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Hawai'i's Forest Resources: Forest Inventory and Analysis, 2010–2015

Suzanne M. Owen, Olaf Kuegler, Ashley D. Lehman, R. Flint Hughes,
Jane Terzibashian, Irene Sprecher, Tom Thompson, Seth Ayotte, Mikhail
Yatskov, and Michelle Silva



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Cover photo: FIA crew member, Reko Libby, taking plot measurements near Wailau Valley on Moloka'i, Hawai'i. Photo by Seth Ayotte.

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Abstract

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Long-term forest monitoring is vital to understand how Hawaiian forests change over time and to manage and conserve natural resources. Forest inventories are assessed about every 10 years in Hawai'i by the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) program, in collaboration with state and federal partners. This report summarizes key findings from 246 forested plots in Hawai'i, inventoried from 2010 to 2015. Estimates were provided for forest area, tree species composition, size distribution, volume, biomass, carbon, understory vegetation, damage to trees, damaging agents, and invasive plant species across all management or owner groups (federal, state and county, and private). Forested FIA plots were located on five of the eight major Hawaiian Islands: Hawai'i, Maui, Lāna'i, O'ahu, and Kaua'i. An estimated 1.5 million ac of forested lands were present state-wide, containing many high-value resources, such as clean water, wood products, and carbon sequestration, and delivering a range of cultural ecosystem services. Hawai'i's forest inventory consisted of an estimated 1.8 billion live trees and 112 distinct tree species, including species that were native (indigenous), introduced (either by early Polynesians or more recently via European and Asian contact with Hawai'i), and invasive (those that cause economic, environmental, or ecological harm). Montane rainforests were the most common forest community type, accounting for 30 percent of Hawai'i's forested lands. 'Ōhi'a lehua (*Metrosideros polymorpha* Gaudich.), an endemic, keystone tree species, was the most common and dominant tree species ≥ 5 inches diameter at breast height (d.b.h.) within Hawai'i's forests, followed by hāpu'u 'i'i (*Cibotium menziesii* Hook.), hāpu'u pulu (*Cibotium glaucum* (Sm.) Hook. & Arn.), and koa (*Acacia koa* A. Gray). Strawberry guava (*Psidium cattleianum* Sabine) was the most abundant tree species ≥ 1 inch d.b.h., followed by 'ōhi'a lehua, invasive haole koa (*Leucaena leucocephala* (Lam.) de Wit), and Christmas berry (*Schinus terebinthifolius* Raddi). Strawberry guava is invasive and degrades Hawai'i's native forests, adversely affecting ecosystem composition, structure, function, and ecosystem services. Hawai'i's live trees represented 51 million U.S. tons of dry mass (46.3 Tg) carbon. A total of 47 percent of Hawai'i's forests were located on reserved land, primarily ceded lands managed by Hawai'i's state and county governments. This report also serves as a baseline for assessing the extent and health of 'ōhi'a prior to the manifestation of rapid 'ōhi'a death, a disease that began causing widespread mortality of 'ōhi'a lehua trees in 2014. This is the first FIA report for Hawai'i using the nationally standardized plot design developed by FIA, and it provides the baseline for future forest assessments and estimates of change in forest composition, structure, and health. Detailed tables and graphical highlights are included to inform resource managers, policymakers, and the public about the status and trends of their local forest ecosystems and resources.

Keywords: Biomass, carbon, damage, FIA, forest land, Hawaii, Hawai'i, invasive plants, inventory, timberland, tropical forest, understory vegetation, volume.

Key Forest Inventory and Analysis Statistics, Hawai‘i

- Estimated total forest area: 1.5 million ac
- Estimated number of live trees (≥ 1 inch diameter): 1.8 billion
- Total number of live-tree species recorded: 112 species
- Estimated total net aboveground live-tree volume: 2.5 billion ft³
- Estimated total aboveground live-tree biomass: 93.1 million dry U.S. tons
- Estimated total aboveground live-tree carbon: 46.6 million dry U.S. tons
- Largest live tree recorded: ‘ōhi‘a lehua (*Metrosideros polymorpha*), located on Hawai‘i Island, 61.5 inches diameter at breast height
- Tallest live tree recorded: swamp mahogany (*Eucalyptus robusta* Sm.) located on Hawai‘i Island, 189 ft

Ua mau ke ea o ka ‘āina i ka pono

The life of the land is perpetuated in righteousness.

—Hawai‘i state motto

Hahai nō ka ua i ka ululā‘au

The rain follows the forest; this highlights the importance of healthy forests for sustaining fresh water in Hawai‘i.

—Hawaiian proverb

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Introduction to Forest Inventory and Analysis

Purpose of This Report

This report summarizes the initial inventory of Hawai'i's forest resources across all owner groups and forest communities based on data collected by the Forest Inventory and Analysis program (FIA) of the U.S. Department of Agriculture, Forest Service from 2010 to 2015. The Pacific Northwest (PNW) FIA program, in collaboration with many partners listed below, implemented this inventory in Hawai'i with a multi-year sampling strategy that measures a full panel of forested plots, with a planned reassessment every 10 years. FIA field crews typically finish inventorying a cycle of plots within 3.5 years, but this 2010–2015 inventory required more time because additional intensification plots were included (see “FIA Intensification Plots in Hawai'i” below). Subsequent plot remeasurements are prioritized based on the year plots were measured in the previous cycle. Future FIA reports will include summaries of trends and comparisons of changes that occur during the roughly 10 years between field visits.

The purpose of this report is to summarize and interpret basic forest resource information, including owner or management groups, forest area, species composition, volume, biomass, carbon, standing dead wood, understory vegetation, and disturbance (e.g., tree damage, damaging agents, and prevalence of invasive plants). The appendices detail inventory methods and experimental design, and they include additional summary tables on forest parameters and characteristics that were measured. PNW-FIA collaborates with scientists and land managers to provide inventory data that addresses local- and national-scale questions about the status and trends of Hawai'i's tropical forests.

Partners are critical to the success of the FIA program in Hawai'i; collectively, they provide local expertise, field assistance, funding support, and capacity building. Partners in this inventory of Hawai'i included the state's Division of Forestry and Wildlife, the University of Hawai'i (UH) at Hilo and the UH-Mānoa Pacific Cooperative Studies Unit, the USDA Forest Service Pacific Southwest Research Station's Institute for Pacific Island Forestry and the Forest Service Pacific Southwest Region's State and Private For-

estry program, Hawai'i Volcanoes National Park, Haleakala National Park, and The Nature Conservancy in Hawai'i.

Forest Inventory and Analysis Program Description

The FIA program was created within the Forest Service in 1928 to continuously monitor the state of our nation's forests. The FIA program collects forest data within a network of permanent field plots, analyzes and synthesizes collected data, creates publicly available databases, and provides summaries and interpretations of collected data. Four FIA units are responsible for inventorying all forested lands in the United States: the PNW, Interior West, Northern, and Southern units. The PNW-FIA unit collects and assesses forest data in the Pacific Coast states of Alaska, California, Oregon, and Washington, and in the state of Hawai'i and the U.S.-Affiliated Pacific Islands, which include the U.S. territories of Guam and American Samoa, the U.S. Commonwealth of the Northern Mariana Islands, and the Freely Associated States of the Republic of Palau, Republic of the Marshall Islands, and Federated States of Micronesia. Historically, FIA plot measurements were completed at various temporal intervals within each jurisdiction. This changed with the passage of the Agricultural Research, Extension, and Education Reform Act of 1998 (known as the Farm Bill), which specified that methodologies be consistent at a national level, and that some portion of the inventory be completed annually. All standardized inventories are spatially and temporally unbiased with respect to forest types and landowner groups (Bechtold and Patterson 2005). PNW-FIA completes a full forest inventory of its various regions every 10 years, and most of the unit collects data from 10 percent of all its inventory plots annually. All FIA units use an identical plot design, a common set of measurement protocols, and a standard database design for compilation and distribution of data. By employing this unified approach, FIA provides accurate estimates of a wide variety of forest conditions over all forested lands in the United States (USDA FS 2021a).

The nationally consistent FIA plot design and measurement protocol was implemented in Hawai'i in 2010. This forest inventory was tailored to include data collection of parameters specific to tropical forests in general and

Hawai'i's forests in particular; these included additional tree branching and rooting forms, additional tree crown measurements, highly invasive plants, and forest pests and pathogens. Hawai'i forest inventory plots were systematically established at 1.9-mi intervals within a hexagonal grid. Additional intensification plots were included to track forest health in critical areas, such as the Laupāhoehoe wet forest, the Pu'uwa'awa'a dry forest, and The Nature Conservancy's Kona Hema Preserve. Forest inventory plots consisted of four, 24-ft (7.3-m) fixed-radius subplots in which a variety of information was collected at the plot, subplot, and individual tree levels (USDA FS 2012). Primary geographic variables collected included location, elevation, aspect, and slope (steepness, position, and shape), while primary tree data variables included species, diameter, height, damage, branching and rooting form, decay, and epiphyte loading.

This report includes findings from 246 forested plots, and 75 percent of these plots were located on Hawai'i Island (fig. 1). Additional information on plot design and annual inventories are available in appendix 1 of this report and at <https://www.fia.fs.usda.gov/> (USDA FS 2020b).

Common FIA Terminology

Trees—

FIA defines a tree as a woody perennial plant, usually with a single, well-defined stem supporting a crown of leaves, attaining a minimum diameter at breast height (d.b.h.) of 3 inches (7.6 cm) and a minimum height of 15 ft (4.6 m) at maturity. Tally trees are defined as all live and standing dead trees (snags) in accessible forest land or measurable nonforest land condition classes (USDA FS 2016). Any plant species on FIA's tree list in the current field manual is measured as a tree.

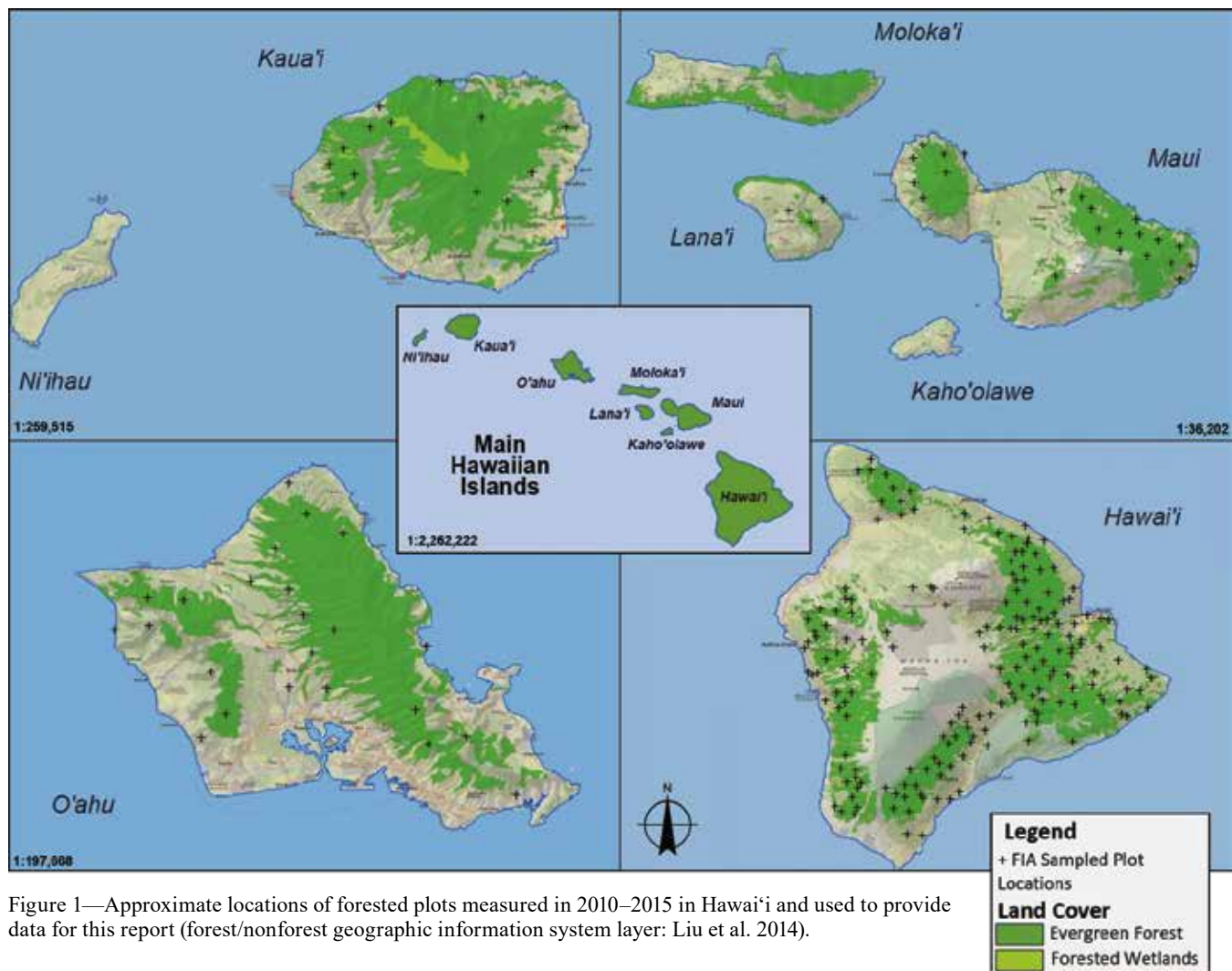


Figure 1—Approximate locations of forested plots measured in 2010–2015 in Hawai'i and used to provide data for this report (forest/nonforest geographic information system layer: Liu et al. 2014).

Snags—

The term “snag” is synonymous with “standing dead tree.” To qualify as a snag, dead trees must be at least 5 inches d.b.h., have a bole that has an unbroken actual length of at least 4.5 ft, and not have a lean that is greater than 45 degrees from vertical.

Forests—

Forests come in many shapes and sizes, and they may vary from complex and species diverse to monoculture plantations. FIA defines forest land as an area currently or formerly (within 30 years) exhibiting at least 10 percent crown cover of trees of any size that is not currently developed for nonforest use (USDA FS 2016). Forest land must occupy at least 1 ac and have a minimum continuous width of 120 ft.

Hawaiian forest communities—

FIA classified forest communities in Hawai'i based on definitions from *Vegetation of the Tropical Pacific Islands* by Mueller-Dombois and Fosberg (1998). FIA categorized nine different forest community types in Hawai'i: montane rainforest, lowland tropical rainforest, moist (mesophytic) forest, dry (xerophytic) forest, cloud forest, strand (halophytic) vegetation, plantations, mangrove swamps, and agroforests (Mueller-Dombois and Fosberg 1998, USDA FS 2019a). Field crews classified forests using these forest community types based on a combination of characteristics, including the dominant tree species determined from both tally trees encountered and crown cover (i.e., canopy strata dominance), positioning of the plot area in relation to the ocean, plot area elevation, plot area rainfall, tree stature, presence and diversity of epiphytes, human-supported activities (agroforestry), and stand origin (plantations). Forest community types are described in more detail under “Hawai'i Forest Community Types” below.

Native, endemic, introduced, Polynesian-introduced, and invasive plant species—

Native plant species are indigenous to an area, e.g., they occur naturally in Hawai'i, but may also be native to other areas outside of Hawai'i. Endemic plant species are unique to a defined geographical location, e.g., species only found in Hawai'i. Introduced plants are nonnative or “naturalized” and are introduced by humans and have established or expanded

their populations (Imada 2012). Polynesian-introduced species, or canoe plants (e.g., ti (*Cordyline fruticosa* (L.) A. Chev), niu (*Cocos nucifera* L.), and hau (*Hibiscus tiliaceus* L.)), are nonnative and were historically introduced by Polynesian ancestors who arrived in Hawai'i around 1200 CE, (Wilmshurst et al. 2011). Invasive plants are introduced to the ecosystem and cause economic or environmental harm, or harm to human, animal, or plant health, e.g., strawberry guava (*Psidium cattleianum* Sabine) in Hawai'i. Invasive plants measured as part of the FIA data collection were designated by invasive species experts across the state. A list of invasive species that were inventoried for this report is included in the field instructions for the Pacific Islands (USDA FS 2013). The origin status associated with the list of species inventoried in this report is from the native and naturalized vascular plants checklist from the Bishop Museum's Hawai'i Biological Survey (Imada 2012). Most nomenclature follows the USDA PLANTS Database (USDA NRCS 2022), but some species include names that are more accepted and recognized by Hawaiians, as recommended by coauthors and reviewers. Some figures and tables include a footnote indicating plant species status as native (n), endemic (e), introduced (i), Polynesian introduced (p), or invasive (*).

FIA land management or owner group designations and how they differ in Hawai'i—

FIA defines a landowner as an individual; a combination of persons, such as a company, cooperation, partnership, club, or trust; or a public agency that, as a legal entity, has ownership interest on a parcel or group of parcels of land. In Hawai'i, federal, state, and county government ceded or administered lands may include long-term lease agreements for the use and management of lands, and for FIA reporting purposes are grouped with other government “owned” lands managed in the public trust. This report further combines numerous owner classifications into three general owner groups: federal, state and county governments, and private. We recognize that the generalization of many different legal land designations into these standardized groupings may appear to be coarse, but scope, scale and utility of summarizing inventory data into these owner groups not only for Hawai'i but across the nation allows FIA to best meet federally mandated reporting requirements.

Reserved forest land—

FIA designates areas as “reserved” if the law prohibits commercial extraction or harvesting of wood products from the land through statute or administrative designation (USDA FS 2016, USDA FS 2019a). All private lands, including inholdings, those owned by conservation groups, those with conservation easements, and tribal protected areas, are considered “not reserved” because it is difficult to determine their legal status (USDA FS 2019b). FIA has adopted a default national list of federal land designations that are considered reserved (USDA FS 2019a). All federally owned lands, or lands managed by the U.S. National Park Service or the U.S. Fish and Wildlife Service, are considered reserved. Certain lands owned, ceded, administered, or managed by state or county governments are considered reserved, even in the absence of specific laws covering them, if the agency mandate for that land designation precludes management to extract wood products (e.g., most state parks). In the absence of state-specific lists of reserved areas, any state or county government land area that includes “wilderness,” “wild river,” “reserve,” or “preserve” in the name is by default considered reserved. Note that harvests may occur in reserved areas at times for restoration, safety, recreation (USDA FS 2019a), or the rare possibility of commercial harvesting with objectives to preserve an intact forest ecosystem. This report summarizes forest data using this FIA definition of reserved or unreserved land status, and some forest data are summarized by Hawai‘i’s Conservation District lands.

Hawai‘i State Conservation District lands—

Hawai‘i’s State Conservation District lands include diverse holdings such as ceded lands that are administered and managed by the state’s Department of Land and Natural Resources. They are divided into five subzones: protected, limited, resource, general, and special. The first four subzones are arranged in a hierarchy of environmental protection, ranging from priority resources that are most protected (“protected”) to those that are less environmentally sensitive (“general”) (DLNR 2020a, Oswalt et al. 2014). “Special” subzones are not common and are defined by a unique land use, on a specific site location. Hawai‘i land use district boundary maps are found at <https://luc.hawaii.gov/maps/>, (State of Hawai‘i 2022a) and rules and regulations for the

use of conservation district lands are found at <https://dlnr.hawaii.gov/occl/conservation-district/> (State of Hawai‘i 2022b). FIA sampled plots were superimposed onto Hawai‘i land use district boundary maps to summarize data in each conservation subzone, and results are presented below under “Hawai‘i State Conservation District Lands.”

Additional Information

- Comprehensive information regarding plot design, data collection, and the FIA database are available at the Forest Inventory and Analysis National Program website: <https://www.fia.fs.usda.gov/library/database-documentation/index.php> (USDA FS 2021b)
- Hawai‘i FIA data are available for download at the Pacific Northwest Forest Inventory and Analysis program website: <https://www.fs.usda.gov/pnw/page/pnw-fia-inventory-data> (USDA FS 2021c)
- National data are available, including Hawai‘i, for download at the Forest Inventory and Analysis National Program website: <https://www.fia.fs.usda.gov/tools-data/index.php> (USDA FS 2021d)
- Glossary of terms is available at the Northern Research Station’s Forest Inventory and Analysis research program website: <https://www.nrs.fs.usda.gov/fia/data-tools/state-reports/glossary/default.asp> (USDA FS 2016)

Hawai‘i Forest Resources**Importance of Hawaiian Forest Resources**

The Hawaiian Islands are home to diverse and culturally important forest resources (fig. 2A). A variety of provisioning, supporting, regulating, and cultural ecosystem services are derived from Hawaiian forests, such as clean water, food, plant and animal habitat, cultural preservation, carbon sequestration, wood and nontimber forest products (NTFPs), recreation, and tourism. These ecosystem services are described in more detail in the Hawai‘i Forest Action Plan (DLNR 2016). Hawai‘i’s forests have changed through time as a result of deforestation, degradation by invasive plant species and nonnative grazing animals, and forest conversion to pastureland or other agricultural land (e.g., eucalyptus timber plantations, coffee and pineapple cultivation

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Figure 2—Forest resources in Hawai'i include endemic and culturally important species, such as (A) 'ōhi'a lehua (*Metrosideros polymorpha*) and (B) grand eucalyptus (*Eucalyptus grandis*), an introduced species grown for commercial purposes.

farms) (Conry and Cannarella 2010). Today, Hawai'i's forests include natural and planted areas composed of varying combinations of native and introduced species (fig. 2B).

One of Hawai'i's most important natural resources is water. Healthy forests recharge underground aquifers (i.e., groundwater) and provide fresh water for streams, wetlands, and nearshore environments. Groundwater provides nearly 99 percent of Hawai'i's domestic water supply and about 50 percent of all fresh water used in the state for commercial and industrial needs (DLNR 2016). Hawai'i's forests cover the state's primary watersheds; collectively the forests prevent soil erosion and reduce the amount of pollutants and sediments in streams and drinking water. As such, Hawai'i's water supply is placed at risk by threats posed to its forests, including deforestation, fire, insects and disease, invasive species, and urban and agricultural development. Hawai'i recently committed to protect 30 percent (i.e., 253,000 ac) of high-priority watershed forests by the year 2030; protection includes fencing, the removal of invasive plants and nonnative hooved animals, planting native species, prevention and prompt control of wildfire, and education and conservation actions that connect people with the land (DLNR 2016, State of Hawai'i 2016, USDA FS 2020a).

Hawaiian forest resources provide numerous cultural, social, and economic benefits to the 1.4 million people who live on the islands and to the additional 8 million people who visit the islands annually (DBEDT 2018, DLNR 2016). For

many in the Native Hawaiian community, as well as local residents, connection with native ecosystems is an integral part of their identity, health, and sense of well-being. Forests in Hawai'i often occur in places that are sacred in Native Hawaiian culture; they serve as cultural gathering locations and supply traditional plant material, including NTFPs used for medicine, cultural activities, food, structural products, floral adornments, jewelry, and tools. Hawaiian forests also provide a myriad of outdoor recreation opportunities. Nature-based activities such as hiking, backpacking, horseback riding, camping, all-terrain vehicle driving, and hunting contribute to Hawai'i's robust tourism industry; an industry that generates nearly \$5 billion in annual revenues. Forest-based tourism activities generate jobs and provide a significant source of state private financial capital (DBEDT 2018, DLNR 2015a). Generating about \$30 million per year in state revenue, Hawai'i's timber industry also contributes to local economies (Yanagida et al. 2004). Timber production is largely centered on salvage logging of high-value native trees, mainly koa (*Acacia koa* A. Gray) and 'iliahi or sandalwood (*Santalum paniculatum* Hook. & Arn.), and plantations consisting of introduced species (e.g., *Eucalyptus robusta* Sm.) (Baker et al. 2009; DLNR 2016, 2018a; Yanagida et al. 2004). Commercial reforestation includes cultivation of high-value native species such as koa and 'iliahi. Other NTFPs and provisioned ecosystem services include craft woods, biomass, and carbon sequestration (DLNR 2016).

Ecological benefits of Hawaiian forests include the provision of habitat for native plant and animal species, 90 percent of which are found nowhere else on the planet, and many are classified as threatened or endangered (DLNR 2020b, 2020c; Eldredge and Evenhuis 2003). Hawaiian forests are home to thousands of endemic plant and animal species that have evolved across an enormous range of habitat types created by Hawai‘i’s isolated location and diverse geology and climate (DLNR 2016, 2020b, 2020c; Eldredge and Evenhuis 2003). Keystone, endemic tree species such as ‘ōhi‘a lehua (*Metrosideros polymorpha* Gaudich.) and koa support a variety of endangered, endemic mollusks (e.g., kāhuli or Hawaiian tree snails (genus *Achatinella*)) and arthropods (e.g., Blackburn’s sphinx moth (*Manduca blackburni*)). Hawai‘i is regarded as the “endangered species capital of the world” because the state is home to 75 percent of all plant and animal extinctions recorded in the United States and 28 percent of the federally listed threatened and endangered species in the country (DLNR 2015b, 2018a, 2020b, 2020c). As Hawai‘i’s native forests provide primary habitat for the bulk of its threatened and endangered species, the health, integrity, and persistence of these forests are paramount.

Article 11 of Hawai‘i’s State Constitution states that, “For the benefit of present and future generations, the state and its political subdivisions shall conserve and protect Hawai‘i’s natural beauty and all natural resources, including land, water, air, minerals and energy sources, and shall promote the development and utilization of these resources in a manner consistent with their conservation and in furtherance of the self-sufficiency of the state” (Haw. Const. art. XI 2006). Consequently, a variety of land acquisition and management programs have been implemented to protect Hawai‘i’s resources; some are outlined by the state’s Department of Land and Natural Resources (DLNR 2015b, 2016, 2018a) and the U.S. Forest Service (USDA FS 2017). On 28 February 2020, Hawai‘i became the 13th U.S. state to sign a shared stewardship agreement with the Forest Service through Hawai‘i’s Department of Land and Natural Resources Division of Forestry and Wildlife. The resulting state-federal memorandum of understanding outlines both agencies’ commitments to increase the scale of management treatments that protect forests, watersheds, and communi-

ties, as well as create and sustain jobs (HDOA 2016a, State of Hawai‘i 2016, USDA FS 2020a). Hence, long-term forest monitoring conducted by the FIA is important because Hawai‘i’s forests play a critical role in the state’s economy, sustaining the provision of ecosystem goods and services, cultural preservation, and the health and well-being of its residents.

Hawai‘i Climate and Geology

Hawai‘i is one of the Earth’s most isolated archipelagos. Collectively, the state spans more than 1,500 mi in the Pacific Ocean and consists of the eight main islands of Kaua‘i, Ni‘ihau, O‘ahu, Moloka‘i, Lāna‘i, Maui, Kaho‘olawe, and Hawai‘i; it also includes numerous additional sea-level islands, atolls, and shoals that form Papahānaumokuākea, or the Northwestern Hawaiian Islands. The Hawaiian Islands include more than two-thirds of the 35 Holdridge life zones (a classification system for defining ecological units based on similar plant and animal communities), with local climates that range from wet tropical to arid subalpine (Asner et al. 2005, Holdridge 1947). The Hawaiian Islands are mountainous; the highest point in the island chain is on Hawai‘i Island at Mauna Kea, a dormant volcano rising from sea level to 13,796 ft, which can receive snowfall during fall, winter, and spring. Statewide, long-term monthly temperatures are relatively stable, and the overall climate is generally mild, with most areas receiving higher precipitation in the winter months (fig. 3). Prevailing trade winds from the northeast, combined with Hawai‘i’s mountainous topography, create sharp orographically driven windward to leeward gradients in precipitation and temperature across the islands. The wettest areas found at mid to upper elevations on the eastern (windward) flanks of the islands receive on average 404 inches of precipitation per year. The driest leeward areas average 8 inches of precipitation per year (Giambelluca et al. 2013).

The Hawaiian Islands were, and continue to be, formed by volcanic activity beneath the ocean. As lava flows above the ocean surface accumulated, weathered, aged, and mixed with volcanic ash and sediment runoff, they created diverse and often fertile soils. Hawai‘i is the youngest island, with soils ranging from porous lava rock

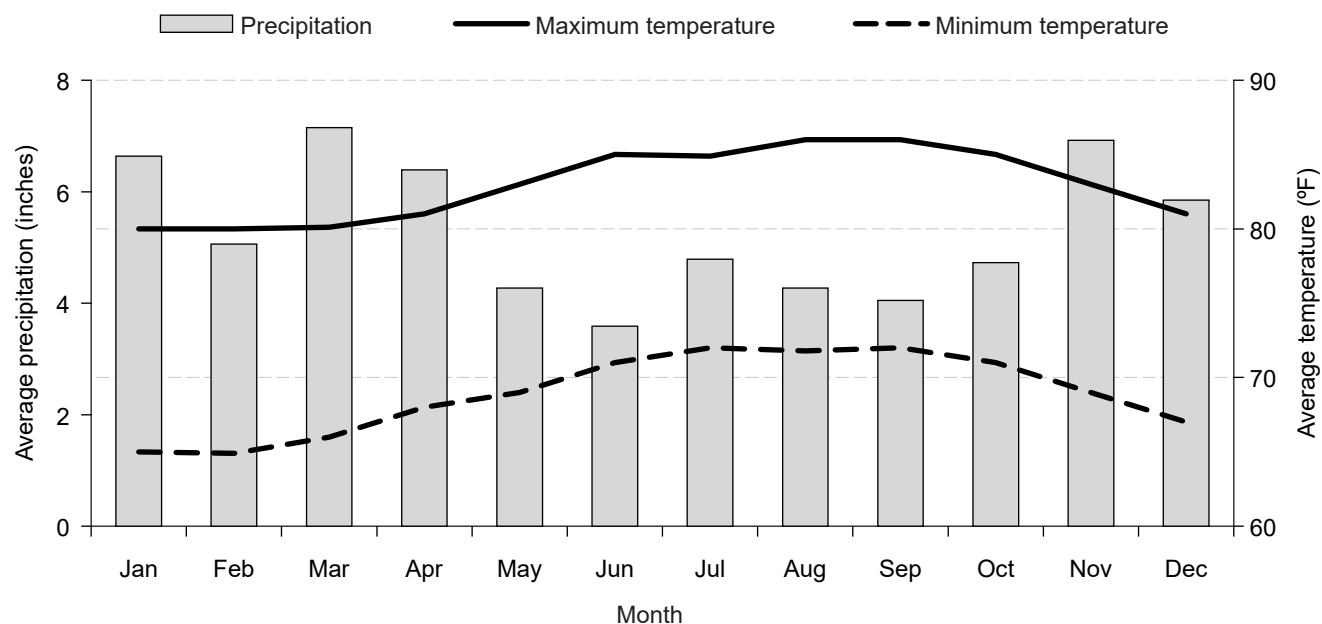


Figure 3—Average statewide maximum and minimum temperature and total monthly precipitation for Hawai'i (Western Regional Climate Center, Hawai'i, https://wrcc.dri.edu/Climate/comp_tables.php). Precipitation and temperature vary greatly with elevation and from the leeward (dry side) compared to the windward (wet side) of the islands; this manifests in the highly variable forest community types of Hawai'i.

in the south and west, to nutrient-rich volcanic soils on the east and north. Kaua'i is the oldest island and exhibits highly weathered and compact soils (DLNR 2016). Half of the Hawaiian Islands soils are classified as Andisols—such soils are formed from weathered volcanic material, are typically young and nutrient-rich, and result in being some of the most productive soils of Hawai'i. The second most common soils in the state are classified as Histosols, which develop from organic materials, have high organic content, and support natural vegetation often dominated by 'ōhi'a lehua and native tree ferns (CTAHR 2014; Deenik and McClellan 2007).

Hawai'i Forest Community Types

The combination of broad variation in climate, elevation, soil type, age of lava flow, and forest management practices manifest in a unique mix of forest community types. The FIA procedure categorized nine different forest community types in Hawai'i: montane rainforest, lowland tropical rainforest, moist (mesophytic) forest, dry (xerophytic) forest, cloud forest, strand (halophytic) vegetation, plantations, mangrove swamps, and agroforestry (Mueller-Dombois and Fosberg 1998, USDA FS 2019a). Mangrove swamps are of

limited extent in Hawai'i in part because mangrove trees are incipient nonnative species to the state. Agroforestry communities also are uncommon in Hawai'i. Consequently, neither were encountered on plots sampled in this inventory, so this report covers seven of the nine forest community types described above.

Montane rainforests were the predominant type of forest community on windward slopes and these forests support a diverse collection of native shrubs and epiphyte species. Dominant endemic species in montane rainforests with the greatest number of estimated tree stems (≥ 5 inches d.b.h.) included 'ōhi'a lehua, a flowering evergreen tree, and hāpu'u pulu (*Cibotium glaucum* (Sm.) Hook. & Arn.), a tree fern that can grow both on the ground and as an epiphyte (table 1). Lowland tropical rainforests are multistoried forests with many canopy-dwelling epiphytes, shrub layers, and patches of open ground. The dominant species in lowland tropical rainforests were 'ōhi'a lehua and hāpu'u 'i'i (*Cibotium menziesii* Hook.) (table 1). This forest type can extend from lowlands up to lower slopes with windward, rainy exposures. Moist forests were widespread on leeward mesic to drier slopes, and were dominated by 'ōhi'a lehua, hāpu'u pulu (table 1), and koa. Dry forests were found on

Table 1—Hawaiian forest community types by estimated top two most abundant tree species in terms of tree numbers (≥5 inches diameter at breast height), Hawai‘i, 2010–2015

Hawaiian forest communities	Species	Number of trees	SE
		<i>Tree number (thousand trees)</i>	
Montane rainforest	‘Ōhi‘a lehua (e)	31,010	4,002
	Hāpu‘u pulu (e)	20,885	5,040
Lowland tropical rainforest	‘Ōhi‘a lehua (e)	10,354	1,765
	Hāpu‘u ‘i‘i (e)	5,928	1,917
Moist forest	‘Ōhi‘a lehua (e)	22,215	4,063
	Hāpu‘u pulu (e)	7,888	2,098
Dry forest	‘Ōhi‘a lehua (e)	3,947	1,446
	Christmas berry*	3,439	2,058
Cloud forest	‘Ōhi‘a lehua (e)	2,832	1,691
	‘Ōlapa‘lapa (e)	211	162
Strand vegetation	Kiawe (i)	45	38
	Ironwood*	40	42
Plantations	Grand eucalyptus (i)	9,587	4,009
	Ironwood*	1,400	1,374

Note: Totals may be off because of rounding; data are subject to sampling error.

SE = standard error, * = invasive, (e) = endemic, (i) = introduced.

some of the driest mountain slopes (i.e., mamani-naio forests of Hawai‘i Island) and lowlands on leeward sides, and they were dominated by ‘ōhi‘a lehua and invasive Christmas berry (*Schinus terebinthifolius* Raddi.). Cloud forests were characterized by their extensive cloud and fog cover. Plants and trees that thrive in the cloudy environment include small-leafed trees extensively covered with epiphytic mosses and ground-dwelling liverworts (forming a deep vegetative ground cover), and low-statured ‘ōhi‘a lehua and ‘ōlapa‘lapa (*Cheirodendron trigynum* (Gaudich.) A. Heller) (table 1).

Strand vegetation and plantations mainly consisted of introduced tree species. Strand vegetation included introduced trees, such as kiawe (*Prosopis pallida* (Humb. & Bonpl. ex Willd.) Kunth) and ironwood (*Casuarina equi-*

setifolia L.). Strand vegetation grows in sandy and rocky areas near the ocean, and often species are adapted to high salt concentrations and high rates of convective evaporation (Mueller-Dombois and Fosberg 1998, USDA 2019a). Plantations are areas consisting of tree species mainly planted for commercial purposes. Plantations primarily consisted of introduced eucalyptus species, such as grand eucalyptus (*Eucalyptus grandis* W. Hill ex Maid.) and swamp mahogany (*E. robusta*), two of the most widely planted eucalyptus species in Hawai‘i. Several large eucalyptus plantations were established in Hawai‘i for production of lumber and other wood products, or for watershed protection.

Although mangrove swamps and agroforestry communities were not encountered on plots sampled in this inventory, they remain important, less common components of Hawai‘i’s forests. Mangrove swamp forests include tree species that have high salt tolerance and grow on tidally inundated shores or in landlocked depressions. Although mangroves can provide flood protection and sediment containment across their native ranges, they were introduced to Hawai‘i where they have the capacity to displace native coastal ecosystems (DLNR 2016). An agroforestry community type refers to a collection of tree species included in crop or agricultural production systems, providing such ecosystem services as food (e.g., fruits and nuts), mulch (e.g., leaves and branches from nitrogen-fixing species), or medicines (Mueller-Dombois and Fosberg 1998, USDA 2019a).

