and bodies, designate appropriate water uses for each, assess attainment of established water quality standards, and determine the principal sources of impairment. Each state or jurisdiction determines its own standards for water quality, which must be in compliance with the CWA and approved by the EPA, but which may not be comparable across states and other jurisdictions. Although these statistics do not directly measure the quality of forest water resources, they do reflect the state of waterways and bodies in most of the island jurisdictions included in this report. Five of the island jurisdictions reported on water quality in 2010. Puerto Rico, Hawaii, American Samoa, and the Marianas reported that the majority of assessed waters in 2010 were impaired or otherwise compromised, largely owing to the effects from agriculture and urban land uses, indicating in part at least the need for continued and enhanced forest and watershed protection (USEPA 2010). Guam was the only jurisdiction to report that a minority of its assessed waters were impaired (USEPA 2010).

Water quality in the USVI was not reported to the EPA in 2010, owing in large part to the absence of perennial streams and rivers and limited supply of aboveground reservoirs and ground water resources. Nevertheless, fresh water supplies are scarce in the USVI, and human activities have further exacerbated water scarcity, particularly as intermittent waterways and other natural channels that once permitted the absorption of water into the water table have been paved over or converted to other land uses. Since the early 1930s, private residences and businesses have been required by law to construct cisterns for the capture and storage of rainwater from rooftops and other impermeable surfaces in the USVI. Nevertheless, increasing demands on water sources and supplies eventually led to the construction of a desalination plant on St. Croix and another on St. Thomas in the 1960s. By the mid-1990s, these plants produced about 65 percent of the islands' freshwater supply (ground water provides 22 percent, cisterns 13 percent) and were noted for producing the most expensive publicly supplied water in the United States ($4.20/1000 liters) (Zack and Larsen 1994).

In Puerto Rico, fresh water supply and maintenance are vital for supporting the island's sizeable population (>3.7 million persons; 1,085 persons/mi^2) (USDC CB 2010). And, although the headwaters of the major rivers and streams, which supply most of the island's 25 reservoirs, lie within protected forested areas, few watersheds remain untapped, and the number of dams and water intakes in Puerto Rico's forests continues to increase (March et al. 2003). For example, Crook et al. (2007) quantified the amount of water withdrawn from El Yunque National Forest (EYNF) in 2004. They found that on an average day, 70 percent of the median flow of the water generated in the EYNF was diverted for municipal use. These water withdrawal levels could potentially alter "stream habitat for migratory shrimps and fishes, and also change the dynamics of downstream transport of sediment, suspended particles, and other food and energy sources to estuaries" (Crook et al. 2007: 17–18). Moreover, water withdrawal from the EYNF is expected to increase in the future, "creating management challenges" for the forest and its watersheds (Crook et al. 2007).

In Puerto Rico, the conversion of forests to agricultural, industrial, and residential use, and increasing population and urban density have affected the physical, chemical, and biological properties of most waterways and bodies (see, for example, Heartsill-Scalley and Aide 2003, Lopez et al. 1998, Lugo et al. 2001). Forest conversion, in particular, has significantly affected water availability and quality, including overutilization of existing water supplies, sedimentation of water reservoirs, and the contamination of surface and ground waters (Zack and

Larsen 1994). Many of Puerto Rico's principal reservoirs have become at least partially filled with sediment, owing to the effects of forest land use change and unsustainable land use practices, reducing their effectiveness in water provision and flood mitigation. By the mid-1990s, most of the major water reservoirs in Puerto Rico stored, on average, about 32 percent of their original storage capacity, attributed largely to sedimentation from inadequate land use practices (Zack and Larsen 1994). Furthermore, as of 2010, much of Puerto Rico's public water supply (60 percent of the 85 percent assessed) was considered "impaired" under the CWA reporting requirements and failed to meet local water quality standards for at least one designated use (table C4-1). Impairment to waterways and bodies was attributed to municipal discharges, agriculture, and urban runoff (USEPA 2010).

Similarly to Puerto Rico, most of the waters assessed in Hawaii for EPA reports on water quality do not meet local water quality standards for at least one of their designated uses and are considered "impaired." Other than the data presented in table C4-1, there are no available quantitative data on forest water resources for Hawaii. Nonetheless, many of the state's rivers and streams have been partially or fully altered (channelized, diverted, or tapped via ground-water pumping) and those that remain are considered to be vulnerable to continued pressure as the demand for fresh water outpaces the supply (State of Hawaii 2010). Moreover, Hawaii's watersheds and (downstream) freshwater habitats have been significantly affected by nonpoint source pollution, sedimentation, storm water runoff, and wildfire (State of Hawaii 2010).

Water resources within forested areas in Hawaii are indirectly altered by three major agents: feral ungulates, nonnative fish, and nonnative plants. Nonnative ungulates affect native vegetation that has no natural protective measures against these animals. Ungulates not only consume and destroy forest ground cover but uproot and expose the soil to increased erosion, which often leads to sedimentation of forested waterways and bodies. Additionally, feral ungulates and other feral animals (e.g., rats, cats, dogs, mongoose) affect water quality by serving as vectors for water-borne diseases such as leptospirosis and cryptosporidiosis. Similarly, nonnative plants have had negative effects on the hydrologic processes of Hawaii's forested watersheds. Some nonnative species, such as miconia (*Miconia calvescens*), have been shown to increase water runoff and decrease the infiltration of rainwater belowground and into the aquifer. *Falcataria moluccana*, a nitrogen-fixing nonnative plant, has been shown to increase significantly nitrogen concentrations in streams that were formerly nitrogen limited; thus, the spread of *Falcataria* results in algal blooms and, ultimately, decreased water quality in streams and downstream nearshore areas (MacKenzie 2015, State of Hawaii 2010).

Similarly to Hawaii, forest water resources in the U.S.-affiliated Pacific Islands are affected by water diversions, feral ungulates, nonnative invasive plants and fish, and

Table C4-1. Water-quality data for five jurisdictions in the Caribbean and the Pacific, 2010

	Puerto Rico		Hawaii	American Samoa	Northern Marianas	Guam
Type of water body	**Rivers and streams**	**Lakes, reservoirs, and ponds**	**Rivers and streams**	**Lakes, reservoirs, and ponds**	**Rivers and streams**	**Rivers and streams**
	Miles	*Acres*	*Miles*	*Acres*	*Miles*	*Miles*
Estimated total waters	5,394	12,146	3,905	45.2	257.5	228.7
	Percent					
Percentage of total waters assessed	88.5	71.1	0.2	ND	89.6	37.0
Percentage of total assessed waters—Impaired[a]	84.8	93.7	100	100	91.1	34.2
Percentage of assessed waters designated as public water supply	77.4	84.8	ND	100	ND	58.3
Percentage of assessed public waters—Impaired	85.3	60.3	ND	100	ND	7.1

[a] Impaired = cannot support one or more designated use.
ND = no data.
Source: USEPA 2010.

pollutants such as bacteria, nutrients, chlorides, and toxic contaminants that result from human activities. Although water resources and the protection of their quantity and quality are important to these islands, very little quantitative, regularly collected data related to this indicator were available at the time this report was prepared, with the exception of data on water quality reported to the EPA by American Samoa, Guam, and the Northern Mariana Islands (table C4-1). Guam reported that the majority of its assessed rivers and streams meet local water quality standards, while most of the assessed waters in American Samoa and the Marianas did not meet local water quality standards for at least one of their designated uses. In American Samoa, impairment to waterways and bodies was attributed to agriculture, livestock, and municipal discharges. Guam and the Marianas did not report on impairment causes.

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Russell and Sidney Poore

Cinnamon Bay Plantation, Saint John, U.S. Virgin Islands.

Criterion 5

Maintenance of Forest Contribution to Global Carbon Cycles

Kathleen S. Friday

Introduction

Increasing carbon dioxide (CO_2) in the atmosphere is driving global climate change, including overall warming and sea-level rise, with consequences for the sustainability of world ecosystems and economies. The effects of climate change on forest health are discussed under Criterion 3. The effects of forests and forest management on carbon cycles are discussed here. Forests are one of the largest terrestrial reservoirs of biomass and soil carbon. **Total forest ecosystem carbon** is encompassed by the following components, or "**pools**": standing wood; other live aboveground biomass (bark, branches, foliage, and smaller plants); live belowground biomass (roots); lying and standing coarse woody debris (dead trees and limbs); and soil carbon. The amount of carbon in each pool is the **stock**, expressed in mass (weight) of carbon (C). Forests influence the chemical composition of the atmosphere, which is also a carbon pool. Vegetation draws CO_2 from the atmosphere through photosynthesis, and returns it through respiration, including that from the decay of organic matter. **Carbon fluxes** refer here to net changes in carbon stocks. **Carbon sequestration** (positive flux) refers to net storage of carbon in the forest, as opposed to net loss of carbon (negative flux) to the atmosphere. Carbon stocks and fluxes per unit area differ by forest type (including climatic life zone), by age class or successional stage, and by management regime. Wet forest pools tend to be larger and faster growing than dry forests; tropical forests are faster growing than temperate forests. Disturbance (including harvesting and fire) typically reduces total carbon stored in the live forest, at least in the short term. Forest products are also a pool of carbon. When a tree is harvested, its wood may be stored in long-lived products for years, while the forest (from which it was taken) sequesters more carbon as it grows back. Forest products thus delay the release of carbon into the atmosphere.

Energy produced from forest biomass may offset the need to burn fossil fuels, while the forest from which it was taken sequesters more carbon as it regrows. The use of renewable forest resources for energy thereby benefits the global carbon budget and lowers net carbon emissions in the medium to long term.

Criterion Summary

Carbon stock estimates available for the different islands differ considerably owing to the size of each island, differences in actual conditions among islands, and different estimation techniques used. Compared to continental forests, total island carbon stocks are small, although some stocks are large per unit area, such as soils of island forested wetlands. Islands have focused on adaptation (managing effects of climate change); climate change is widely considered a cross-cutting issue threatening forest biodiversity and forest extent (Criterion 1) and forest health (Criterion 3), freshwater resources (Criterion 4) , coastal and marine resources, and migration. Islands have had relatively little focus on mitigation (managing carbon stocks and fluxes), although where per-acre fluxes are potentially large, there are opportunities for sequestration incentives and bioenergy generation, subject to data limitations, socioeconomic conditions (Criterion 6), and institutional capacity (Criterion 7) .