Forest Area, Owner Groups, and Composition

Results from this FIA inventory indicate that, collectively, Hawai‘i, Kaua‘i, O‘ahu, Lāna‘i, and Maui supported about 1.5 million ac of forested land, representing more than 35 percent of the state’s total land area (table 2). Half of this forest land (734,956 ac) was managed by state and county governments, with the majority (591,373 ac) in reserved areas (table 2). Hawai‘i has the eighth largest state-administered forest reserve system in the United States (DBEDT 2018, DLNR 2016). Hawai‘i does not host national forest lands. Nonforest land area occupied 2.6 million ac of the state and included urban, agricultural, and rangeland areas, and the sparsely vegetated regions on Hawai‘i and Maui Islands (table 2) (DLNR 2016). Most nonforest land was privately owned

Table 2—Estimated land area by land status and owner group, Hawai'i, 2010–2015

Land status	Owner group								Number of plots
	Federal government		State and county governments		Private		All owners		
	Total	SE	Total	SE	Total	SE	Total	SE	
Forest land area:	----- <i>Thousand acres</i> -----								
Unreserved forest land	62	20	144	28	581	43	786	48	129
Reserved forest land	94	12	591	38	—	—	685	40	117
All accessible forest land	156	23	735	39	581	43	1,471	53	246
Nonforest land area:	----- <i>Thousand acres</i> -----								
Agricultural land	5	5	67	18	147	27	219	32	44
Rangeland	85	20	483	44	782	53	1,349	67	233
Developed land	10	7	58	19	172	30	240	34	50
Other ¹	267	19	323	31	240	32	831	46	174
All nonforest and other	367	23	931	45	1,341	49	2,639	54	500
Total land area:	523	29	1,666	43	1,924	42	4,110	17	716

Note: Totals may be off because of rounding and they do not include census and noncensus water; data subject to sampling error.

SE = standard error, — = less than 50 ac was estimated.

¹ Other includes undeveloped areas such as beaches, marshes, and bogs.

(1.3 million ac) (table 2). Privately owned land accounted for nearly 40 percent (580,599 ac) of the state's forest land area and 51 percent (1.3 million ac) of the state's nonforest land area (table 2). Public lands occurred on all islands except Ni'ihau and Lāna'i (DLNR 2016). About 11 percent of forest land and 14 percent of nonforest land was managed by federal agencies, such as the National Park Service, Fish and Wildlife Service, and Department of Defense (table 2) (DLNR 2016).

Montane rainforests, moist forests, and lowland tropical rainforests were the most common forest community types in Hawai'i. Montane rainforests accounted for the most forest area (29.6 percent), followed by moist forests (25.7 percent), and lowland tropical rainforests (25.3 percent) (fig. 4). Together, these three

forest community types accounted for more than 80 percent of the total forest area of the five main Hawaiian Islands inventoried for this report—Hawai'i, Maui, Lāna'i, O'ahu, and Kaua'i—covering about 1.2 million ac of land (fig. 4). Dry forests and cloud forests accounted for 12.7 percent and

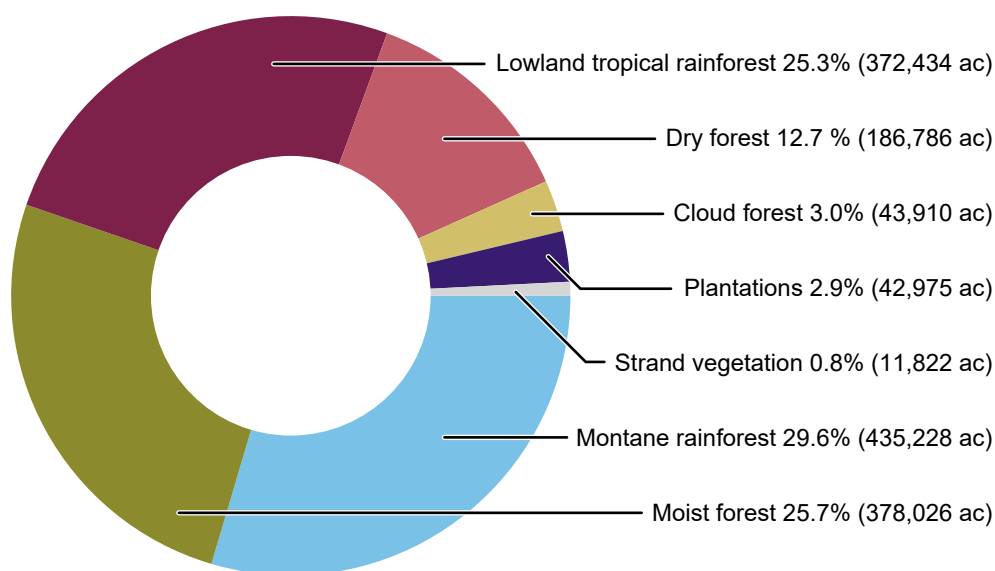


Figure 4—Percentage (and approximate acreage) of each forest community type, classified by Mueller-Dombois and Fosberg (1998), on forest land across the state of Hawai'i, 2010–2015.

3 percent of Hawai'i's forest area, respectively. Plantations, found primarily on Hawai'i Island, accounted for roughly 3 percent of total forest area, with strand vegetation accounting for another 0.8 percent (fig. 4).

Forest land was inventoried on the five main islands of Hawai'i, Maui, Lāna'i, O'ahu, and Kaua'i, and area occupied by different forest community types varied among these islands. Hawai'i Island, the youngest and largest island in the state, encompassed the most forest land area, with an estimated 921,964 ac; it also had the greatest diversity with regard to forest community types (fig. 5). Montane rainforests occupied the majority of forest land area on Hawai'i Island, followed by moist forests. Most plantations were located on Hawai'i Island, where they occupied an estimated 42,975 ac (4 percent) of total forest land area (fig. 5). Forest land occupied an estimated 206,680 ac on O'ahu, primarily consisting of lowland tropical rainforests (48 percent), followed by moist (35 percent), and dry (16 percent) forests (fig. 5). O'ahu is also the most populous island and home to 80 percent of the state's residents, with the majority

concentrated in the urban core of Honolulu (DLNR 2016). Maui supported an estimated 210,392 ac of forest land; the majority was accounted for by montane rainforests (39 percent) and lowland tropical rainforests (31 percent).

Kaua'i, the oldest island, supported an estimated 109,373 ac of forest land, and forests were evenly distributed among cloud forests (37 percent), montane rainforests (34 percent), and lowland tropical rainforests (29 percent). The privately owned island of Lāna'i supported an estimated 22,771 ac of forest land, 56 percent of which were dry forests and 44 percent of which were moist forests (fig. 5). The main Hawaiian Islands of Ni'ihau, Kaho'olawe, and Moloka'i were not sampled as part of this inventory because of logistical challenges during this project; in some cases landowners denied access to field crews, or potential plot locations were too hazardous to access. However, field crews were able to sample plots on Kaho'olawe and Moloka'i in 2020–2021 and these data will be included in future reports.

The majority of dominant forest communities, including montane rainforests, moist forests, and lowland tropical

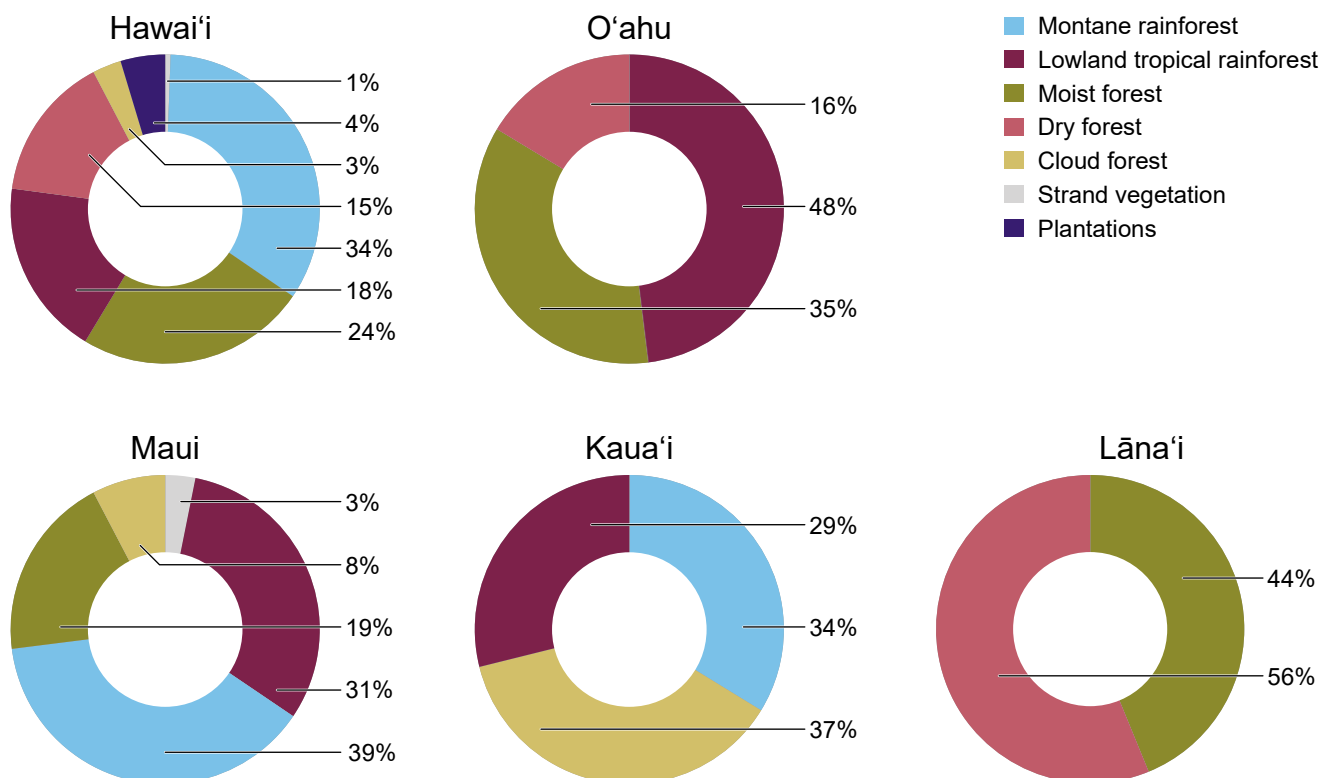


Figure 5—Percentage of estimated forest land area in each forest community type on each island, classified by Mueller-Dombois and Fosberg (1998), Hawai'i, 2010–2015.

rainforest, were either found on reserved lands managed by state and county governments, collectively occupying 503,470 ac, or on unreserved, privately owned land occupying 440,708 ac (fig. 6). Most cloud forests were found on reserved lands managed by state and county governments. All strand vegetation, and most dry forests and plantations occurred on unreserved, privately owned land (fig. 6).

Results from this inventory documented a total of 112 live-tree species and estimated that 1.8 billion trees were living within the forests of the Hawaiian Islands (i.e., live trees with stems ≥ 1 inch in diameter) (table A2-2). Regarding total number of live stems with diameters ≥ 1 inch, five of the ten most abundant trees were invasive species (table 3). Strawberry guava was the most abundant species by stem count for total trees with diameters ≥ 1 inch (721,937 stems) (table 3), followed by haole koa (*Leucaena leucocephala* (Lam.) de Wit) (60,819 stems), and Christmas berry (60,286 stems). Strawberry guava is the most damaging invasive tree species in the state. Once established, strawberry guava forms dense thickets that displace native species, alter ecosystem processes such as water production, and provide habitat and food for other nonnative pests such as fruit flies and nonnative feral pigs (Asner et al. 2008, Takahashi et al. 2011). Haole koa is a fast-growing, nitro-

gen-fixing leguminous tree, and Christmas berry is capable of shading out native plants in dry and mesic lowland areas; both of these invasive species are readily dispersed by birds, animals, and human activities (Wagner et al. 1999) (table 3).

Regarding larger trees with live stems ≥ 5 inches in diameter, 'ōhi'a lehua was most abundant (70,383 stems) followed by two endemic tree ferns: hāpu'u pulu (33,761 stems) and hāpu'u 'i'i (17,498 stems) (table 3). 'Ōhi'a lehua was not only the most abundant endemic tree, it was also the most morphologically variable. 'Ōhi'a lehua varies from tree to shrub form as it grows in both wet and dry forests, having diverse leaf and flower shapes and colors (Adee and Conrad 1990). 'Ōhi'a lehua is an ecological and cultural keystone species vital to the ecosystems and people of Hawai'i (see "'Ōhi'a Lehua and Rapid 'Ōhi'a Death" below). Hāpu'u 'i'i is the states' largest tree fern, and both hāpu'u 'i'i and hāpu'u pulu are important culturally and to forest structure. Another dominant high-value tree was *Acacia koa* (koa), however, this species occurred in our plots less frequently than some introduced and invasive species (table 3). Koa has been harvested from local Hawaiian forests for more than a century for its highly prized wood, which led to vast reductions of koa-dominated forests (Baker et al. 2009). Koa is highly prized for its ecological, cultural, and

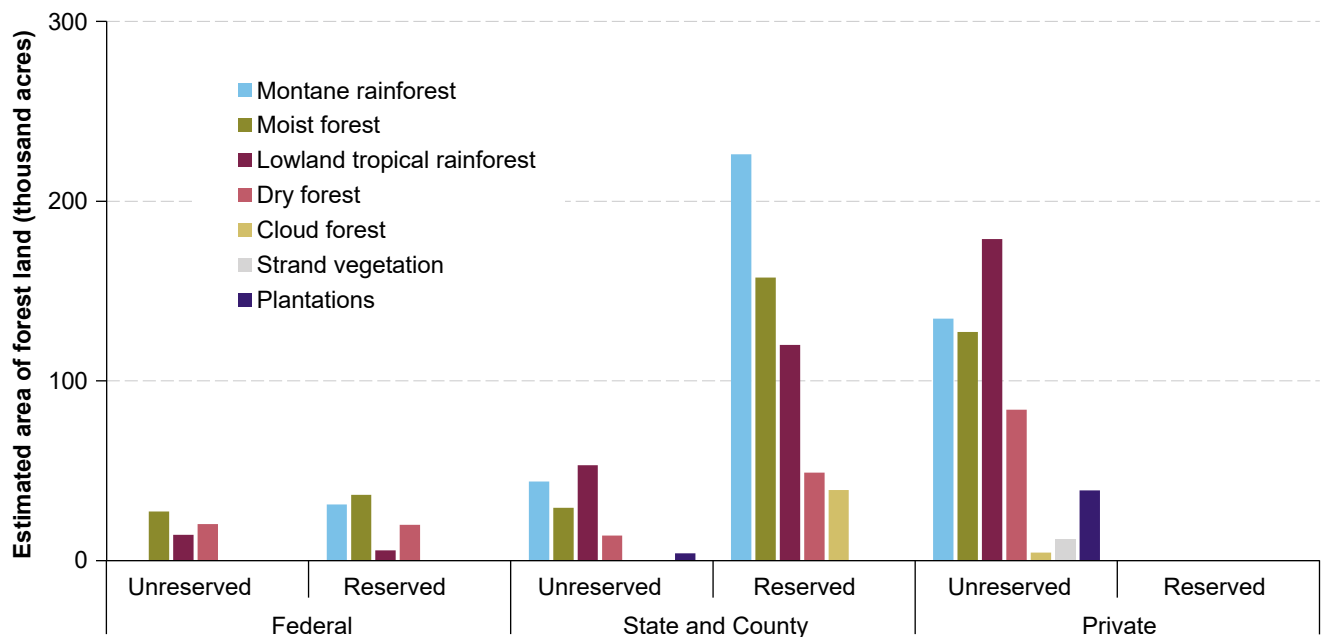


Figure 6—Forest land area, by forest community type, land status, and owner group across the state of Hawai'i, 2010–2015.

Table 3—Top 10 most dominant tree species, in terms of estimated stem numbers, for trees ≥1 inch and ≥5 inches in diameter, Hawai‘i, 2010–2015

Tree species	Total	SE	Tree species	Total	SE
Top 10 species ≥1 inch diameter	<i>Number of trees (thousands)</i>		Top 10 species ≥5 inches diameter	<i>Number of trees (thousands)</i>	
Strawberry guava*	721,937	126,162	‘Ōhi‘a lehua (e)	70,383	5,073
‘Ōhi‘a lehua (e)	360,890	38,506	Hāpu‘u pulu (e)	33,761	5,431
Haole koa*	60,819	22,647	Hāpu‘u i‘i (e)	17,498	2,730
Christmas berry*	60,286	18,020	Christmas berry*	9,830	2,932
Shoebuttan Ardisia*	57,607	36,150	Grand eucalyptus (i)	9,786	4,014
Kanawao (e)	42,863	15,651	Strawberry guava*	9,209	2,697
Olapa‘lapa (e)	40,600	6,748	Koa (e)	9,069	3,809
Hāpu‘u pulu (e)	33,760	5,431	Swamp mahogany (i)	4,551	1,958
Common guava*	27,889	10,499	‘Ōlapa‘lapa (e)	4,544	982
Small Philippine acacia (i)	23,957	14,759	Java plum*	4,138	1,434

Note: Totals may be off because of rounding; data are subject to sampling error. SE = standard error, * = invasive, (e) = endemic, (i) = introduced species.

economic characteristics, and it is used for products such as outrigger canoes, surfboards, furniture, and guitars (Baker et al. 2009, DLNR 2016).

Large-, medium-, and small-diameter forest stand size classes—defined by predominant diameter-at-breast-height (d.b.h.) ranges among all live trees, seedlings, and saplings—tended to occupy similar land area across Hawai‘i; however, there was a greater number of smaller trees (<9.9 inches d.b.h.) (figs. 7 and 8). The pattern shown in figure 8 indicates that regeneration was abundant, but this pattern was most likely driven by numerous small-diameter stems of invasive species (i.e., strawberry guava and haole koa). Also, many native species (with the notable exception of ‘ōhi‘a and koa) were small-stature trees by nature that were most commonly <10 inches d.b.h. Tree stems <5 inches d.b.h. were the most widespread size class (table A2-2), followed by those between 5 and 9.9 inches d.b.h. (figs. 8 and 9). Plantations had the greatest average number of live-tree stems (≥5.0 inches in diameter) per acre, with about 301 stems ac⁻¹ between 5 and 14.9 inches in diameter, which was higher than other forest communities (from 7 to 189 stems ac⁻¹, mostly between 5 and 14.9 inches in diameter) (fig. 9). Stand size class characteristics have shifted in the past century as many high-value koa and ‘iliahi trees were harvested and exported to foreign markets (DLNR 2016).

Deforestation and degradation of native forests occupied by koa, ‘ōhi‘a, and ‘iliahi, along with impacts associated with invasive species have reduced the area of these forests and resulted in low densities of large-diameter trees. FIA

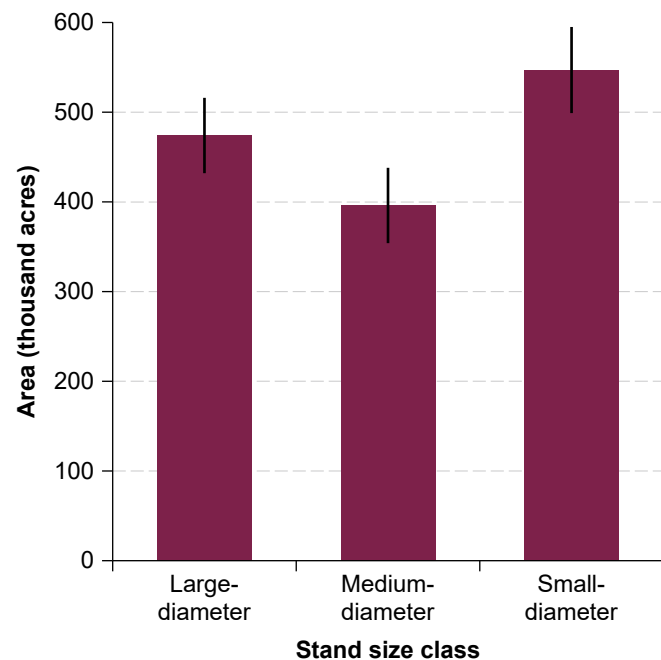


Figure 7—Forest land area by stand size class. Forests with small-diameter classes have a majority of trees <5 inches d.b.h., forests with medium-diameter classes have a majority of trees 5–11 inches d.b.h., and forests with large-diameter classes have a majority of trees ≥11.0 inches d.b.h.

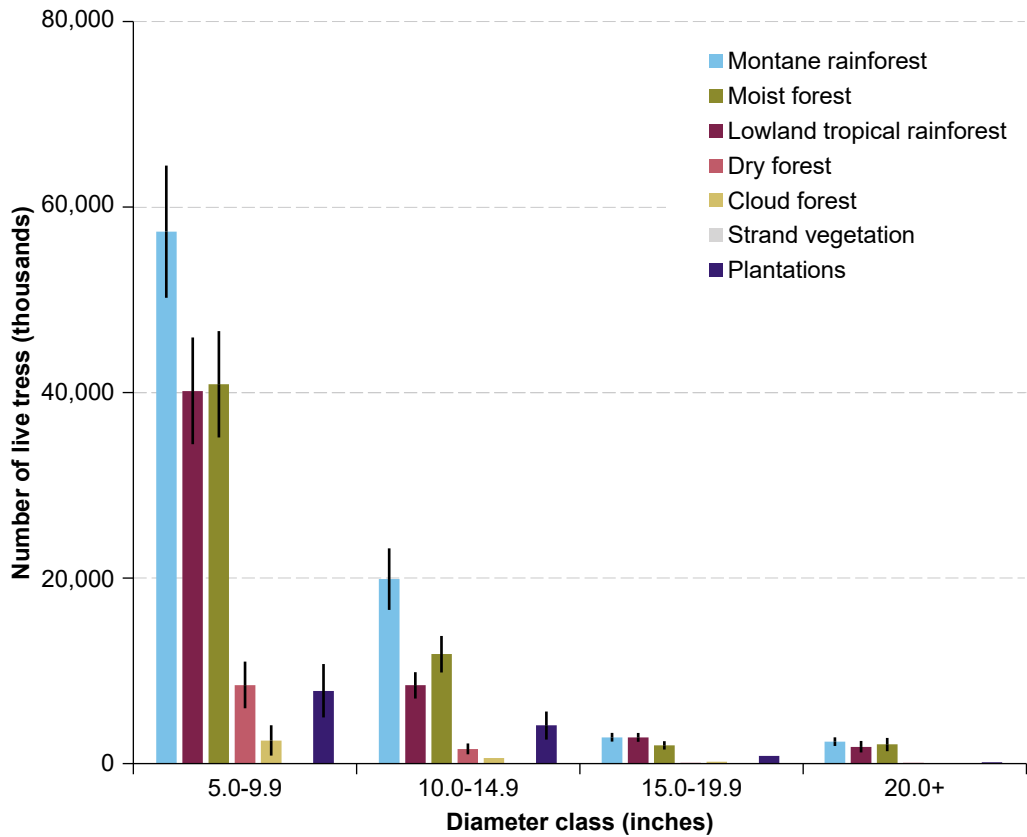


Figure 8—Estimated number of live trees in Hawaiian forest community types by diameter class, Hawai'i, 2010–2015.

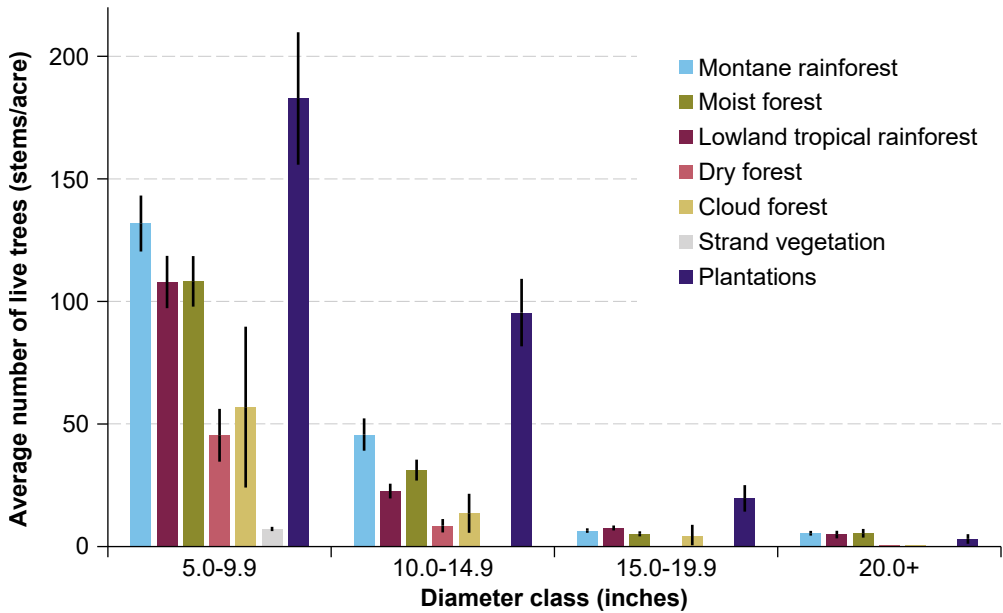


Figure 9—Estimated average number of live trees in Hawaiian forest community types by diameter class, 2010–2015.

crews did not encounter any ‘iliahi trees ≥ 5 inches d.b.h. on measured plots. Native tree plantations remain at an experimental stage in Hawai‘i, and consist of young, small-diameter individuals. Currently, harvesting of native tree species occurs outside plantations (DLNR 2016, 2018a). Federal and state agencies, such as the Hakalau Forest National Wildlife Refuge, Hawai‘i Volcanoes National Park, Hawai‘i Department of Land and Natural Resources, and the University of Hawai‘i, as well as nonprofit organizations and private landowners, are planting native trees to restore areas that have been deforested in the past (DLNR 2016). Over time, stem number dominance by smaller size trees, shown in figure 8, may shift to larger trees, depending on forest management activities, tree mortality, and other disturbances.

Biomass, Carbon, and Volume

Biomass and carbon—

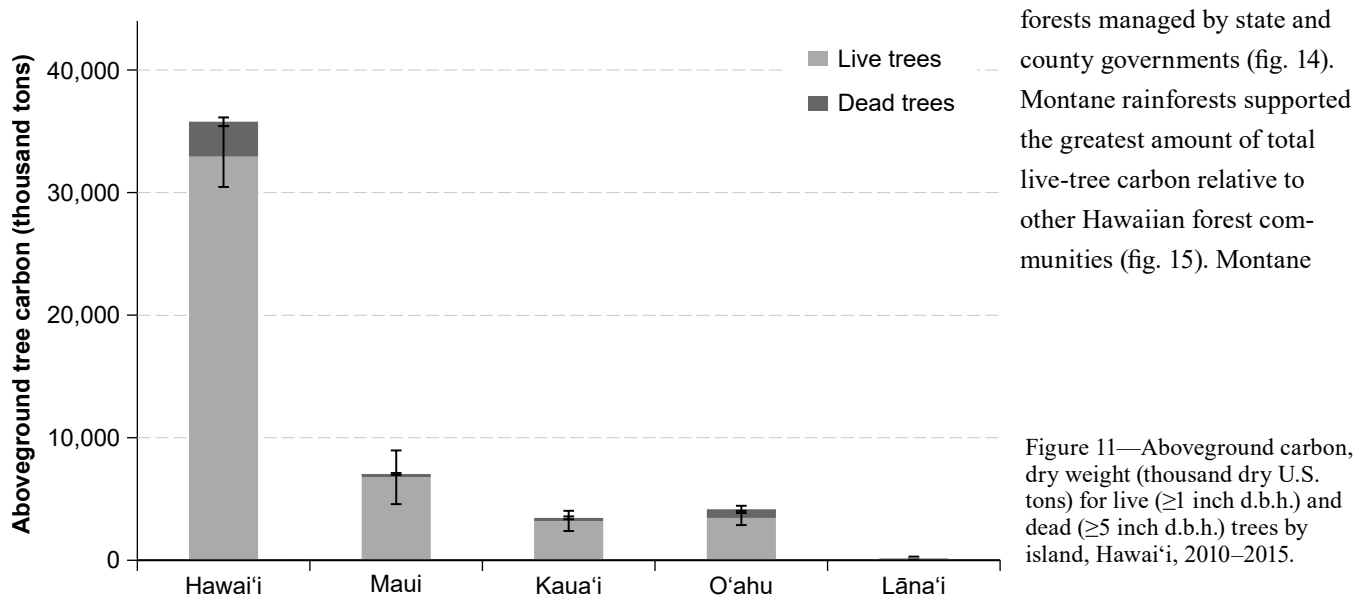
Estimates of aboveground tree biomass and carbon include direct measures of tree diameter and height (fig. 10), wood density, and species- and site-specific equations similar to those described in Asner et al. (2011). Variations in aboveground biomass and carbon can be explained by factors such as topography, climate, species composition, stand age, and forest management. FIA inventory-based estimates and associated remote-sensing data also indicate that the displacement of native forests by invasive tree species can influence carbon dynamics and occasionally result in lower aboveground carbon storage across Hawaiian forests (Asner et al. 2009, Hughes et al. 2018, Selmants et al. 2017) (see box on p. 46). Change in carbon mass is directly proportional to change in biomass because carbon makes up roughly 50 percent of living tissue. Determining forest carbon stocks can help determine whether a forest is carbon neutral (having a balance between emitting and absorbing carbon from the atmosphere), a carbon sink (net accumulation of forest carbon exceeds emissions), or a carbon source (net loss of carbon to the atmosphere exceed inputs). Estimates of live and dead aboveground biomass and carbon can provide insights into stand productivity and help inform management or conservation decisions.

The 2010–2015 survey indicated that forests of Hawai‘i supported 93 million U.S. tons (84 Tg) of aboveground live-tree biomass and 47 million U.S. tons (43 Tg) of aboveground live-tree carbon mass (table A2-9). For comparison, Selmants



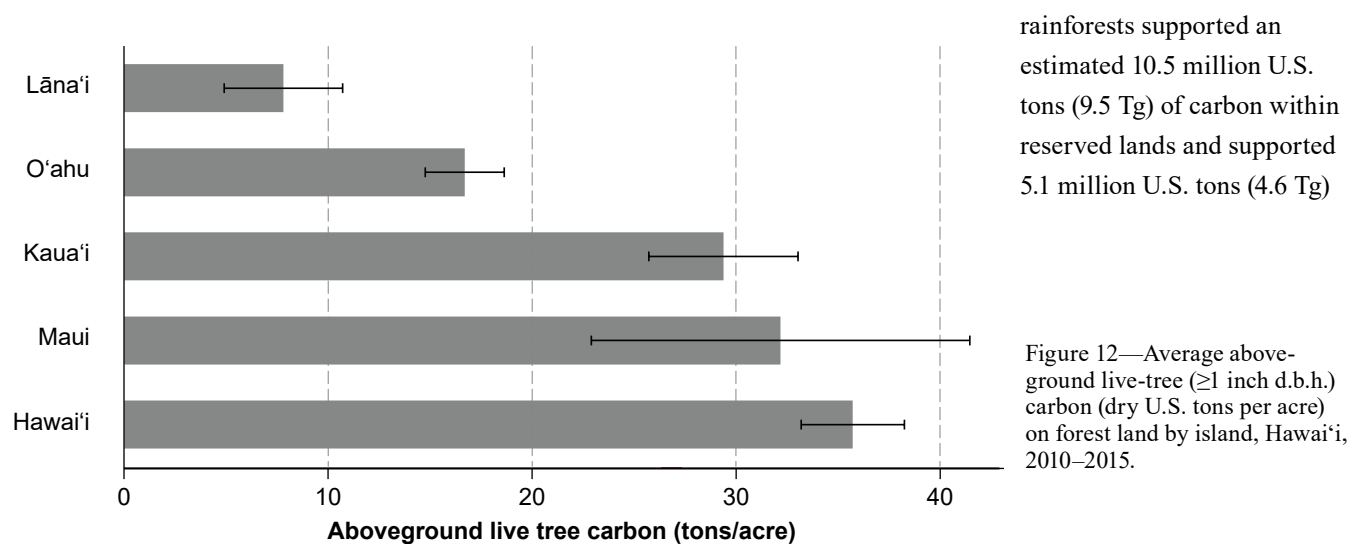
Figure 10—Field crew member Kalena Shiroma measures tree height. Tree height and diameter are used to calculate tree volume, biomass, and carbon.

et al. (2017) reported a total of 44.2 Tg of aboveground live carbon in Hawai‘i using different methods and including nonforested areas. Aboveground dead trees accounted for 8.1 million U.S. tons (7.3 Tg) of aboveground biomass and stored an estimated 4.1 million U.S. tons (3.7 Tg) of carbon in Hawai‘i’s forests (table A2-9). Standing dead trees (i.e., snags) are important components of aboveground forest carbon storage and serve many ecological functions associated with forest structure and wildlife habitat. Large-scale disturbances caused by weather-related events, diseases, fire, and insects can substantially increase the dead wood portion of aboveground carbon mass. The majority of aboveground live and dead tree carbon occurred on Hawai‘i Island, which supported about 71 percent of the state’s live-tree carbon and 70 percent of the state’s dead-tree carbon (fig. 11). On average, forests of Hawai‘i Island supported 36 U.S. tons of aboveground live-tree carbon per ac (81 Mg per hectare) (fig. 12). Forests of Maui, O‘ahu, and Kaua‘i exhibited an average



forests managed by state and county governments (fig. 14). Montane rainforests supported the greatest amount of total live-tree carbon relative to other Hawaiian forest communities (fig. 15). Montane

Figure 11—Aboveground carbon, dry weight (thousand dry U.S. tons) for live (≥ 1 inch d.b.h.) and dead (≥ 5 inch d.b.h.) trees by island, Hawai'i, 2010–2015.



rainforests supported an estimated 10.5 million U.S. tons (9.5 Tg) of carbon within reserved lands and supported 5.1 million U.S. tons (4.6 Tg)

Figure 12—Average above-ground live-tree (≥ 1 inch d.b.h.) carbon (dry U.S. tons per acre) on forest land by island, Hawai'i, 2010–2015.

range of 17 to 32 U.S. tons per ac (38 to 72 Mg per ha) of aboveground live-tree carbon (fig. 12).

Live and dead carbon stores differed among land owner or management groups (fig. 13), likely as a result of differences in forest community types, management strategies, disturbance histories, and site quality. Forests managed by state and county governments supported the greatest amount (54 percent) of total aboveground live-tree carbon (25 million U.S. tons, or 23 Tg) compared to other land management or owner groups (fig. 13). Carbon per acre estimates were more similar among owner groups, ranging from 28.2 U.S. tons per ac (63.2 Mg per ha) in privately owned forests to 34.3 U.S. tons per ac (76.9 Mg per ha) in

of carbon within unreserved lands (fig. 15). Plantations stored by far the most carbon per acre (108 U.S. tons per ac (242 Mg per ha); carbon storage in other Hawaiian forest community types ranged from 1.6 U.S. tons per ac (3.6 Mg per ha) in strand vegetation to 35.9 U.S. tons per ac (80.5 Mg per ha) in montane rainforests (fig. 16). Figure 17 shows the top 10 tree species ≥ 1 inch d.b.h. that stored the most aboveground live carbon across the state. Hawai'i's dominant tree species, 'ōhi'a lehua, stored the greatest amount of carbon, accounting for about 19.2 million U.S. tons (17.4 Tg) or 41 percent of total live-tree carbon, followed by strawberry guava, which stored about 5.2 million U.S. tons (4.7 Tg) or 11 percent of total

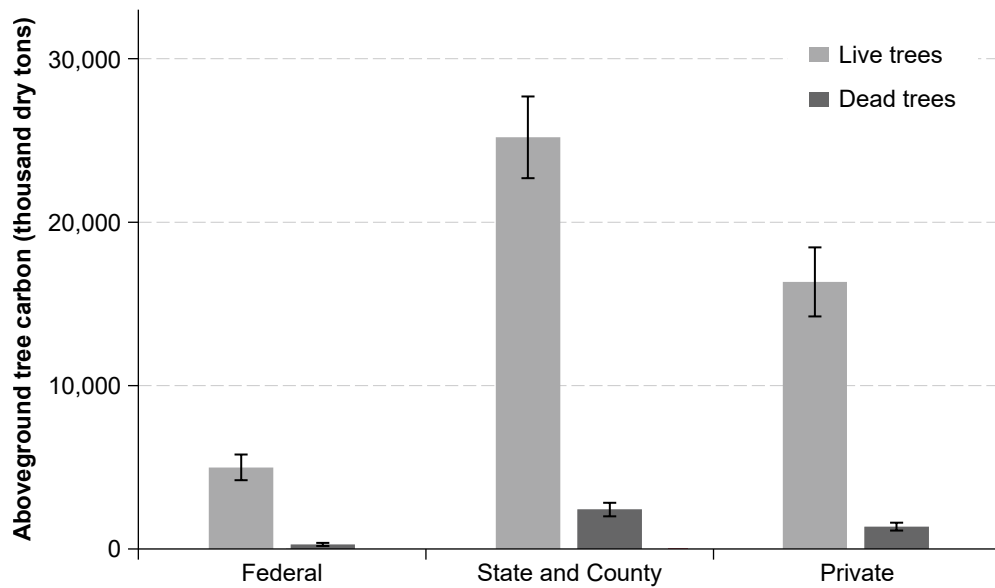


Figure 13—Aboveground carbon, dry weight (thousand dry U.S. tons) for live (≥ 1 inch d.b.h.) and dead (≥ 5 inch d.b.h.) trees by land owner group, Hawai'i, 2010–2015.

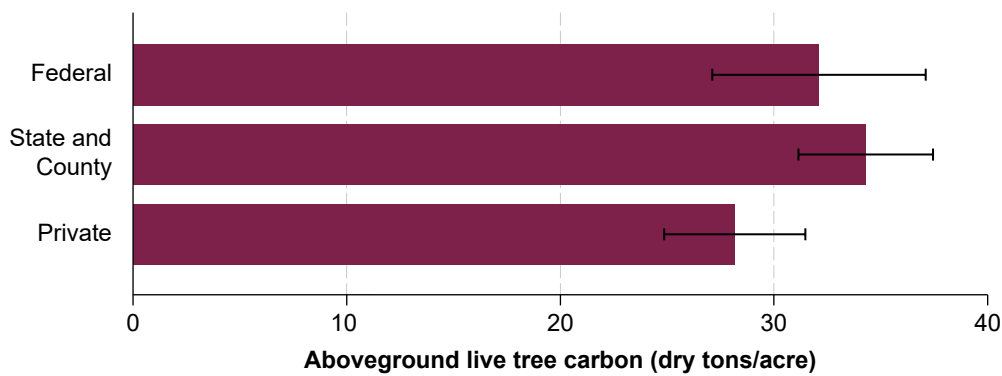


Figure 14—Average aboveground live-tree (≥ 1 inch d.b.h.) carbon (dry U.S. tons per acre) on forest land by owner group, Hawai'i, 2010–2015.

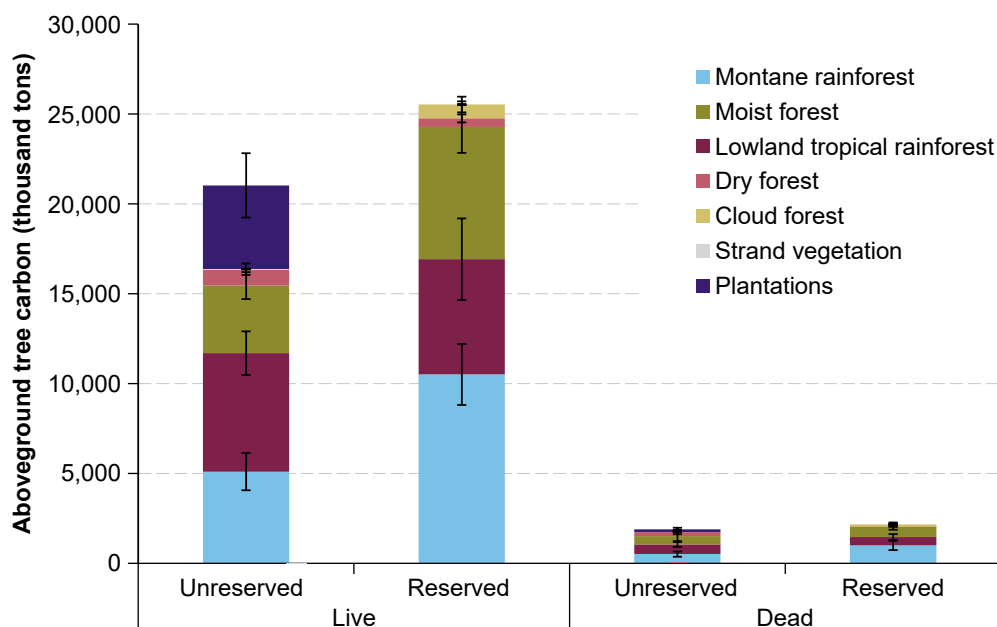


Figure 15—Aboveground carbon, dry weight (thousand dry U.S. tons) for live (≥ 1 inch d.b.h.) and dead (≥ 5 inch d.b.h.) trees on reserved and unreserved land by forest community type, Hawai'i, 2010–2015.

live-tree carbon (fig. 17). 'Ōhi'a lehua also stored the greatest amount of aboveground carbon (45 percent) for all trees ≥ 5 inches d.b.h.; strawberry guava only stored 2.4 percent of total aboveground carbon for trees larger ≥ 5 inches d.b.h. The complexities of these comparisons are discussed with the focus on strawberry guava's impacts on carbon storage in the box on p. 46. Live-tree carbon was concentrated in smaller diameter size classes (i.e., 1 to 14.9 inches d.b.h.) and most dead-tree carbon was stored in snags between 5

and 19.9 inches d.b.h. (fig. 18). Snags < 5 inches d.b.h. were not measured as part of this study.

Hawai'i's variable climate, elevational gradients, and soils all affect carbon input, storage, and sequestration (Crow et al. 2016, Selmants et al. 2017). Areas that received more than 50 inches of precipitation per year supported the greatest amount of total and per-acre, aboveground live-tree carbon (figs. 19 and 20). Total and per-acre, aboveground live-tree carbon was similar across elevation gradients (figs.

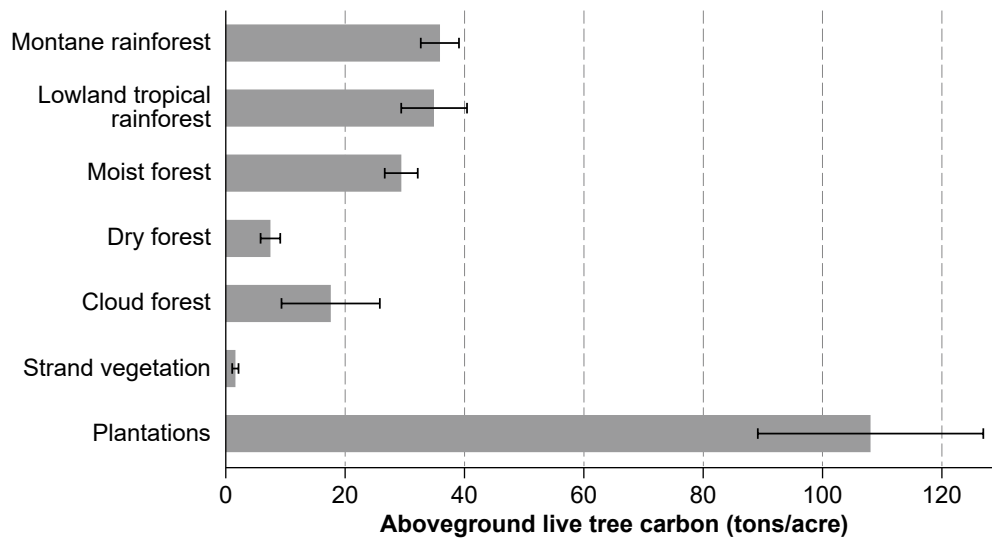


Figure 16—Average aboveground live-tree (≥ 1 inch d.b.h.) carbon (dry U.S. tons per acre) on forest land by forest community type, Hawai'i, 2010–2015.

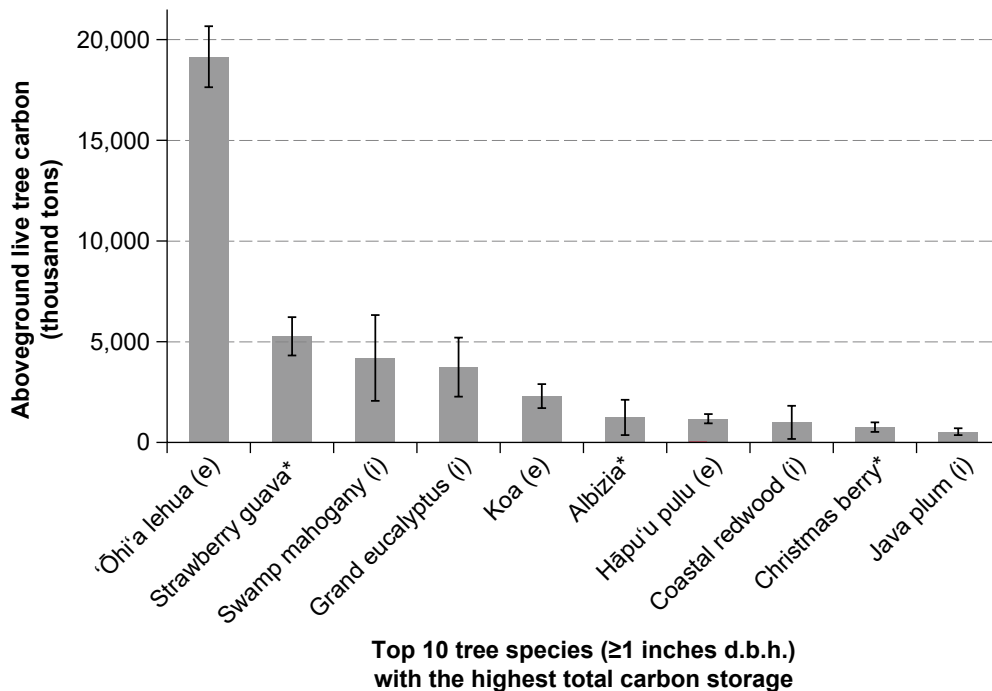


Figure 17—Aboveground carbon, dry weight (thousand dry U.S. tons) for the top 10 species of live trees (≥ 1 inch d.b.h.) that store the most carbon, Hawai'i, 2010–2015. * = invasive species, (e) = endemic species, (i) = introduced species.

19 and 20). Forest products derived from wood extraction should also be considered part of the overall carbon balance, but were not addressed here.

Volume—

Estimates of stand volume are used to predict stocks of merchantable wood, with repeat volume measurements used

to understand changes in growth and loss to removals and mortality. Hawai'i's forests contained about 2.5 billion ft³ of aboveground live-tree volume. Montane rainforests accounted for the majority of live-tree wood volume (919 million ft³) (fig. 21). Volume per acre is highly dependent on the relative stem density, with young stands typically carrying less volume

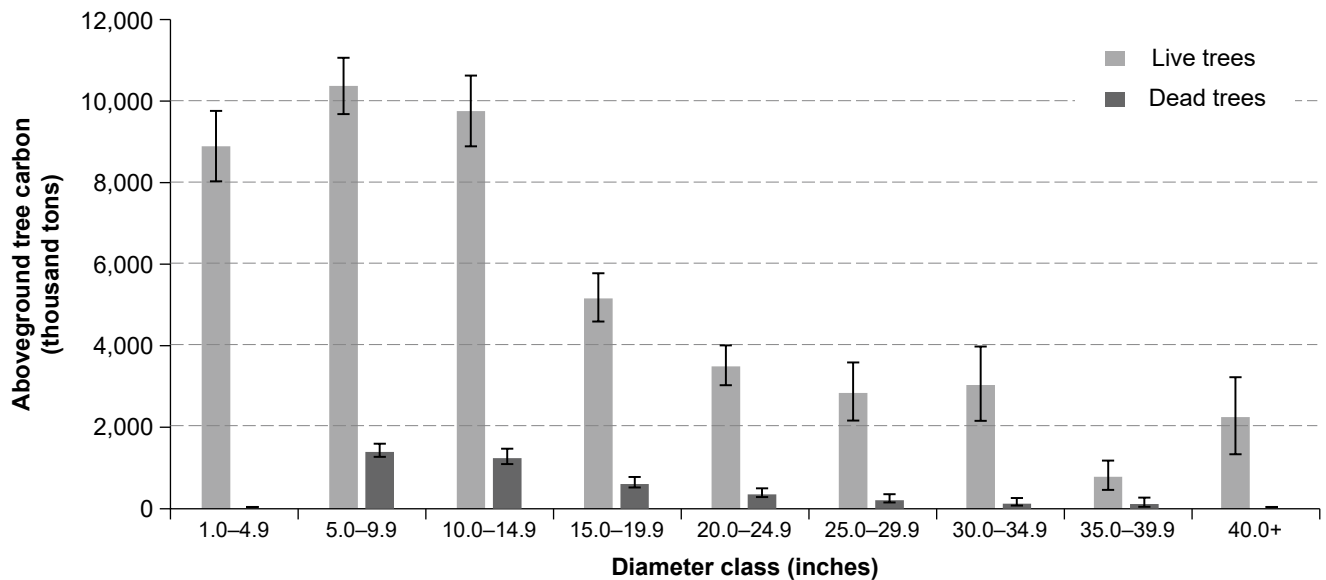


Figure 18—Aboveground carbon, dry weight (thousand dry U.S. tons) for live and dead trees by diameter class (inches), Hawai'i, 2010–2015.

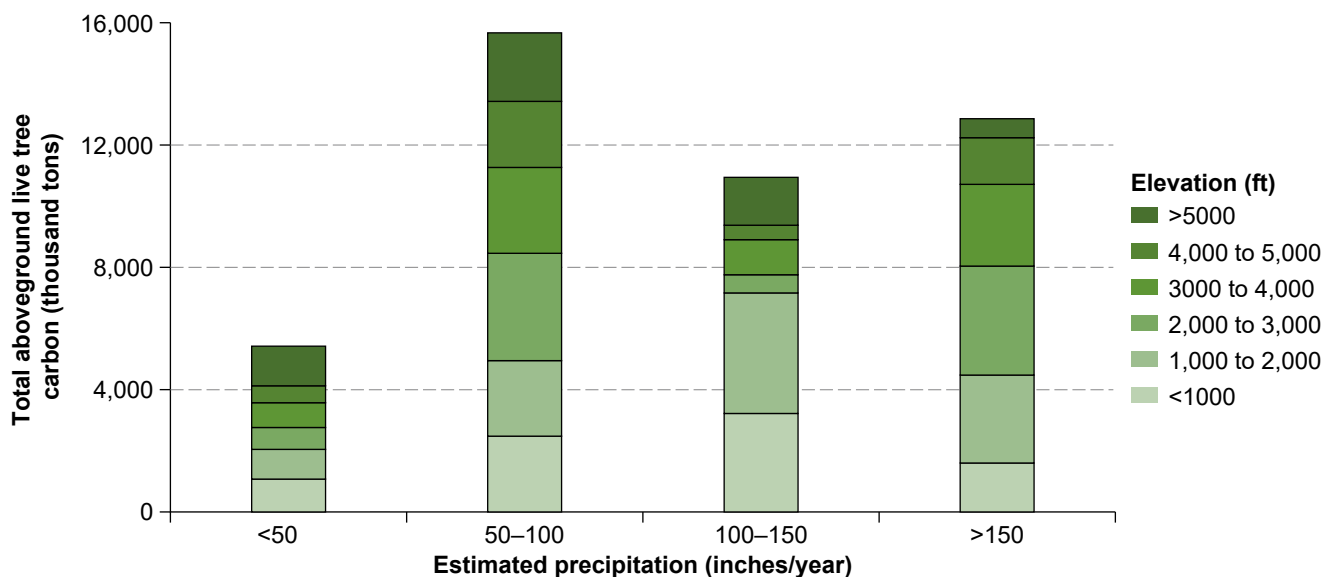


Figure 19—Aboveground carbon, dry weight (thousand dry U.S. tons) of live trees (≥ 1 inch d.b.h.) by estimated amount of precipitation and elevation, Hawai'i, 2010–2015.

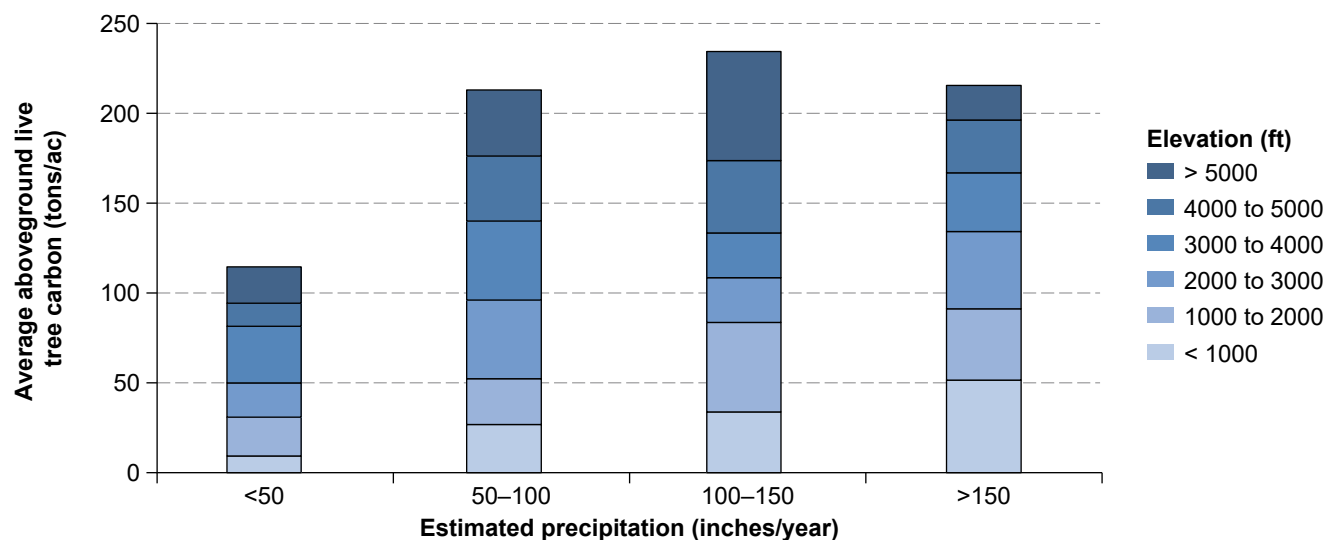


Figure 20—Average aboveground carbon per acre, dry weight (thousand dry U.S. tons) of live trees (≥ 1 inch d.b.h.) by estimated amount of precipitation (inches) per year and elevation (feet), Hawai'i, 2010–2015.

per acre than mature stands. Across all forest communities, Hawai'i averaged 1,701 ft³ of net live-tree wood volume on a per acre basis. Hawai'i's plantations exhibited the highest levels of standing volume (7,325 ft³ net volume ac⁻¹), followed by montane rainforests (2,112 ft³ net volume ac⁻¹) (fig. 22).

Accurate volume estimates of koa and identified plantation species may be informative for economic decisions in Hawai'i. Hawai'i's forest industry is a multimillion-dollar industry. Three-quarters of Hawai'i-grown wood products are from koa, but harvests from forests followed by conversions to ranch lands have nearly depleted the supply of high-quality, old-growth trees. Reduced availability on private lands coupled with elimination of commercial harvests on state lands has greatly increased the price of koa wood over the past 2 decades (DLNR 2016, Friday et al. 2006, Idol et al. 2017). Koa plantations have not gone through a full rotation, and commercial harvests continue to rely on removing large mature koa trees from Hawai'i's forests (DLNR 2016, Inman-Narahari 2015). Koa exhibited 133 million ft³ of live aboveground volume. The volume distribution of koa was relatively similar across all diameter classes, although less volume was found in the 25–29.9- and 35–39.9-inches diameter classes (fig. 23A). Most (54 percent) koa stand volume occurred on lands managed by state and county governments, and 36 and 10 percent of koa volume occurred on private and federally managed lands, respectively (fig. 23B).

Hawai'i's plantation forests consist primarily of introduced eucalyptus species on Hawai'i Island. Eucalyptus species have value for commercial timber and may help protect island watersheds, but they could also spread into ranch lands (DLNR 2016). Results show that grand eucalyptus and swamp mahogany accounted for the most volume of inventoried eucalyptus species, with the former accumulating 253 million ft³ of live aboveground net volume, mainly in smaller diameter classes (5–19.9 inches) (fig. 24A), and the latter accumulating 214 million ft³ of live aboveground volume, primarily within larger diameter classes (25–34.9, and ≥ 40 inches) (fig. 24A). Most grand eucalyptus volume (95 percent) occurred on private lands (fig. 24B). In contrast, the majority of swamp mahogany volume (76 percent) occurred on state and county administered lands, and 23 percent occurred on private lands (fig. 24B).

Understory Vegetation

Understory forest vegetation is important to Hawaiian ecosystems, contributing to nutrient cycling, soil stability, and carbon storage (fig. 25). The percentage cover of predominant understory species (i.e., ≥ 3 percent canopy cover) in each growth habit (i.e., shrubs, forbs, and graminoids) was measured in forest plots. Shrubs included woody, multiple-stemmed plants of any size and woody vines; forbs consisted of herbaceous, broad-leaved plants,

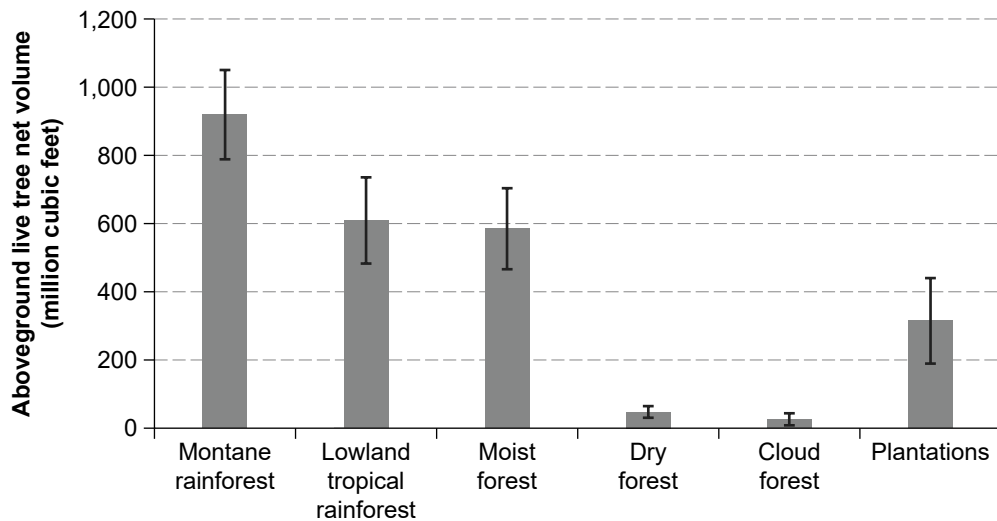


Figure 21—Aboveground net volume of live trees (≥ 5 inches d.b.h.) on forest land by forest community type, Hawai'i, 2010–2015. Trees in the strand forest type contained <1 percent of live tree volume and are not shown in this figure.

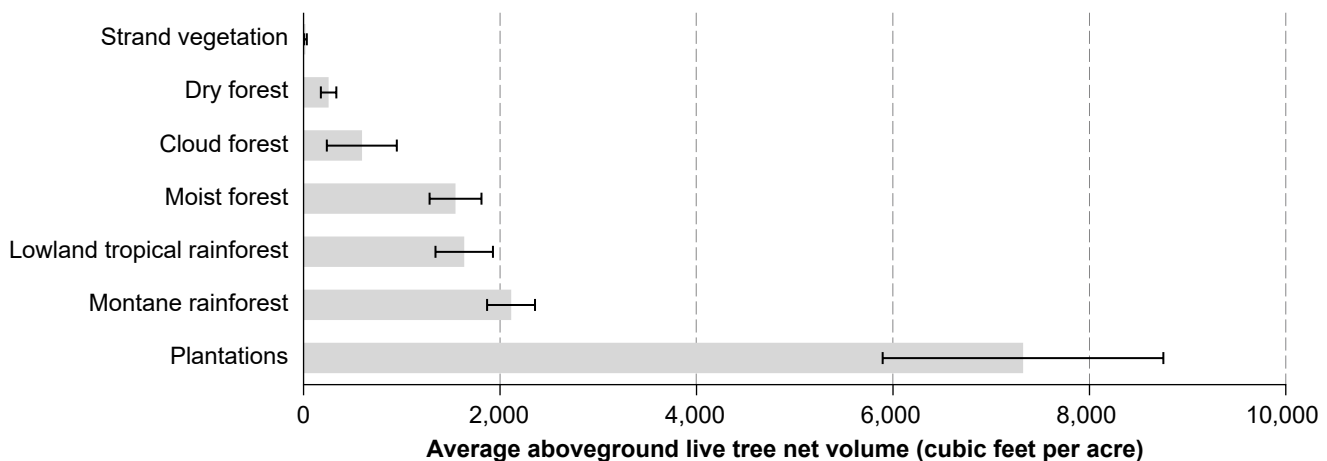


Figure 22—Average net aboveground live-tree volume (≥ 5 inches d.b.h.) cubic feet per acre on forest land by forest community type, Hawai'i, 2010–2015.

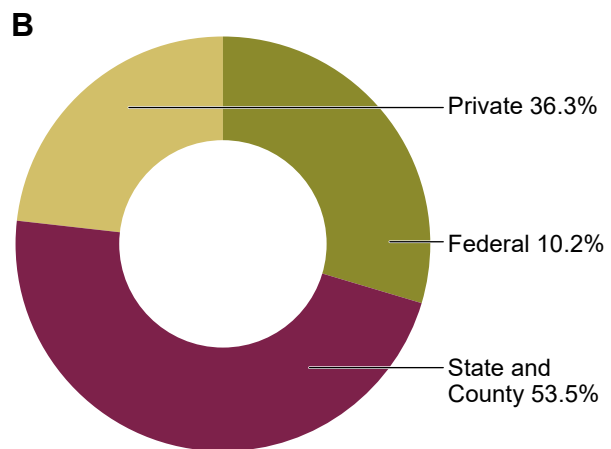
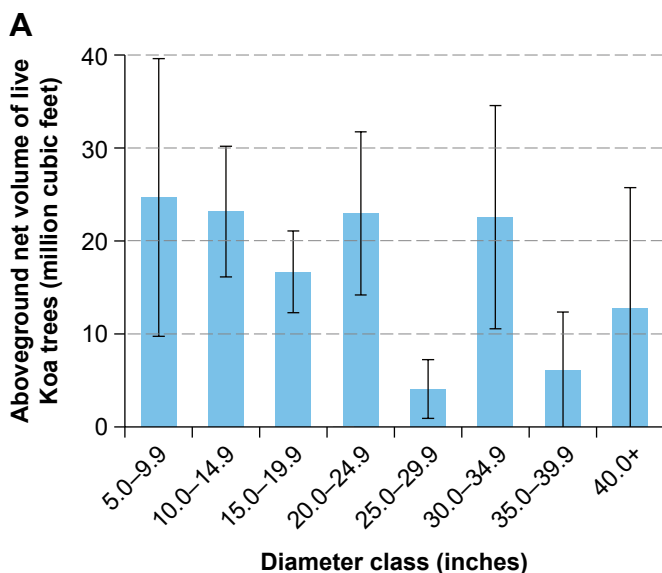


Figure 23—Net aboveground volume (million cubic feet) of live koa trees (≥ 5 inches d.b.h.) by (A) diameter class and (B) land owner group, Hawai'i, 2010–2015.

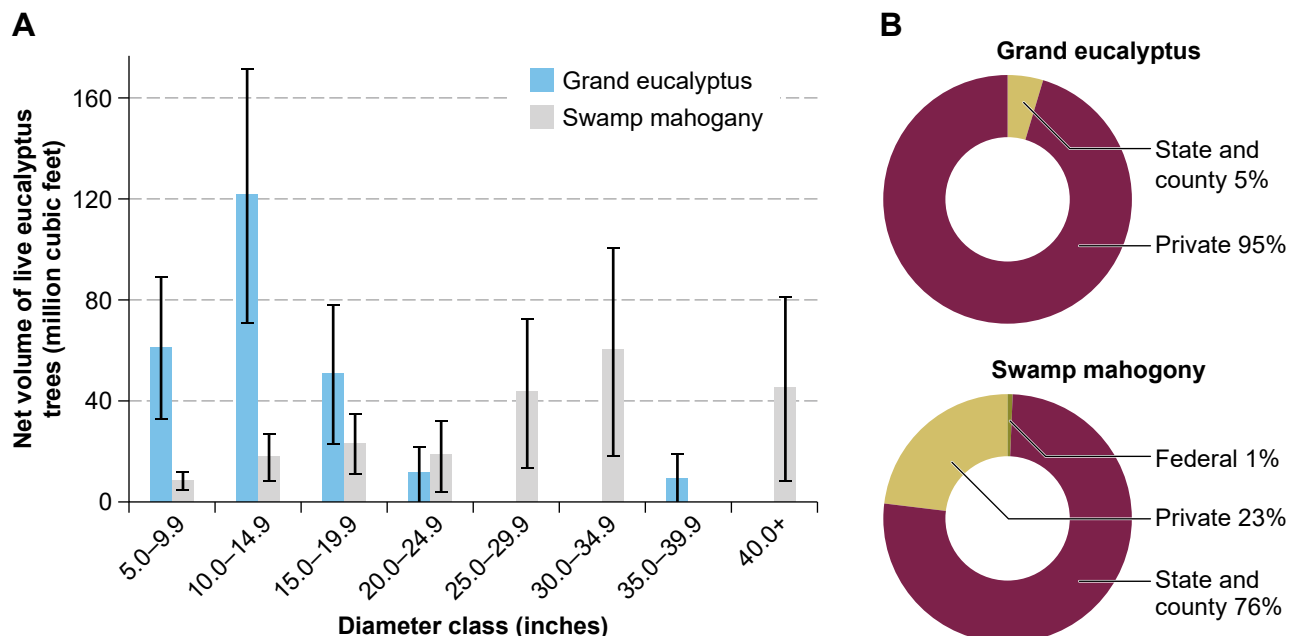


Figure 24—Net aboveground volume (million cubic feet) of live grand eucalyptus and swamp mahogany trees (≥ 5 inches d.b.h.) by (A) diameter class and (B) land owner group, Hawai'i, 2010–2015.

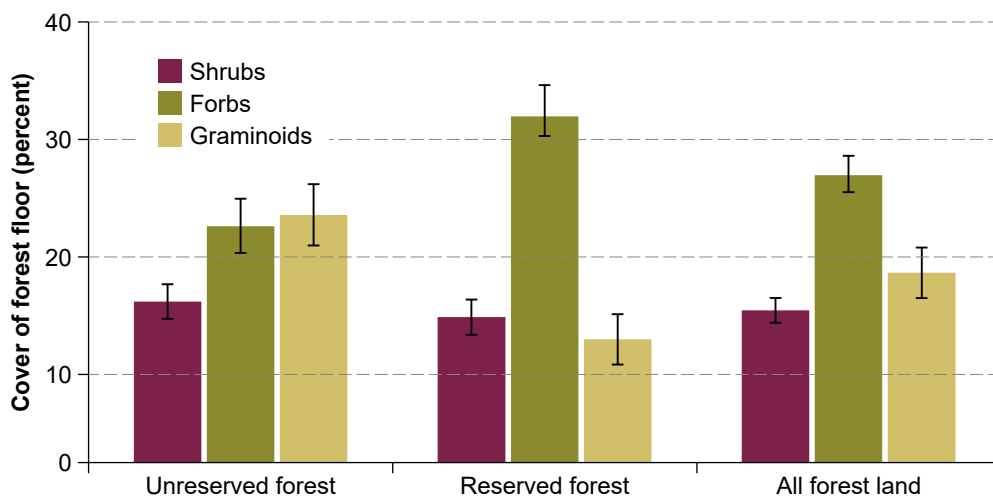
including nonwoody vines and ferns; and graminoids consisted of grasses and grass-like plants, including rushes and sedges. Structural classification of each growth habit provided information on the vertical layering of understory vegetation. Characterization of understory composition and structure is useful for assessing large-scale species trends, stand-level attributes, forest successional stage, wildlife habitat, and extent of invasive species.

Understory vegetation cover in Hawai'i's forests varied by growth habit, reserved status, forest community type, and dominant species cover. Across all forest lands, percentage cover values for forbs (26 percent) were greater than graminoids (17 percent) and shrub cover (14 percent) (fig. 26). The distribution of forb and graminoid growth habits differed between reserved and unreserved forest lands. Graminoid cover averaged 23 percent in unreserved and 11 percent in reserved forest areas, and forb cover tended to be lower in unreserved (22 percent) than reserved (31 percent) forest areas (fig. 26). Shrub cover was similar between unreserved and reserved forest areas at about 13 to 14 percent. Plantations exhibited the greatest understory graminoid cover (37 percent) relative to other forest communities (all others < 26 percent) (fig. 27). Montane, lowland tropical rainforests, and cloud forests



Molly Murphy

Figure 25—U.S. Forest Service Forest Inventory and Analysis crew members, Kai Hiraoka and Ambrose Canton, measure understory plant cover. Understory vegetation is an important measure of forest resources in Hawai'i.



in unreserved, and 2,000 ac in reserved areas (fig. 28). Both Koster's curse and Asian melastome are considered major threats to Hawaiian forests because they grow

Figure 26—Average percentage of shrub, forb, and graminoid cover by U.S. Forest Service Forest Inventory and Analysis-defined unreserved, reserved, and all forest land, Hawai'i, 2010–2015.

all exhibited the greatest forb cover, ranging from 32 to 40 percent compared to other forest communities (<20 percent), and shrub cover was below 18 percent in all forest communities (fig. 27).

Understory forest species with the greatest land cover in each growth habit in reserved and unreserved areas are summarized in figure 28, and a full understory species list by owner group with scientific and common names is shown in appendix 2 (table A2-12). The greatest estimated shrub cover was from two invasive shrubs—Koster's curse (*Clidemia hirta* (L.) D. Don), covering about 20,000 ac each in reserved and unreserved areas, and Asian melastome (*Melastoma candidum* D. Don), covering about 23,000 ac

quickly, produce dense understory canopies and thousands of easily dispersed fruits each year, and easily outcompete many native understory species (CABI 2019, GISD 2020). Following these two invasive shrubs, Pūkiawe (*Styphelia tameiameia* (Cham. & Schltdl.) F. Muell.) had the third-greatest estimated land cover out of all shrubs and in contrast to the previous two, it is a slow-growing native species, known for its medicinal properties and berries for foraging birds (UH 2009). Uluhe (*Dicranopteris linearis* (Burm.) Underw.) had the greatest amount of understory cover for forbs in both reserved and unreserved areas (fig. 28). Uluhe is a native fern and a keystone species in Hawaiian forests because it promotes nutri-

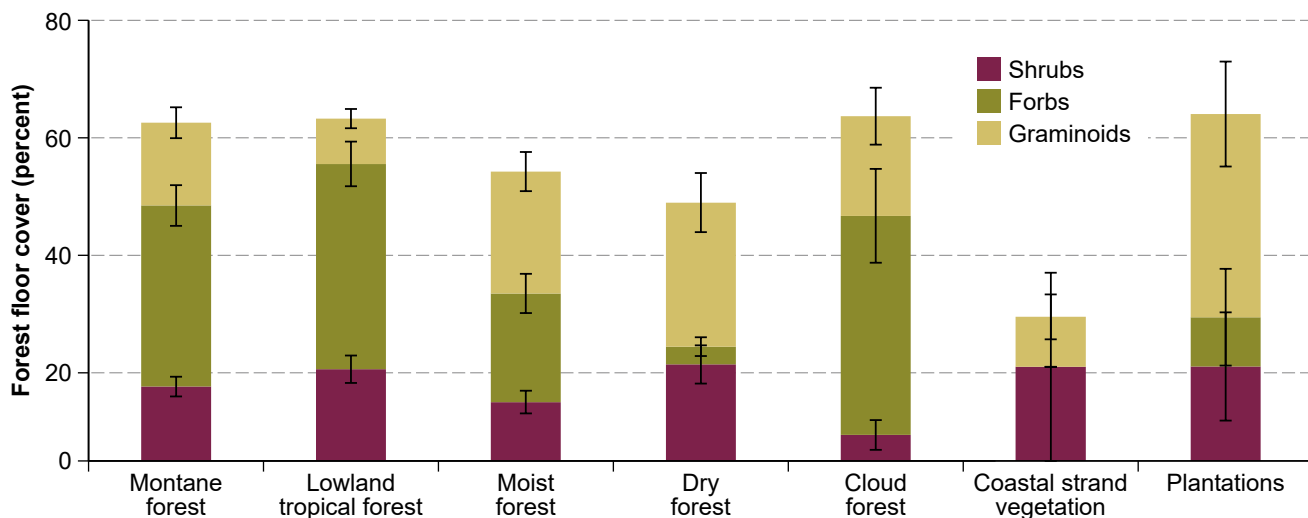


Figure 27—Average percentage of shrub, forb, and graminoid cover on forest land in each forest community type. Error bars are ± 1 standard error, stacked bars show cover percentage of each life form separately; totals are not additive within each stacked bar.

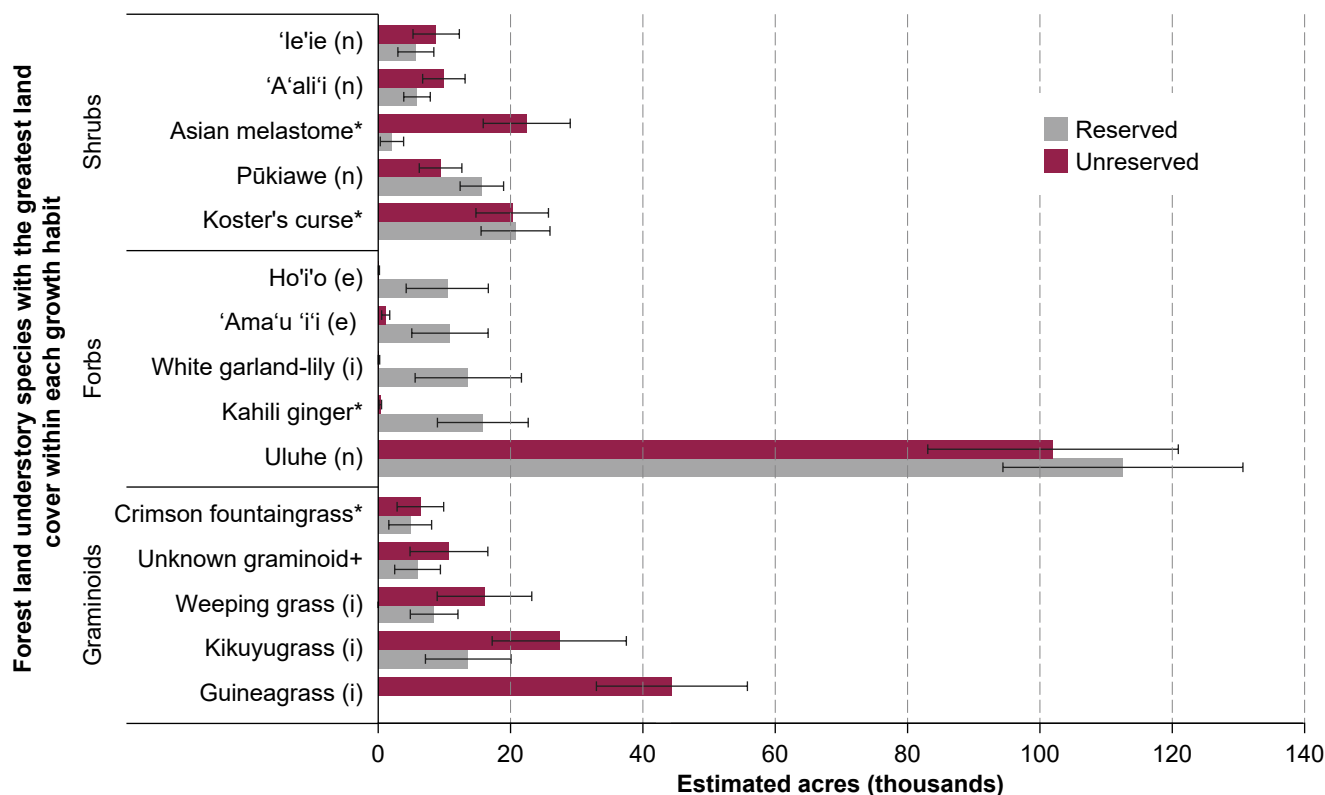


Figure 28—Top five species with the greatest estimated land cover (thousand acres) in each growth habit (shrubs, forbs, and graminoids) on U.S. Forest Service Forest Inventory and Analysis (FIA)-defined unreserved and reserved forest land. Error bars are ± 1 standard error. + = unknown nativity, (n) native, (e) = endemic, (i) = introduced, and * = invasive species listed in the FIA field manual. Different species often share the same Hawaiian name; Ho'i'o in this figure refers to *Diplazium sandwichianum*.

ent cycling, and it forms a thick litter layer that prevents the spread of invasive plants (Russell et al. 1998). Uluhe is also an important pioneer species, colonizing landslides and lava flows, and dominating the understory layer in primary and secondary successional forests (Russell et al. 1999). All graminoids with the greatest land cover were introduced and are largely invasive species. Both guineagrass (*Urochloa maxima* (Jacq.) R. Webster) and kikuyugrass (*Pennisetum clandestinum* Hochst. ex Chiov.) had the greatest estimated land cover for graminoids and covered more area in unreserved areas compared to reserved areas (fig. 28). Guineagrass and kikuyugrass both form dense mats in disturbed areas and can suppress or replace native plants and alter fire regimes (GISD 2020).