The Indicators

Carbon stocks and fluxes are estimated by various techniques and metrics. Measurements may include different components of the total forest ecosystem: trees or shrubs; live or dead biomass; wood or other vegetative material; and aboveground or belowground biomass. Different conversion factors may be applied to convert local field data into total carbon estimates. The Forest Service's Forest Inventory and Analysis (FIA) program provides data for aboveground live trees using a consistent methodology in the U.S.-affiliated Pacific Islands (west of Hawaii): FIA plot data for live trees at least 5 inches in diameter at breast height (≥5inches dbh) were converted to C mass of woody stems and extrapolated using contemporary forest extent maps for each island. FIA carbon estimates for Puerto Rico and the U.S. Virgin Islands (USVI) included live trees ≥1 inch dbh, but noted the percentages of biomass in the 1 to 4.9-inch dbh class (27 percent in Puerto Rico, 67 percent in the USVI), thus facilitating comparison with the Pacific (Brandeis and Turner 2013a, 2013b). Asner et al. (2016) estimated biomass for Hawaii based on a combination of LiDAR and satellite imagery validated by FIA plot data. Donato et al. (2012) extrapolated plot data (stems ≥2 inches dbh) over three mapped vegetation types in Yap and Palau, and also measured soil carbon.

Estimates of total carbon stocks for the U.S.-affiliated Pacific Islands are based on FIA plot data extrapolated using standard United Nations Food and Agriculture Organization (FAO) and International Panel on Climate Change (IPCC) conversion factors (FAO 2008). For Hawaii, Asner et al. (2011) found that their estimates were much lower than if the same field data were interpreted using IPCC conversion factors. For Palau, Donato et al. (2012) had results roughly a third lower than Donnegan and Holm (2010) using IPCC methodology.

Few data are available concerning forest product carbon stocks and fluxes, or avoided fossil fuel carbon emissions.

- **5.22:** Total forest ecosystem carbon pools and fluxes.
- **5.23:** Total forest product carbon pools and fluxes.
- **5.24:** Avoided fossil fuel carbon emissions by using forest biomass for energy.

Indicator 5.22
Total Forest Ecosystem Carbon Pools and Fluxes

Stocks in Carbon Pools

Total jurisdiction carbon (C) stocks in vegetation range from 0.28 to 39.67 million tons, depending upon the size of each island, the nature of its forest, and differing vegetation pools and methodologies (table C5-1). For the U.S.-affiliated Pacific Islands, Donnegan et al. (2004a, 2004b, 2007, 2011a, 2011b, 2011c) provide C estimates for woody stems of trees for the year in which FIA plots were installed. Donnegan (2010a, 2010b, 2010c, 2010d, 2010e), and Donnegan and Holm (2010) provided estimates of carbon in aboveground living tree biomass and aboveground and belowground living tree biomass using the same

Table C5-1. Total carbon stocks per island jurisdiction

Island jurisdiction (year of inventory)	In woody stems of trees ≥5 inches dbh	In aboveground living forest biomass	In aboveground living tree biomass	In aboveground and belowground living tree biomass
	Thousand tons of carbon stock			
U.S. Virgin Islands (2009)			609	737
Puerto Rico (2009)			22,537	27,016
Hawaii (~2009–2014)		39,672		
American Samoa (2001, 2010a)	539		1,726	2,140
Republic of the Marshall Islands (2008, 2010[a])	427		2,006	2,546
Federated States of Micronesia (2005–2006, 2010[a])	4,545		17,676	22,459
Saipan, Tinian, Rota [Commonwealth of the Northern Mariana Islands] (2004, 2005[b])	281		1,796	2,281
Guam (2002)	490		1,561	1,982
Republic of Palau (2003, 2010[a])	2,297		9,246	11,747

[a] Aboveground and belowground living tree biomass was extrapolated forward from date of inventory to 2010 by Donnegan (2010a, 2010c, 2010e).
[b] Aboveground and belowground living tree biomass was extrapolated forward from date of inventory to 2005 by Donnegan (2010b).

dbh = diameter at breast height.

Source: Asner et al. 2016; Brandeis and Turner 2013a, 2013b; Donnegan 2010a, 2010b, 2010c, 2010d, 2010e; Donnegan and Holm 2010; Donnegan et al. 2004a, 2004b, 2007, 2011a, 2011b, 2011c.

data but extrapolated forward to 2010. For the Caribbean, Brandeis and Turner (2013a, 2013b) also provided estimates of carbon in aboveground living tree biomass for 2009, based on data for trees ≥1 inches dbh in that year. Hawaii's data are drawn from FIA plots installed over a period of about 6 years.

Jurisdiction average carbon stocks per unit of forested land range from 5.6 to 29.2 tons of carbon per acre, and again are shown based on differing vegetation pools and methodologies (table C5-2). Carbon stocks are spatially heterogeneous in the islands; in Hawaii, the highest forest stand aboveground carbon density reached 240 tons C/ac (Asner et al. 2016).

Inclusion of the soil carbon pool results in larger figures for stocks. In Puerto Rico, additional plot data on downed wood and forest litter was also used to estimate total (above- and belowground, living and dead, litter and forest floor) carbon stock of 40.3 million tons (Brandeis et al. 2007). Donato et al. (2012) noted that the deep organic soils of Micronesian mangroves store more carbon per unit area (281 to 336 tons C/ac) than all other pools combined on those islands. Using different methodologies, Donato et al. (2012) had significantly different summaries of total carbon stocks. FIA-based estimates in table C5-1 show Palau's living tree stock as 2.3 to 11.7 million tons; Donato et al. estimated that Palau's living tree stock is 7.3 million tons and its total carbon stock, including mangrove soils, is 16.8 million tons.

Carbon Fluxes

Carbon fluxes for the U.S.-affiliated Pacific Islands may be quantifiable by future analysis of 2012–2018 remeasurement of FIA plots (see chapter 2). Carbon stocks inferred from Pacific timber inventories of the 1980s (for

Table C5-2. Carbon stocks per unit area of forest for each island jurisdiction

Island jurisdiction (year of inventory)	In woody stems of trees ≥5 inches dbh	In aboveground living forest biomass	In aboveground living tree biomass	In aboveground and belowground living tree biomass
	Tons of carbon per forested acre			
U.S. Virgin Islands (2009)			13.5	16.0
Puerto Rico (2009)			18.5	22.0
Hawaii (~2009–2014)		29.2		
American Samoa (2001)	12.4			
Republic of the Marshall Islands (2008)	18.4			
Federated States of Micronesia (2005–2006)	31.7			
Commonwealth of the Northern Mariana Islands: Saipan, Tinian, Rota (2004)	5.6			
Guam (2002)	7.7			
Republic of Palau (2003)	25.3			

dbh = diameter at breast height.
Source: Asner et al. 2016; Brandeis and Turner 2013a, 2013b; Donnegan and Holm, 2010; Donnegan et al. 2004a, 2004b, 2007, 2011a, 2011b, 2011c.

example, Cole et al. 1988) cannot be directly compared with carbon stocks based on total forest biomass from 2001–2007 FIA data; therefore flux cannot be quantified over that two-decade interval. Because there are few data now available for carbon fluxes, table C5-3 presents change in forest area and other published observations for an entire jurisdiction as a proxy for carbon flux.

Positive carbon sequestration rates in Puerto Rico are inferred from net shifts of agricultural land to forest land from 1980 to 2003 (Brandeis et al. 2007) and high rates of sequestration by young secondary forests (Grau et al. 2003, further explained under Criterion 2). Brandeis and Turner (2013a) calculated a net gain of 170 million cubic feet of wood during 2004–2009 (considering growth, mortality, harvesting, and clearing) and described Puerto Rico as a carbon sink. Likewise, for the USVI, Brandeis and Turner (2013b) calculated a net gain of 4.7 million cubic feet of wood during 2004–2009. Sequestration is taking place on forested land, owing to the early successional stage of forests (as in Puerto Rico). During 1994–2004, there were net losses of forest carbon resulting from the loss of forested area (Brandeis and Oswalt 2007), but forest loss during 2004–2009 slowed and approached stability (Brandeis and Turner 2013b).

Stocks of carbon in living biomass in Guam are assumed to fluctuate with typhoons, as total forest area is fairly stable but frequent typhoons cause damage, followed by sequestration as forests recover. The clearing of mangrove forests may have a large impact on carbon fluxes if significant portions of the soil organic matter are oxidized (Donato et al. 2012). Plantations of *Eucalyptus* spp. (Hawaii) or rapid growth of large trees such as *Falcataria moluccana* (especially in Hawaii and American Samoa) sequester large amounts of carbon; because these species are not native, such sequestration entails a tradeoff with biodiversity values (Hughes et al. 2014).

Indicator 5.23
Total Forest Product Carbon Pools and Fluxes

Less than 0.01 percent of Puerto Rico's annual forest wood production was harvested for wood products (Brandeis et al. 2007), and 0.13 percent was harvested for any purpose including clearing (Brandeis and Turner 2013a). Overall, the amount of carbon being removed as wood products from Puerto Rico's forests is negligible compared to that being stored, and accumulating, in the forest vegetation, floor, and soils. Likewise, the amount of

Table C5-3. Trends contributing to flux in carbon stocks by jurisdiction

Island jurisdiction and time frame	Carbon sequestration per unit area of forest	Change in forest area	Flux (per jurisdiction)
		Percent	
U.S. Virgin Islands:			
1994–2004	Positive	-7	Negative
2004–2009		Stable	Positive
Puerto Rico:			
2003	Positive	Positive	Positive
2004–2009		Stable	Positive
Hawaii			Unknown
American Samoa (1986–2001)		-3	Negative
Republic of the Marshall Islands			Unknown
Federated States of Micronesia (2005)			Slightly positive
Commonwealth of the Northern Mariana Islands (2005)		Negative	Negative
Guam (2000)		Negligible	Fluctuating (typhoons)
Republic of Palau (2005)	Positive	May be at a peak	Unknown

Sources: Brandeis and Oswalt 2007; Brandeis and Turner 2013a, 2013b; Brandeis et al. 2007; Donnegan 2010a, 2010b, 2010c, 2010d, 2010e; Donnegan and Holm 2010; Donnegan et al. 2004b.

carbon being removed as forest products from the forests of the USVI is nominal (Pierce and Hultgren 1997). Harvesting for wood products in Hawaii is primarily for low-volume, high-value woods; large-scale harvesting of *Eucalyptus* spp. plantations was not yet underway by 2010. Data are not available for the other Pacific Islands, but because wood products are harvested only for local and subsistence use, it may be assumed that sequestration in wood products of Pacific Island origin is not significant locally or globally.

Indicator 5.24
Avoided Fossil Fuel Carbon Emissions By Using Forest Biomass for Energy

No data were available for Puerto Rico and the USVI at the time this report was prepared. The use of forest biomass for energy in Hawaii was still at the trial stage in 2010. Fuelwood is commonly used in the Federated States of Micronesia and some other Pacific islands as an extension of traditional and subsistence use for cooking, and as a substitute for more expensive imported energy, but data documenting this use are not available, and overall effects on carbon emissions are likely insignificant. Coconut oil (a forest product) is being used in the Marshall Islands as a substitute for fossil fuels for vehicles, but quantitative data are likewise lacking.