Understory forest species cover by growth habit also varied with height layers (fig. 29). Canopy height layers illustrate the vertical diversity of the most abundant species found on FIA subplots. Graminoids and forbs had the highest, and shrubs had the lowest aerial cover; and most

understory cover was between 0 and 6 feet tall (fig. 29). The distribution of growth habits varied within the four height layers and some species found in higher canopies included tall growing vines, bamboo species, and uluhe.

Nontimber Forest Products

Nontimber forest products, or NTFPs, play an important role in Hawaiian traditions and cultural events in many communities across the Hawaiian Islands (Kamelamela et al. in press). NTFPs are important to Hawaiian culture, but also to diverse ethnic communities that have relocated to Hawai'i (Kuokkanen 2011). NTFPs support local livelihoods and add cultural and economic value to forests (Shackleton 2011). Local harvesters collect many different plant materials across Hawai'i's ecosystems, including leaves, flowers, bark, inner bark, sap, seeds, fruits, stems, roots, fronds, down wood, and whole plants (Chamberlain et al. 2018). Historically, NTFPs were harvested for a wide range of uses, including boat building, cord and fabric construction, basket

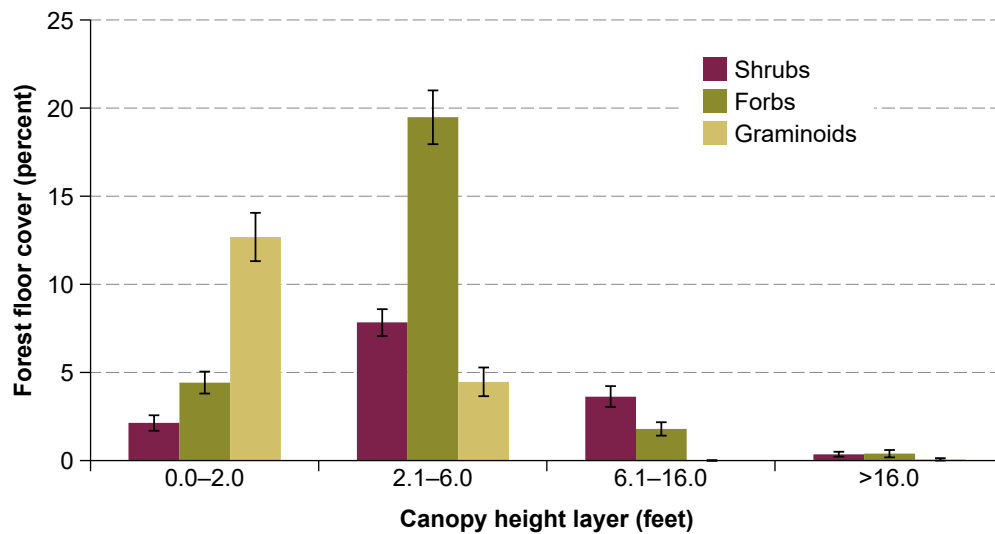


Figure 29—Average percentage of shrub, forb, and graminoid cover by canopy height layer.

weaving, weapons construction, fuel, food, medicine, and floral decorations (Abbott 1992). Although numerous NTFPs are currently collected for traditional uses, lei material and floral decorations dominate current NTFP usage throughout the state. For example, leis are commonly presented and displayed at many events such as graduations, festivals, parades, and hula performances (Kamelamela 2019).

NTFPs remain important in Hawaiian culture, provide income opportunities, and are sold at local markets as food, medicine, traditional handicrafts, and wood products (Kamelamela 2019). Personal and cultural use permits are required for collecting NTFPs on state forest reserve lands at no charge. The state of Hawai'i has recently compiled a central online application and database to track harvests and improve the access and management of NTFPs. A recent summary of NTFP permits attained between 2015 and 2017 showed that maile (*Alyxia oliviformis* Gaudich.) and palapalai fern (*Microlepia strigosa* (Thunb.) C. Presl) are the most common species permitted for personal use (Kamelamela 2019). These plants are used in many Hawaiian events for lei and hula materials (Ticktin et al. 2006, Whitehead 2015). About 22,355 gallons of material were permitted for collection of these two species over a 3-year period (Kamelamela 2019).

A review of the FIA data for common NTFP species was conducted to identify their presence and quantity within Hawaiian forests. Figures 30 and 31 show the number of trees and percentage of understory cover of selected

species important for NTFP on reserved and unreserved land. Endemic koa, hāpu'u pulu, and 'ōhi'a lehua were more abundant in reserves versus unreserved forested areas (fig. 30). 'Ōhi'a lehua was the most abundant endemic tree species in Hawai'i and holds significant biological, cultural, and ecological value (Mueller-Dombois et al. 2013). The wood from this tree is used culturally for traditional construction of homes, tools, weapons, religious structures, and food preparation implements; foliage and flowers continue to be used in highly valued lei; and tender parts of the flower, foliage, and roots are used in herbal medicine (Abbott 1992). 'Ōhi'a lehua is also harvested at a small scale for commercial wood products, such as flooring and architectural posts. High-valued wood products are made from koa, including wooden bowls, musical instruments, picture frames, high-end furniture, and canoes—making up a large percentage of a \$24 million retail industry in Hawai'i (Friday 2010, Friday et al. 2006). Additional locally grown tree species have contributed substantially to these sales, including mahogany, eucalyptus, milo (*Thespesia populnea* (L.) Sol. ex Corrêa), kou (*Cordia subcordata* Lam.), kamani (*Calophyllum inophyllum* L.), silkoak (*Grevillea robusta* A. Cunn. ex R. Br.), 'ōhi'a lehua, and koa.

Other native NTFP trees include hāpu'u pulu, historically valued for its fronds and inner core as a starchy food product, and ti (*Cordyline fruticosa*), the leaves from this species are harvested for wrapping food to cook in imu (traditional underground steam ovens), hula skirts,

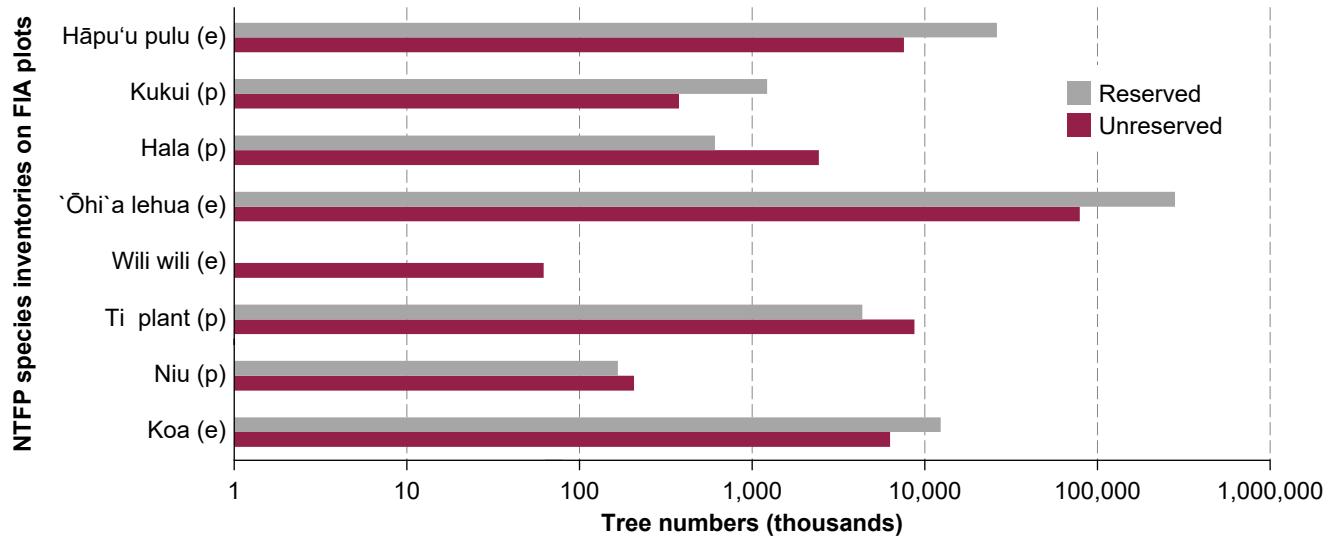


Figure 30—Estimated number (thousands) of tree stems (≥1 inch d.b.h.) by species and forest land status (unreserved and reserved) that are important for nontimber forest products (NTFPs), inventoried on U.S. Forest Service Forest Inventory and Analysis (FIA) plots in Hawai'i. (e) = endemic, (p) = Polynesian-introduced species.

and traditional thatch roofing—among many other uses. Sandalwood, or 'iliahi, both historically and currently, is a highly valued native tree. In the late 1700s, the increase in trade put a large demand on sandalwood harvesting. This demand, along with grazing animals, pests, and diseases depleted the population; and large recent restoration efforts have been made to increase the number of species (Merlin and VanRavenswaay 1990). Recently, some small-scale companies have been harvesting and extracting highly valued sandalwood oil in Hawai'i.

Native and endemic understory species important for NTFPs generally had a higher level of vegetation cover in forest reserves than unreserved forests and covered more forest acreage compared to invasive species (figs. 31 and 32). Pūkiawe (*Styphelia tameiameia*)—a native forb used for lei material, medicine, and making dyes for tapa cloth—had the greatest percentage of cover and estimated acreage of land cover in montane rainforest and moist forest communities, followed by a'ali'i (*Dodonaea viscosa*), a native and medicinal shrub commonly used for lei material (figs. 31 and 32). The native fern palapalai had a lower percentage of cover than pūkiawe and a'ali'i, but higher percentage of cover in reserved than unreserved forests (figs. 31 and 32). Palapalai is found in moist forest communities in Hawai'i (mostly in cloud forests in our inventory), is important to hula, and used as adornment

and lei material (fig. 32). Palapalai was found to be the second most permitted species in state forest reserves in Hawai'i, which may align with assessments indicating gatherers are actively managing forested areas for higher frond density and production (Kamelamela 2019, Ticktin et al. 2007). Some invasive species found in our inventory are also important for NTFPs, such as strawberry guava, which is used for scents and decorative arrangements, and Job's tears (*Coix lacryma-jobi* L.), an invasive grass harvested from lowland tropical forest communities for its seeds, which is used to make lei.

Important NTFP species in Hawai'i are presented in table 4 by growth habit, native status, common local uses, and whether they were inventoried on FIA plots. Because the FIA vegetation monitoring only noted dominant species that met a ≥3 percent coverage, this report cannot address the presence of species with very small populations. This methodology likely led to the result that only four (maile, hāpu'u pule, palapalai, 'ohelo'ai (*Vaccinium reticulatum* Sm.)) of the top five state forest reserve-permitted species were found in the FIA dataset (table 4). For example, the widely collected Mokihana was not found in the FIA data, possibly because of its limited geographic range on Kaua'i and fewer monitoring plots in these locations. In other parts of the country, additional inventory and monitoring protocols were created to better capture the biomass and

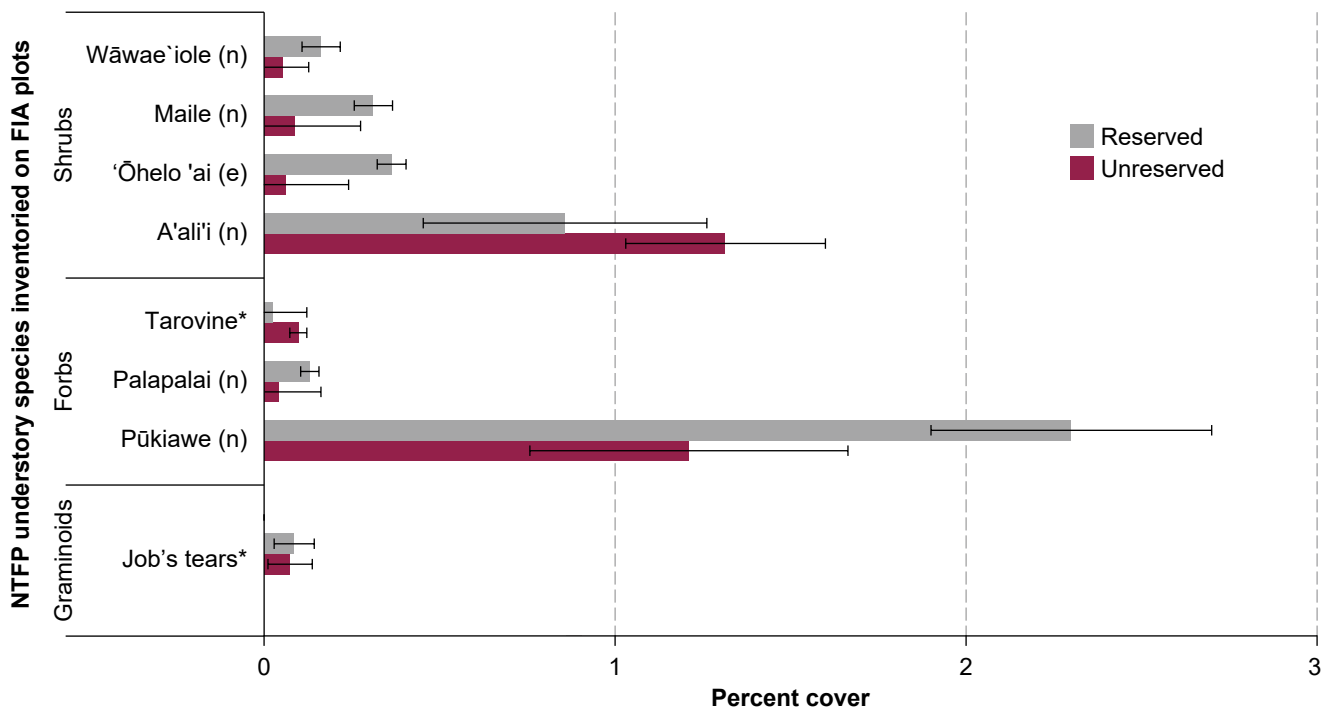


Figure 31—Percentage cover of understory species that are important for nontimber forest products (NTFPs), in unreserved and reserved forests land, inventoried on U.S. Forest Service Forest Inventory and Analysis (FIA) plots in Hawai'i. * = invasive, (n) = native, and (e) = endemic species.

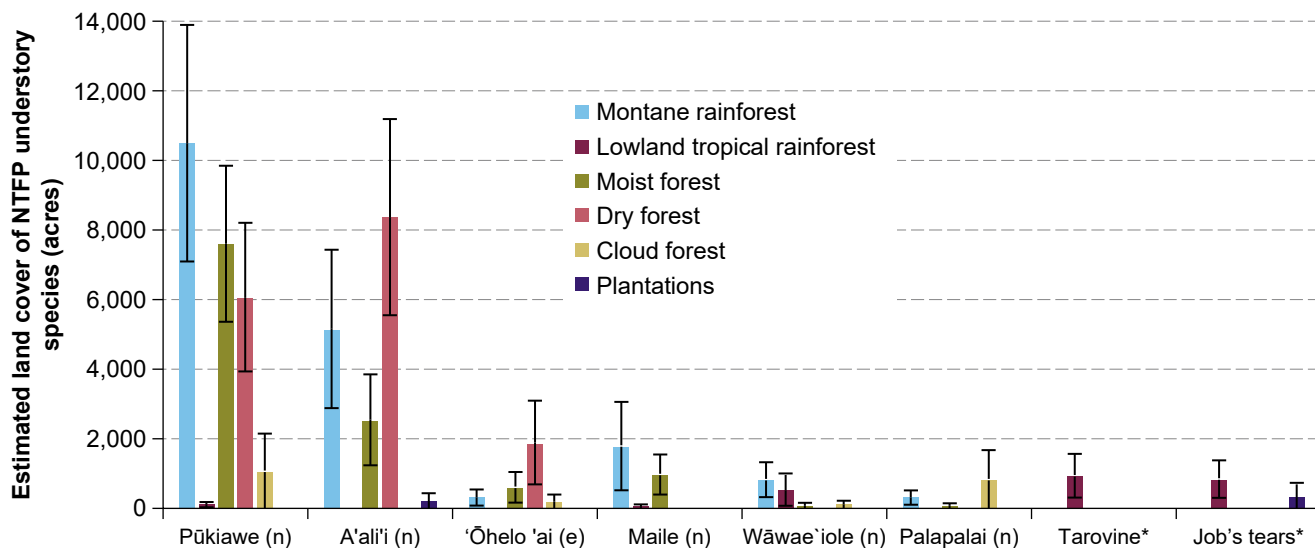


Figure 32—Estimated land cover (acres) by understory plant species that are important for nontimber forest products (NTFPs), by Hawaiian forest communities. * = invasive, (n) = native, and (e) = endemic species.

abundance of important NTFP species; these could be used for improving monitoring understory species, such as maile, to better inform harvesters and land managers on preferred harvest sites (Chamberlain 2013, 2018).

FIA Intensification Plots in Hawai'i

On Hawai'i Island, three distinct forest types (tropical wet, mesic, and dry) were identified for the intensification of FIA

Table 4—Species that are important as a source of nontimber forest products (NTFPs) in Hawai'i, by growth habit, native status, and common local uses

Growth habit	Scientific name	Species	Native status	Local use
Trees	<i>Acacia koa</i>	Koa*	Endemic	wood crafts, canoes
	<i>Aleurites moluccana</i>	Kukui*	Polynesian introduced	fragrance, lei material
	<i>Bruguiera gymnorrhiza</i>	Oriental mangrove	Introduced	lei material
	<i>Calophyllum inophyllum</i>	Kamani	Polynesian introduced	turned bowls, lei material
	<i>Cibotium glaucum</i>	Hāpu'u* (3)	Endemic	food, medicine
	<i>Cocos nucifera</i>	Niu*	Polynesian introduced	food, fragrance
	<i>Cordia subcordata</i>	Kou	Native	wood products
	<i>Cordyline fruticosa</i>	Ti plant*	Polynesian introduced	food, hula, lei material
	<i>Erythrina sandwicensis</i>	Wiliwili*	Endemic	boat material
	<i>Melicope hawaiiensis</i>	Mokihana (5)	Endemic	lei material, fragrance
	<i>Metrosideros polymorpha</i>	ʻŌhi'a*	Endemic	lei material, wood products, wreaths
	<i>Pandanus tectorius</i>	Hala*	Native	basketry, mats, floral, lei material, medicine
Shrubs/woody vines	<i>Santalum paniculatum</i>	ʻIliahi	Endemic	fragrance, medicine
	<i>Alyxia oliviformis</i>	Maile (1)	Endemic	lei material
	<i>Dodonaea viscosa</i>	ʻA'ali'i*	Native	lei material, wreaths
	<i>Thespesia populnea</i>	Milo	Polynesian introduced	Carvings, wood bowls, medicine
	<i>Vaccinium reticulatum</i>	ʻŌhelo 'ai* (4)	Endemic	food
Forbs/ferns	<i>Cassytha filiformis</i>	Kauna'oa	Native	lei material
	<i>Cuscuta sandwichiana</i>	Kauna'oa	Endemic	lei material
	<i>Heliotropium anomalum</i>	Hinahina	Native	lei material, tea, medicine
	<i>Huperzia pyllantha</i>	Wāwae'iole	Native	wreaths
	<i>Lycopodiella cernua</i>	Wāwae'iole*	Native	wreaths
	<i>Microlepia strigosa</i>	Palapalai* (2)	Native	hula
	<i>Monstera deliciosa</i>	Tarovine*	Invasive	lei material
	<i>Psilotum nudum</i>	Moa	Native	lei material
Graminoid	<i>Coix lacryma-jobi</i>	Job's tears	Introduced	lei material

(1)–(5) = rank of the five most permitted species from 2015 to 2017.

*Species present in current FIA inventory.

plots to track forest health and resources in critical areas. Two areas were located within the Hawai'i Experimental Tropical Forest (HETF): the Laupāhoehoe Natural Area Reserve/Hilo Forest Reserve (wet forest unit) and the Pu'u Wa'awa'a Forest Reserve (dry forest unit). Together, the two units accounted for 51,154 ac (20 706 ha) of forest land and

spanned enormous gradients in rainfall, temperature, and ecological condition. The HETF was established in 2007 to support the long-term research needs of Hawai'i, including addressing tropical forest management issues. The HETF is cooperatively managed by the USDA Forest Service Institute of Pacific Islands Forestry and Hawai'i's Division of Forestry

and Wildlife. The third area included for plot intensification was The Nature Conservancy's Kona Hema Preserve (tropical mesic forest). The Kona Hema Preserve was established by 2003 as an 8,089-ac (3,274-ha) native forest preserve, funded by the Forest Service's Forest Legacy Program, and managed by The Nature Conservancy in Hawai'i.

FIA field crews installed 29 plots in the wet forest unit and 22 plots in the dry forest unit of the HETF, and another 31 plots in the Kona Hema Preserve. These 82 plots were all above 2,000 ft in elevation. Most FIA intensification plots were between 3,000 and 5,000 ft in elevation (55 plots), 10 plots were between 2,000 and 3,000 ft, and 17 plots were $\geq 5,000$ ft elevation. Experimental forest plots were inventoried using identical methods as other FIA plots, with the exception that (1) trees ≥ 5 inches in diameter were measured on the macroplots to better assess biomass, and (2) field crews collected survey-grade Global Positioning System coordinates to precisely link plot information with remotely sensed imagery and data (USDA FS 2013). A goal of this more intensive sampling was to develop a more complete picture of forest conditions in critical reserved areas and provide additional information on high-priority invasive plants and carbon storage. Additional information on the methods used for identifying and measuring high-priority invasive plants are described in the "Invasive Vegetation" section of this report and in field instructions for the inventory of the Pacific Islands (USDA FS 2013). Further research products identified using data collected from FIA intensification plots in Hawai'i are highlighted in Dean and Block (2012).

Invasive species cover was greater in forested areas of the Pu'uwa'awa'a unit compared to other FIA plot intensification areas, mostly because of crimson fountaingrass (*Pennisetum setaceum* (Forssk.) Chiov.) (34 percent cover), an invasive graminoid that degrades dry areas and can increase the spread and intensity of wildfires (table 5). Plots sampled in the Laupāhoehoe unit of the HETF had more individual invasive species (8) relative to other sampled FIA intensification plots (1 to 4) (table 5). It is important to note that sampled plots on the Laupāhoehoe unit were entirely forested, whereas plots sampled on both the Pu'uwa'awa'a unit and the Kona Hema Preserve were a mix of forested

and nonforested areas.

On average, forests on FIA intensification plots supported 37 U.S. tons ac^{-1} (83 Mg ha^{-1}) of live aboveground tree carbon (fig. 33). Plots sampled on the Laupāhoehoe unit of the HETF had the greatest average aboveground live-tree carbon per acre (i.e., 65 U.S. tons ac^{-1} , or 146 Mg ha^{-1}), mainly in montane, lowland tropical rainforests, and moist forests, relative to other intensification plots (fig. 33). The Pu'uwa'awa'a unit of the HETF stored most aboveground live-tree carbon per acre in dry forests (i.e., 24 U.S. tons ac^{-1} , or 54 Mg ha^{-1}) and the Kona Hema preserve stored more carbon in montane rainforests (i.e., 30 U.S. tons ac^{-1} , or 67 Mg ha^{-1}) relative to other forest communities (fig. 33). Past research combined FIA plot-derived estimates with remote sensing from the Global Airborne Observatory and airborne LiDAR data to improve the accuracy of carbon and biomass estimates across heterogeneous landscapes (Asner et al. 2008, 2009; Hughes et al. 2018; Selmants et al. 2017). Results from this research indicated that increased spread of invasive trees corresponded to a decline in aboveground tree biomass and carbon stores. Elevation, substrate type and age, prior land use, and precipitation were also predictors of aboveground biomass and carbon storage in these studies (Asner et al. 2008, 2009; Hughes et al. 2017, 2018). Data from intensified FIA plots in the HETF can be used to determine the severity of current threats, track emerging threats, and monitor the outcomes of management efforts.

Hawai'i State Conservation District Lands

Hawai'i State Conservation District lands are managed by the Department of Land and Natural Resources, and are divided into five subzones: protected, limited, resource, general, and special (fig. 34). The first four subzones are arranged in a hierarchy of environmental protection, ranging from priority resources that are most protected ("protected") to those that are less environmentally sensitive ("general") (DBEDT 2018, Oswalt et al. 2014). "Special" subzones are less common and defined by unique land uses on specific sites. Areas outside conservation districts may be designated as agricultural, rural, or urban. Hawai'i land use district boundary maps (<https://luc.hawaii.gov/maps/>), and rules and regulations for the use of Conservation District lands (<https://dlnr.hawaii.gov/occl/conservation-district/>) are

Table 5—Percent canopy cover of priority invasive plants (considered a major threat to Hawaiian forests) in FIA intensification plots, from three intensification areas and different forest types (Laupāhoehoe Natural Area Reserve/Hilo Forest Reserve (wet forest), Pu'u Wa'awa'a Forest Reserve (dry forest), and The Nature Conservancy's Kona Hema Preserve (tropical mesic forest), and the number of FIA plots where invasive species were observed, Hawai'i, 2010–2015

Invasive species (growth habit)	Laupāhoehoe			Pu'u Wa'awa'a			Kona Hema		
	Total	SE	Number of plots	Total	SE	Number of plots	Total	SE	Number of plots
	<i>Percent cover</i>			<i>Percent cover</i>			<i>Percent cover</i>		
Strawberry guava (tree)	9.64	3.66	13	—	—	0	0.2	0.1	6
Koster's curse (shrub)	5.7	2.91	9	—	—	0	—	—	0
Asian melastome (shrub)	0.04	0.03	2	—	—	0	—	—	0
Kahili ginger (forb)	3.33	2.17	7	—	—	0	—	—	0
Crimson fountaingrass (graminoid)	—	—	0	34.01	14.4	11	—	—	0
Lantana (shrub)	—	—	0	2.77	2.12	2	—	—	0
Silver oak (tree)	—	—	0	5.69	4.55	2	—	—	0
Banana poka (shrub)	3.59	1.31	14	3.22	1.52	15	—	—	0
Yellow blackberry (shrub)	0.01	0.01	1	—	—	0	—	—	0
Sawtooth blackberry (shrub)	0.14	0.13	2	—	—	0	—	—	0
Port Jackson fig (tree)	0.68	0.68	1	—	—	0	—	—	0

Note: Totals may be off because of rounding; data are subject to sampling error; SE = standard error; — less than 0.01 percent cover was estimated. See appendices A2-1 and A2-12 for species scientific names.

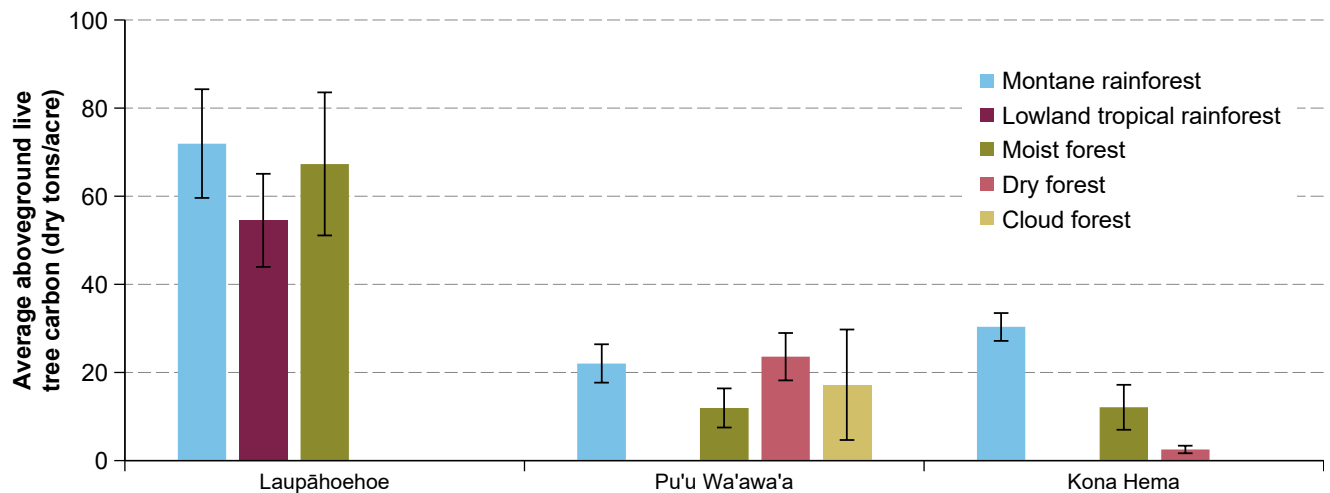


Figure 33—Average aboveground live-tree (≥ 1 inch d.b.h.) carbon (dry U.S. tons per acre) in U.S. Forest Service Forest Inventory and Analysis (FIA) intensification plots (Laupāhoehoe [wet forest natural area reserve/Hilo Forest Reserve], Pu'u Wa'awa'a [dry forest reserve], and Kona Hema [The Nature Conservancy's tropical mesic forest preserve]) by FIA-defined community types.

available to the public (State of Hawai'i 2022a, 2022b).

We summarized FIA plot data for lands with FIA-defined reserved and unreserved status and use these designations throughout this report to maintain consistency with other FIA state reports. However, we added select analyses by state conservation district subzones relevant to local land managers in Hawai'i. Analyses included total and average aboveground live-tree carbon mass and estimated land cover of high-priority invasive plant species across conservation district subzones. No FIA plots occurred within special land use subzones, therefore only protected, limited, resource, and general subzones, and areas outside the conservation district subzones were summarized. Areas outside the conservation district had the greatest estimated forest land area (5.4 million ac) and also had the most FIA plots (98), followed by the resource (4.9 million ac; 46 plots) and protected (3.7 million

ac; 57 plots) subzones (fig. 34). Limited and general subzones combined had about 66 million ac of forest, and only 6 FIA plots were in each of these subzones.

Combined, the resource, protected, and areas outside the conservation district had an estimated 93 percent of total aboveground live-tree carbon in the state, mainly on Hawai'i Island (fig. 35). The majority of total aboveground live-tree (≥ 1 inch) carbon was found in the resource (16 million dry U.S. tons, or 15 Tg) and protected (12 million dry U.S. tons, or 11 Tg) subzones, and areas outside the conservation district (15 million dry U.S. tons, or 14 Tg) (fig. 35). Aboveground live-tree carbon per acre ranged from 28 U.S. tons ac^{-1} (63 Mg ha^{-1}) outside the conservation district to 51 U.S. tons ac^{-1} (114 Mg ha^{-1}) in the general subzone, mainly on Hawai'i, Maui, and Kaua'i Islands (fig. 36).

State and county governments managed 54 percent of

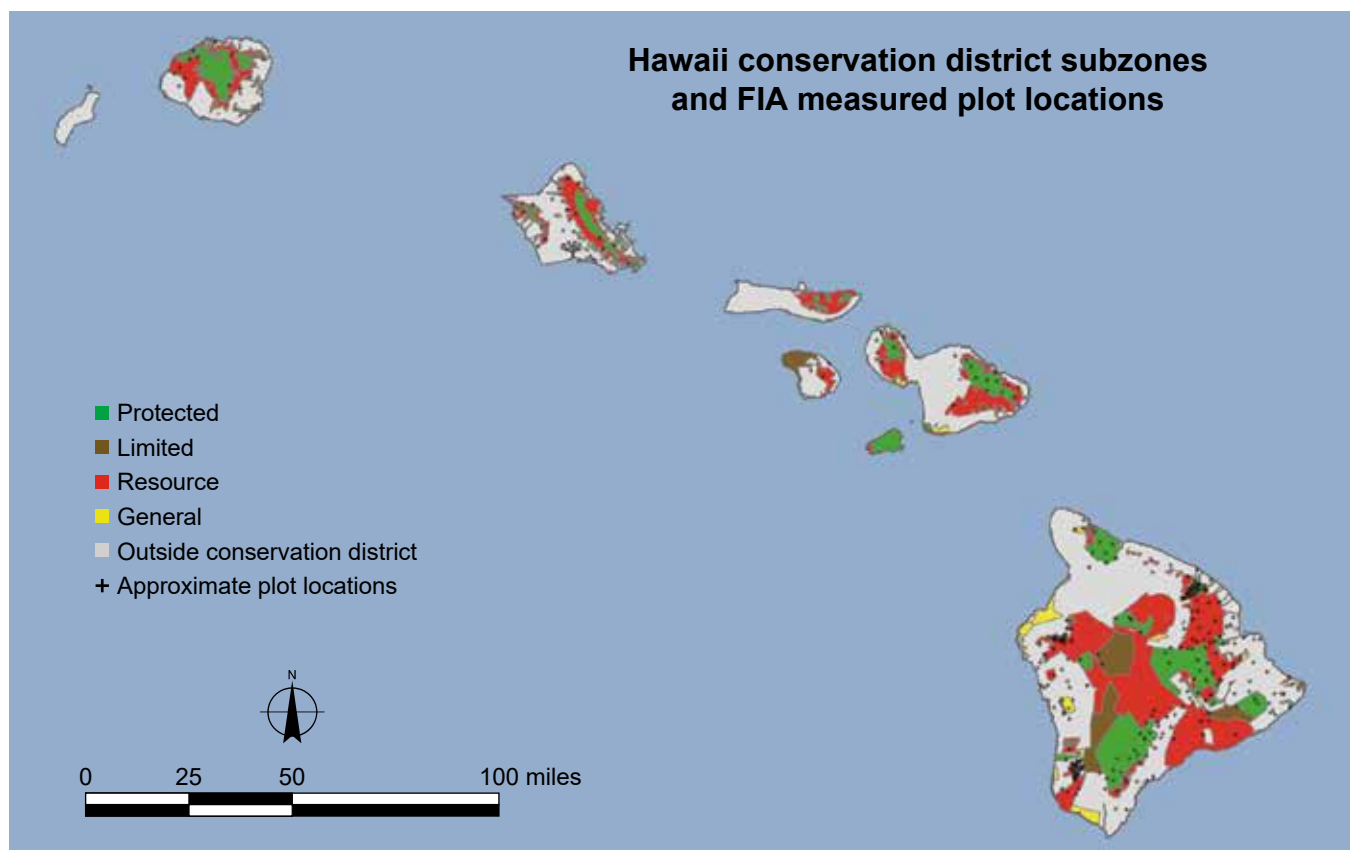


Figure 34—Approximate locations of U.S. Forest Service Forest Inventory and Analysis (FIA) forested plots measured in 2010–2015 on Hawai'i State Conservation District lands managed by the Department of Land and Natural Resources. These lands are divided into five subzones: protected (green); limited (brown); resource (red); general (yellow); special (not shown because of small area and lack of plots); and areas outside of the conservation district (grey), which may fall in agricultural, rural, or urban areas. Hawai'i land use district boundary maps were used to distinguish subzones (State of Hawai'i 2022a).

total aboveground live-tree carbon on forest lands, mainly in protected (9.8 million U.S. tons, or 8.9 Tg) and resource (7.9 million U.S. tons, or 7.2 Tg) subzones (fig. 37). Thirty five percent of total aboveground live-tree carbon (16 million U.S. tons, or 15 Tg) occurred on privately owned forests, largely outside of the conservation district (11 million U.S. tons, or 9.9 Tg), and the remaining 11 percent of live aboveground tree carbon was managed by the federal government, mainly on the resource subzone (fig. 37). State and county governments managed the most aboveground live-tree carbon per acre in protected subzones (36 dry U.S. tons ac^{-1} (81 Mg ha^{-1}), private landowners managed the most general subzones (64 dry U.S. tons ac^{-1} (143 Mg ha^{-1}), while both land owner groups managed the majority of carbon per acre in limited subzones (fig. 38). Aboveground live-tree carbon per acre outside the conservation district was more similar among owner groups, ranging from 25 to 27 U.S. tons ac^{-1} (56 to 61 Mg ha^{-1}) (fig. 38).

Forested areas outside the conservation district had the greatest estimated average percentage of canopy cover of high-priority invasive plant species (i.e., averaging 10.3 percent invasive plant cover), followed by the resource (averag-

ing 6.4 percent invasive plant cover) and protected (4.1 percent invasive plant cover) subzones (fig. 39), compared to other conservation subzones. Lowland tropical rainforests accounted for the greatest invasive plant cover, especially in areas outside the conservation district, averaging 25 percent invasive plant cover. Within the resource and protected subzones, invasive plant cover was also greatest in lowland tropical rainforests, with 10 and 8 percent invasive plant cover, respectively. In most subzones and in areas outside of the conservation district, strawberry guava had the greatest invasive plant cover. Invasive plant species and methods involved in this analysis are described in more detail in the “Invasive Vegetation” section below.

Forest Health

Overview

Hawai'i's forests tend to be particularly vulnerable to invasive plants and introduced animals, insects, and diseases that affect forest health, and watersheds, and threaten native and endangered species. These vulnerabilities are a result

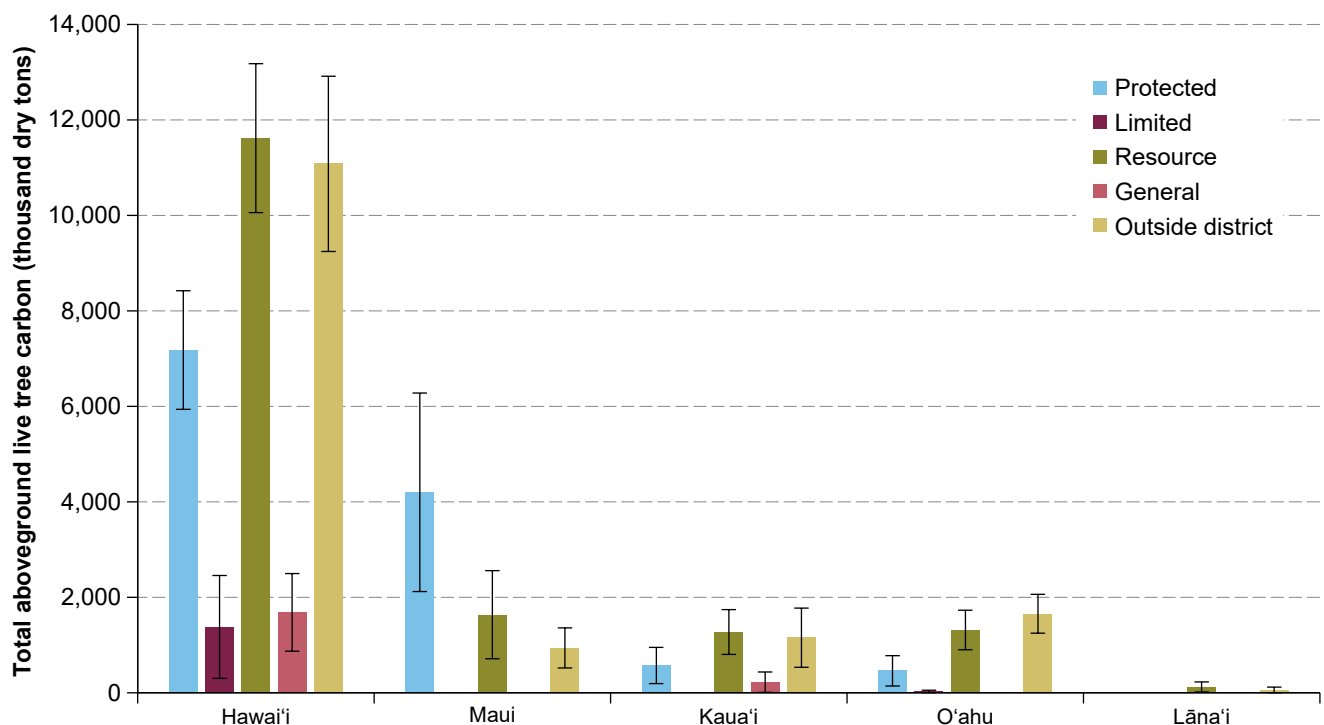


Figure 35—Total aboveground live-tree (≥ 1 inch) carbon (thousand dry U.S. tons) on Hawai'i State Conservation District lands (subzones: protected, limited, resource, general) and outside district boundaries, by island, 2010–2015. Hawai'i land use district boundary maps were used to distinguish subzones (State of Hawai'i 2022a).

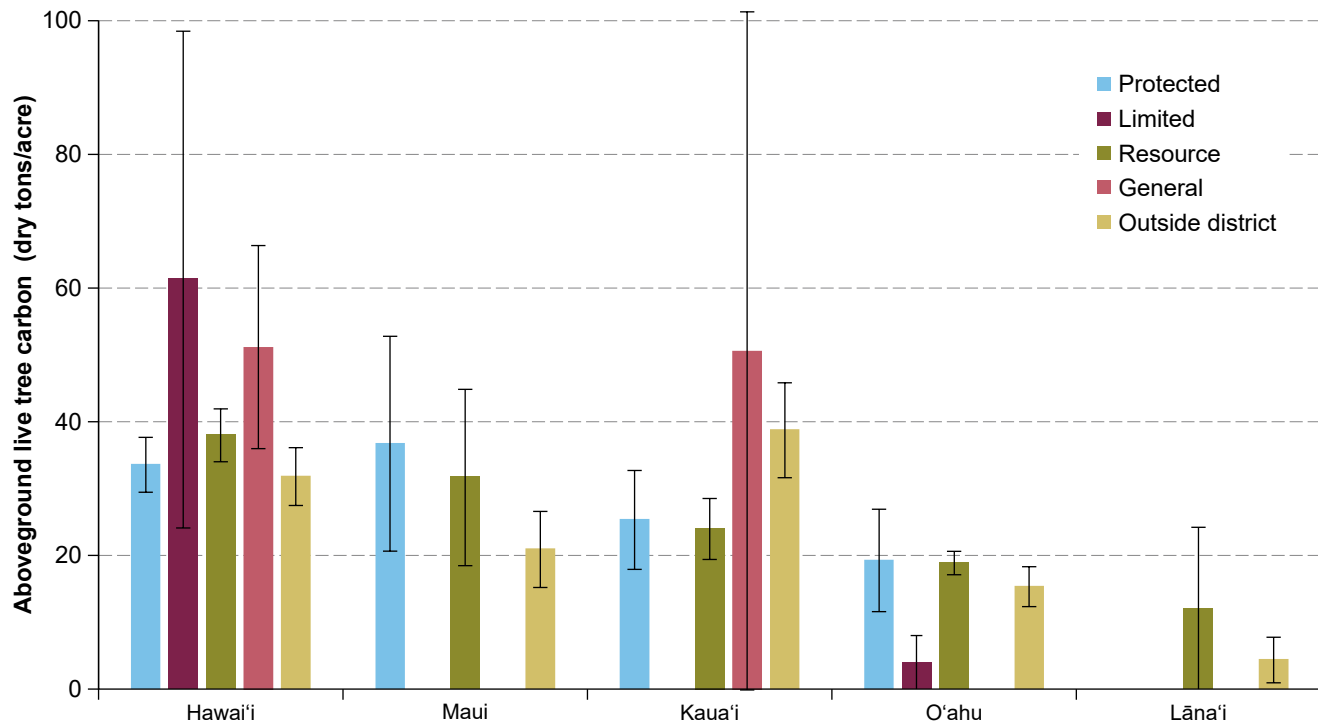


Figure 36—Average aboveground live-tree (≥ 1 inch d.b.h.) carbon (dry U.S. tons per acre) on Hawai'i State Conservation District lands (subzones: protected, limited, resource, general) and outside district boundaries, by island, 2010–2015. Hawai'i land use district boundary maps were used to distinguish subzones (State of Hawai'i 2022a).

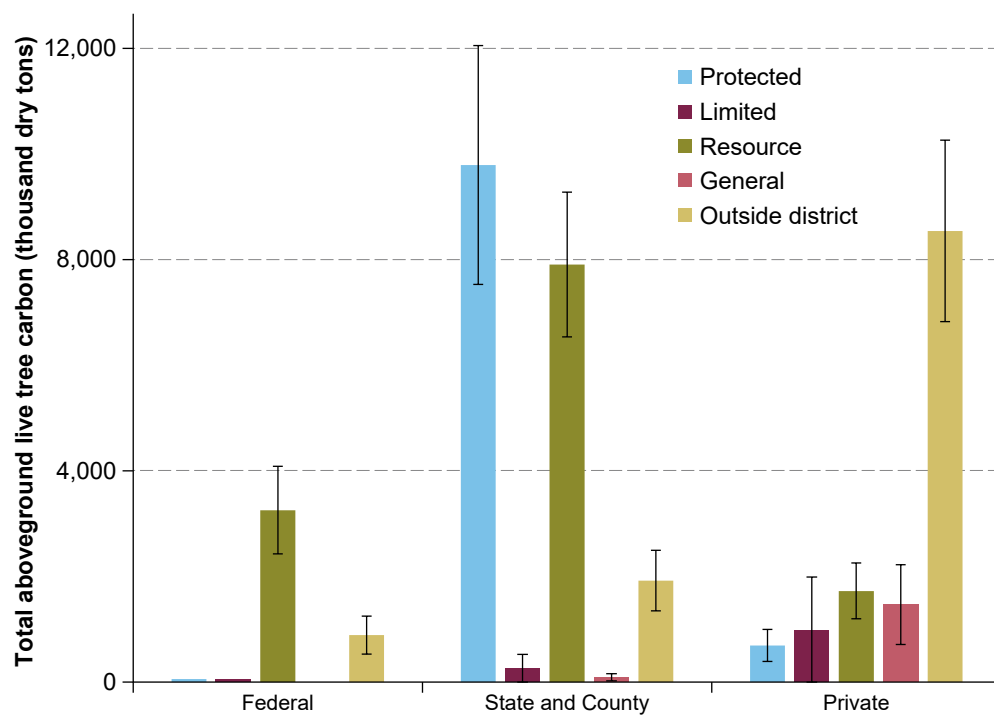


Figure 37—Aboveground carbon, dry weight (thousand dry U.S. tons) for live trees (≥ 1 inch) on Hawai'i State Conservation District lands (subzones: protected, limited, resource, general) and outside district boundaries, by land owner group, 2010–2015. Hawai'i land use district boundary maps were used to distinguish subzones (State of Hawai'i 2022a).

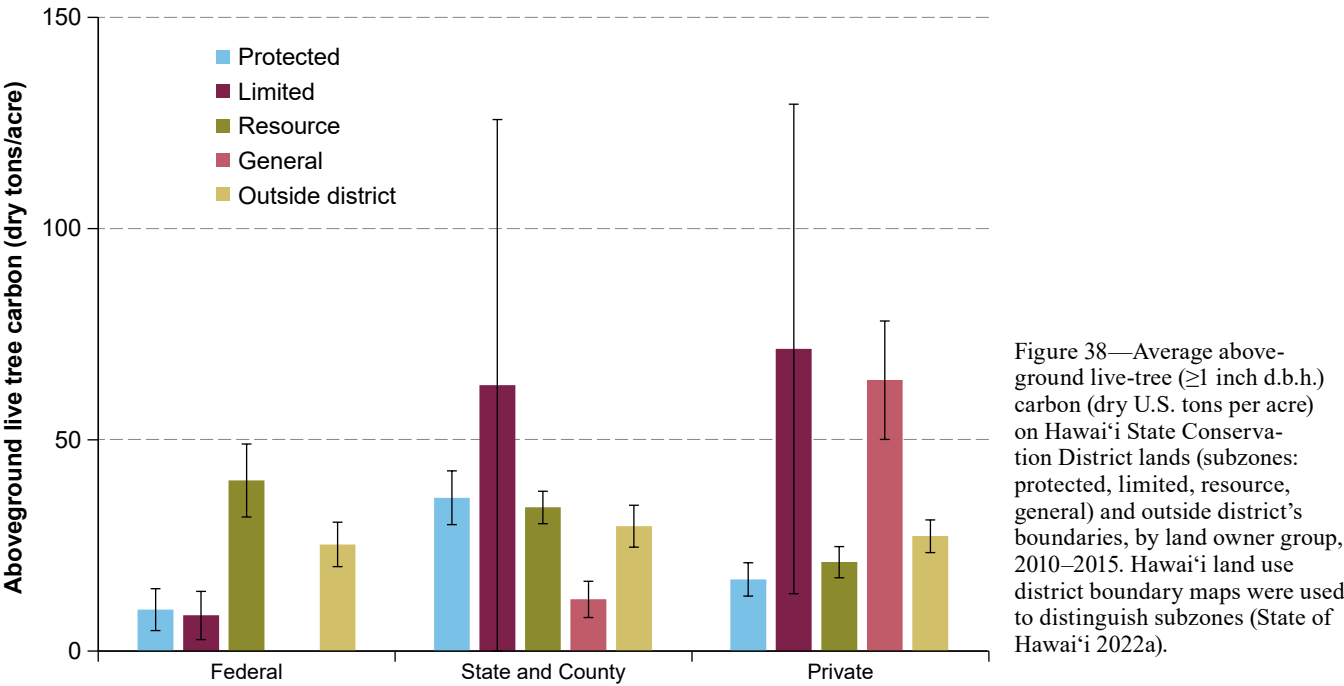


Figure 38—Average above-ground live-tree (≥ 1 inch d.b.h.) carbon (dry U.S. tons per acre) on Hawai'i State Conservation District lands (subzones: protected, limited, resource, general) and outside district's boundaries, by land owner group, 2010–2015. Hawai'i land use district boundary maps were used to distinguish subzones (State of Hawai'i 2022a).

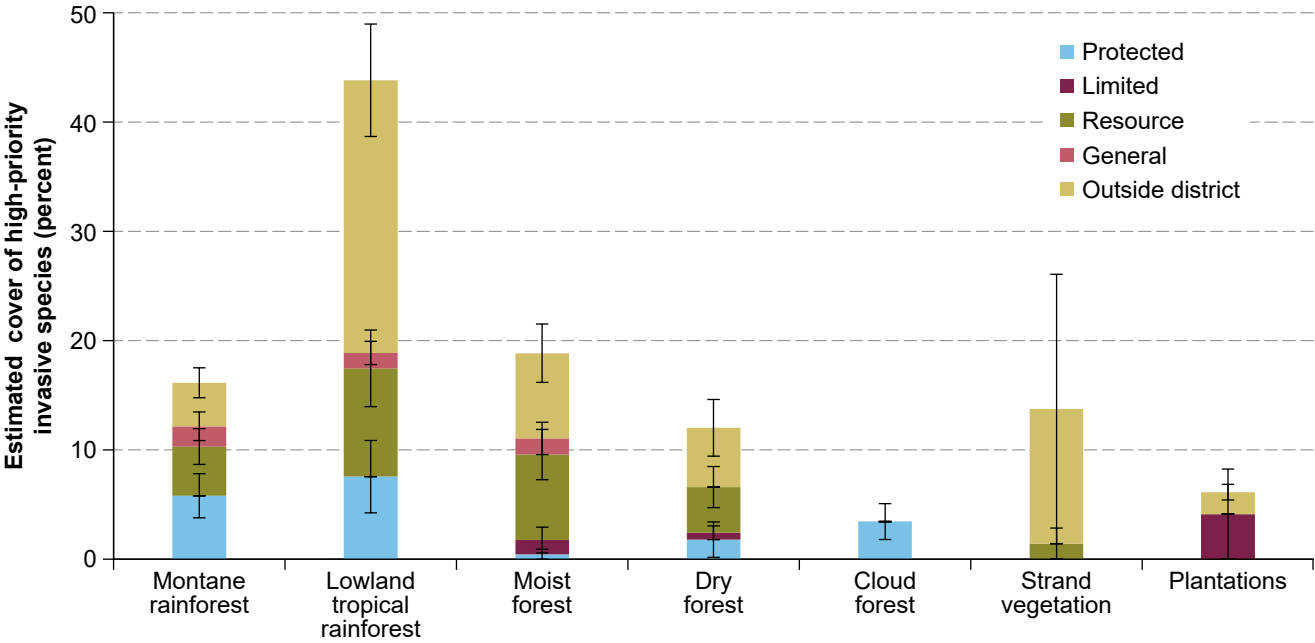


Figure 39—Estimated cover percentage of high-priority invasive species across Hawaiian forest community types by Hawai'i State Conservation District lands (protected, limited, resource, general) and outside district boundaries, 2010–2015. A complete invasive species list and detailed methods are described in field instructions for the inventory of the Pacific Islands (USDA FS 2013). Hawai'i land use district boundary maps were used to distinguish subzones (State of Hawai'i 2022a).

of Hawai'i being a hub for travel and trade, having a large range of habitats for invaders to occupy, and native species lacking adaptations to compete with mainland invaders (DLNR 2016, Selmants et al. 2017). Human-caused disturbances also directly affect forests through agricultural practices and urban expansion. Human population is positively correlated with wildfire ignition frequency across the Hawaiian Islands; and wildfires occur mostly in introduced grass-dominated landscapes and can threaten nearby forests and watersheds (Trauernicht et al. 2015). Climate change is expected to increase temperatures and the frequency of severe and longer lasting droughts paired with more severe storms, all of which could increase native tree mortality, wildfires, vulnerability to pest damage and invasions, and blowdown or damage to live trees (DLNR 2016).

Priority forest health issues are outlined in the Hawai'i Forest Action Plan, which is a planning document produced by Hawai'i's Department of Land and Natural Resources Division of Forestry and Wildlife and their partners to identify areas of greatest need and opportunity for forests across the state. Areas identified include (1) insect pests and diseases that harm essential forest species, such as koa and 'ōhi'a; (2) invasive plants that adversely affect watersheds and native plant communities, such as strawberry guava; (3) ungulate species, including feral pigs, sheep, goats, and cattle, that can destroy vegetation, disturb soil, and degrade watersheds; and (4) pests, such as the coconut rhinoceros beetle (*Oryctes rhinoceros*), a major pest of coconut palms, the coqui frog (*Eleutherodactylus coqui*) that threatens native insects and spiders and competes with native birds and fauna, and little fire ants (*Wasmannia auropunctata*) that can invade native forests and sting people and animals (DLNR 2016). Long-term monitoring of forest health in Hawai'i across different land use practices, owner groups, and forest communities is crucial to identifying the extent of disturbances and disturbance agents contributing to forest degradation, and recognizing priority areas to protect and restore.

FIA data may be used to monitor forest health and disturbances in numerous ways (fig. 40). Physical signs of stress and damage to live trees, and damaging agents themselves, are recorded on each FIA plot. Although tree damage may not necessarily result in mortality, records of damaging agents and damage severity to live trees can help assess how

and why forests may be changing. Long-term inventory data provides the opportunity to monitor the presence of pathogens and invasive plants over large areas through time, quantify effects of large-scale weather and fire events, and give insight into forest resiliency. FIA data also provide historical baselines and allow for comparison to future inventories to track trends in forest structure and composition and increases our understanding of forest variability over time.

Disturbances and Damaging Agents

Disturbances and tree damage may occur from numerous



Ian Kottke

Figure 40—U.S. Forest Service Forest Inventory and Analysis crew member Reko Libby records measurements of forest health.

factors, including insects and diseases, animals, weather, landslides, fire, or physical defects. Disturbances were recorded on FIA plots if they affected an area of at least 1 ac around plots, and 25 percent of all trees in a stand, or 50 percent of an individual species in a stand, or at least 25 percent of the soil surface or understory vegetation. FIA field crews assessed each measured live tree for damage location, type, severity, and agent (USDA FS 2013). Damaging agents play a role in forest succession and may contribute to forest degradation. Detecting trends in tree damage may help predict the composition and resiliency of future forests.

Data from FIA inventories indicated that about 17 percent of Hawai'i's forests were affected by disturbances. Domestic livestock grazing was the most prevalent forest disturbance, covering an estimated 66,342 ac (4.5 percent of total forest area), followed by disease disturbance (to both understory and overstory), which covered 45,112 ac (3.1 percent of total forest area) (fig. 41). The area of disturbances recorded across the state's forest land was similar between

state and county government (17 percent) and private (21 percent) owner groups, and lowest in federally managed forests (9 percent). The types of disturbance differed among owner groups. Federally managed forest land disturbances included insect, feral pig, and unknown disturbance agents. Disturbances on forest land managed by state and county governments were primarily domestic livestock grazing, feral pig activity, and disease damage. Disturbances on privately owned forest lands tended to be from domestic livestock grazing, deer and other ungulates, and suppressive vegetation (e.g., parasitic plants or vines covering ≥ 50 percent of crown) (fig. 41). Montane rainforest and moist and dry forests had the largest areas of recorded disturbances, averaging a combined 208,818 ac (85 percent) of forest land area with signs of disturbances (fig. 42). Both domestic livestock grazing, and evidence of disease accounted for the largest areas of disturbance in montane rainforest and moist forest communities. Evidence of nonnative feral pig disturbance covered an estimated 16,586 ac in lowland tropical

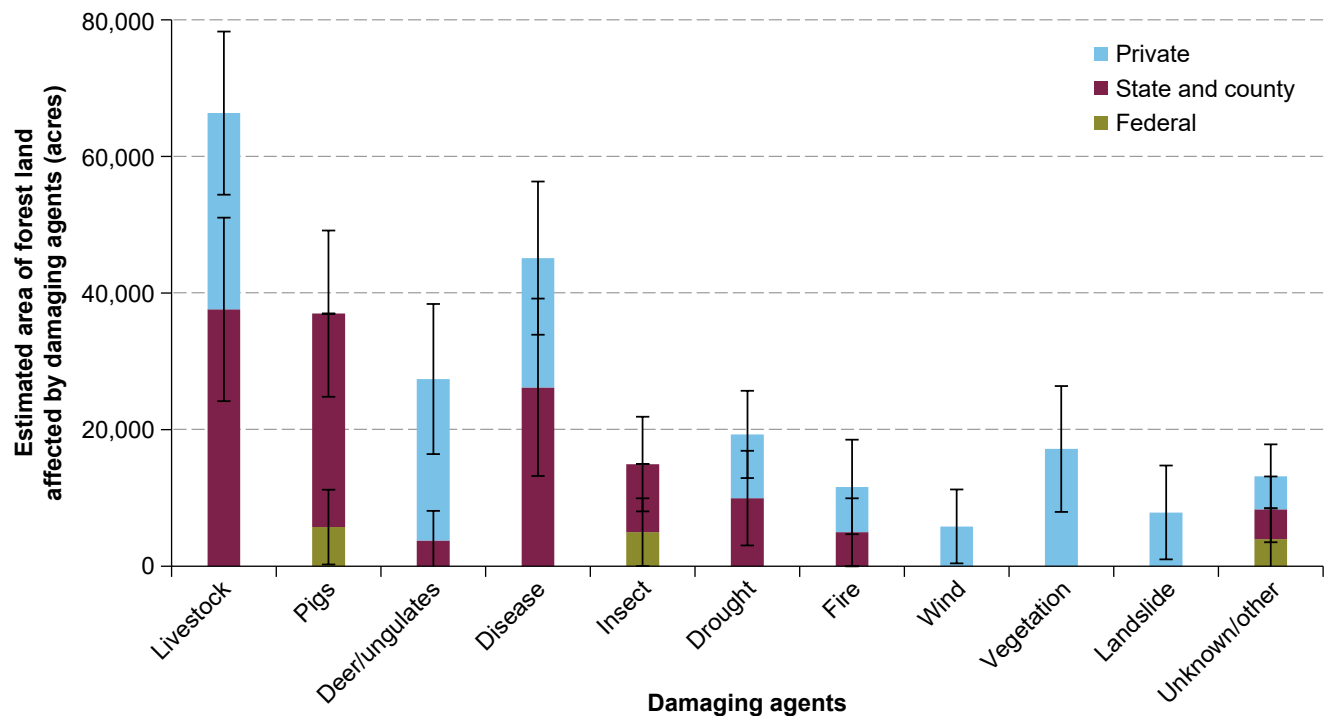


Figure 41—Estimated area affected by one or more types of disturbance on forest land, within land owner groups, Hawai'i, 2010–2015. Livestock disturbance includes domestic livestock grazing; disease and insect damage include understory or overstory; evidence of fire includes tree or ground damage; vegetation disturbance was caused by parasitic plants, suppression, or competition (e.g., parasitic plants or vines covering ≥ 50 percent of crown). Disturbances summarized in this figure were recorded on an estimated 17 percent (247,192 ac) of forest land. No disturbances were recorded for most forest land (83 percent, or 1.2 million ac).

rainforests and 9,142 to 11,254 ac in montane rainforest and moist forest communities, respectively (fig. 42).

About 15 percent of the trees measured during the inventory showed some form of visible damage. A loss of apical dominance (broken or dead top) was the most prevalent damage (30 percent of recorded damages) to saplings and trees, followed by broken or dead portions of trees (23 percent of recorded damages), fungal fruiting bodies and other signs of decay (20 percent of recorded damages), and vines in tree crowns (11 percent of recorded damages) (fig. 43). The “other” category (fig. 44) includes damage, such as broken boles or roots, and resinosis or gummosis (signs of pathogens or disease). FIA field crews assigned a causal damage agent to the damages to help local forest managers assess forest pest problems. Causal agents were determined by studying the area surrounding the inventory plot, looking for patterns, such as branch breakage or blowdown, signs of pest infestation, or human activities. Sometimes, however, the cause of the damage could not be reliably identified and was assigned an unknown cause code. Most identifiable damaging agents were from vegetation (e.g., parasitic plants or vines covering

≥50 percent of crown) (24 percent), disease (12 percent), weather (5 percent), and physical damages (undermined, falling trees, rockslides, etc.) (5 percent) (fig. 44). Damage severity was visually estimated as a proportion of damage to affected trees. Vegetation damages to trees mostly ranged from 1–9 to 20–39 percent severity, while disease damages typically ranged from 1 to 9 percent severity (fig. 45).

The estimated number of dominant tree species with damage varied by the type of damaging agent (table 6). Damage recorded for native dominant tree species, including ‘ōhi‘a lehua, koa, and koai‘a, were mainly from vegetation (table 6). Damage recorded for invasive and introduced dominant tree species, such as strawberry guava, guava, Christmas berry, haole koa, grand eucalyptus, and swamp mahogany, were driven mainly by vegetation, disease, and weather (table 6). Trees that are heavily covered in vines or parasitic plants, such as mistletoe, may be more susceptible to disease and have slower growth than other trees due to competition for light and other resources. Introduced plant diseases are a continual threat to Hawai‘i’s native trees and violent weather events can increase damages and the spread

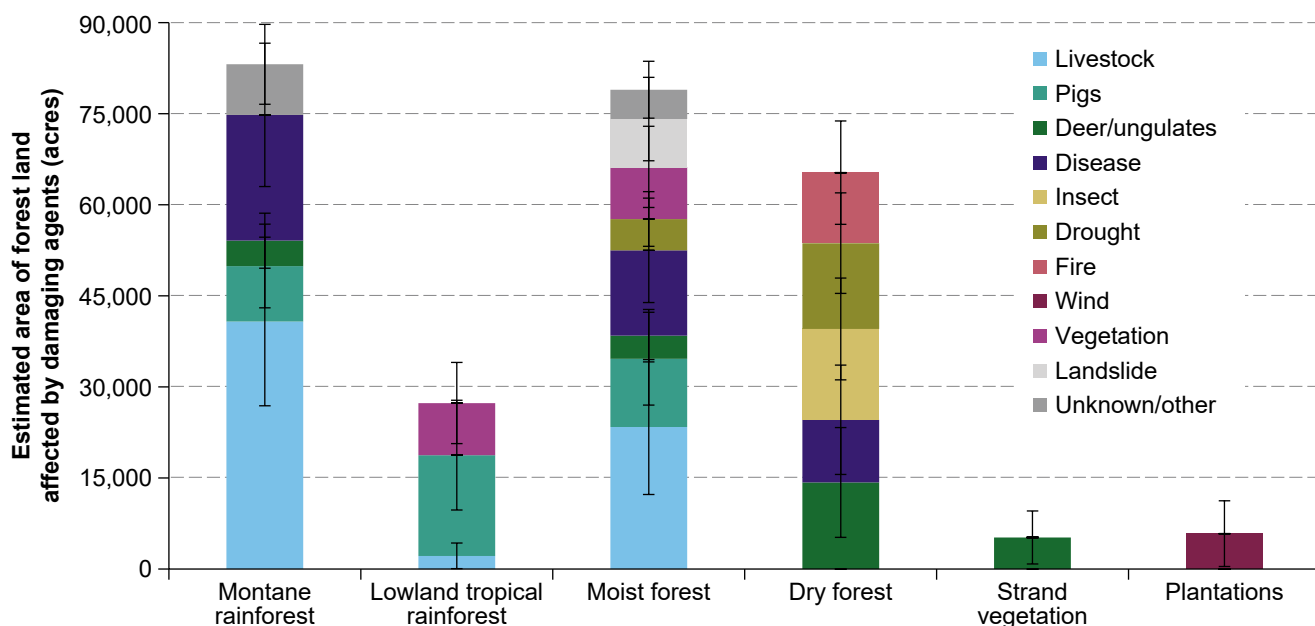


Figure 42—Estimated area affected by one or more types of disturbance on forest land, by forest community types with recorded disturbances, Hawai‘i, 2010–2015. Livestock disturbance is from domestic livestock grazing; disease and insect damage includes understory or overstory; evidence of fire includes tree or ground damage; vegetation disturbance was caused by parasitic plants, suppression, or competition (e.g., parasitic plants or vines covering ≥50 percent of crown). Disturbances summarized in this figure were recorded on an estimated 17 percent (247,192 ac) of forest land. No disturbances were recorded for moist forest land (83 percent, or 1.2 million ac).

Figure 43—Tree damage types occurring on live trees and saplings, Hawai'i, 2010–2015. Most damages to saplings and trees occurred as a loss of apical dominance, broken or dead parts of the tree, and conks and other signs of decay. About 83 percent of measured trees did not have visible damage.

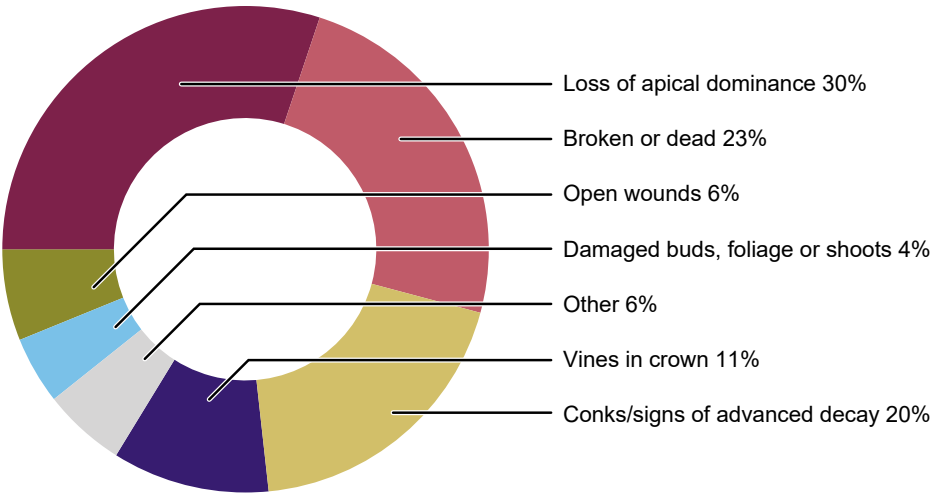


Figure 44—Tree and sapling damage agents, Hawai'i, 2010–2015. Most identifiable damage was caused by vegetation disturbance (e.g., parasitic plants or vines covering ≥ 50 percent of crown), and diseases.

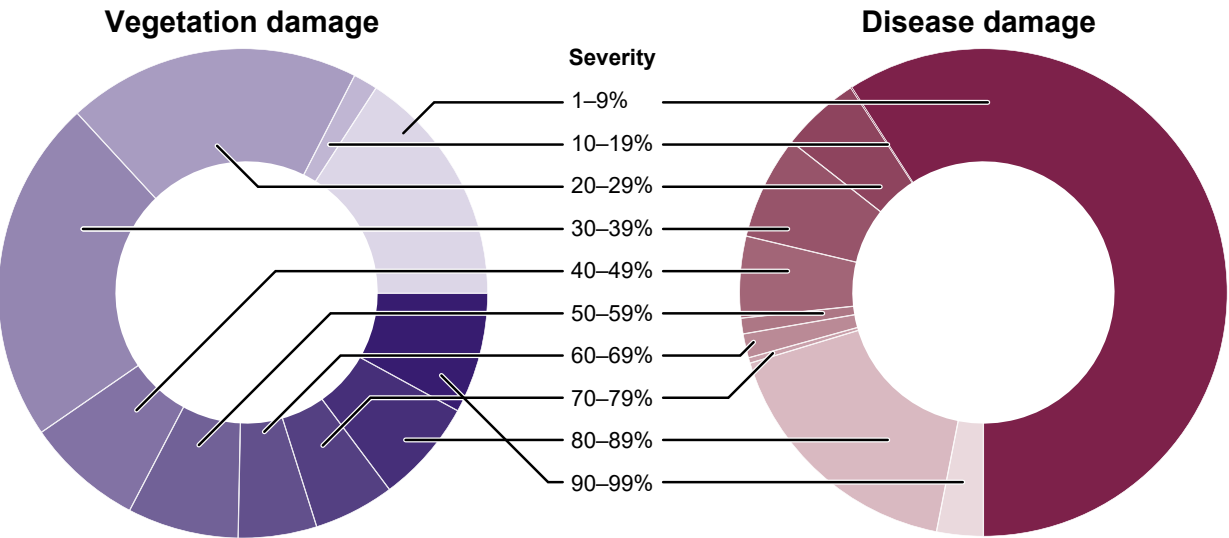
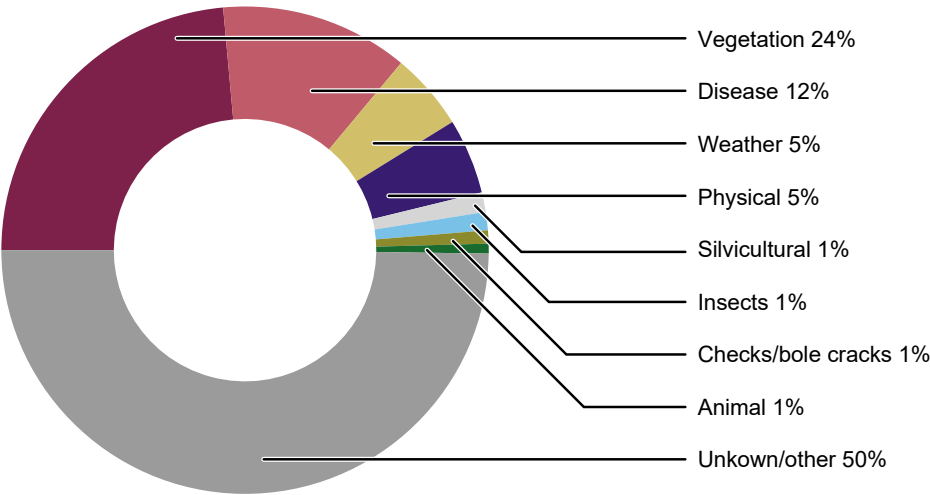


Figure 45—Damage severity to trees and saplings caused by vegetation suppression (e.g., parasitic plants or vines covering ≥ 50 percent of crown) and diseases, Hawai'i, 2010–2015.

Table 6—Estimated number of dominant tree species (≥ 1 -inch in diameter) affected by one or more type of damaging agents, on forest land, Hawai'i, 2010-2015

	Vegetation		Disease		Insect		Animal		Weather		Other/ unknown	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
Dominant tree species												
‘Ōhi‘a lehua (e)	12,763	4,878	6,236	2,633	1,550	944	1,047	546	1,501	847	67,845	10,540
Strawberry guava*	16,788	5,005	643	501	—	—	—	—	1,142	750	20,577	9,524
Koa (e)	3,916	2,165	243	135	1,010	681	312	340	173	120	2,487	1,009
Christmas berry*	6,131	3,114	2,115	2,078	—	—	—	—	1,377	950	7,958	5,127
Haole koa*	62	54	—	—	—	—	—	—	5,735	3,944	6,728	3,569
Hāpu‘u pulu (e)	254	98	25	28	—	—	422	119	87	65	2,230	610
Grand eucalyptus (i)	135	92	105	98	—	—	—	—	762	684	59	43
Swamp mahogany (i)	933	722	—	—	33	33	—	—	91	71	260	139
Guava*	710	713	1,536	834	—	—	—	—	—	—	2,365	1,593
Koai‘a (e)	1,089	1,337	—	—	32	39	—	—	32	39	814	691

Note: Totals may be off because of rounding; data subject to sampling error; SE = standard error; — = fewer than 50 trees were estimated. * = invasive; (e) = endemic; (i) = introduced species.

of invasive species. Insect damage was fairly low compared to impacts by other damaging agents, but nonnative insects such as the coconut rhinoceros beetle are concerning to land managers because they are known to feed on economically important species such as coconut palms (niu), bananas, and pineapples. Endemic insects, such as the koa moth (*Scotorythra paludicola*) can also have occasional outbreaks that cause extensive defoliation of native koa trees (see “Effects of Koa Moth Outbreaks on Koa Tree Stands” below).