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Kathleen Friday

Portable sawmill in Palau milling *Swietenia macrophylla* (Honduran mahogany), a nonnative species that is produced for local use and limited exports. Local uses include furniture and elaborately carved storyboards that illustrate Palauan legends.

Criterion 6

Maintenance and Enhancement of Long-Term Multiple Socioeconomic Benefits to Meet the Needs of Societies

Guy C. Robertson and Constance A. Carpenter

Introduction

Through an emphasis on concepts such as the "triple-bottom-line," researchers and sustainability advocates have highlighted the linkages between social and economic measures of sustainability and those from the ecological realm (Floyd 2002). The Montréal Process Criteria and Indicators (MP C&I) mainly address the socioeconomic dimensions of forest sustainability in Criterion 6 ("Maintenance and Enhancement of Long-Term Socioeconomic Benefits to Meet the Needs of Societies"), whose 20 indicators are arranged into five subcriteria and cover an array of topics, ranging from forest products trade and production to spiritual benefits from forests and the well-being of forest-dependent communities. The following chapter applies Criterion 6 to the U.S. and U.S.-affiliated tropical islands considered in this report.

Forests are often essential to the well-being of island populations. Small and isolated island ecologies reinforce the linkages among forests, agriculture, and coastal fisheries. Traditional economies and subsistence activity make use of the total ecosystem, including forests, and tourism relies on the unique beauty provided by healthy island ecosystems (of which forests are an integral part). Historical and archaeological analysis of places like Easter Island has highlighted the crucial linkage between human populations and forest resources, and conveys the tragic results when forests are not sustained (Rolett and Diamond 2004). Nevertheless, the discrete and heterogeneous island geographies that are the subject of this report present several challenges when applying the Criterion 6 indicators of the MP C&I. In the first place, many of the island jurisdictions considered here lack a well-defined forest sector from which statistical measures can be drawn. Most, in fact, have little or no industrial wood products manufacturing and therefore no "forest-dependent" economic activities or communities as defined or measured in an industrial sense. Unlike the continental United States, many of these islands are so small that forests are integrated across their landscapes and cannot be isolated to a geographic "region" where social and economic activities can be analyzed specifically in regard to their relation to forest resources. And, finally, the ubiquitous lack of data that challenges our reporting in the other criteria is evident in Criterion 6 as well. As a result, with the exception of certain statistics for Hawaii and Puerto Rico, there is little or no specific information as to the production and trade of forest products, forest-sector investment, forest-based recreation, or the economic and social well-being of forest-dependent communities.

So, although the socioeconomic dimensions of forests are every bit as important in this island context as in the continental United States, the measures for describing this importance are less defined and developed. As a result, in addressing Criterion 6 for these tropical island jurisdictions, we take a more flexible approach than in previous criteria, treating each of the criterion's five subcriteria, using available data to say what we can but not reporting out on each indicator. For several of the subcriteria there is very little information to provide, and in these cases we briefly describe why each subcriterion is important and identify what sorts of data would be helpful if available. In other cases, owing to the nature of small island geographies, we have supplied additional information not called for in the MP C&I. In particular, we have included a discussion of demographic information on population density and growth.

Criterion Summary

When considering the social and economic dimensions of forest sustainability for the islands treated in this report, the most important characteristic to bear in mind is the high variability in social and economic circumstances found between them. Cultural roots and specific histories radically differ between regions and islands. Economic conditions vary, ranging from high-income jurisdictions comparable to the U.S. mainland to lower income jurisdictions that have more in common with developing nations. Income sources likewise differ, with high reliance on exports and expatriate remittances in some places, tourism in others, and diverse activities commensurate with developed, large-scale economies in yet others. Governmental arrangements also differ, ranging from full U.S. statehood to compacts of free association, and these arrangements drive differences in economic practices and institutions as well as the resources available for forest management. All these differences are reinforced by the relative isolation imposed by island geography, whose effects in the social and economic realms are analogous to those imposed in the ecological realm.

Overall, there are few hard data on the social and economic dimensions of forest sustainability for the islands considered in this report. The general absence of commercial wood products industries means that none of the traditional economic statistics associated with forests, such as production volumes, incomes, and jobs, are available. Nonetheless, in many places, the production of wooden building and craft materials is identified as an important forest contribution. Tourism is the most identifiable industry that is at least partially linked to forests, but here the statistics are cursory at best and the actual role of forests in that industry is not clear. Food production, through gathering, hunting, and agroforestry, is identified as an essential function of forests, particularly in lower income islands, but there is little consistent information on the actual contribution of these activities to inhabitant's welfares. And finally, forests are an important source of aesthetic beauty and spiritual sustenance across the islands, though these values are difficult to quantify.

A review of "Statewide Assessments and Resource Strategies," or SWARS) (see chapter 3) produced for each of the jurisdictions considered in this report (NASF 2016) indicates that forest functions are recognized and valued as essential contributions to society. The tropical islands have deep cultural traditions that have evolved in tandem with local ecosystems. This history, combined with the isolated character of these places, means that residents no doubt have a profound sense of place that is strongly linked to local environments, including forests. Part of this sense of place involves an understanding of the linkages between forests and society, between human actions and environmental conditions, which is the hard-won knowledge held by people who have lived in the same place for many generations. This knowledge is an important first step in sustainably managing forests, but conditions are changing rapidly in many of these places, and management practices will have to adapt to meet these changes. On many islands, balancing population growth, tourism activity, and general economic development with the maintenance of healthy and intact forest ecosystems will be an ongoing challenge. On others, managing forest resources to meet the material needs of growing populations and providing additional economic opportunities where possible will be the major challenge.

Montréal Process Criterion 6 Subcriteria

The Montréal Process Criterion 6 contains 20 indicators arranged under five subcriteria. We address each of these subcriteria, but not the individual indicators contained within them, in the following sections. Additionally, we have included a section on demographic conditions as these are often essential in understanding forest sustainability in an island context. Accordingly, the six subcriteria addressed in this chapter are:

- Demographics (not included in MP C&I)
- Production, consumption, and trade (of forest products, including nontimber products)
- Investment in the forest sector
- Employment and community needs
- Recreation and tourism
- Cultural, social, and spiritual needs and values

Given the close linkage between human populations and ecological conditions throughout the islands, basic demographic information provides an essential context for understanding forest sustainability. Table C6-1 shows basic demographic information (current population, population growth trends and densities, and per capita incomes) for the Caribbean Islands, Hawaii, and the other Pacific Islands.

The diversity of data sources in table C6-1 points to the lack of consistency in data reporting for the island jurisdictions. Population growth and gross domestic product per capita figures are particularly problematic, with variable data sources, reporting dates, and estimation techniques. Also, smaller jurisdictions may be subject to abrupt changes owing not only to changing conditions but also reporting conventions and immigration laws. The Commonwealth of the Northern Mariana Islands (CNMI) is a case in point, where a nonresident contract worker program was phased out in 2009 in response to U.S. legislation, resulting in the departure of thousands of guest workers and closure of the local garment industry.

The data demonstrate the diversity of demographic conditions found across the islands. With the exception of Hawaii and Puerto Rico, the jurisdictions in our sample are quite small both in terms of land area and of population, and they all have higher population densities than listed for the continental United States. Common sense tells us that population density will be strongly linked to forest sustainability, but the density numbers should be interpreted with caution. Several places listed in table C6-1 are actually comprised of numerous small

Table C6-1. Demographic information for islands considered in this report

	Land area	Population: In 2010[a]	Population: Growth from 2000 to 2010[b]	Population: Per square kilometer	GDP per capita (2013)[c]
	Square kilometers	*Number*	*Percent*	*Number*	*U.S. dollars*
Caribbean:					
U.S. Virgin Islands (USVI)	346	106,405	-2.0	308	36,100
Puerto Rico (PR)	8,870	3,725,789	-2.3	420	28,500
Pacific:					
Hawaii (HI)	16,635	1,360,301	12.6	82	44,024
American Samoa (AS)	199	55,519	-3.1	279	13,000
Guam	544	159,358	2.9	293	30,500
Marshall Islands (RMI)	181	69,747	16.6	385	3,400
Micronesia (FSM)	702	102,843	-3.7	151	3,100
Northern Marianas (CNMI)	464	53,883	-22.2	116	13,300
Palau	459	21,108	3.4	46	13,600
United States	9.8 million	309 million	9.7	32	53,600

[a] USVI, PR, HI, AS, CNMI, Guam, United States = U.S. Census; RMI, FSM, Palau = CIA World Factbook 2014 estimates.

[b] USVI, PR, HI, AS, CNMI, Guam, United States = U.S. Census; RMI, FSM, Palau = estimated from data from Statistics for Development (SDD) (http://www.spc.int/sdd/index.php).

[c] CIA World Factbook (except Hawaii, which was calculated using state gross domestic product (GDP) and population—may not be directly comparable with other jurisdictions).

Sources: U.S. Census, CIA World Factbook, SDD.

islands (notably the CNMI, Federated States of Micronesia [FSM], Palau, and Republic of the Marshall Islands [RMI]), and densities will not be distributed evenly, particularly given the high number of uninhabited islands in many jurisdictions. Except for the FSM, the percentage of total population living in urban areas (as defined by the CIA World Factbook, https://www.cia.gov/library/publications/the-world-factbook/) is well in excess of 70 percent, and the process of urbanization is continuing everywhere, meaning that the populations, and many of their impacts, are concentrated primarily in urban centers. The dominant role of Honolulu in Hawaii is an example of this.

Urbanization brings altered relationships between people and forests; in some cases reducing direct pressures on forests as rural residents migrate to urban centers, but also resulting in some forest loss, from conversion to development and timber consumption for building materials, for example. Additional effects occur when urbanization expands in an unplanned or haphazard fashion across the landscape, fragmenting forests and other natural areas, a situation that is common in the tropical island jurisdictions considered here. In any case, the influence of population density and urbanization on forest sustainability, both in the tropical context studied here and elsewhere, is a complex issue (Nowak and Walton 2005, van den Berg et al. 2007). Also, with the exception of Puerto Rico and Hawaii, the populations listed here are relatively small, and although they might be considered predominantly "urban" by definition, the towns are necessarily quite small relative to the urban centers found in the continental United States and often retain a strong rural character. Concern over the loss of forest cover and associated forest values resulting from development is a common theme in the related literature and the SWARS reports (this was particularly so in Guam, which has been anticipating a marked increase in U.S. military presence through base expansions).

Population growth is likewise variable across the places described in table C6-1. Four jurisdictions exhibited negative population growth between 2000 and 2010. Of the rest, the RMI, and, to a lesser extent Hawaii, stand out as high-growth locales. Moreover, most of the jurisdictions (notably Palau and the RMI) had seen substantially higher growth rates prior to 2000. However, the growth figures presented here may be at least partially an artifact of reporting and estimation techniques, particularly for those jurisdictions not covered by the U.S. Census (the RMI, FSM, and Palau).

It is tempting to equate high population growth with growing threats to forest sustainability, but this determination can only be made while considering other important social and environmental factors. While the high growth rates in the RMI, as well as the high population densities in Puerto Rico, the U.S. Virgin Islands (USVI), American Samoa, Guam, and the RMI are not by themselves indicators for major concern regarding forest sustainability, they should be monitored alongside other key data to determine their effects on forests in the future. High population growth and density in a limited geographic space will undoubtedly present major challenges for forest sustainability if they continue in the long term. Moreover, in places such as the USVI or Hawaii where tourism significantly increases the number and impact of people present at any given time, resident population levels and their growth will underestimate actual population pressure for development and local demand for environmental services.

The final column in table C6-1 shows per-capita income, and here again the conditions differ greatly throughout the islands. Hawaii, which is fully incorporated into the U.S. economy and political system, enjoys income levels similar to those of the other 50 states. The USVI, Guam, and Puerto Rico occupy a middle income range, and the remaining islands show annual incomes ranging from $3,000 to $13,000, a fraction of those generated in the 50 U.S. states.

The relationship between income and sustainability is a complex one. In general, rising incomes are associated with negative environmental effects at the lower end of the income scale but may result in reduced negative effects (at least locally) at the higher end of the scale as residents gain more wealth and security and are able to "afford" more environmental protection or management of ecosystems (Bhattarai and Hammig 2001, Dinda 2004). The extent to which this sort of dynamic is working in any of the places considered here, however, will depend on specific local conditions, the ways in which subsistence and agricultural activities interact with local ecosystems, and the economic activities that are driving development. Economic growth from timber harvest or agricultural activity for export, for example, will have radically different effects on the environment than growth from tourism development. In other words, forests and their sustainability will be determined by actual management and use and not simply by general levels of economic activity or development (Cropper and Griffiths 1994).

Production, Consumption, and Trade of Forest Products

When considering production, consumption, and trade of forest products, we immediately run into the lack of data that also challenges much of our forest sustainability reporting for the other criteria. Outside of Hawaii, there is very little commercial production of wood products for export or sale through formal distribution channels. None of the islands reported significant harvests of industrial roundwood or fuelwood in the most recent report of the Food and Agriculture Organizations Global Forest Resource Assessment (FAO 2015). Likewise, in the recent round of area forest assessments undertaken in the SWARS reporting exercise, the promotion of industrial wood products is not mentioned as a central objective for forest management in any of the area reports.

However, the lack of both data and a stated focus on industrial-scale wood products production notwithstanding, there is a great deal of informal production of both wood and nonwood products for local use on many islands, some of which may be sold in local markets but much of which is for subsistence use or barter trade. Although little or none of this activity is measured in terms of formal economic statistics of production and trade, its role in providing sustenance and other benefits for local residents can be crucial and has been documented in a few case studies that provide valuation of forest products such as mangrove crabs, wild pig meat, crops, and timber in the subsistence economy (Drew et al. 2005, Naylor and Drew 1998). Asian Development Bank reports for the lower income islands show that agroforest-related production is important in household production. For example, copra production, handicrafts, and "subsistence" use were found to comprise 54 percent of household production in the RMI (Asian Development Bank 2005). With the exception of copra, none of these products are explicitly delineated in production statistics.

Table C6-2 lists products emphasized or otherwise mentioned in the SWARS reports and in other literature covering the islands considered in this report. The lists are not exhaustive—no doubt many uses are not included—but they do provide a gauge of the relative emphasis that

Table C6-2. Forest products production and use

	Wood products	Nonwood products
Caribbean:		
U.S. Virgin Islands	Mahogany (*Swietenia* spp.) and tibet (*Albizia lebbeck*) for craft and building materials The last reported data from 1997 indicated approximate production of 189,000 board feet per year. (The Nature Conservancy 2003, see also Pierce and Hultgren 1997).	Food (tropical fruits) and medicinals
Puerto Rico	Limited plantation activity for timber production and forest restoration. Some timber production for local use, craft, and specialty products (musical instruments) (Brandeis et al. 2007, Kicliter 1997)	Agroforestry, food and medicinals, craft materials, resins, and oils
Pacific:		
Hawaii	Craft and furniture production using native hardwoods; small volumes of pulp production using nonnative species (eucalypts)	Game animals for personal use; plant materials for traditional craft use; edible and medicinal plants and fungi for traditional and commercial use
American Samoa	Building materials for local use, fuelwood, wood for craft production (no formal sector)	Subsistence harvest of food and medicinals, craft materials, traditional agroforestry systems
Republic of the Marshall Islands	Wood for craft production	Extensive agroforestry and coconut plantations; coconut and pandanus fiber for craft production
Federated States of Micronesia	Sawnwood production for domestic consumption and limited export. Mangrove wood for woodcarving	Agroforestry systems
Commonwealth of the Northern Mariana Islands	Fuel, fiber, lumber, and poles for local use	Agroforestry systems, medicinals and foodstuffs, game animals as important traditional source of protein (though increasingly scarce)
Guam	None identified	Game animals (wild pig and deer) for personal use; gathering of betel nuts
Republic of Palau	Building materials for local use, fuelwood, mahogany (*Swietenia* spp.) wood for carved storyboards	Agroforestry systems, medicinals, foodstuffs, craft materials, and other cultural resources

Note: Products are culled from various publications, and the listing here likely does not include all products and uses.
Source: Statewide Assessments and Resource Strategies reports and miscellaneous.

different outputs are given in different places. Though commercial production of forest products is noted for several islands, it is very limited and nowhere rises to the economic importance of major activities such as, for example, tourism or fishing. Rather, wood products production for export, where it is considered, is seen as a limited opportunity for additional income. This is in keeping with the fact that forestry is an extensive land use activity, and land is precisely the commodity that the islands have in short supply. Those islands reporting commercial production or an interest in production are either the larger islands (Hawaii and Puerto Rico), or smaller entities with lower population densities (FSM and Palau).

Wood products production for local consumption is much more common, with local-use building materials listed for more isolated and less affluent islands, and wood for crafts listed throughout the SWARS reports. Craft products can be used in cultural applications or as a source of additional income associated with the tourist trade. Fuelwood is another important use in some places, especially as required for “imu” (pit oven) cooking of traditional foods, still common in the Pacific.

Nontimber forest products such as foodstuffs, medicinals, and craft materials are commonly mentioned, either as a source for local subsistence use or as inputs for the tourist trade. Wild game, and the role of forests in providing habitat for game animals, figures prominently in several locations, notably in Guam and the RMI, where traditional game species (primarily pigs or deer introduced by Micronesians or the Spanish) are reportedly in sharp decline owing in part to overhunting and a lack of habitat. Finally, agroforestry systems, in which trees and food crops are intentionally integrated, are a common land use throughout these tropical islands. In the Pacific, agroforestry practices have deep roots associated with the traditional multistory agroforest, tree fallow, or mulch systems carried from island to island by Polynesian and Micronesian cultures as they successively colonized the region. The SWARS reports for the RMI and FSM place particular stress on traditional agroforestry as a means of providing food security and improved nutrition for residents, and similar objectives are undoubtedly important elsewhere in the region. Awareness is rising that traditional agroforest foods (breadfruit, taro, coconut, banana, pandanus, foliage, citrus, and other fruits) provide more fiber and vitamins than the highly processed Western foods that are commonly imported (white rice and bread, canned vegetables, and sweetened drinks).

In the Caribbean, agroforestry is seldom explicitly mentioned in the SWARS and other published literature, but small-scale agroforestry home gardens are common, and the biological legacy of plantation history in the region presents opportunities in the area of, for example, copra production (from coconuts), bananas, and especially shade-grown coffee in combination with various tree species (Borkhataria et al. 2012). The extent to which this activity is considered to be forest-based as opposed to strictly agricultural will vary from place to place, but in many instances it is integral to the question of forest use and sustainability (MacFarland et al., in press.)

The area and percentage of forests managed for subsistence uses is essentially synonymous with the extent of agroforests in the Pacific (excluding Hawaii), although subsistence gathering and some management also takes place in mangrove forests (crabs) and upland native forests. The extremely high percent of Marshallese land managed as agroforest (see table C6-3) reflects the limited land base of this atoll nation and the extensive coconut plantations that were established after Western colonization.

Data on the extent of agroforest are depend on the vegetation classification systems used; Forest Service vegetation surveys in the 1980s specifically mapped a variety of agroforest types, including secondary vegetation associated with long-term agroforest management, while current maps of American Samoa in particular do not attempt to map agroforest separately, instead including agroforest variously within other landcover types ("forest," "agriculture" including coconut plantations, and "urban cultivated," including home tree gardens).

Investment in the Forest Sector

Because little in the way of production forestry is present on the islands considered in this report, standard investment activity in forestry (i.e., commercial plantations or wood processing facilities) is also largely absent. Specifically, there is little or no quantified data on investment

Table C6-3. Extent of agroforest in Pacific islands

Island/country	Source and year(s) of assessment	Agroforest extent	Share of total forest
		Acres	*Percent*
American Samoa	1984 (Cole et al. 1988)	15,510	35
	2003 (Donnegan et al. 2004)	0 to 9,000	0–20
Republic of the Marshall Islands	2006–2008 (Donnegan et al. 2011b)	20,000	85
Federated States of Micronesia	1975–1976 (Falanruw et al. 1987a, 1987b; MacLean et al. 1986; Whitesell et al. 1986)	30,308	25
	2005–2006 (Donnegan et al. 2006)	35,655	25
Commonwealth of the Northern Mariana Islands	1976 (Falanruw et al. 1989)	4,488	8
	2003 (Donnegan et al. 2011b)	1,313	3
Guam	2002 (Donnegan et al. 2004)	1,921	2
Republic of Palau	1976 (Cole et al. 1987)	2,740	4

expenditures or outcomes. At the same time, however, many of the islands (Hawaii, Puerto Rico, the USVI, and Palau) note in their respective SWARS reports limited plantations of mahogany and similar tropical species, either as ongoing activity or a legacy of past investments. In the Caribbean, many areas experienced severe deforestation in the late 19th and early 20th centuries, owing in large part to clearing for agriculture. By the 1930s, efforts emerged to reforest less productive (agriculturally) and sensitive (e.g., slopes) areas. Plantations of high-value species (e.g., mahogany or cedar) and fast-growing species (e.g., eucalyptus) were established across the islands. Initially, these plantations received sound management and investment, but over the years management effort has dwindled, and it is highly unlikely that these stands will receive significant management investments in the future. Nonetheless, the reforested areas have served as important vectors for forest restoration in Puerto Rico and the USVI. In the Pacific Region, opportunities for investment in extensive forestry appear to be much more limited (as is the land area, except for Hawaii), and where growing trees for commercial production is mentioned, it is restricted to relatively small plots and focused on the production of specialty woods for high-value export. Hawaii is an exception, with plantations of eucalypts for pulp production having been established in the past; eucalyptus plantations from the 1990s are now beginning to be harvested for biofuel, but whether this activity emerges as a major end use or motivates new plantings remains to be seen. In total, tree plantations of native and nonnative species cover nearly 90,000 ac and account for almost 6 percent of all forest land in Hawaii, though the extent to which these lands receive ongoing management investments is unclear.