Nonnative Feral Pigs

Nonnative feral pigs pose a serious threat to native Hawaiian forest communities and watersheds. European wild boars (*Sus scrofa*), or feral pigs, were introduced to Hawai‘i in the latter part of the 18th century, and they have no natural predators on the islands. Nonnative feral pigs threaten native species and alter the structure and function of forests by trampling on and eating native seeds and seedlings, increasing soil erosion, and facilitating the spread of invasive species (Gawel et al. 2018, Long et al. 2017, Murphy et al. 2014). Feral pigs can also act as vectors for disease and pathogens (Barrios-Garcia and Ballari 2012, Li et al. 2013). In light of damages feral pigs cause to Hawai‘i’s natural resources, FIA field crews assessed the proportion of the FIA subplot area with noticeable pig damage to the ground or ground vegetation within each sampled condition class.

Percentage of feral pig damage varied by land owner groups, forest community type, elevation, and land status. Moist forest communities on federally managed land had the highest average percentage of pig damage (8.4 percent), followed by montane rainforests managed by state and county governments (4.9 percent) (fig. 46). Overall, average pig damage was lowest in dry forests (0.1 percent) compared to other forest community types, and on privately owned forest land (1.6 percent) compared to other land designations (fig. 46). Average percentage of pig damage tended to be higher on reserved forests at elevations ranging from 1,000 to 4,000 ft (5.9 to 6.8 percent pig damage) compared to elevations below 1,000 ft or above 4,000 ft (0.3 to 3 percent feral pig damage) or unreserved forests. Unreserved forests exhibited 1 to 2.7 percent feral pig damage across all elevation ranges (fig. 47).

Effects of Koa Moth Outbreaks on Koa Tree Stands

R. Flint Hughes, Ecologist, USDA Forest Service, Pacific Southwest Research Station

The native Hawaiian koa looper moth (*Scotorythra paludicola*) has defoliated entire stands of the high-value native koa (*Acacia koa* A. Gray) tree over relatively short periods of time. Outbreaks of this insect are infrequent but impressive when they occur; an outbreak on Hawai'i Island in 2013–2014 encompassed an estimated 100 km² of koa stands across a variety of landscapes.

In order to assess the long-term impact of koa looper moth outbreaks on koa stands in Hawai'i's forests, we used the 184 Forest Inventory and Analysis (FIA) plots across Hawai'i Island. We focused on a subset of 36 FIA plots that (1) were located in areas known to have experienced recent koa moth outbreaks, (2) contained koa trees, and (3) were measured prior

to koa moth defoliation episodes. Measured parameters included tree species, diameter (all trees ≥ 1 inch diameter were measured), height, and status (i.e., live or dead). The 36 selected plots were measured a second time about 18 months after the last koa moth outbreak to provide pre- and post-outbreak evaluations of forest composition, structure, and health. Our specific objectives were to determine (1) how koa stands changed between initial measurement and remeasurement and (2) whether and to what degree defoliation by koa moth resulted in mortality of affected koa trees.

Numbers of living koa trees post-outbreak relative to preoutbreak measures varied greatly among plots: mortality ranged from 0 to as high as 80 percent (figs. A and B).

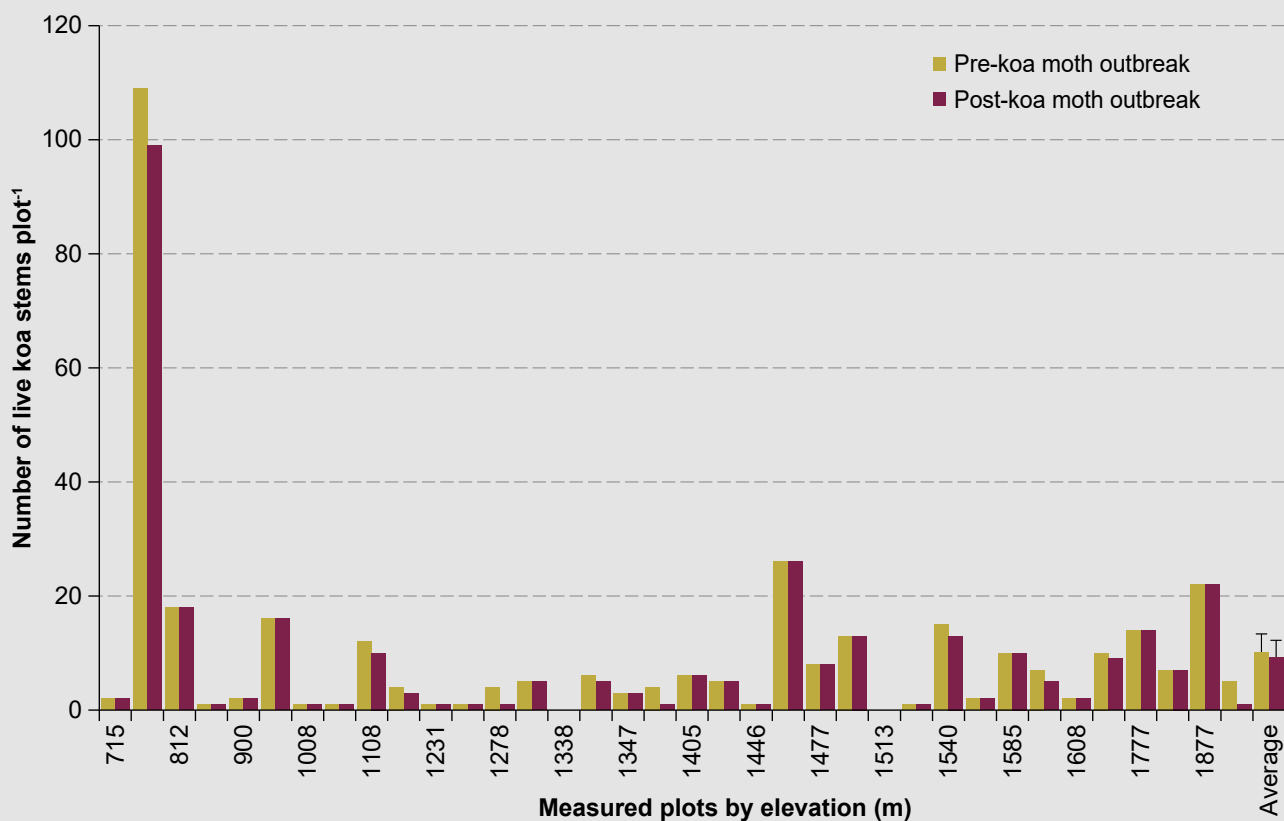


Figure A—Comparison of the number of standing live koa stems (≥ 1 -inch diameter) from the pre-outbreak and post-outbreak survey, by elevation. Analysis and figure provided by R. Flint Hughes, USDA Forest Service.

Across plots, mortality averaged one dead koa tree per plot, a mortality level that was significant, though small (fig. A), and koa tree mortality levels averaged 8 percent of the total individuals found on the plots (fig. B). In comparison, mortality of ‘ōhi‘a lehua (*Metrosideros polymorpha* Gaudich.)—Hawai‘i’s most abundant native forest tree and a species that is not susceptible to koa loop moth defoliation—was also variable among plots, ranging from 0 to 58 percent of total ‘ōhi‘a lehua stems (fig. B). On average,

mortality levels were 1.6 ‘ōhi‘a lehua trees per plot (fig. B). This translated to an average 21 percent ‘ōhi‘a lehua mortality level across all plots, more than double that of sampled koa trees. ‘ōhi‘a lehua trees were not defoliated during koa moth outbreaks. Our results indicated that the effects of widespread defoliation events by the native koa moth, which were variable, but dramatic during and shortly after the outbreak, also resulted in substantial levels of mortality of koa trees in the long term.

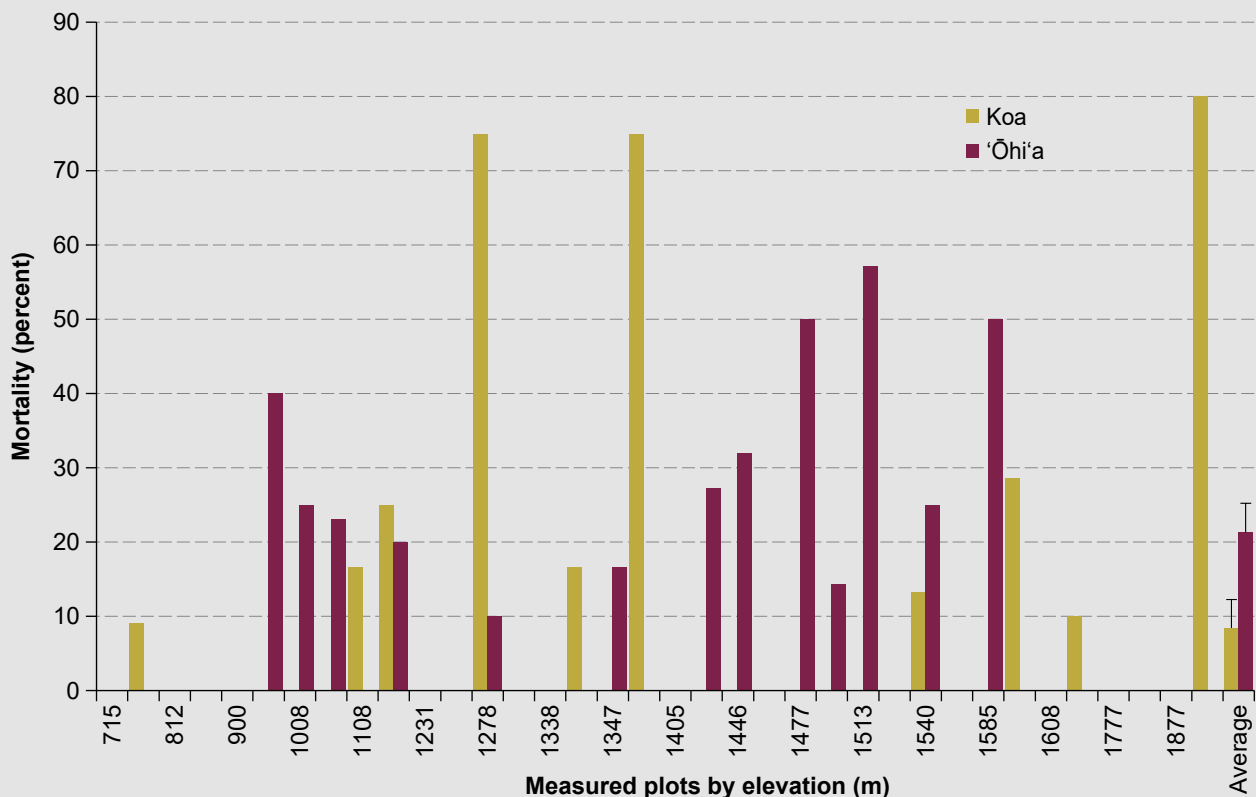


Figure B—Mortality (percentage of total living and dead trees) of both koa and ‘ōhi‘a lehua trees from pre- and post-outbreak measurements, by elevation. Analysis and figure provided by R. Flint Hughes, USDA Forest Service.

Average percentage of feral pig damages tended to be higher in medium and large stand size classes compared to smaller stands, and percentage of damages varied in areas with different dominant tree species (table 7). The greatest average percentage of pig damage was found in dominant medium (7.5 percent) and large (2.9 percent) hāpu‘u pulu stand size classes, followed by dominant small-diameter

strawberry guava (3.3 percent) stands (table 7). Feral pigs can damage native trees, such as hāpu‘u pulu and other “tree fern” species in the *Cibotium* genus, reducing their growth and survival, and contributing to long-term shifts in species composition (Friday et al. 2008, Murphy et al. 2014). There is also a feedback loop between feral pigs and strawberry guava: feral pigs spread strawberry guava seeds

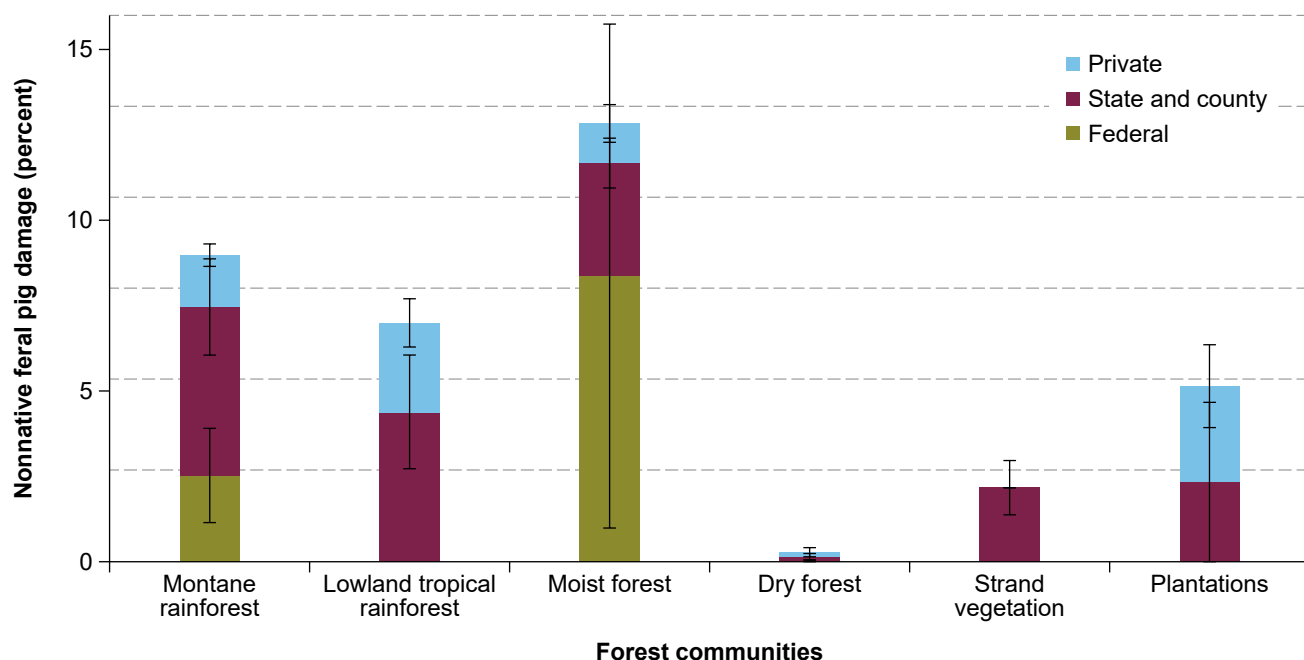


Figure 46—Percentage of nonnative feral pig damage to understory by forest community type and owner group, Hawai'i, 2010–2015.

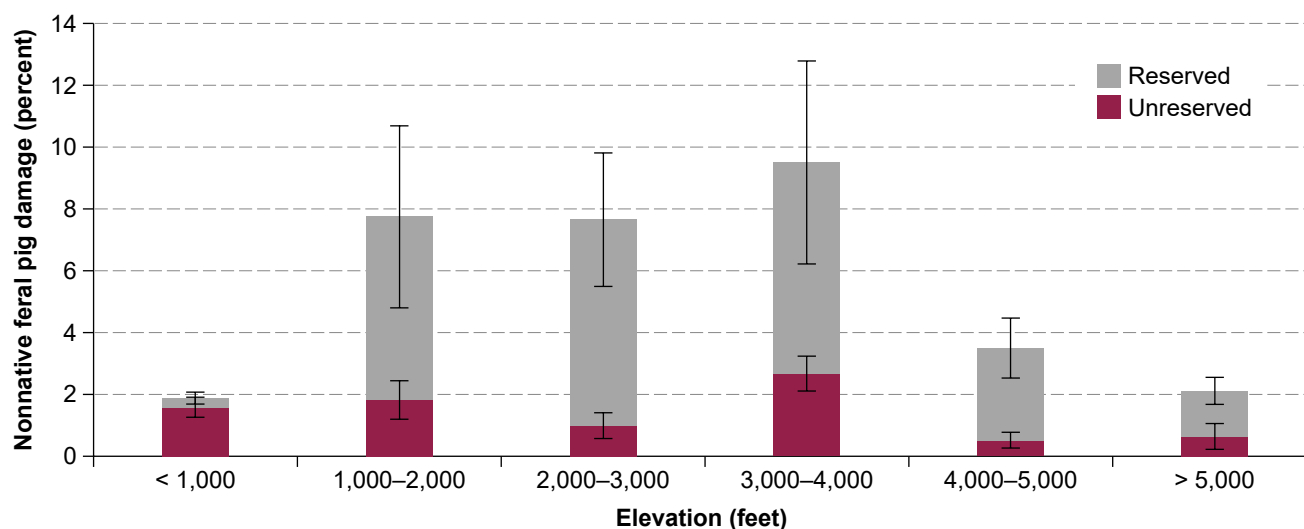


Figure 47—Percentage of nonnative feral pig damage to understory by land status and elevation, Hawai'i, 2010–2015.

via their scat after consuming the fruit. Percentage of feral pig damages tended to be higher (ranging from 10 to >20 percent damage) with greater plant canopy cover and height for both *Cibotium* spp. and strawberry guava, compared to lower canopy cover (i.e., ≤ 10 percent canopy cover) and heights (i.e., ≤ 6.6 ft.) (fig. 48). A study conducted by Cole et al. (2012) found that young native *Cibotium* spp. density

increased in fenced areas with the removal of nonnative pigs, compared to unfenced areas. However, the density of invasive plant species also increased in pig-free sites. This study highlights the complexity of controlling pigs and other introduced species (Cole et al. 2012).

Management of introduced feral pigs in Hawai'i is complex and sometimes controversial. Several management

Table 7—Percentage of understory feral pig damage, by dominant tree species and stand size class, Hawai‘i, 2010–2015

Dominant tree species	Stand size class					
	Large		Medium		Small	
	Total	SE	Total	SE	Total	SE
----- Feral pig damage (percent) -----						
‘Ōhi‘a lehua (e)	1.6	0.5	1.8	0.8	0.3	0.1
Strawberry guava*	1.0	0.8	0.4	0.3	3.3	1.2
Koa (e)	0.5	0.2	0.1	0.1	0.1	0.1
Christmas-berry*	0.3	0.3	0.5	0.3	0.0	0.0
Haole koa*	—	—	—	—	—	—
Hāpu‘u pulu (e)	2.9	2.1	7.5	6.8	—	—
Grand eucalyptus (i)	2.6	1.5	—	—	—	—
Swamp mahogany (i)	2.0	1.1	—	—	—	—
Guava*	—	—	0.2	0.2	0.3	0.3
Koai‘a (e)	0.5	0.2	0.1	0.1	0.1	0.1

Note: Totals may be off because of rounding; data subject to sampling error; SE = standard error; — less than 0.1 percent cover was estimated.

* = invasive; (e) = endemic; (i) = introduced species.

techniques are used to control and limit the damages caused by feral pigs. Hawai‘i’s game management program supports hunting pigs on public and private lands, whereas fencing has been used to deter pigs from conservation areas of high ecological and biodiversity importance; fencing is often paired with snares to catch and remove pigs (Tep and Gaines 2003). Similar to the study above, several other studies have found that the abundance of native plants, tree regeneration, cover of litter, and bryophytes, as well as soil stability all increased with pig removal; however, some invasive plant species, such as strawberry guava, also increased after pig removal (Cole and Litton 2014, Cole et al. 2012, Hart et al. 2020, Long et al. 2017).

Invasive Vegetation

Invasive plant species can significantly alter forest structure and species composition, as well as reduce ecosystem resilience to other disturbances (fig. 49). Accidental or intentional introductions of forbs, grasses, shrubs, vines, and trees have had a profound effect on the environment and economy in Hawai‘i (D’Antonio 1992, D’Antonio et al. 2017, Dawson et al. 2017, Vitousek 1990). Invasive plants tend to dominate because their natural enemies are absent on the islands and the ability of native plant species to compete

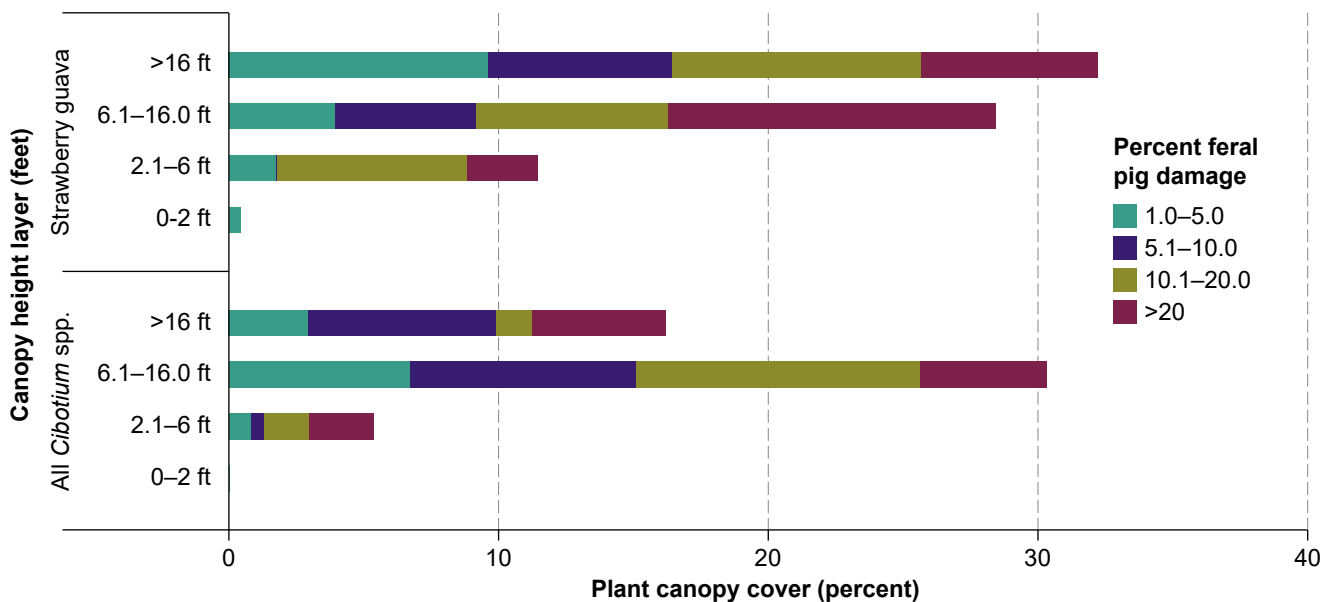


Figure 48—Percentage of nonnative feral pig damage to ground and understory by strawberry guava and *Cibotium* spp. canopy cover and canopy height layer, Hawai‘i, 2010–2015. *Cibotium* spp. includes, hāpu‘u pulu (*Cibotium glaucum*), hāpu‘u meu (*Cibotium chamissoi*), and hāpu‘u ‘i‘i (*Cibotium menziesii*).

with the sheer volume of introduced species is limited. Invasive species are a main threat to watershed health and a primary agent of continuing forest degradation in Hawai'i, causing tremendous economic losses for the state (DLNR 2016, Loope et al. 2013). FIA plots are valuable for understanding Hawai'i's statewide abundance and distribution of invasive species across all forested areas and owner groups.

FIA monitors specific, high-priority invasive plant species (those considered to be a major threat to Hawaiian forests and that cause environmental or economic harm) to document their abundance and changes over time (USDA FS 2013). Canopy cover estimates were recorded for each species across all height layers in FIA subplots. All vegetation and plant parts that were alive during the current growing season were included in the cover estimates using methods similar to Daubenmire (1959). A complete invasive species list and detailed methods are described in field instructions for the inventory of the Pacific Islands (USDA FS 2013, sec. 11 app. 1). FIA crews were trained on invasive plant protocols and extra precautions were taken to prevent the spread of invasive species while and after visiting plots (e.g., removing seeds from boots and clothing and washing tools and vehicles before entering forests, particularly in remote areas that are rarely visited). Providing accurate estimates of the distribution and abundance of the most damaging species gives managers and policymakers a better understanding of the problem and potential treatment options.

Invasive plant cover varied by elevation, forest community type, and land owner groups, but was similar across reserved and unreserved areas. Most invasive plant cover on Hawai'i, Kaua'i, Maui, and O'ahu Islands was found below 3,000 ft elevation (fig. 50). Lowland tropical rainforests had the most invasive plant cover (44 percent) compared to other forest community types (each below 20 percent) (fig. 51). Reserved and unreserved forest lands had similar invasive plant cover, each averaging 20 to 25 percent (fig. 51). On privately owned forest land, invasive plant cover was greatest below 2,000 ft, compared to other elevations (fig. 52). Forests managed by state and county governments had the most invasive plant cover below 1,000 ft and within the range of 2,000 and 3,000 ft (55 and 44 percent invasive plant cover, respectively). Forests managed by the federal govern-



Ashley Lehman

Figure 49—Field crew member Kalena Shiroma walks through a dense patch of invasive strawberry guava (*Psidium cattleianum*), which outcompetes and displaces native forest species in Hawai'i.

ment were mainly found above 2,000 ft, and they had the greatest invasive plant cover between 2,000 and 3,000 ft (23 percent cover) (fig. 52).

There were 27 high-priority invasive species recorded across all inventory plots, and percentage of cover by each varied by owner groups (table 8). Overall, strawberry guava had the most cover, accounting for 37 percent of all invasive species cover (see Gray et al. 2021 for a distribution map of strawberry guava in FIA plots across Hawai'i). Strawberry guava had an estimated cover of 9 to 10 percent on privately owned forest land and those lands managed by state and county governments (table 8). Koster's curse, Christmas berry, and Asian melastome were the next most common invasive species, each covering about 3 percent, mostly on state, county, and private lands (table 8). Negative consequences caused by the presence of strawberry guava and Christmas berry, and similarly with Koster's curse and Asian melastome, are devastating to Hawai'i's native forests and economy. Koster's

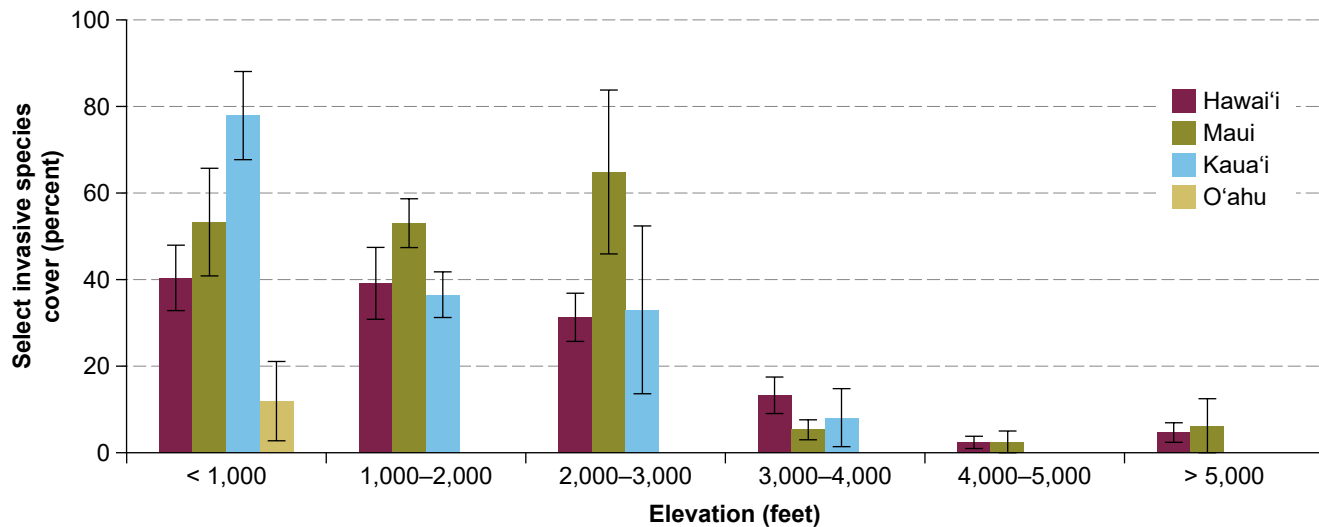


Figure 50—Canopy cover percentage of select high-priority invasive species on forest land by island and elevation. See table 8 for a list of invasive species included in this analysis.

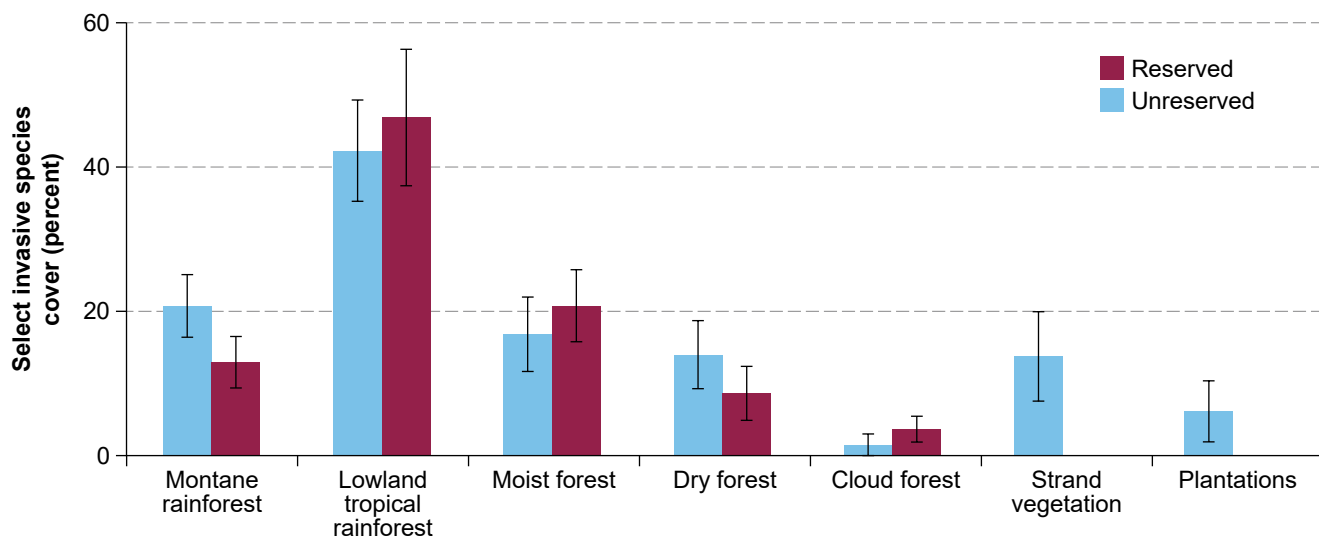


Figure 51—Canopy cover percentage of select high-priority invasive species on forest land by forest community type and U.S. Forest Service Forest Inventory and Analysis-defined unreserved and reserved forest areas.

curse and Asian melastome produce thousands of seeds that are spread by birds and other animals, and these invasive species are rapidly replacing endemic species and threatening their extinction by quickly filling in forest gaps and preventing or smothering native plant growth (CABI 2019, GISD 2020).

Most high-priority invasive species were trees and shrubs, except for one forb, kahili ginger (*Hedygium gardnerianum* Shepard ex Ker Gawl.) (fig. 53; table 8), and two graminoids, palmgrass (*Setaria palmifolia* auct. non (J. Koenig) Stapf) and fountaingrass (table 8). Kahili ginger has

deep matted roots and is more adept at acquiring resources than some shallow-rooted native species (CABI 2019). Invasive grasses in Hawai'i can alter resource availability and forest structure by replacing native species that lack adaptations to fire and creating low-diversity grasslands (D'Antonio and Vitousek 1992). Most invasive species listed in table 8 were identified as among the world's worst ecosystem-modifying invasive plant species (Vorsino et al. 2014). Risk assessment screening systems, such as Hawai'i Pacific Weed Risk Assessments (<https://sites.google.com/site/weedriskas->

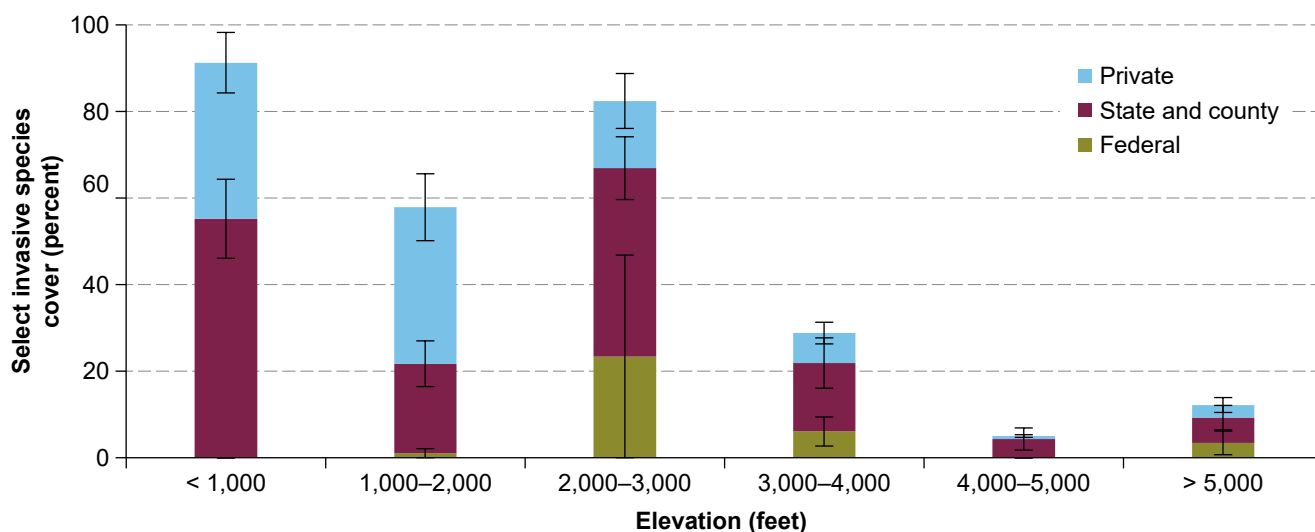


Figure 52—Canopy cover percentage of select high-priority invasive species by elevation, and owner group.

Table 8—Average cover percentage of priority invasive species (considered a major threat to Hawaiian forests) included in the subplot inventory, by owner group

Invasive species	Life form	Federal		State and county		Private		All owners	
		Total	SE	Total	SE	Total	SE	Total	SE
----- Percent cover -----									
Strawberry guava	Tree	1.19	1.06	8.7	1.91	9.69	2	8.3	1.25
Koster’s curse	Shrub	0.37	0.37	2.94	0.68	2.78	0.91	2.61	0.5
Christmas berry	Tree	0.05	0.05	1.02	0.47	3.04	1.09	1.71	0.49
Asian melastome	Tree	—	—	1	0.42	3.08	1.04	1.72	0.46
Guava	Tree	0.1	0.1	2.38	0.96	0.82	0.34	1.53	0.5
Kahili ginger	Forb	0.13	0.13	2.17	0.93	0.11	0.03	1.14	0.47
Fountain-grass	Graminoid	0.75	0.75	1.12	0.63	0.54	0.46	0.85	0.36
Shoebuttan ardisia	Tree	—	—	0.73	0.54	1.62	1.07	1	0.5
Palmgrass	Graminoid	0.08	0.08	1.09	0.37	0.13	0.1	0.6	0.19
Albizia	Tree	—	—	0.22	0.22	1.19	0.73	0.58	0.3
Lantana	Shrub	0.08	0.08	0.67	0.36	0.4	0.3	0.5	0.22
Haole koa	Tree	—	—	—	—	0.83	0.42	0.33	0.17
Firetree	Tree	0.73	0.61	0.6	0.33	0	0	0.38	0.18
Madagascar ragwort	Forb	—	—	0.43	0.41	0.11	0.08	0.26	0.21
Silver oak	Tree	—	—	0.43	0.27	0	0	0.22	0.14
Banana poka	Shrub	—	—	0.31	0.2	0.05	0.03	0.18	0.1
Herbaceous glorytree	Shrub	—	—	0.4	0.11	0.17	0.07	0.27	0.06
African tulip-tree	Tree	—	—	0.4	0.2	0.06	0.05	0.22	0.1
Night jasmine	Shrub	—	—	0.12	0.12	—	—	0.06	0.06
Chinese banyan	Tree	—	—	0.01	0.01	0.21	0.16	0.09	0.06
Yellow Himalayan raspberry	Shrub	0.22	0.23	0.02	0.01	—	—	0.03	0.03
Sawtooth blackberry	Shrub	—	—	—	—	0.07	0.05	0.03	0.02
Mysore raspberry	Shrub	0.11	0.09	—	—	0.01	0.01	0.01	0.01
Miconia	Tree	—	—	0.02	0.01	0	0	0.01	0.01
Parrotweed	Tree	—	—	0.02	0.02	—	—	0.01	0.01
Australian tree fern	Tree	—	—	—	—	0	0	0	0
Port Jackson fig	Tree	—	—	—	—	—	—	—	—

Note: Totals may be off because of rounding; data are subject to sampling error; SE = standard error; — less than 0.1 percent cover was estimated. See figures A2-1 and A2-12 for species scientific names.