Investment in wood processing facilities is even less apparent. Many of the islands cite small-scale production of lumber for local use, though it is likely that this occurs with simple equipment (e.g., portable sawmills) and minimal investment in processing facilities. The FSM is the only place that cites sawmilling as a major concern in its SWARS report, and it is mentioned primarily in regard to the threat local sawmills pose for forest sustainability. However, small but ongoing investment in processing capacity is occurring here. In any case, the SWARS reports nowhere mention a desire or plans for major investments in production forestry, either in plantation establishment or production facilities.

Investments in various other facets of forest sustainability, on the other hand, do receive considerable attention. The need for urban forestry enhancements, investments in agroforestry, and the establishment of forest management and conservation plans are a common theme throughout the SWARS reports and other literature on island forestry. Many of the islands have forest management departments, educational/research facilities, and functional forest management activities, and the SWARS reports, including detailed spatial data of forest extent and conditions, represent a considerable investment in forest management and sustainability. The fact that these investments often occur in places with limited resources and other pressing problems testifies both to the importance of forests and the desire of local governments and peoples to manage them wisely.

Employment and Community Needs

In line with the general absence of measurable production forestry for processing and export, there is little evidence that commercial logging or wood products production play an important role in the overall economic landscape of the islands considered in this report. Certainly in some instances, such as the sawmilling activity noted in the FSM, the eucalypt harvests in Hawaii, or the mahogany plantations in Palau, forestry and wood products provide direct formal employment, but the overall dependency of island economies on these activities appears to be quite small.

At the same time, however, the various forest outputs listed in the previous section point to a level of dependence on forests for local sustenance and well-being in island communities that is rare in the continental United States. For rural communities, forests are fully integrated into daily life, and, in urban settings, the maintenance of urban forest resources is a common theme throughout the SWARS reports. Add to this the tight feedback loop between forest conditions and those of other island ecosystems, and it is clear that forest health and sustainability are of crucial importance to local communities and their inhabitants. In particular, relationships among forestry, agroforestry, and agriculture form an essential link in the socioecological systems that feed many islanders, especially in the more isolated islands in the Pacific region. And finally, forests provide important amenities (and outputs) that support tourism, an important source of external income in many of the places considered here.

Beyond these broad statements of the role of forests in local lives, the challenge is to find concrete data describing the specific linkages between forests and communities, and, in this regard, there is very little in the way of quantified information to show. Employment and income statistics for forest-specific activities, for example, are essentially nonexistent. Nonetheless, the per capita income data presented above can provide some general indications about the relationship between forests and local peoples. In the lower income places, where available money is not sufficient to import many of the items needed on a daily basis, we can assume importance of local forests in supplying food, building materials, and other subsistence goods to be relatively high. In higher income locations, forests may play a lesser role in supplying daily needs but may be an important component in generating income from, say, tourism or the export of agricultural products. With the exception of Hawaii, incomes are significantly lower than in the continental United States. In this setting, the sustainable management of forests for the benefit of local people clearly will help determine the long-term viability of island ecosystems and the survival of their inhabitants.

Recreation and Tourism

Although recreation and tourism are lumped together in the MP C&I, these two categories represent often fundamentally different activities with fundamentally different economic and social implications. This is especially true for the islands considered in this report, where tourists usually come from great distances, the amount of money they spend is an essential income source for many island communities, and the sorts of places they go and activities they engage in are separate from those of local residents. In fact, for most of the places here included, tourism is identified as the major industry and income source. Before turning to tourism and its relationship to forests, however, we will take time to address the question of local recreation.

Local Recreation

Local recreation refers to time spent and activities undertaken in the forest by local residents for personal enjoyment. Recreation can include activities ranging from hunting or mountain climbing to simply taking a walk in the woods. Unfortunately, with the exception of the El Yunque National Forest in Puerto Rico and a few state forests, once again there are no consistent data measuring recreation use for the islands considered here. However, owing to their relatively rural settings and the closeness of their residents to traditional rural lifestyles, we can assume that recreation use, both in and outside the forest, is considerable.

The preceding section on forest products outlines the various uses and noncommercial products obtained by local residents from their forests. These uses are commonly considered under the heading of "subsistence," a concept denoting work as much as play. But subsistence has a deeper connotation than simply gathering food or materials for daily needs. In addition to providing direct and tangible benefits to local residents, subsistence is often seen as a central component in many rural lifestyles, with strong links to local cultural traditions and fostering strong, even spiritual, connections between people and their natural environment (Emery and Pierce 2005). In this context, subsistence is similar to recreation, but it also includes aspects of economic dependence as well as cultural and spiritual values. It no doubt plays an important role in the lives of many residents, particularly those of limited incomes or those living more traditional rural lifestyles, but just how large a role is unclear. Though information on the harvest of nonwood forest products is included in the Criterion 2 chapter in this report, the available information is not equal to the importance of this topic. Finally, hunting, particularly for nonnative species (feral pigs and deer), is an important subsistence/recreation activity in several Pacific islands, and this points to the effects of long-term ecosystem change on local culture and the complexity of defining desirable conditions to be pursued through forest management and restoration.

Tourism

As opposed to recreation, tourism in the islands is a business, often a big one that contributes significantly to the gross domestic product. Visitor arrival rates are given in table C6-4. For many of the islands, arrivals are well in excess of the local population (though, of course, the visits often last only a few days), and visitors may comprise a majority of the total population present in certain locales at any given time. The relative importance of tourism, however, varies considerably across the islands, ranging from major tourist destinations such as Hawaii or Guam to less frequented places, where tourist activity may be sought but is much less developed. In the former, tourism is the number-one industry, generating incomes that dwarf all other sources. The Guam Visitor Bureau, for example, estimates that tourism accounts for 60 percent of the country's major income sources. The FSM, on the other hand, has a limited number of visitor arrivals and stresses its "unspoiled" character while actively seeking ecotourism development. At between 5,000 and 10,000 visitors per year, the RMI has the lowest visitation rate, equivalent to just 9 percent of the population as opposed to 400- to 700-percent levels for the major destinations such as Hawaii or Guam.

Table C6-4. Visitor arrivals, 2000–2010

	2000	2005	2010	2010 as percentage of population	Notes
	Thousands			*Percent*	
Caribbean:					
U.S. Virgin Islands	546	593	590	464	
Puerto Rico	3,300	3,700	3,100	83	Air arrivals only
Pacific:					
Hawaii	6,900	7,000	9,900	728	Air arrivals only
American Samoa	44	24	23	41	
Republic of the Marshall Islands	5	9	5	7	Air only (2005 air and sea)
Federated States of Micronesia	21	19	45	44	
Commonwealth of the Northern Mariana Islands	517	498	375	696	Air arrivals only
Guam	1,300	1,200	1,200	753	
Republic of Palau	58	81	86	407	Air arrivals only

Note: Cruise ship visitations are omitted for five of the nine countries listed in the table. In comparison to air arrivals, cruise ship activity usually generates less local income, but will also have fewer negative environmental impacts. However, the decisions by major cruise operators to visit, or not to visit, a given port of call can have major consequences for local communities, with abrupt shifts in conditions resulting in the need for rapid adaptation.

Source: United Nations, UNData (http://data.un.org/Default.aspx). Hawaii Tourism Authority (for Hawaii only).

There is a strong correlation between country visitation rates and per-capita income (as shown in table C6-1), and high tourism activity no doubt plays a role in boosting local incomes, though the actual relationship between these variables is more complex than a simple one-way formula in which more tourism produces more income—higher income islands, for example, may be more successful at attracting tourists in the first place.

Following their rapid expansion in the 1980s and 1990s, visitation rates appear to have leveled off or even declined over the last decade (note the sharp drop in American Samoa, for example). Major recessions that began in the early 1990s in Japan and in 2008 in the United States, as well as sharply increasing airfares, are likely responsible for a large proportion of these observed declines. Whether visitation rates have stabilized or will return to a growth trajectory when the global economy fully recovers is an open question. The answer will have important implications for forest sustainability, as it is much easier to adjust in a stable environment than in one characterized by continued rapid growth in visitation. In the poorer locations, however, persistent poverty and the failure of tourism to help boost local incomes may also have negative impacts in regards to sustainability.

Tourism affects local societies and ecologies in different ways. On the positive side, it constitutes a substantial opportunity to garner income without directly exploiting or depleting local resources. As a result, it is often presented as a relatively sustainable form of development in an island setting, as compared to more resource-intensive forms such as logging or mining. Nonetheless, tourist infrastructure developments, such as airports, cruise ship landings, and hotels, have various and direct environmental consequences. Likewise, the effect of large concentrations of visitors in a limited space can have numerous negative impacts both to the environment and to the host society, impacts ranging from waste and sewage generation to the social and economic impacts that arise when local communities become “overrun” by visitors and the businesses that cater to them.

As regards forests in particular, significant impacts of tourism include (1) the effects of onsite activity such as soil erosion and compaction, human-wildlife interactions, littering, and general crowding affecting the natural character of the setting; and (2) effects from infrastructure development such as forest fragmentation and conversion, introduction of nonnative species, and changing hydrological properties as forest cover is replaced by impermeable surfaces. At the same time, however, tourism provides economic opportunities that directly or indirectly rely on the maintenance of local environmental quality, including the quality of forests. Upland and mangrove forests provide tourist opportunities in hiking, waterfall visits, and novel boat tours; forests provide background scenery and watershed protection that enhance the experience of tourists focused mainly on beaches and oceans. The relationship between tourism income and environmental quality is one area in which sustainable resource management and tangible economic benefits in the form of hard cash can be explicitly linked. This linkage can foster considerable political support for forest sustainability efforts.

The SWARS reports for the islands considered here reflect this ambiguous relationship between tourism and forest sustainability. The desire to preserve and enhance forest resources as a means of supporting tourism activity is a common theme running throughout the SWARS reports, but the need to manage tourism and mitigate its potential negative impacts is also noted in many places in the reports and is incorporated in specific management prescriptions. Particularly in places that have already experienced substantial tourism development, the need to manage tourism activity, both from an environmental standpoint and a social standpoint, is well recognized. Finding a good balance between generating local incomes and managing the complex effects tourism entails, however, will be an ongoing challenge.

Cultural, Social, and Spiritual Needs and Values

The MP C&I contain two indicators in this subcriterion: (1) "Area and percentage of forests managed primarily to protect the range of cultural, social, and spiritual needs and values;" and (2) "The importance of forests to people." The values measured in this subcriterion are of crucial importance, but measuring them in a concise and replicated fashion is extremely difficult.