Impacts of Invasive Strawberry Guava on Native Plant Communities and Forest Carbon Storage

R. Flint Hughes, Ecologist, USDA Forest Service, Pacific Southwest Research Station

Strawberry guava (*Psidium cattleianum* Sabine) was introduced to Hawai'i from Brazil in the early 1800s, becoming widespread across all eight main Hawaiian Islands, except N'ihau and Kaho'olawe. It is now considered one of Hawai'i's most serious weeds (Smith 1985). Currently, strawberry guava is Hawai'i's most abundant tree; FIA results estimate 7.2 million live strawberry guava stems (>1 inch diameter at breast height [d.b.h.]), which is about 41 percent of all stems from live woody species that grow in Hawaiian forests. However, due to its typically small stature, estimated total carbon mass (899,775 U.S. tons) of live strawberry guava (≥ 5 inches d.b.h.) across all Hawai'i's forests was only the eighth highest out of other species. Strawberry guava's carbon mass accounted for 2.4 percent of the carbon mass of all trees ≥ 5 inches d.b.h., preceded by 'ōhi'a lehua, eucalyptus species, koa, and others (fig. C).

Strawberry guava's capacity to reproduce vegetatively via root sprouts or suckers and tolerance of low-light environments enable it to rapidly invade otherwise undisturbed native forests; it is currently the

most widespread invasive woody species in Hawai'i's mesic, moist, and wet forest zones. Once established, strawberry guava often forms dense, impenetrable thickets in understories of dominant canopy trees, whether native (e.g., *M. polymorpha*) or invasive (e.g., Moluccan albizia (*Falcataria moluccana* (Miq.) Barneby & Grimes) (Asner et al. 2008, Hughes and Denslow 2005). Across most of its range in Hawai'i, strawberry guava is a strong competitor for resources such as light, water, and nutrients; and it is a daunting obstacle to native species recruitment. Forest stands characterized by a native overstory canopy and a dense subcanopy of strawberry guava typically retrogress to monotypic thickets of this aggressive invader once the mature native trees senesce (Hughes et al. 2014, Zimmerman et al. 2008). Asner et al. (2008b) reported reductions in aboveground carbon mass across areas of strawberry guava invasion. Forest stands codominated by strawberry guava and Port Jackson fig (*Ficus rubiginosa* Desf. ex Vent.), another invasive tree species, showed significantly lower aboveground carbon

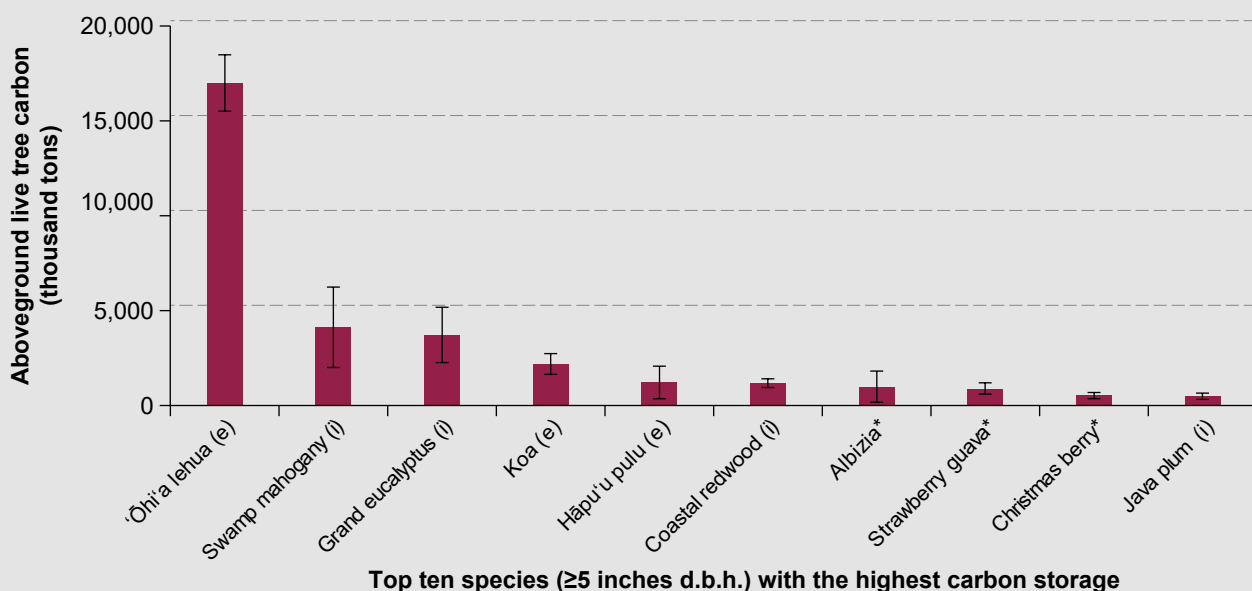


Figure C—Aboveground carbon, dry weight (thousand U.S. dry tons) for the top ten species of live trees (≥ 5 inches d.b.h.) that store the most carbon, Hawai'i, 2010–2015. * = invasive; (e) = endemic; (i) = introduced species.

mass than their native-dominated counterparts on 5,000-, 20,000-, and 65,000-year-old lava substrates of the Hawai'i Experimental Tropical Forest Laupāhoehoe unit.

As a relatively small tree (i.e., typically 6- to 18-ft tall), strawberry guava-dominated forests would be expected to exhibit lower aboveground carbon mass values than large-stature, native forest trees that they replace. In cases where stands of this species have matured to their fullest extent, however, it is possible for such stands to exhibit carbon mass roughly equivalent to that of native forests. Regardless of whether strawberry guava increases or decreases forest carbon mass of the ecosystems it invades, its impacts on the diversity of Hawai'i's native biodiversity are categorically detrimental.

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essment/home), are helpful for identifying future high-risk introduced and invasive species (HPWRA 2021).

‘Ōhi‘a Lehua and Rapid ‘Ōhi‘a Death

‘Ōhi‘a lehua is Hawai'i's most dominant endemic tree species (fig. 54). ‘Ōhi‘a lehua inhabits wet to dry forests at elevations from sea level to 9,190 ft above sea level, and early- and late-seral stands. As a keystone species, ‘ōhi‘a lehua is important for maintaining forest structure, function, and succession, and supporting many native plants and animals (Fortini et al. 2019, Mueller-Dombois et al. 2013). ‘Ōhi‘a lehua is also one of the most culturally significant trees of the Hawaiian Islands. Native Hawaiians often view it as sacred, a kinolau, or bodily manifestation, of an akua (god) such as Laka, the goddess of hula. Its wood is used to make houses and weapons, its leaves for medicinal tea, and its blossoms for hula and other ceremonies (DLNR 2016, 2018b).



Figure 53—An invasive forb, Kahili ginger (*Hedychium gardnerianum*), harvested outside a Forest Inventory and Analysis (FIA) plot by FIA crew member Kalena Shiroma.

Ian Kottke

‘Ōhi‘a lehua is threatened by various pathogens and diseases, but two are newly described fungal species, *Ceratocystis lukuohia* and *Ceratocystis huliohia*, which cause rapid ‘ōhi‘a death (ROD), a forest disease driving extensive and rapid tree mortality (Barnes et al. 2018, Keith et al. 2015). *C. lukuohia* causes large mortality events, whereas *C. huliohia* causes more localized mortality events. The fungi quickly kill ‘ōhi‘a trees by blocking the tree’s vasculature, thus compromising water transport. Signs of ROD were initially detected on Hawai‘i Island in 2012, and the disease has already spread to other Hawaiian Islands (DLNR 2016, 2018b; Fortini et al. 2019). Recently, *C. huliohia* was detected on dying trees on the islands of Kaua‘i, O‘ahu and Maui (CTAHR 2021, Heller et al. 2019). No other trees in the same family (*Myrtaceae*) have been found to be susceptible to

the disease. Preliminary evidence indicates that nonnative feral ungulates may be promoting *Ceratocystis* infection by causing physical damage to ‘ōhi‘a trees and creating pathways for the fungus to enter and infect trees. Other vectors of *Ceratocystis* spread include insects and humans via equipment, clothing, and vehicles (DLNR 2016, Fortini et al. 2019). Many native plants, animals, and entire watersheds are vulnerable to large ‘ōhi‘a mortality events caused by ROD.

FIA field crews started collecting data on ROD after the completion of the 2010–2015 inventory. Therefore, the data presented in this report serves as important baseline information on ‘ōhi‘a lehua extent and conditions prior to the spread of ROD across many forests of Hawai‘i Island. Field crews started identifying the presence of the *Ceratocystis* fungal pathogens and collecting samples on field plots

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Figure 54—‘Ōhi‘a lehua (*Metrosideros polymorpha*) with prominent red flowers is a critically important endemic tree in Hawaiian forests.

in the most recent 2019–2021 inventory cycle. Field crews also followed the ROD sanitation protocol for Hawai'i to reduce the potential of spreading these pathogens (CTAHR 2021USDA FS 2019a). Future FIA reports will summarize the presence of the *Ceratocystis* fungal pathogens and assess how ROD has affected 'ōhi'a lehua trees and stands over time.

'Ōhi'a lehua biomass and tree numbers were considerably higher for live than dead trees in this baseline inventory. Hawai'i Island exhibited the most total and average per acre aboveground live and dead 'ōhi'a lehua biomass compared to other islands (figs. 55 and 56). On Hawai'i Island, there were an estimated 34 million U.S. tons (31 Tg) of total live aboveground 'ōhi'a lehua biomass (fig. 55), and an average 37 U.S. tons of live aboveground 'ōhi'a lehua biomass per acre (83 Mg per ha) (fig. 56). Across the state, the majority of total live (60 percent) and dead (57 percent) aboveground biomass was located on forests managed by state and county governments (fig. 55). Forests managed by the federal government had the most live aboveground 'ōhi'a lehua biomass per acre (i.e., 59 U.S. tons ac^{-1} , or 41 percent) (fig. 56). Montane rainforests and reserved forest lands supported the majority of total and per acre live and dead 'ōhi'a lehua biomass compared to

other forest community types and unreserved areas (figs. 57 and 58). There were an estimated 70 million live and 11 million dead 'ōhi'a lehua trees (>5 inches d.b.h.), and most aboveground live and dead trees were concentrated in smaller diameter classes between 5 and 14.9 inches (fig. 59). There were an estimated 291 million live 'ōhi'a lehua stems from 1 to 4.9 inches d.b.h. (table A2-2). Dead trees <5 d.b.h. were not measured under the protocol used for this inventory.

Identifiable damaging agents recorded for 'ōhi'a lehua were mostly vegetation (e.g., parasitic plants or vines covering ≥ 50 percent of crown) and disease (fig. 60). Together, bole cracks, insects, weather, and animals made up the remaining identifiable damaging agents. The severity of damage recorded (proportion of the tree affected by damage) was mostly between 20 to 39 percent (fig. 60). Evidence of ROD and presence of the *Ceratocystis* fungal pathogens on FIA plots will be summarized in the next FIA forest resources report.

Managing for ROD is challenging and requires an understanding of its range and potential threats or resistances. Data from FIA-measured plots and aerial surveys were recently used to examine the range and spread of *C. lukuohia*, and researchers modeled its potential spread to

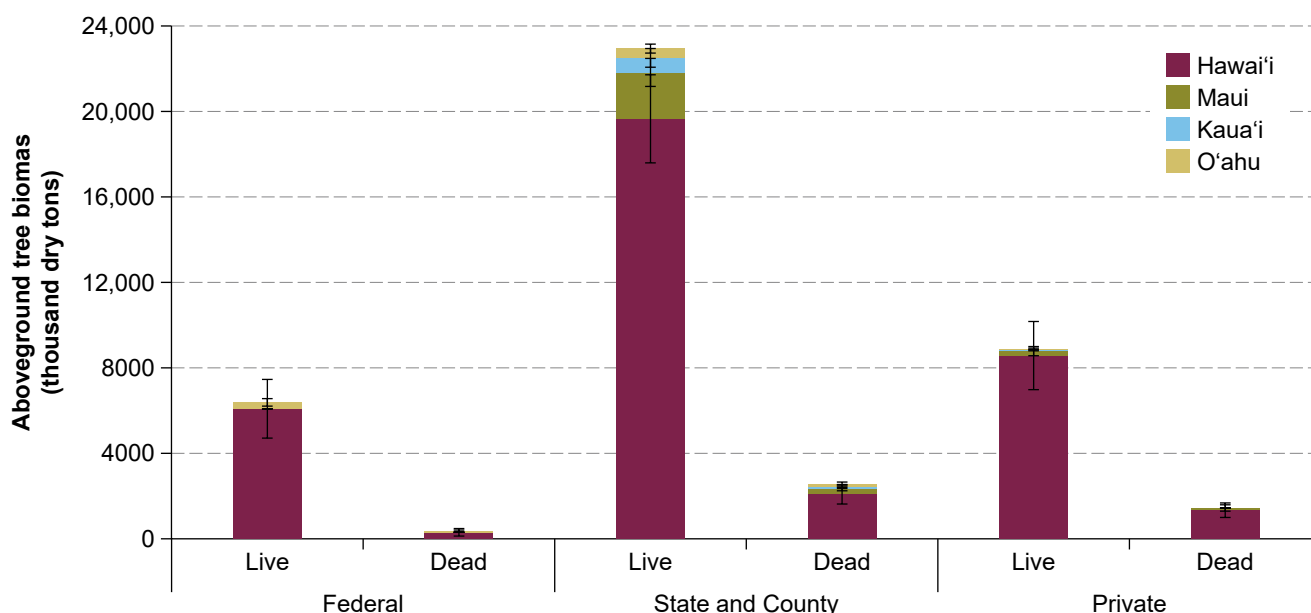


Figure 55—Total aboveground biomass of live (≥ 1 inch d.b.h.) and dead (≥ 5 inch d.b.h.) 'ōhi'a lehua trees on forest land by island and land owner group, Hawai'i, 2010–2015.

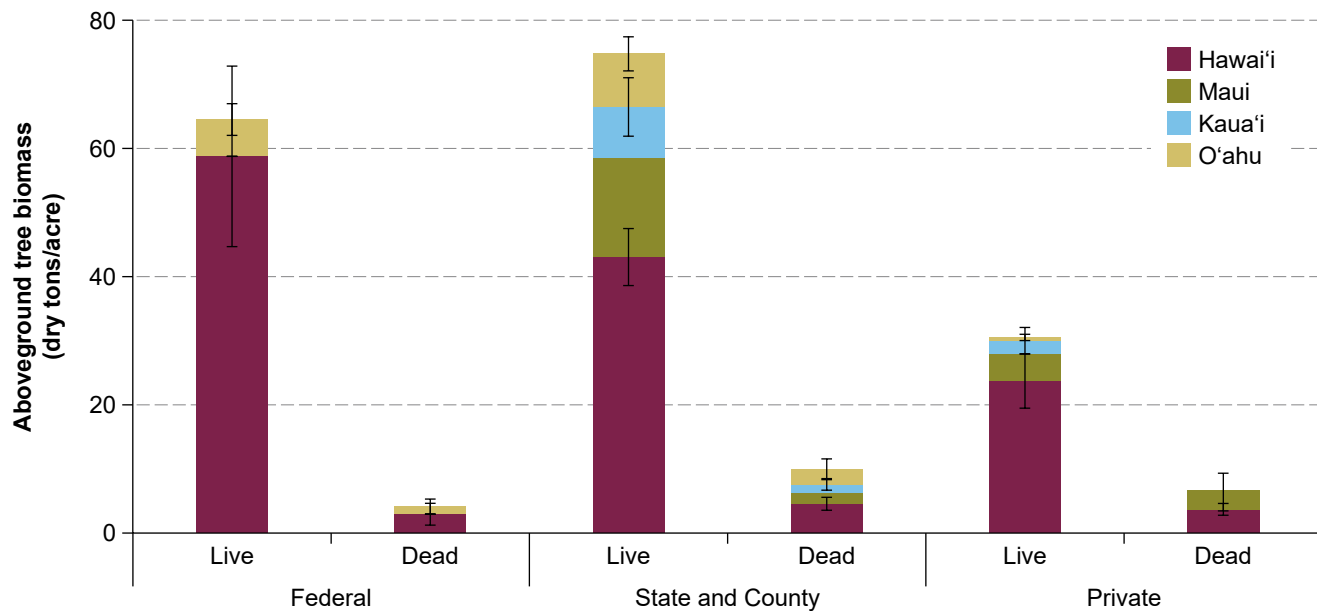


Figure 56—Average aboveground biomass of live (≥ 1 inch d.b.h.) and dead (≥ 5 inch d.b.h.) 'ōhi'a lehua trees per acre on forest land by island and land owner group, Hawai'i, 2010–2015.

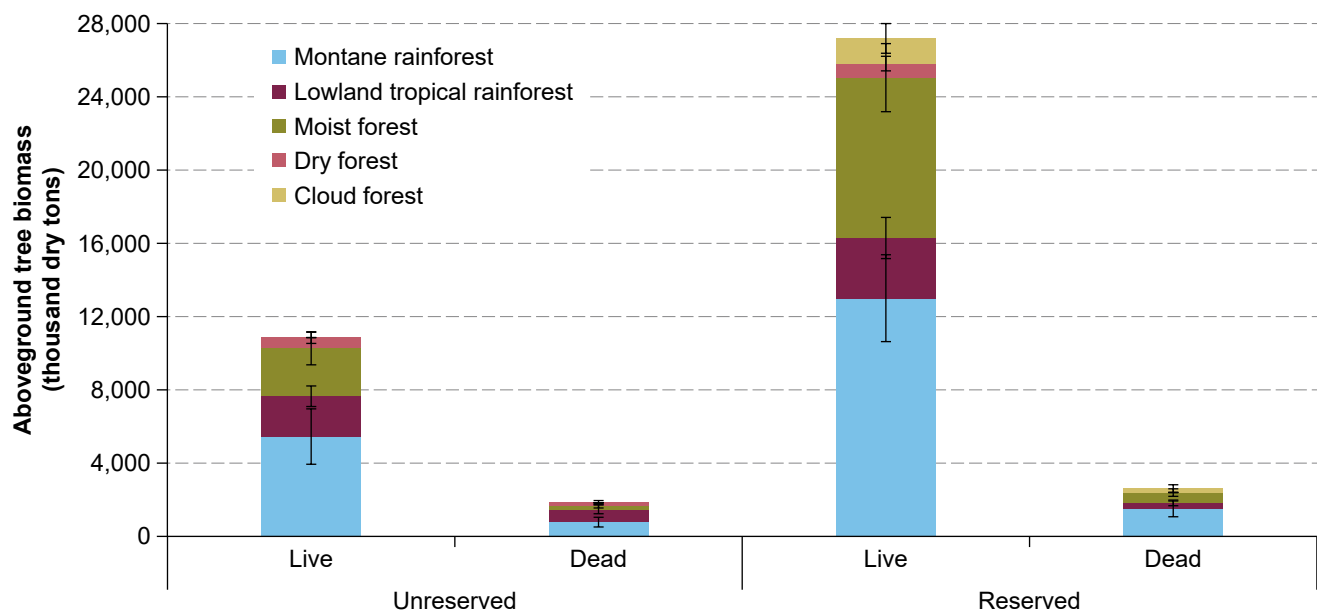


Figure 57—Total aboveground dry biomass of live (≥ 1 inch d.b.h.) and dead (≥ 5 inch d.b.h.) 'ōhi'a lehua trees on forest land by forest community type and land status, Hawai'i, 2010–2015.

estimate the risk of ROD spreading to other islands (Fortini et al. 2019). They developed a dynamic Web portal to host their results online, where most models and analyses are regularly updated to provide managers with tools to help monitor the risk of *C. lukuohia* spread (Fortini et al.

2019). The University of Hawai'i Lyon Arboretum Seed Conservation Lab is working on collecting seeds of 'ōhi'a species for conservation and researching plants resistant to ROD. Additionally, new techniques have been developed to better detect and identify ROD pathogens (Asner et al.

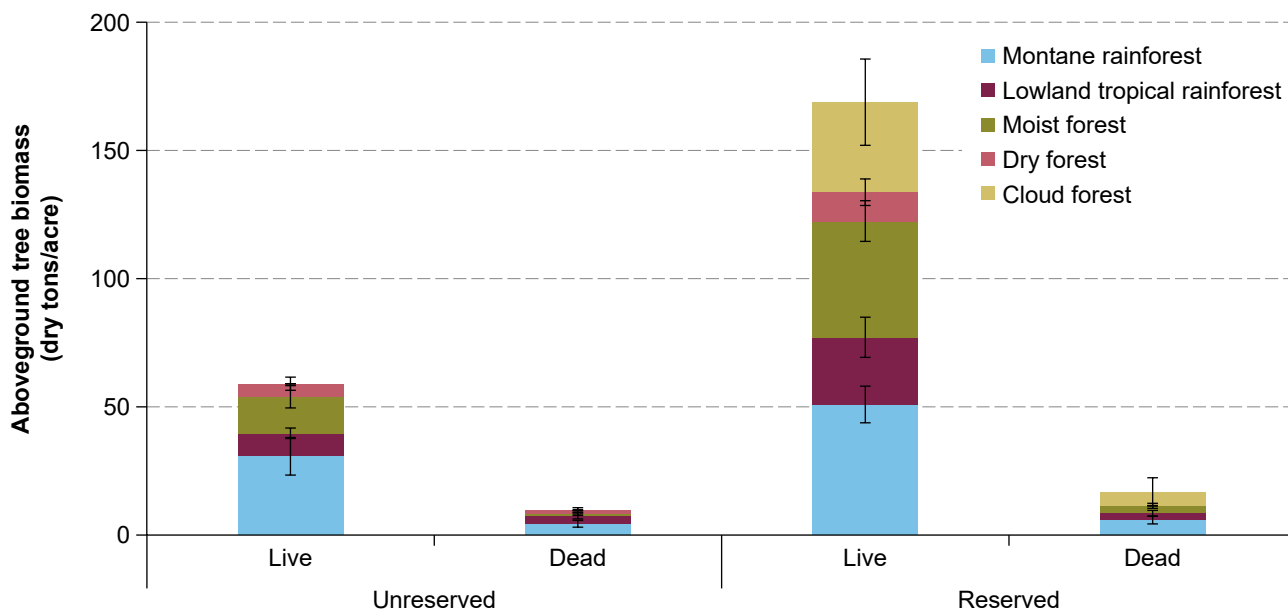


Figure 58—Average aboveground biomass of live (≥ 1 inch d.b.h.) and dead (≥ 5 inch d.b.h.) 'ōhi'a lehua trees per acre on forest land by forest community type and land status, Hawai'i, 2010–2015.

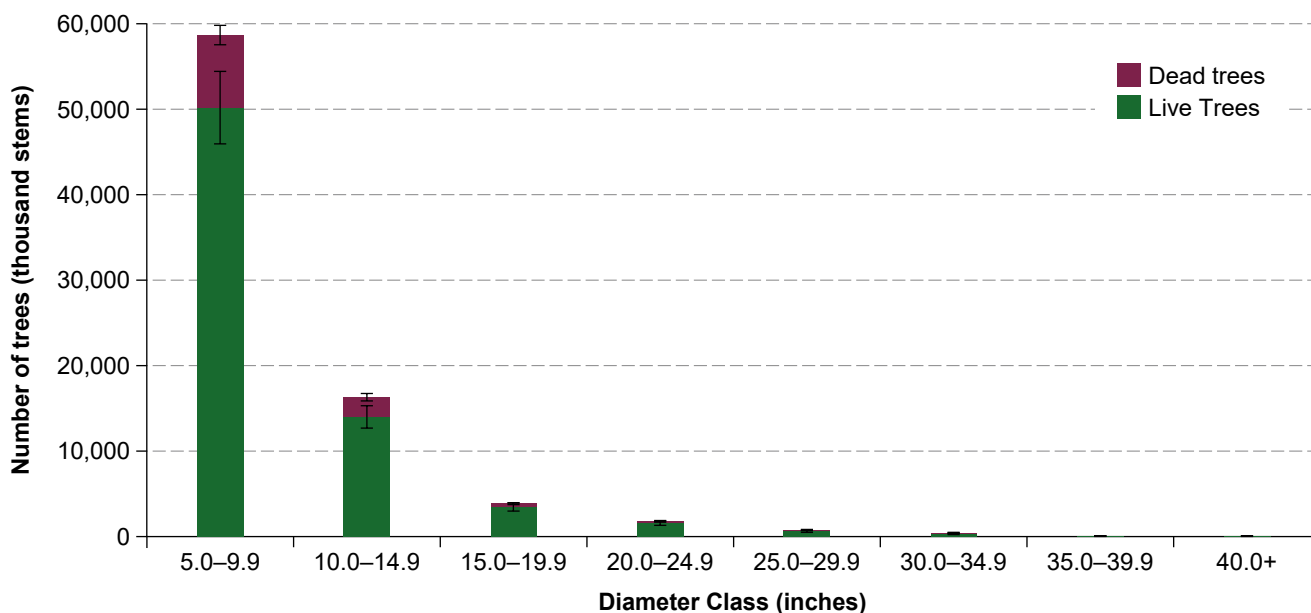


Figure 59—Number of live and dead 'ōhi'a lehua trees (≥ 5 inches) on forest land by diameter class, Hawai'i, 2010–2015.

2018, Heller and Keith 2018). The State of Hawai'i Department of Agriculture enforces a quarantine that prohibits the movement of all 'ōhi'a plants or plant parts without a permit (HDOA 2016b) and recommendations are currently available to help reduce the spread of ROD (CTAHR 2021, DLNR 2018).

Conclusions

This report presents an overview of Hawai'i's statewide forest resources, including the abundance and distribution of native and invasive species and measures of forest health across all forested areas and land owner group. Hawai'i's forests provide a wide range of ecosystem services, such

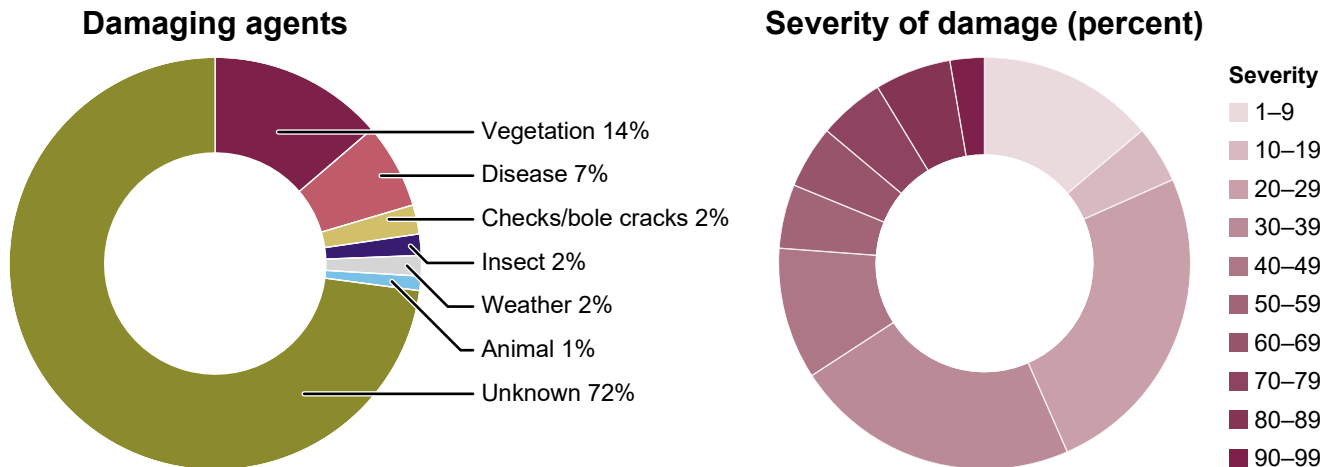


Figure 60—Damaging agents and severity of damages recorded for ‘Ōhi’a lehua. Damaging agents and severity of damages shown in this figure were recorded on 25.1 percent of all measured ‘Ōhi’a lehua trees, and no damages were observed on the remaining 74.9 percent of ‘Ōhi’a lehua trees, Hawai‘i, 2010–2015.

as wildlife habitat, protection of watersheds and soil, and regulation of temperature, as well as production timber, food, medicine, and other NTFPs. Hawai‘i’s forests are also biodiversity hotspots that contain many endemic and culturally important species. There are about 3,000 different native and nonnative plant species in Hawai‘i, with nearly 90 percent of native Hawaiian plant species being Hawai‘i endemics (DLNR 2020c). This inventory only captured about 15 percent of Hawai‘i’s total plant species diversity. Many species that were not inventoried on FIA plots were likely rare or had low canopy cover in field sampled locations, and thus were omitted because of the inventory sampling design.

Hawai‘i’s forest resources are sensitive to changes and many native species have declined over time as a result of introduced and invasive species that threaten forest health and burden local economies. Some of the biggest threats to Hawai‘i’s native species include invasive and introduced plants and animals, such as strawberry guava and hooved animals, which outcompete or damage native species that evolved without defenses against these competitive or destructive forces. Diseases and insects such as ROD and the coconut rhinoceros beetle are also of high concern because of their potential effects to Hawai‘i’s forests, economy, and cultural heritage. A vital component of this inventory is to serve as baseline information on the extent and conditions of Hawai‘i’s forests, highlighting the

impacts and changes over time, such as with collecting ‘Ōhi’a lehua baseline information prior to the evidence of extensive ROD spread that was collected after this inventory. Along with biological invasions, climate change is expected to increase temperatures and lead to more frequent droughts and severe storms, thus increasing forest vulnerability to damages, wildfires, and invasions (DLNR 2016). FIA’s ongoing monitoring of Hawaii’s forests are important for detecting and responding to these changes over time.

Changes in forest composition, structure, function, and dynamics are not all related to biological invasions and climate change. Policy, land designation, and management objectives, as well as human population expansion, also play roles. About half of Hawai‘i’s forest land is managed by the state and county government, and a large proportion is on FIA-defined reserved lands or protected areas (priority resources that are most protected in Hawai‘i’s conservation district). There are numerous policies, programs, and restoration projects aiming to protect and restore Hawai‘i’s forests. Long-term forest monitoring in FIA plots is vital to understand how forests may change over time and for planning to protect and restore Hawai‘i’s natural resources. FIA’s standardized sampling protocols and plot design will allow for additional future assessments of change that occurred during the 10 years between field visits.

Acknowledgments

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters (cm)
Feet (ft)	0.3048	Meters (m)
Miles	1.609	Kilometers (km)
Acres (ac)	0.405	Hectares (ha)
Board feet	0.0024	Cubic meters (m ³)
Cubic feet (ft ³)	0.0283	Cubic meters
Cubic feet per acre	0.06997	Cubic meters per hectare
U.S. tons	0.90719	Megagrams (Mg)
U.S. tons	9.0718e ⁻⁷	Teragram (Tg)
Pounds per cubic foot	16.018	Kilograms per cubic meter
U.S. tons per acre	2.24	Megagrams per hectare
U.S. tons per acre	2.2417e ⁻⁶	Teragrams per hectare
Pounds per cubic foot	0.016	Grams per cubic centimeter

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Appendix 1: Inventory Design and Methods

Field Design and Sampling Method

The USDA Forest Service Forest Inventory and Analysis (FIA) program conducts a systematic, sample-based, field inventory across all owner groups on a periodic basis, remeasuring the same plots roughly every 10 years. All FIA units use a common plot design, common set of measurement protocols, and a standard database design for compilation and distribution of data. Adaptations were made to the national design for the Hawai'i inventory in order to include additional branching and rooting forms, additional tree crown measurements, as well as special interest species

Distance between subplot centers: 120 ft
 Distance from subplot center to microplot center: 12 ft
 ■ 6.8-ft radius microplot: seedlings + saplings
 ■ 24-ft radius subplot: all trees (≥5 inches)

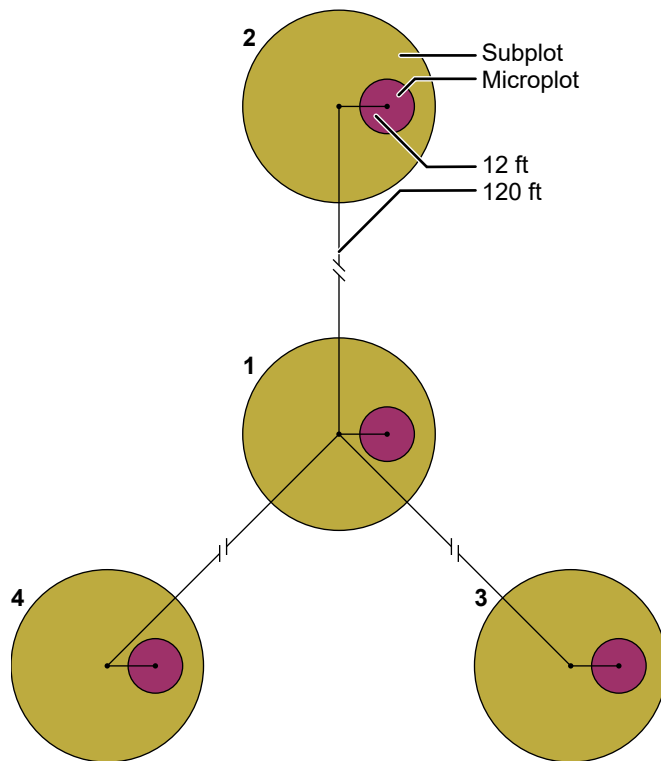


Figure A1-1—The Forest Inventory and Analysis plot design used in Hawai'i is a cluster of four subplots spaced 120 ft apart. Subplot 1 is in the center, with subplots 2 through 4 distributed radially around it. Each point serves as the center of a 1/24-ac circular subplot used to sample all live and dead trees at least 5.0 inches in diameter at breast height (d.b.h.). A 1/300-ac microplot (yellow), with its center located 12 ft east of each subplot center, is used to sample trees 1.0 to 4.9 inches d.b.h., as well as seedlings.

ranging from invasive plants, to pathogens, to culturally or economically important plants. FIA field manuals, including the most recent Hawai'i field manual, can be viewed here: <https://www.fs.usda.gov/pnw/page/pnw-fia-field-manuals-0> (USDA FS 2021e).

All plots classified, using aerial photography, as potentially forested are established in the field without regard to land use or land cover. Field crews delineate areas within the plot that are comparatively less heterogeneous than the plot as a whole, regarding reserved status, owner group, forest community type, stand size class, and tree density; these areas are described as condition classes. The process of delineating these condition classes on a fixed-radius subplot is called condition mapping. The forest condition characteristics measured on the entire plot footprint include forest disturbance, forest community type, and dominant tree species. All measured trees are assigned to the mapped condition class in which they are located.

On each plot, crews assess physical characteristics, such as slope, aspect, and elevation; stand characteristics, such as age, size class, forest community type, disturbance, site productivity, and regeneration status; and tree characteristics, such as tree species, diameter, height, damages, decay, and vertical crown dimensions. They also collect general descriptive information, such as proximity to water and roads, and the geographic position of the plot on the larger landscape.

FIA sampled 246 forested plots in Hawai'i. Estimates of tree volume and other forest attributes were derived from tree measurements and classifications made at each plot. Several other variables are unique to the Pacific Northwest FIA. These are “regional” variables and include such items as insect and disease damage, and a record of previous disturbance on the plot. The FIA standardized plot installed at each forested location is a cluster of four subplots spaced 120 ft apart (fig. A1-1). Subplot 1 is in the center, with subplots 2 through 4 distributed radially around it. Each point serves as the center of a 1/24-ac circular subplot used to sample all live and dead trees at least 5 inches in diameter at breast height (d.b.h.). A 1/300-ac microplot, with its center 12 ft east of each subplot center, is used to sample trees 1 to 4.9 inches d.b.h., as well as seedlings (trees less than 1-inch d.b.h.) (fig. A1-1). Percentage of cover of vascular plant

species covering at least 3 percent of subplot area are also recorded. The inventory included additional measurements of invasive plant species (percentage of cover of species covering at least 1 percent of subplot area), and percentage of live canopy cover.

Data Processing and Statistical Estimates

The data used for this report are stored in the FIA National Information Management System (NIMS). NIMS provides a means to input, edit, process, manage, and distribute FIA data. It includes a process for data loading, a national set of edit checks to ensure data consistency, an error-correction process, approved equations and algorithms, code to compile and calculate attributes, a table report generator, and routines to populate the presentation database. It applies numerous algorithms and equations to calculate, for example, stand size, volume, and biomass. The NIMS also generates estimates and associated statistics based on county areas and stratum weights developed outside of NIMS. Additional FIA statistical design and estimation techniques are presented in Bechtold and Patterson (2005).

FIA uses a statistical method called poststratification (based on the number of forest pixels in the satellite image in combination with owner group, precipitation, and canopy cover) to generate the estimated totals at the jurisdictional level from the plot-level data. This allows for estimates of total numbers or percentage of trees by species or diameter class, forest area by jurisdiction, or percentage of total forest area by forest community type, disturbance, canopy cover, etc. Estimates were calculated based on the FIA estimation procedures (Bechtold and Patterson 2005).

Throughout this report, we have published standard errors for most of our estimates. These standard errors account for the fact that we measured only a small sample of the forest (thereby producing a sample-based estimate) and not the entire forest (which is the population parameter of interest). Because of small sample sizes or high variability within the population, some estimates can be less precise than others. The reader is encouraged to take the standard error into account when drawing any inference.

Access Denied, Hazardous, or Inaccessible Plots

About 33 percent of all FIA plots were not sampled in the 2010–2015 inventory. Although every effort was made to visit all field plots that were entirely or partially forested, some were not sampled for a variety of reasons. Field crews may have been unable to obtain permission from the landowner to access the plot, and there were some plots that were impossible for crews to safely reach or access. Some private landowners deny access to their land, but privately owned plots usually are not as hazardous or inaccessible as plots on public lands. Although permission to visit public lands is almost always granted, some public land is in areas with higher elevations and steep slopes that can be dangerous or impossible to reach.