A major challenge in reporting out in the national report (USDA FS 2011) for the first indicator identified above arises from the fact that most public forests in the United States are managed for multiple objectives, among them the sorts of values included in this indicator. Designated wilderness, for example, may help address people's spiritual need for wild places, but it is also designed to preserve habitats or provide backcountry recreation opportunities. The same challenge applies to measuring the cultural, social, and spiritual contribution of forests in the tropics. In addressing forests on the mainland, the national report simply presents information on the amount of forest in various protected statuses, with special emphasis on public lands—a reasonable approach because private lands are generally not subject to the same legal protections (although land trusts and conservation easements constitute an important exception). The same approach can be applied to the islands considered in this report. Indicator 1 and 2 in Criterion 1 provide information about forest ownership and protected status (see Criterion 1 chapter). Hawaii exhibits the highest proportion of forest land in public ownership (53 percent) and formally protected status (43 percent). Guam has high public ownership but an extremely low proportion of formally protected forest land. The remaining islands either have relatively low levels of public ownership and protected status or lack available data to address the question.

In addressing the second indicator, "the importance of forests to people," the national report relied on response data from focus groups, an approach that was not practical for this report. Although we have few data directly linked to this question, much of the information in the foregoing sections and chapters help flesh out the various ways in which tropical forests are important to island inhabitants. These range from direct sustenance through subsistence gathering to support for commercial economic activity, notably tourism. Likewise, the aesthetic and spiritual values associated with forest environments on the islands provides residents and visitors with substantial benefits on a daily basis. The fact that we have little quantified information to measure the magnitude of these values in no way indicates a lack of importance.

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Kathleen Friday

A community meeting as part of an adaptive management project encouraging municipalities to manage their mangrove crab resources. The crabs (*Scylla serrata*) were found to be the most economically valuable product of mangrove forests in Kosrae, Federated States of Micronesia.

Criterion 7

Legal, Institutional, and Economic Framework for Forest Conservation and Sustainable Management

Guy C. Robertson and Kathleen S. Friday

Introduction

The Montréal Process Criterion 7, which addresses the institutional, legal, and economic frameworks needed to support sustainable forest management, is the final criterion in the Montréal Process Criteria and Indicators and the last to be considered in this report. Understanding the nature and status of these frameworks is an essential part of any assessment of forest sustainability, and it is doubly important because the laws, policies, and institutions governing forest management are directly under our control as a society. These are the tools we use to effect forest sustainability.

However, policies and institutions are extremely difficult to characterize concisely. Criterion 7 has proven to be one of the most difficult criteria to address in the *National Report on Sustainable Forests* (USDA FS 2011). Moreover, when extending this criterion to the U.S. tropics, there is little in the way of consistent datasets covering these topics for the island jurisdictions considered in this report. As a result, instead of addressing each of the indicators in a separate section, this chapter provides a narrative description of the institutions and activities affecting forest management in the islands. A general summary of Criterion 7 is followed by a look at (1) local government institutions; (2) academic institutions; (3) nongovernmental organizations; (4) the engagement of island entities with the U.S. federal government, notably the U.S. Forest Service; and (5) regional collaborative efforts. Land tenure and the rights of indigenous peoples to forest access and use are crucial concerns that are addressed in the section covering local government. Although this treatment may not approach the comprehensive assessment of institutions envisioned by the Montréal Process, it does provide a compendium of reference information and a discussion of local capacities for conducting sustainable forest management.

Criterion Summary

The heterogeneity that characterizes ecological and social conditions in the islands is equally evident in their institutional, legal, and economic arrangements. Part of this stems from the varying degrees of association the islands have with the United States, ranging from statehood (Hawaii) to commonwealth or territorial status (Commonwealth of the Northern Mariana Islands [CNMI], American Samoa [AS], Guam, Puerto Rico, and the U.S. Virgin Islands [USVI]) to independent countries in compacts of free association with the United States (Federated States of Micronesia [FSM], Republic of the Marshall Islands [RMI], and Republic of Palau). But much of the difference results from different economic and social conditions, simple geography, and the histories and traditions unique to each of the islands. Total populations and economies are small relative to the U.S. mainland (see table C6-1 in Criterion 6). Institutions, like many businesses, are subject to economies of scale, and many of the islands lack the depth and breadth of institutional support for forestry that may be taken for granted in the contiguous United States. Likewise, the contiguous states are served by many national programs that do not fully extend to the islands for reasons of political status, program scope, or travel expense, leaving these smaller island economies without the benefits of those programs and without sufficient local resources to conduct equivalent programs locally. Even if funding is offered at a generous level on a per-capita or per-acre basis, total funding may be insufficient to replicate national program functions, or small local staffs without required specialists may be unable to fully utilize or qualify for a given funding opportunity.

The islands do benefit, however, from collaboration with their neighbors to address similar challenges, and from the activities of dedicated individuals interested in sustaining forests. And they actively seek engagement from U.S. federal agencies and non-U.S. entities such as the Secretariat of the Pacific Community (SPC). The Forest Service, for example, inventories island forest resources through its Forest Inventory and Analysis (FIA) program; provides assistance in inter-island collaboration and on-the-ground project implementation through its State and Private Forestry division; and undertakes focused research on tropical forestry issues through its International Institute of Tropical Forestry, based in Puerto Rico, and its Institute of Pacific Islands Forestry, based in Hawaii. Many islands, particularly in the Pacific, may also benefit from a strong "community infrastructure" based on a history of communal ownership and resource management, something that is difficult to gauge from official documents but is an extremely valuable institutional resource nonetheless. The overlap of traditional or communal land management systems with Western ownership and management systems based on private and public property distinctions have resulted in checks and balances, and some novel, complex strategies in the Pacific. Depending on their political status in relation to certain international agencies, the Pacific freely associated states benefit from international funding sources which are unavailable to the state of Hawaii, the territories, and the commonwealths.

Montréal Process Criterion 7 Indicators

Recognizing the challenges presented by Criterion 7, in 2009 the Montréal Process Working Group revised the criterion, reducing the number of indicators from 20 to 10 and reformulating the remaining indicators, making them more concise, streamlined, and measurable than previous versions (Montréal Process 2015). The resulting indicator set covers topics ranging from forest policy to public participation to research and monitoring activities. For reference, the 10 Montréal Process Criterion 7 indicators are (in abbreviated form):

- **7.45:** Legislation and polices supporting the sustainable management of forests
- **7.46:** Cross-sectoral policy and program coordination
- **7.47:** Taxation and other economic strategies that affect the sustainable management of forests
- **7.48:** Clarity and security of land and resource tenure and property rights
- **7.49:** Enforcement of laws related to forests
- **7.50:** Programs, services and other resources supporting the sustainable management of forests
- **7.51:** Development and application of research and technologies for the sustainable management of forests
- **7.52:** Partnerships to support the sustainable management of forests
- **7.53:** Public participation and conflict resolution in forest-related decision making
- **7.54:** Monitoring, assessment and reporting on progress towards sustainable management of forests

However, owing to a lack of data combined with the heterogeneity of the island jurisdictions and the challenges associated with reporting out on each indicator for each jurisdiction separately, we have consolidated the Criterion 7 reporting here into the following categories: (1) local government (with an emphasis on land tenure arrangements), (2) academic institutions, (3) nongovernmental organizations (NGOs), (4) cooperative activities with the U.S. federal government, and (5) regional collaboration. Although these categories diverge from the Montréal Process indicators for Criterion 7, they do address specific, important metrics associated with the revised set and provide a useful framework for describing the institutional setting in which sustainable forest management can occur. They also serve as a reference for interested readers wishing to identify specific organizations.

Local Government

The Pacific and Caribbean island governments considered in this report range from full U.S. statehood, to U.S. territories, to "freely associated states" in voluntary association with the U.S. government (see table C7-1). Each of these relationships carries with it different rights, constraints, and institutional arrangements in regards to the U.S. Government in general, and the U.S Forest Service in particular. More importantly, the size and nature of local government institutions largely determine the ability of the islands to actively engage in forest management activities and to avail themselves of the various federal and international programs available to help in this effort. Six of the nine island entities have government units explicitly focused on forestry, with the largest (Puerto Rico and Hawaii) displaying the greatest capacity and range of activities. The absence of explicitly identified, locally funded forestry agencies in several of the Pacific Islands reflects a lack of resources associated with smaller populations and therefore smaller governments, which in some cases have a single locally funded "state forester." It also often reflects greater integration of tropical forestry with other land management activities such as coastal management or agriculture. In 2010, all the island entities completed statewide assessments and resource strategy reports (SWARS—later called State Forest Action Plans) as a prerequisite for participation in Cooperative Forestry Assistance Act programs. These reports compile and evaluate large amounts of data, and testify to the willingness and capacity of island governments to generate and analyze forestry information.

Government and Land Tenure

Land tenure, or the means by which land rights and ownership are allocated within a given society, strongly determines how forests are managed, who does the management, and who benefits from resulting forest

Table C7-1. Government institutions responsible for forest management activities in the Pacific and Caribbean islands

Jurisdiction	Relation to United States	Relevant local agency	Relevant agency website
Caribbean:			
U.S. Virgin Islands	Territory	Department of Agriculture, Forestry Division	http://www.vifresh.com/forestry.php
Puerto Rico	Commonwealth	Department of Natural and Environmental Resources, Forest Service Bureau	http://www.drna.gobierno.pr/
Pacific:			
Hawaii	U.S. state	Department of Lands and Natural Resources, Division of Forestry and Wildlife	http://hawaii.gov/dlnr/dofaw
American Samoa	Territory	American Samoa Environmental Protection Agency	http://www.epa.as.gov/
Republic of the Marshall Islands	Freely associated state	Ministry of Resources and Development, Department of Agriculture	http://www.rmiembassyus.org/Government.htm[a]
Federated States of Micronesia	Freely associated state	Department of Resources and Development (delegated to each state)	http://www.fsmrd.fm/
Commonwealth of the Northern Mariana Islands	Commonwealth	Department of Lands and Natural Resources	http://gov.mp/[a]
Guam	Territory	Department of Agriculture, Division of Forestry	http://www.guam.gov[a]
Republic of Palau	Freely associated state	Ministry of Natural Resources, Bureau of Agriculture, Forestry Section	http://palaugov.org[a]

[a] General government website. No agency-specific website available.

conditions and outputs. Land tenure arrangements in the islands considered in this report, particularly in the Pacific, include various combinations of traditional tenure arrangements and private ownership modeled on U.S. legal concepts and practices. All the islands have systems in place that identify property and outline the rights associated with that property and its transfer, and they also have systems to provide landowners due process relative to the loss of property or property rights. Some islands have dual systems, with different lands under different tenure systems and subject to different processes, including incremental surveying and registration of parcels under private ownership.

Formal Relations With the United States

As a state, Hawaii adheres to all U.S. laws concerning private property in accordance with the U.S. Constitution. Congress has the power to govern U.S. territories and commonwealths, and to make rules for disposing of federal property under the Territorial Clause (Article 4, Section 3) of the U.S. Constitution. The relationship differs between each jurisdiction and the United States. The Commonwealth of the Northern Mariana Islands, Puerto Rico, and the USVI are self-governing according to constitutions that are recognized by Congress. Guam is governed according to the Guam Organic Act of 1950. Each sets forth the specifics of the relationship with the United States and the local governing structure, including judicial systems to protect property rights. Territorial courts established by Congress are available in the CNMI, Guam, and the USVI, while Puerto Rico participates in the U.S. federal judicial system.

American Samoa is an unincorporated and unorganized territory administered by the Bureau of Insular Affairs, U.S. Department of the Interior. Although the Territorial Clause generally applies, the relationship between the United States and AS is further set forth in several Acts of Secession and in the AS constitution. It is not part of the federal judicial system, nor does it have a territorial court set up by Congress. American Samoa's judiciary was initially created and administered by the U.S. Navy, and now is operated under the authority of the Secretary of the Interior, who appoints the chief justice and associate justice. The AS courts can adjudicate property rights and conservation-related cases.

The FSM, RMI, and Palau are sovereign nations that have entered into compacts of free association with the United States. As such, they are guaranteed military protection and certain types of financial assistance administered through the Office of Insular Affairs or other legislatively designated federal agencies.

Traditional Land Tenure Arrangements

At the same time, the Pacific islands, including Hawaii, have a long history of self-government that evolved in relative isolation over many centuries as part of their Polynesian or Micronesian heritage. The resulting structures and practices focus upon, among other things, land use and the allocation of scarce island resources, and they constitute a different land tenure system than the standard public-private system found on the U.S. mainland and the U.S. territories in the Caribbean. Moreover, Pacific islands have been wary of the sale of lands to outside parties, and there are traditional customs in many places that ban property sales to keep land in family or local ownership. Public or communal ownership and restrictions on transference of land to nonresidents are common.

In AS, 88.4 percent of the land is "communal," held under a *Matai* or chiefly system. The *Matai*, who is generally a familial head, has authority over this land and those who live and work on it. Property taxes are levied on individuals working familial land in accordance with direction from the *Matai*. Permission must be granted from the *Matai* to clear, plant, or build on communal lands. Permission tends to be granted only for those purposes, however, and other management activities (e.g., those associated with conservation management) do not constitute grounds to apply to a *Matai* for personal use and management of communal land. Leases or other designations on communal land cannot last more than 55 years. For example, the National Park of American Samoa encompasses 13,500 ac across three islands that are leased by the U.S. Department of the Interior from the *Matai*, who maintains authority over this land.

The FSM constitution bars any noncitizen or corporation, not wholly owned by citizens, from acquiring title to land. Most of the native forest land has not been formally surveyed, mapped, registered, or titled, but ownership of these lands is generally recognized under traditional land tenure systems, including traditional overlapping rights (akin to easements) and traditional roles of chiefs in land allocation and land use decisions. Formal designation and management of some forest lands as public property on some islands has remained subject to negotiation with chiefs or adjacent landowners, and traditional prerogatives have largely been recognized in this process. Property rights, land ownership, and inheritance follow traditional patterns, but some sales between indigenous landowners do take place within and outside the government land court system. The CNMI constitution likewise provides that land can be privately owned only by people of Northern Mariana (Chamorro or Carolinian) descent, but others may lease land for up to 55 years.

In the RMI, nonresidents may not purchase land, and individual parcels of land may be owned by multiple individuals simultaneously through the country's complex customary land tenure system. Three general forms of land tenure occur in Palau: public community tenure, kin group tenure, and individual tenure.

Reconciling Western and traditional governance and land tenure practices is often a difficult task requiring a certain degree of flexibility. The leasing practice described above is one approach that seeks to combine traditional structures with modern tenure and management needs (e.g., the management of national parks). A sample of other recent examples includes:

- **Pohnpei (FSM).** Some chiefs and municipal leaders have incrementally accepted the boundaries of the central "Watershed Reserve" that designates much of Pohnpei's native forest as pubic property; physical marking of the boundary line has proceeded as each community has agreed to honor it.[1]
- **Kosrae (FSM):** The central, forested uplands were considered government property until a 1995 constitutional amendment allowed reclamation by the descendants of original landowners. It is significant that, by 2010, no certificates of title had in fact been issued for these lands.[2]
- **Hawaii:** In 2006, the Wao Kele o Puna forest (27,785 ac) became the property of the Office of Hawaiian Affairs (OHA), the acquisition partially funded by the Forest Service's Forest Legacy Program. This forest was ceded land (former crown lands) held in trust under state ownership until the state sold it to a private estate in 1986, triggering major protests. Not only was its

[1] **Kostka, W. 2014.** Personal communication. Executive director, Micronesia Conservation Trust, PO Box 2177, Kolonia, Pohnpei, FSM 96941.

[2] **Charley, B. 2014.** Personal communication. Forest Legacy Program Manager, Kosrae Island Resource Management Authority, PO Box 480, Tofol, Kosrae, FSM 96944.

return to public ownership therefore significant, but its titling to OHA instead of the state forestry agency represented a new landowning role for OHA and a possibly important precedent for the future of ceded forest lands.

These examples involve the transference of lands, back and forth, between traditional, public, and private ownership categories, indicating the need for modern and traditional systems to accommodate one another.

In contrast to the Pacific islands, pre-Colombian inhabitants of the Caribbean Islands, including the Caribs, Arawaks, Ciboneys, and Tainos, were decimated during periods of colonization by European nations, and their traditional tenure and land management practices were all but lost (Saunders 2005). The islands are today inhabited by colonial and post-colonial immigrants and the descendants of Africans who were enslaved and remained following emancipation. Although indigenous groups no longer exist as separate and identifiable races or cultures in Puerto Rico or the USVI, many hold significant reverence for their pre-Colombian predecessors, and these groups continue to be very important to the islands' culture and identity (See, for example, Maldonado et al. 1999). Cultural and historical traditions are recognized through historical preservation laws, but no property rights or land tenure privileges are accorded through traditional practices or to any one group to the exclusion of others.

Academic Institutions

Universities, colleges, and community colleges can serve as reservoirs of forestry knowledge and expertise, as training grounds for future managers, as windows on techniques and practices carried out in other places, and as focal points for collaborative efforts between government, communities, and private-sector entities. The academic institutions present on the islands (see table C7-2) range considerably in their size and the degrees they confer, depending in large part on the size and resources of their respective island jurisdictions. Hawaii and Puerto Rico, for example, have multiple institutions with programs ranging from associate degrees to full doctorates, while the two island jurisdictions with the smallest populations, Palau and American Samoa, are restricted to community colleges granting associate degrees in agriculture and general resource management. Many of these institutions appear to have strong concentrations in marine and terrestrial resource management relative to their other offerings, reflecting local awareness of the importance of resource management in island ecologies. Universities in Hawaii, Puerto Rico, and Guam often serve as hubs, hosting students from other islands in their respective regions.

Seven of the nine jurisdictions host land-grant universities or colleges. (Land grant programs in the remaining two, Palau and the RMI, are delivered by the College of Micronesia–FSM Land Grant program in affiliation with Palau Community College and the College of the Marshall Islands.) These institutions receive Hatch and Smith-Lever funding for agricultural research and extension, respectively, funds which are often used for agroforestry-related work in the islands. Also, the Renewable Resources Extension Act (RREA) provides funding for extension activities related to forestry and natural resources at certain land-grant institutions, and McIntire-Stennis formula funds may support land-grant institutions' cooperative forestry research programs. Qualification and receipt or non-receipt of RREA and McIntire-Stennis funds is an indicator of each island's staff capacity and activity in forestry extension and research.

Nongovernmental Organizations

Nongovernmental organizations (NGOs) play a crucial role in promoting resource conservation and local development needs throughout the islands. They facilitate community participation and act as a link between local, national, and international actors, and the resources they control. In addition to the organizations listed in table C7-3, international NGOs are active throughout the Caribbean and Pacific regions. Through its offices in Palau and the USVI, The Nature Conservancy has conservation programs focused on Micronesia and the Caribbean, and, in line with its domestic U.S. focus, the Sierra Club maintains offices and local chapters in Hawaii and Puerto Rico.

Cooperative Activities with the U.S. Federal Government

Applicable U.S. national laws and regulations protect public benefits arising from forests and prevent damage to natural resources such as wetlands, water and air quality, wildlife, and threatened and endangered species. Tax, business, and health and safety laws and regulations also affect private forestry, forest-based industries, and community stability. Federal regulatory programs affecting private forest lands are administered by agencies such as the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, and the U.S. Fish and Wildlife Service. These laws apply in Hawaii and in the U.S. territories. Also, certain of these laws, notably the

Table C7-2. Sample of academic institutions related to forests and forest management[a]

	Academic institutions	Relevant programs[b]	Website	Land-grant status and programs
Caribbean:				
USVI	University of the Virgin Islands	M.S. in marine and environmental science; minor in environmental science	http://www.uvi.edu/default.aspx	Land-grant McIntire-Stennis RREA
Puerto Rico	University of Puerto Rico at Mayaguez	B.S., M.S. in agricultural sciences and M.S. in horticulture	http://www.uprm.edu/portada/	Land-grant McIntire-Stennis RREA
	University of Puerto Rico at Rio Piedras	B.S., M.S., Ph.D in biology (including forest ecology) and environmental science	http://biology.uprrp.edu/ http://envsci.uprrp.edu/	None
	Universidad Metropolitana School of Environmental Affairs	M.S. in environmental management; M.A. in environmental affairs	http://umet.suagm.edu/	None
	Universidad Interamericana	Environmental planning	http://inter.edu/i2/	None
Pacific:				
Hawaii:	University of Hawaii at Manoa, College of Tropical Agriculture and Human Resources	B.S., M.S., Ph.D. degrees awarded in natural resources management and related fields	http://www.ctahr.hawaii.edu/site/	Land-grant RREA McIntire-Stennis
	University of Hawaii at Hilo	M.S. in tropical conservation biology and environmental science; forest resource management and conservation certificate	http://hilo.hawaii.edu/	None
	Hawaii Community College	A.S. in tropical forest ecosystem and agroforestry management	http://hawaii.hawaii.edu/forestteam/	None
	Windward Community College	Certificate of Completion for "subtropical urban tree care"	https://windward.hawaii.edu/academics/Tree_Care_CC/	None
American Samoa	American Samoa Community College	A.S. in agriculture, community and natural resources (forestry program housed in Division of Community and Natural Resources)	http://www.amsamoa.edu/	Land-grant McIntire-Stennis
RMI	College of Marshall Islands		http://www.cmi.edu/	Affiliation with COM-FSM
FSM	College of Micronesia–FSM	A.S. in agriculture and natural resource management	http://www.comfsm.fm/	Land-grant
CNMI	Northern Marianas College	A.S. in natural resource management	http://www.marianas.edu/	Land-grant
Guam	University of Guam, College of Natural and Applied Sciences	B.A. in agriculture, biology; M.S. in biology, environmental sciences	http://www.uog.edu/schools-and-colleges/college-of-natural-and-applied-science/cnas-home	Land-grant RREA McIntire-Stennis
Palau	Palau Community College	A.S. in agricultural science	http://pcc.palau.edu/	Affiliation with COM-FSM

[a] Sample is based on authors' knowledge, Web search, and reviewer response. Some institutions are not listed.

[b] Degree titles are approximate. A.S. = Associate in Science.

USVI = U.S. Virgin Islands; RREA = Renewable Resources Extension Act; RMI = Republic of the Marshall Islands; FSM = Federated States of Micronesia; CNMI = Commonwealth of the Northern Mariana Islands.

Source: Hollyer, J. 2008. An inventory of federal agriculturally related programs in the Pacific, 2008. Unpublished report. On file with: James Hollyer, College of Natural and Applied Sciences, University of Guam, UOG Station, Mangilao, Guam 96923.

Table C7-3. Sample of nongovernmental environmental organizations[a]

	Local, island-based organizations	Relevant websites
Caribbean:		
Regional	The Caribbean Landscape Conservation Cooperative	http://caribbeanlcc.org/
USVI	St. Croix Environmental Association	http://stxenvironmental.org/
	Trust for Virgin Island Lands	http://www.virginislandslandtrust.org/
	Virgin Islands Conservation Society	http://viconservationsociety.org/
Puerto Rico	Caborrojeños Pro Salud y Ambiente	http://www.ccpsai.org/web/
	Ciudadanos del Karso	http://www.cdk-pr.org/en/
	Fundación Amigos del Yunque	http://www.amigosdelyunque.org/
	Para la Naturaleza, nonprofit branch of the Conservation Trust of Puerto Rico	http://paralanaturaleza.org//
	Tropic Ventures	http://www.globalecotechnics.com/2012/05/tropic-ventures-sustainable-forestry-project-in-puerto-rico
Pacific:		
Hawaii	Hawaiian Islands Land Trust	http://www.hilt.org/
	Hawai'i Forest Industry Association	http://www.hawaiiforest.org/
	Natural Resources Council of Hawaii	—
	The Nature Conservancy, Hawaii Program	http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/hawaii/index.htm
	Trust for Public Land	http://www.tpl.org/what-we-do/where-we-work/hawaii
Regional	Micronesia Conservation Trust	http://www.ourmicronesia.org/
	Nature Conservancy Micronesia Program	http://www.nature.org/ourinitiatives/regions/asiaandthepacific/micronesia/index.htm
American Samoa	(None found)	
RMI	Marshall Islands Conservation Society	
FSM	Chuuk Conservation Society	—
	Conservation Society of Pohnpei	http://www.serehd.org/
	Kosrae Conservation and Safety Organization	http://kosraeconservation.blogspot.com/
	Yap Community Action Program	—
	Yap Institute of Natural Science	https://www.facebook.com/pages/Yap-Institute-of-Natural-Science/149847135051994
	Yela Environmental Landowners' Authority Kosrae)	—
CNMI	Micronesia Islands Nature Alliance	http://www.minapacific.org/
Guam	Guam Environmental Alliance	https://sites.google.com/site/guamenvironmentalalliance/
Palau	Palau Conservation Society	http://www.palauconservation.org/cms/index.php

[a] Sample is based on authors' knowledge, Web search, and reviewer input. Not all organizations are included. USVI = U.S. Virgin Islands; RMI = Republic of the Marshall Islands; FSM = Federated States of Micronesia; CNMI = Commonwealth of the Northern Mariana Islands.

Endangered Species Act of 1973 (ESA; 7 U.S.C. § 136, 16 U.S.C. § 1531 et seq.) are applied in the freely associated states of the FSM, Palau, and the RMI as a legacy of these islands' status until 1986 as Trust Territories administered by the United States.

Differing political status in relationship to the U.S. government amongst the island entities requires different bureaucratic arrangements and has different implications for the applicability of federal laws or eligibility for federal programs. Whereas Hawaii and the U.S. territories have consistently been eligible for all U.S. domestic forestry programs, this eligibility had to be clarified for the freely associated states in the 2008 Farm Bill. All the islands now avail themselves of a broad range of forest management programs offered by the Forest Service (see table C7-4). For the purposes of this report, the extension

Table C7-4. Participation in U.S. Forest Service programs through 2010

	Forest Stewardship Program	Cooperative Forestry Assistance	Urban and Community Forestry	Forest Health Protection	Forest Legacy	Fire and Aviation Management	Forest Inventory and Analysis	Research and Development
Caribbean:								
USVI	Yes	Yes	Yes	Partial	Yes	Yes	Yes	Yes
Puerto Rico	Yes	Yes	Yes	Partial	Yes	Yes	Yes	Yes
Pacific:								
Hawaii	Yes	Yes	Yes	Yes	Yes	Yes	2010	Yes
American Samoa	Yes	Yes	Yes	Yes	Partial	Yes	2001	Yes
RMI	2008 Partial	Yes	Yes	Yes	No	No	2008	No
FSM	2008 Partial	Yes	Yes	Yes	2008+	2008 Partial	2005	Yes
CNMI	Yes	Yes	Yes	Yes	No	Yes	2004	No
Guam	Yes	Yes	Yes	Yes	Partial	Yes	2002	Yes
Palau	2008 Partial	Yes	Yes	Yes	No	2008	2003	Yes

USVI = U.S. Virgin Islands; RMI = Republic of the Marshall Islands; FSM = Federated States of Micronesia; CNMI = Commonwealth of the Northern Mariana Islands.

of Forest Service inventory activities through FIA to all the islands is of particular importance. One area where political status has resulted in definite distinctions between jurisdictions in federal treatment related to forestry is in the area of international aid, where, owing to their status as sovereign countries, the freely associated states are eligible for U.S. foreign assistance through the U.S. Agency for International Development and other channels.

In addition to providing assistance for public and private forest management on the islands, the Forest Service also directly manages forest lands that are part of the National Forest System. The El Yunque National Forest (NF) in Puerto Rico is the only national forest among the islands. It was designated in its entirety as the Luquillo Experimental Forest in 1956, as a UNESCO[3] Biosphere Reserve in 1976, and as a Long-Term Ecological Research (LTER) site in 1988. The El Yunque NF includes the federally designated El Toro Wilderness and three federally designated wild and scenic river segments. Estate Thomas Experimental Forest in the USVI was acquired in 1963 by the U.S. government to conduct tropical forest management research and currently is managed by the International Institute of Tropical Forestry for research and conservation education. The Hawaii Experimental Tropical Forest was established in 2007 as an experimental forest, but underlying ownership and resource management responsibilities are held by the state of Hawaii. The National Park Service manages national parks with forest resources in the USVI, Hawaii, Guam, and AS (under a lease of communal lands), and the U.S. Department of Defense manages natural resources existing on military bases in Puerto Rico, Hawaii, Guam, and the CNMI. For each agency, management responsibilities include the need to gather information and solicit public comment in the formulation of management plans in compliance with the National Environmental Policy Act, Endangered Species Act, and other federal laws and regulations.

Forest Inventory and Analysis is a Forest Service program administered by the agency's Research and Development (R&D) division. The "Research" column in table C7-4 indicates field activities undertaken by R&D scientists within each state/island during the 2003–2010 period. The other programs listed are implemented by state/island forestry agencies (see table C7-1) with grants from the Forest Service. "Yes" means the state/island has participated fully in the program since well before 2003. Dates indicate when the state/island first began participation during the 2003–2010 period (in most cases when the 2008 Farm Bill made the freely associated states eligible). "Partial" means that the state/island had not yet engaged in full program implementation by 2010.

[3] United Nations Educational, Scientific, and Cultural Organization.

Regional Collaboration

Regional collaboration provides an opportunity for islands to pool their resources, learn from each other, and leverage outside resources from academia, the federal government or NGOs. A significant development in the Pacific has been the adoption and institutionalization of the "Micronesia Challenge." In 2006, the heads of state of the RMI, FSM, CNMI, Guam, and Palau committed to "effectively conserve" at least 20 percent of the terrestrial resources (land acreage) in each jurisdiction by 2020. This effort provided the high-level political support that had been lacking for conservation in the region. The "Challenge" is institutionalized in the establishment of the regional Micronesian Conservation Trust, which is accumulating an endowment for conservation and implementing a variety of capacity-building programs; for the "Challenge" this includes a small staff and a steering committee representing regional and island government agencies and local NGOs. The "Challenge" necessarily requires the involvement and support of landowners, the general public, or both, depending upon the land tenure systems in place on each island or for each target ecosystem. Strategies and definitions have been developed; monitoring protocols for forested areas are being developed and will rely in part on FIA.

The islands host several research activities that represent the outermost geographic extent of broad-scale U.S. national research initiatives. Two such activities funded by the National Science Foundation (NSF) are the National Ecological Observatory Network (NEON) and the U.S. Critical Zone Observatory (CZO) program. NEON, with 60 sites ranging from Alaska and Hawaii across the United States to Puerto Rico, will be the first truly standardized continental network of research sites set up to discern ecological trends at such a large scale. The CZO program has six observatories across the United States, including one in Puerto Rico, to study the outer layer of the earth that sustains human life. It will provide data on interacting physical and biological systems that occur for watersheds with contrasting bedrock lithology but similar climatic and environmental histories. Another example is the Luquillo LTER site in Puerto Rico, which exists as part of a broader network of sites established by the NSF in North America, the Pacific, and Antarctica to conduct research on ecological issues over time. Puerto Rico also hosts the U.S. Department of Agriculture Caribbean Climate "Sub-Hub," administered by the International Institute of Tropical Forestry. The site is part of a national network of climate hubs designed to share studies of climate change and adaptation strategies.

In 2009, the Secretary of the Interior, under Secretarial Order No. 3289, stipulated, and provided funding for the establishment 22 applied conservation science partnerships called Landscape Conservation Cooperatives. These relatively new efforts have the potential to affect sustainable forest management across all the islands. The Pacific Islands Climate Change Cooperative (http://piccc.net) and the Caribbean Landscape Conservation Cooperative (http://caribbeanlcc.org) are part of this network. They consist of state and federal agencies, regional organizations, tribes, NGOs, universities, and other entities, and were founded with the intention of informing resource management decisions in an integrated fashion across landscapes—at a broader scale than any individual partner can encompass.

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