This kind of missing data can introduce bias into the estimates if the nonsampled plots tend to be different from the entire population. Plots that are obviously nonforested (based on aerial photos or satellite imagery) are rarely visited, and therefore the proportion of denied-access, hazardous, or inaccessible plots is significantly smaller than it is for forested plots. The poststratification approach outlined in Bechtold and Patterson (2005) removes nonsampled plots from the sample. Estimates are adjusted for plots that are partially nonsampled by increasing the estimates by the nonsampled proportion within each stratum.

Appendix 2: Summary Data Tables

The following tables contain basic information about the forest resources of Hawai'i as they relate to the discussion of current forest issues and basic forest resource information presented in this report. Data are also available for download in nonsummarized form at by choosing “Data and Tools” at <https://www.fia.fs.usda.gov/> (USDA FS 2020b).

Number of Live and Dead Trees

Table A2-1—Percentage of estimated number of live trees on forest land by species

Table A2-2—Number of live trees on forest land by species and diameter class

Table A2-3—Number of dead trees on forest land by species and diameter class

Table A2-4—Number of live trees on forest land by species and forest community type

Table A2-5—Number of dead trees on forest land by species and forest community type

Tree Volume

Table A2-6—Estimated net volume of live trees on forest land by forest community type and diameter class

Table A2-7—Estimated net volume of live trees on forest land by species and diameter class

Table A2-8—Estimated net, sound, and gross volume of live trees on forest land by diameter class

Biomass and Carbon

Table A2-9—Aboveground biomass and carbon of live and dead trees on forest land by diameter class

Table A2-10—Aboveground biomass of live trees on forest land by species and diameter class

Table A2-11—Aboveground biomass of dead trees on forest land by species and diameter class

Understory Vegetation

Table A2-12—Estimated area of understory vegetation cover by life form and owner group, and number of Forest Inventory and Analysis plots where the species occurred

Table A2-1—Percentage of estimated number of live trees^a on forest land, by species

Scientific name	Common or Hawaiian name	Native (N), Endemic (E), Introduced (I), Polynesian Introduced (P), Introduced and invasive (I*)	Percentage of all trees
<i>Psidium cattleianum</i> Sabine	Strawberry guava	I*	40.56
<i>Metrosideros polymorpha</i> Gaudich.	‘Ōhi‘a lehua	E	20.28
<i>Leucaena leucocephala</i> (Lam.) de Wit	Haole koa	I*	3.42
<i>Schinus terebinthifolius</i> Raddi	Christmas berry	I*	3.39
<i>Ardisia elliptica</i> Thunb.	Shoebutton	I*	3.24
<i>Broussaisia arguta</i> Gaudich.	Kanawao	E	2.41
<i>Cheirodendron trigynum</i> (Gaudich.) A. Heller	‘Ōlapa’lapa	E	2.28
<i>Cibotium glaucum</i> (Sm.) Hook. & Arn.	Hāpu‘u pulu	E	1.90
<i>Psidium guajava</i> L.	Guava	I*	1.57
<i>Acacia confusa</i> Merr.	Small philippine acacia	I	1.35
<i>Acacia koa</i> A. Gray	Koa	E	1.05
<i>Cibotium menziesii</i> Hook.	Hāpu‘u ‘i‘i	E	1.00
<i>Syzygium cumini</i> (L.) Skeels	Java Plum	I	0.86
<i>Casuarina equisetifolia</i> L.	Ironwood	I	0.81
<i>Morinda citrifolia</i> L.	Noni	P	0.79
<i>Syzygium malaccense</i> (L.) Merr. & L.M. Perry	Ohī‘a ‘ai	P	0.77
<i>Prosopis pallida</i> (Humb. & Bonpl. ex Willd.) Kunth	Kiawe	I	0.75
<i>Cordyline fruticosa</i> (L.) A. Chev	Ti	P	0.73
<i>Ilex anomala</i> Hook. & Arn.	Kāwa‘u	N	0.67
<i>Bambusa</i> spp.	Bamboo	I	0.62
<i>Eucalyptus robusta</i> Sm.	swamp mahogany	I	0.60
<i>Eucalyptus grandis</i> W. Hill ex Maid.	Grand eucalyptus	I	0.59
<i>Cecropia obtusifolia</i> Bertol.	Trumpet tree	I	0.54
<i>Hibiscus tiliaceus</i> L.	Hau	N	0.53
<i>Antidesma platyphyllum</i> H. Mann	Hame	E	0.51
<i>Myrsine lessertiana</i> A. DC.	Kōlea lau nui	E	0.50
<i>Morella faya</i> (Aiton) Wilbur	Firetree	I*	0.47
<i>Syzygium jambos</i> (L.) Alston	Rose apple	I	0.43
<i>Spathodea campanulata</i> P. Beauv.	African tuliptree	I*	0.35
<i>Myrsine sandwicensis</i> A. DC.	Kōlea lau li‘i	E	0.35
<i>Melicope clusiifolia</i> (A. Gray) T.G. Hartley & B.C. Stone	Alani	E	0.35
<i>Hedyotis hillebrandii</i> (Fosberg) W.L. Wagner & D.R. Herbst	Manono	E	0.31
<i>Psychotria hawaiiensis</i> (A. Gray) Fosberg	Kōpiko ‘ula	E	0.30
<i>Melaleuca</i> spp.	Melaleuca	I	0.28
<i>Citharexylum caudatum</i> L.	Juniper berry	I	0.28
<i>Psychotria mariniana</i> (Cham. & Schltdl.) Fosberg	Kōpiko	E	0.24
<i>Falcataria moluccana</i> (Miq.) Barneby & Grimes	Albizia	I*	0.23
<i>Coprosma</i> spp.	Pilo	N/A	0.21
Unknown tree spp.	Unknown tree spp.	N/A	0.20

Table A2-1—Percentage of estimated number of live trees^a on forest land, by species (continued)

Scientific name	Common or Hawaiian name	Native (N), Endemic (E), Introduced (I), Polynesian Introduced (P), Introduced and invasive (I*)	Percentage of all trees
<i>Grevillea robusta</i> A. Cunn. ex R. Br.	Silkoak	I*	0.20
<i>Cinnamomum burmannii</i> (Nees & Th. Nees) Nees ex Blume	Cinnamon	I	0.19
<i>Coprosma longifolia</i> A. Gray	Pilo	E	0.18
<i>Pisonia brunoniana</i> Endl.	Pāpala kēpau	N	0.17
<i>Pandanus tectorius</i> Parkinson ex Zucc.	Hala	P	0.17
<i>Psydrax odorata</i> (G. Forst.) A.C. Sm. & S. Darwin	Alahe‘e	N	0.16
<i>Dillenia suffruticosa</i> (Griffith ex Hook. f. & Thomson) Martelli	Shrubby dillenia	I	0.16
<i>Nestegis sandwicensis</i> (A. Gray) O. Deg. & I. Deg. & L.A.S. Johnson	Olopua	E	0.15
<i>Cheirodendron forbesii</i> (Sherff) Lowry	‘Ōlapa	E	0.15
<i>Wikstroemia</i> spp.	‘Ākia	E	0.15
<i>Perrottetia sandwicensis</i> A. Gray	Olomea	E	0.14
<i>Myoporum sandwicense</i> (A. DC.) A. Gray	Naio	N	0.12
<i>Sequoia sempervirens</i> (Lamb. ex D. Don) Endl.	Coastal redwood	I	0.12
<i>Ficus microcarpa</i> L. f.	Chinese banyan	I*	0.12
<i>Santalum paniculatum</i> Hook. & Arn.	‘Iliahi	E	0.11
<i>Myrsine</i> spp.	Kōlea	E	0.10
<i>Xylosma hawaiiensis</i> Seem.	Maua	E	0.10
<i>Coprosma rhynchocarpa</i> A. Gray	Pilo	E	0.09
<i>Melochia umbellata</i> (Houtt.) Stapf	Melochia	I	0.09
<i>Aleurites moluccana</i> (L.) Willd.	Kukui	P	0.09
<i>Cibotium chamissoi</i> Kaulf.	Hāpu‘u meu	E	0.09
<i>Leptospermum scoparium</i> (Maiden & Betcher) F.A. Rodway ex Cheel	Manuka	I*	0.09
<i>Heliocarpus popayanensis</i> Kunth	Moho	I	0.09
<i>Bobea sandwicensis</i> Kunth	‘Ahakea	E	0.08
<i>Cinnamomum verum</i> J. Presl	Cinnamon	I	0.08
<i>Pithecellobium dulce</i> (Roxb.) Benth.	Opiuma	I	0.08
<i>Sophora chrysophylla</i> (Salisb.) Seem.	Māmane	E	0.07
<i>Syzygium sandwicense</i> (A. Gray) Nied.	‘Ōhia hā	E	0.07
<i>Fraxinus uhdei</i> (Wenzig) Lingelsh.	Tropical ash	I	0.06
<i>Tetraplasandra oahuensis</i> (A. Gray) Harms	‘Ohe mauka	E	0.06
<i>Melochia</i> spp.	Melochia	I	0.05
<i>Pinus patula</i> Schiede ex Schltdl. & Cham.	Mexican weeping pine	I	0.04
<i>Melaleuca quinquenervia</i> (Cav.) S.F. Blake	Paperbark	I*	0.04
<i>Psychotria grandiflora</i> H. Mann	Kōpiko	E	0.04
<i>Psychotria kaduana</i> (Cham. & Schltdl.) Fosberg	Kōpiko kea	E	0.04
<i>Chrysophyllum oliviforme</i> L.	Satin Leaf	I	0.04
<i>Eucalyptus deglupta</i> Blume	Rainbow eucalyptus	I	0.04

Table A2-1—Percentage of estimated number of live trees^a on forest land, by species (continued)

Scientific name	Common or Hawaiian name	Native (N), Endemic (E), Introduced (I), Polynesian Introduced (P), Introduced and invasive (I*)	Percentage of all trees
<i>Macaranga mappa</i> (L.) Müll. Arg.	Bingabing	I	0.04
<i>Rhodomirtus tomentosa</i> (Aiton) Hassk.	Downy rose myrtle	I*	0.04
<i>Acacia</i> spp.	Acacia spp.	N/A	0.03
<i>Toona ciliata</i> Roem.	Toon	I	0.03
<i>Melicope kaalaensis</i> (H. St. John) T.G. Hartley & B.C. Stone	Alani	E	0.02
<i>Hedyotis terminalis</i> (Hook. & Arn.) W.L. Wagner & D.R. Herbst	Variable starviolet	E	0.02
<i>Melicope</i> spp.	Alani	N/A	0.02
<i>Psychotria fauriei</i> (Levl.) Fosberg	Kōpiko	E	0.02
<i>Chenopodium oahuense</i> (Meyen) Aellen	Āweoweo	E	0.02
<i>Cocos nucifera</i> L.	Niu	P	0.02
<i>Coprosma montana</i> Hillebr.	Pilo	E	0.02
<i>Antidesma pulvinatum</i> Hillebr.	Hame	E	0.02
<i>Cryptomeria</i> spp.	Japanese cedar	I	0.02
<i>Trema orientalis</i> (L.) Blume	Gunpowder tree	I	0.02
<i>Swietenia macrophylla</i> King	Honduran mahogany	I	0.01
<i>Schefflera actinophylla</i> (Endl.) Harms	Octopus tree	I	0.01
<i>Persea americana</i> Mill	Avocado	I	0.01
<i>Diospyros sandwicensis</i> (A. DC.) Fosberg	Lama	E	0.01
<i>Acacia koaia</i> Hillebr.	Koai'a	E	0.01
<i>Eucalyptus</i> spp.	Eucalyptus spp.	I	0.01
<i>Syzygium</i> spp.	Syzygium	N/A	0.01
<i>Archontophoenix alexandrae</i> (F. Muell.) H. Wendl. & Drude	Alexandra palm	I	0.01
<i>Casuarina glauca</i> Siebold ex Spreng.	Swamp sheoak	I	0.01
<i>Samanea saman</i> (Jacq.) Merr.	Monkey pod tree	I	0.01
<i>Mangifera</i> spp.	Mango	I	< 0.01
<i>Psychotria</i> spp.	Kōpiko	E	< 0.01
<i>Clusia rosea</i> Jacq.	Autograph tree	I	< 0.01
<i>Erythrina sandwicensis</i> O. Deg.	Wiliwili	E	< 0.01
<i>Casuarina cunninghamiana</i> Miq.	River oak casuarina	I	< 0.01
<i>Pritchardia</i> spp.	Loulu	E	< 0.01
<i>Pittosporum</i> spp.	Ho'awa	N/A	< 0.01
<i>Pritchardia munroi</i> Rock	Loulu	E	< 0.01
<i>Ilex paraguariensis</i> A. St.-Hil.	Yerba mate	I	< 0.01
<i>Coprosma ochracea</i> W.R.B. Oliv.	Pilo	E	< 0.01
<i>Eucalyptus saligna</i> Sm.	Sydney bluegum	I	< 0.01
<i>Pinus pinaster</i> Aiton	Maritime pine	I	< 0.01

^a Includes all live trees ≥1 inches in diameter at breast height.

N/A = unknown native status.

Most nomenclature follows USDA PLANTS Database (NRCS 2022), but some species include names that are more accepted and recognized by Hawaiians, as recommended by coauthors and reviewers.

Table A2-2—Number of live trees^a on forest land by species and diameter class

Scientific name	Diameter class (inches)															
	<5		5.0–9.9		10.0–14.9		15.0–19.9		20.0–24.9		25.0–29.9		30.0–34.9		35.0–39.9	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
----- Number of trees (thousand trees) -----																
<i>Psidium cattleianum</i>	712,728	125,288	8,791	2,496	366	205	52	51	—	—	—	—	—	—	—	721,937 126,162
<i>Metrosideros polymorpha</i>	290,507	36,830	50,185	4,240	14,000	1,308	3,450	468	1,597	282	664	172	366	131	61	44 360,890 38,506
<i>Leucaena leucocephala</i>	59,436	22,251	1,383	558	—	—	—	—	—	—	—	—	—	—	—	60,819 22,647
<i>Schinus terebinthifolius</i>	50,456	15,564	8,773	2,618	1,056	452	—	—	—	—	—	—	—	—	—	60,286 18,020
<i>Ardisia elliptica</i>	57,447	36,125	108	72	—	—	52	51	—	—	—	—	—	—	—	57,607 36,150
<i>Broussaia arguta</i>	42,834	15,631	29	30	—	—	—	—	—	—	—	—	—	—	—	42,863 15,651
<i>Cheirodendron trigynum</i>	36,056	6,684	4,176	920	333	145	34	33	—	—	—	—	—	—	—	40,600 6,748
<i>Cibotium glaucum</i>	—	—	19,874	3,089	13,559	2,948	328	169	—	—	—	—	—	—	—	33,760 5,431
<i>Psidium guajava</i>	25,841	10,241	2,048	618	—	—	—	—	—	—	—	—	—	—	—	27,889 10,499
<i>Acacia confusa</i>	21,851	13,699	2,051	1,451	55	51	—	—	—	—	—	—	—	—	—	23,957 14,759
<i>Acacia koa</i>	9,558	4,201	6,165	3,277	1,722	538	536	145	400	148	56	42	132	63	29	30 18,627 7,802
<i>Cibotium menziesii</i>	321	368	14,012	2,238	3,110	577	377	120	—	—	—	—	—	—	—	17,819 2,754
<i>Syzygium cumini</i>	11,144	6,333	2,993	1,104	682	296	378	170	84	64	—	—	—	—	—	15,281 6,738
<i>Casuarina equisetifolia</i>	11,989	8,357	2,023	1,235	386	255	67	65	33	33	—	—	—	—	—	14,499 9,466
<i>Morinda citrifolia</i>	14,074	10,536	52	40	—	—	—	—	—	—	—	—	—	—	—	14,126 10,576
<i>Syzygium malaccense</i>	13,058	10,805	279	231	279	231	—	—	—	—	—	—	—	—	—	13,616 11,266
<i>Prosopis pallida</i>	13,158	10,276	147	78	—	—	124	108	—	—	—	—	—	—	—	13,430 10,299
<i>Cordyline fruticosa</i>	13,058	7,802	—	—	—	—	—	—	—	—	—	—	—	—	—	13,058 7,802
<i>Ilex anomala</i>	10,144	2,825	1,579	368	208	112	—	—	—	—	—	—	—	—	—	11,931 2,969
<i>Bambusa ssp.</i>	11,084	10,947	—	—	—	—	—	—	—	—	—	—	—	—	—	11,084 10,947
<i>Eucalyptus robusta</i>	6,094	4,326	1,863	975	1,024	489	656	330	231	198	345	235	337	235	—	10,645 5,942
<i>Eucalyptus grandis</i>	643	501	5,432	2,340	3,577	1,474	653	353	100	96	—	—	25	28	—	10,430 4,282
<i>Cecropia obtusifolia</i>	8,046	4,278	1,425	737	78	49	—	—	—	—	—	—	—	—	—	9,549 4,971
<i>Hibiscus tiliaceus</i>	6,824	4,747	1,925	981	545	359	90	76	90	76	—	—	—	—	—	9,473 5,804
<i>Antidesma platyphyllum</i>	8,676	2,839	319	124	33	32	—	—	—	—	—	—	—	—	—	9,028 2,901
<i>Myrsine lessertiana</i>	8,260	2,333	602	194	123	82	—	—	—	—	—	—	—	—	—	8,985 2,424
<i>Morella faya</i>	7,835	6,483	320	196	145	148	—	—	—	—	—	—	—	—	—	8,300 6,660
<i>Syzygium jambos</i>	5,559	5,087	1,991	1,266	103	80	52	51	—	—	—	—	—	—	—	7,706 6,238
<i>Spathodea campanulata</i>	4,949	3,026	431	231	510	255	236	136	62	54	—	—	—	—	—	6,188 3,190
<i>Myrsine sandwicensis</i>	6,173	3,934	—	—	—	—	—	—	—	—	—	—	—	—	—	6,173 3,934

Scientific name	Diameter class (inches)																				
	<5		5.0–9.9		10.0–14.9		15.0–19.9		20.0–24.9		25.0–29.9		30.0–34.9		35.0–39.9		40+		All classes		
Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
-----Number of trees (thousand trees)-----																					
Melicope clusiifolia	6,095	2,820	52	40	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6,147	2,819
Hedyotis hillebrandii	5,157	2,551	290	190	87	62	—	—	—	—	—	—	—	—	—	—	—	—	—	5,534	2,538
Psychotria hawaiiensis	4,422	1,782	842	315	52	40	—	—	—	—	—	—	—	—	—	—	—	—	—	5,316	1,937
Melaleuca ssp.	4,982	4,891	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4,982	4,891
Citharexylum caudatum	4,864	3,167	55	51	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4,919	3,171
Psychotria mariniana	4,169	3,815	55	51	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4,225	3,866
Falcattaria moluccana	1,926	1,553	1,274	854	240	141	363	211	52	40	52	51	103	80	—	—	—	—	—	4,061	2,360
Coprosma ssp.	3,604	2,322	206	107	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3,810	2,332
Unknown tree ssp.	2,926	2,212	574	270	103	66	—	—	—	—	—	—	—	—	—	—	—	—	—	3,604	2,228
Grevillea robusta	1,140	767	1,331	617	770	384	197	117	88	61	—	—	—	—	—	—	—	—	—	3,527	1,340
Cinnamomum burmannii	2,085	1,908	1,106	958	166	152	55	51	—	—	—	—	—	—	—	—	—	—	—	3,412	3,013
Coprosma longifolia	3,184	1,184	33	33	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3,217	1,183
Pisonia brunioides	3,088	2,693	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3,088	2,693
Pandanus tectorius	415	408	2,623	1,369	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3,039	1,465
Psydrax odorata	2,844	2,558	25	28	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2,869	2,586
Dillenia suffruticosa	2,728	1,972	50	55	50	55	—	—	—	—	—	—	—	—	—	—	—	—	—	2,828	1,975
Nestegis sandwicensis	2,612	2,161	70	58	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2,681	2,219
Cheirodendron forbesii	2,612	2,161	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2,612	2,161
Wikstroemia ssp.	2,612	2,161	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2,612	2,161
Perrottetia sandwicensis	2,542	1,634	34	33	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2,576	1,633
Myoporium sandwicense	1,588	921	599	276	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2,187	1,095
Sequoia sempervirens	871	720	—	—	209	173	279	231	—	—	488	404	139	115	139	115	—	—	—	2,126	1,759
Ficus microcarpa	2,059	1,208	52	40	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2,111	1,241
Santalum paniculatum	2,000	2,455	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2,000	2,455
Myrsine ssp.	1,829	1,005	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1,829	1,005
Xylosma hawaiiensis	1,741	1,441	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1,741	1,441
Coprosma rhynchocharpa	1,560	1,699	70	58	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1,630	1,700
Melochia umbellata	1,284	1,224	310	209	—	—	34	33	—	—	—	—	—	—	—	—	—	—	—	1,628	1,455
Aleurites moluccana	—	—	1,318	748	282	121	—	—	—	—	—	—	—	—	—	—	—	—	—	1,600	813
Cibotium chamissoi	—	—	1,287	555	292	204	—	—	—	—	—	—	—	—	—	—	—	—	—	1,578	730

Table A2-2—Number of live trees^a on forest land by species and diameter class (continued)

Scientific name	Diameter class (inches)															
	<5		5.0–9.9		10.0–14.9		15.0–19.9		20.0–24.9		25.0–29.9		30.0–34.9		35.0–39.9	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
----- Number of trees (thousand trees) -----																
<i>Leptospermum scoparium</i>	1,544	1,347	—	—	—	—	—	—	—	—	—	—	—	—	—	1,544
<i>Heliocarpus popayanensis</i>	695	636	615	509	111	101	111	101	—	—	—	—	—	—	—	1,531
<i>Bobea sandwicensis</i>	1,390	1,272	—	—	87	62	—	—	—	—	—	—	—	—	—	1,477
<i>Cinnamomum verum</i>	772	673	684	596	—	—	—	—	—	—	—	—	—	—	—	1,456
<i>Pithecellobium dulce</i>	927	769	398	339	25	28	—	—	—	—	—	—	—	—	—	1,350
<i>Sophora chrysophylla</i>	1,122	823	170	100	—	—	—	—	—	—	—	—	—	—	—	1,292
<i>Syzygium sandwicense</i>	1,085	778	87	62	—	—	—	—	—	—	—	—	—	—	—	1,172
<i>Fraxinus uhdei</i>	561	471	209	173	275	162	45	38	—	—	—	—	—	—	—	1,090
<i>Tetraplasandra oahuensis</i>	1,085	778	—	—	—	—	—	—	—	—	—	—	—	—	—	1,085
<i>Melochia</i> ssp.	828	800	133	128	—	—	—	—	—	—	—	—	—	—	—	961
<i>Pinus patula</i>	—	—	540	451	245	199	—	—	—	—	—	—	—	—	—	785
<i>Melaleuca quinquenervia</i>	—	—	166	109	55	51	166	152	276	204	111	101	—	—	—	774
<i>Psychotria grandiflora</i>	772	673	—	—	—	—	—	—	—	—	—	—	—	—	—	772
<i>Psychotria kaduana</i>	648	722	55	51	26	29	—	—	—	—	—	—	—	—	—	730
<i>Chrysophyllum oliviforme</i>	695	636	—	—	—	—	—	—	—	—	—	—	—	—	—	695
<i>Eucalyptus deglupta</i>	414	400	166	160	100	96	—	—	—	—	—	—	—	—	—	680
<i>Macaranga mappa</i>	655	712	—	—	—	—	—	—	—	—	—	—	—	—	—	655
<i>Rhodomirtus tomentosa</i>	649	629	—	—	—	—	—	—	—	—	—	—	—	—	—	649
<i>Acacia</i> ssp.	—	—	497	434	62	54	62	54	—	—	—	—	—	—	—	621
<i>Toona ciliata</i>	—	—	381	203	88	61	80	58	—	—	—	—	—	—	—	549
<i>Melicope kaalaensis</i>	—	—	435	445	—	—	—	—	—	—	—	—	—	—	—	435
<i>Hedyotis terminalis</i>	414	400	—	—	—	—	—	—	—	—	—	—	—	—	—	414
<i>Melicope</i> ssp.	411	405	—	—	—	—	—	—	—	—	—	—	—	—	—	411
<i>Psychotria fauriei</i>	411	405	—	—	—	—	—	—	—	—	—	—	—	—	—	411
<i>Chenopodium oahuense</i>	324	361	66	64	—	—	—	—	—	—	—	—	—	—	—	391
<i>Cocos nucifera</i>	—	—	—	—	373	229	—	—	—	—	—	—	—	—	—	373
<i>Coprosma montana</i>	361	370	—	—	—	—	—	—	—	—	—	—	—	—	—	361
<i>Anidesma pulvinatum</i>	324	361	—	—	—	—	—	—	—	—	—	—	—	—	—	324
<i>Cryptomeria</i> ssp.	—	—	124	108	124	108	—	—	—	—	62	54	—	—	—	311
<i>Trema orientalis</i>	—	—	—	—	172	122	104	66	—	—	—	—	—	—	—	276

Table A2-2—Number of live trees^a on forest land by species and diameter class (continued)

Scientific name	Diameter class (inches)															
	<5		5.0–9.9		10.0–14.9		15.0–19.9		20.0–24.9		25.0–29.9		30.0–34.9		35.0–39.9	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
----- Number of trees (thousand trees) -----																
<i>Swietenia macrophylla</i>	—	—	175	197	50	56	25	28	—	—	—	—	—	—	—	250
<i>Schefflera actinophylla</i>	—	—	224	122	—	—	—	—	—	—	—	—	—	—	—	224
<i>Persea americana</i>	—	—	121	70	70	58	—	—	—	—	—	—	—	—	—	191
<i>Diospyros sandwicensis</i>	—	—	190	120	—	—	—	—	—	—	—	—	—	—	—	190
<i>Acacia koa</i>	—	—	60	53	120	105	—	—	—	—	—	—	—	—	—	181
<i>Eucalyptus</i> ssp.	—	—	—	—	66	64	66	64	33	32	—	—	—	—	—	166
<i>Syzygium</i> ssp.	—	—	140	130	—	—	—	—	—	—	—	—	—	—	—	140
<i>Archontophoenix alexandrae</i>	—	—	—	—	128	79	—	—	—	—	—	—	—	—	—	128
<i>Casuarina glauca</i>	—	—	52	51	52	51	—	—	—	—	—	—	—	—	—	105
<i>Samanea saman</i>	—	—	—	—	—	—	—	—	25	27	76	49	—	—	—	101
<i>Mangifera</i> ssp.	—	—	33	33	—	—	33	33	—	—	—	—	—	—	—	67
<i>Psychotria</i> ssp.	—	—	67	65	—	—	—	—	—	—	—	—	—	—	—	67
<i>Clusia rosea</i>	—	—	62	54	—	—	—	—	—	—	—	—	—	—	—	62
<i>Erythrina sandwicensis</i>	—	—	62	54	—	—	—	—	—	—	—	—	—	—	—	62
<i>Casuarina cunninghamiana</i>	—	—	52	51	—	—	—	—	—	—	—	—	—	—	—	52
<i>Pritchardia</i> ssp.	—	—	52	41	—	—	—	—	—	—	—	—	—	—	—	52
<i>Pittosporum</i> ssp.	—	—	45	38	—	—	—	—	—	—	—	—	—	—	—	45
<i>Pritchardia munroi</i>	—	—	45	38	—	—	—	—	—	—	—	—	—	—	—	45
<i>Ilex paraguariensis</i>	—	—	—	—	30	30	—	—	—	—	—	—	—	—	—	30
<i>Coprosma ochracea</i>	—	—	26	29	—	—	—	—	—	—	—	—	—	—	—	26
<i>Eucalyptus saligna</i>	—	—	—	—	—	—	—	—	25	27	—	—	—	—	—	25
<i>Pinus pinaster</i>	—	—	—	—	—	—	25	27	—	—	—	—	—	—	—	25
Total	1,560,825	138,086	157,368	8,671	46,404	3,702	8,733	813	3,097	439	1,854	502	1,078	302	254	139,360

Note: Totals may be off because of rounding; estimates are subject to sampling error. SE = sampling error; — = fewer than 50 trees were estimated.

^a Includes all live trees ≥1 inch in diameter at breast height.

Table A2-3—Number of dead trees^a on forest land by species and diameter class

Scientific name	Diameter class (inches)															
	5.0–9.9		10.0–14.9		15.0–19.9		20.0–24.9		25.0–29.9		30.0–34.9		35.0–39.9		All classes	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
----- Number of trees (thousand trees) -----																
<i>Metrosideros polymorpha</i>	8,490	1,135	2,306	435	403	115	155	66	59	43	26	29	—	—	11,439	1,466
<i>Cibotium glaucum</i>	1,758	455	582	211	45	38	45	38	—	—	—	—	—	—	2,430	637
<i>Acacia koa</i>	1,510	531	322	145	323	123	95	63	62	54	33	32	33	32	2,378	656
<i>Cibotium menziesii</i>	1,836	401	365	105	—	—	—	—	—	—	—	—	—	—	2,201	443
<i>Psidium cattleianum</i>	922	760	311	271	—	—	—	—	—	—	—	—	—	—	1,233	1,031
<i>Schinus terebinthifolius</i>	875	327	177	89	—	—	—	—	—	—	—	—	—	—	1,052	393
<i>Grevillea robusta</i>	182	96	371	276	249	167	60	53	—	—	—	—	—	—	862	503
<i>Eucalyptus robusta</i>	557	269	227	127	33	33	—	—	33	33	—	—	—	—	849	419
<i>Cibotium</i> spp.	527	155	247	158	45	38	—	—	—	—	—	—	—	—	818	271
<i>Melaleuca quinquenervia</i>	276	253	111	101	221	202	—	—	—	—	—	—	—	—	608	557
<i>Leucaena leucocephala</i>	497	295	—	—	—	—	—	—	—	—	—	—	—	—	497	295
<i>Cheirodendron trigynum</i>	319	106	62	44	—	—	—	—	—	—	—	—	—	—	381	112
<i>Eucalyptus grandis</i>	351	186	25	28	—	—	—	—	—	—	—	—	—	—	376	188
<i>Myoporum sandwicense</i>	315	130	25	27	—	—	—	—	—	—	—	—	—	—	340	138
Unknown tree spp.	251	120	52	40	33	32	—	—	—	—	—	—	—	—	336	130
<i>Sophora chrysophylla</i>	316	280	—	—	—	—	—	—	—	—	—	—	—	—	316	280
<i>Eucalyptus</i> spp.	247	171	—	—	33	32	—	—	—	—	—	—	—	—	280	185
<i>Fraxinus uhdei</i>	230	138	—	—	—	—	—	—	—	—	—	—	—	—	230	138
<i>Pandanus tectorius</i>	168	125	—	—	—	—	—	—	—	—	—	—	—	—	168	125
<i>Acacia confusa</i>	166	152	—	—	—	—	—	—	—	—	—	—	—	—	166	152
<i>Falcataria moluccana</i>	155	121	—	—	—	—	—	—	—	—	—	—	—	—	155	121
<i>Ilex anomala</i>	111	59	33	33	—	—	—	—	—	—	—	—	—	—	144	67
<i>Myrsine lessertiana</i>	141	86	—	—	—	—	—	—	—	—	—	—	—	—	141	86
<i>Pinus patula</i>	75	82	25	27	25	27	—	—	—	—	—	—	—	—	125	136
<i>Syzygium cumini</i>	107	66	—	—	—	—	—	—	—	—	—	—	—	—	107	66
<i>Melochia umbellata</i>	69	65	34	33	—	—	—	—	—	—	—	—	—	—	103	98
<i>Cecropia obtusifolia</i>	33	33	52	40	—	—	—	—	—	—	—	—	—	—	85	52
<i>Cocos nucifera</i>	—	—	85	52	—	—	—	—	—	—	—	—	—	—	85	52

Table A2-3—Number of dead trees^a on forest land by species and diameter class (continued)

Scientific name	Diameter class (inches)															
	5.0–9.9		10.0–14.9		15.0–19.9		20.0–24.9		25.0–29.9		30.0–34.9		35.0–39.9		All classes	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
----- Number of trees (thousand trees) -----																
<i>Xylosma hawaiiensis</i>	70	58	—	—	—	—	—	—	—	—	—	—	—	—	70	58
<i>Aleurites moluccana</i>	62	54	—	—	—	—	—	—	—	—	—	—	—	—	62	54
<i>Erythrina sandwicensis</i>	—	—	—	—	62	54	—	—	—	—	—	—	—	—	62	54
<i>Acacia koaia</i>	—	—	60	53	—	—	—	—	—	—	—	—	—	—	60	53
<i>Cinnamomum burmannii</i>	55	51	—	—	—	—	—	—	—	—	—	—	—	—	55	51
<i>Heliocarpus popayanensis</i>	—	—	—	—	—	—	55	51	—	—	—	—	—	—	55	51
<i>Albizia chinensis</i>	—	—	52	51	—	—	—	—	—	—	—	—	—	—	52	51
<i>Psychotria hawaiiensis</i>	52	40	—	—	—	—	—	—	—	—	—	—	—	—	52	40
<i>Swietenia macrophylla</i>	—	—	—	—	—	—	25	28	25	28	—	—	—	—	50	56
<i>Antidesma platyphyllum</i>	33	33	—	—	—	—	—	—	—	—	—	—	—	—	33	33
<i>Eucalyptus deglupta</i>	33	32	—	—	—	—	—	—	—	—	—	—	—	—	33	32
<i>Coprosma</i> ssp.	29	30	—	—	—	—	—	—	—	—	—	—	—	—	29	30
<i>Dillenia suffruticosa</i>	25	27	—	—	—	—	—	—	—	—	—	—	—	—	25	27
<i>Pithecellobium dulce</i>	25	28	—	—	—	—	—	—	—	—	—	—	—	—	25	28
Total	20,870	1,839	5,522	742	1,472	324	436	126	179	82	59	43	33	32	28,571	2,598

Note: Dead trees were not inventoried in the <5 inches diameter class. Totals may be off because of rounding; estimates are subject to sampling error. SE = sampling error; — = fewer than 50 trees were estimated.

^a Includes all live trees ≥5 inches in diameter at breast height.

Table A2-4—Number of live trees^a on forest land by species and forest community

Scientific name	Forest community types											
	Montane rainforest			Lowland tropical rainforest			Moist forest			Dry forest		
	Total	SE		Total	SE		Total	SE		Total	SE	
	----- Number of trees (thousand trees) -----											
<i>Psidium cattleianum</i>	149,321	65,428	446,642	98,398	98,398	125,974	56,751	—	—	—	—	—
<i>Metrosideros polymorpha</i>	156,953	27,015	38,477	9,694	9,694	110,414	23,835	19,587	7,577	35,435	19,018	25
<i>Leucaena leucocephala</i>	—	—	7,126	5,841	5,841	25,849	12,868	27,844	20,488	—	—	—
<i>Schinus terebinthifolius</i>	602	368	15,041	9,967	9,967	16,078	6,263	22,583	13,496	—	—	25
<i>Ardisia elliptica</i>	—	—	5,343	4,552	4,552	52,264	35,880	—	—	—	—	28
<i>Broussaia arguta</i>	40,093	15,512	—	—	—	2,360	2,203	—	—	411	405	—
<i>Cheirodendron trigynum</i>	25,215	5,850	4,652	1,628	1,628	7,480	3,245	—	—	3,252	1,895	—
<i>Cibotium glaucum</i>	20,885	5,040	4,428	2,074	2,074	7,888	2,098	—	—	161	134	399
<i>Psidium guajava</i>	15,998	9,163	7,445	4,627	4,627	3,961	2,425	486	508	—	—	451
<i>Acacia confusa</i>	—	—	87	62	62	15,433	12,283	8,438	8,182	—	—	—
<i>Acacia koa</i>	14,327	7,626	1,149	470	470	3,033	1,646	—	—	118	121	—
<i>Cibotium menziesii</i>	8,738	2,174	6,248	1,951	1,951	2,409	884	—	—	—	—	424
<i>Syzygium cumini</i>	7,032	6,035	5,036	2,570	2,570	3,213	2,165	—	—	—	—	479
<i>Casuarina equisetifolia</i>	—	—	—	—	—	10,983	8,829	—	—	—	—	—
<i>Morinda citrifolia</i>	561	471	13,565	10,565	10,565	—	—	—	—	—	—	3,412
<i>Syzygium malaccense</i>	—	—	—	—	—	13,616	11,266	—	—	—	—	—
<i>Prosopis pallida</i>	—	—	12,848	10,286	10,286	—	—	536	519	—	—	—
<i>Cordyline fruticosa</i>	4,353	3,602	—	—	—	8,705	7,203	—	—	—	—	38
<i>Ilex anomala</i>	5,160	1,770	2,693	1,239	1,239	4,078	2,157	—	—	—	—	—
<i>Bambusa</i> ssp.	—	—	—	—	—	—	—	11,084	10,947	—	—	—
<i>Eucalyptus robusta</i>	1,186	1,172	1,667	1,301	1,301	7,691	5,778	—	—	—	—	100
<i>Eucalyptus grandis</i>	199	193	—	—	—	—	—	—	—	—	—	113
<i>Cecropia obtusifolia</i>	—	—	8,196	4,801	4,801	1,352	1,289	—	—	—	—	4,278
<i>Hibiscus tiliaceus</i>	1,036	870	8,438	5,738	5,738	—	—	—	—	—	—	—
<i>Antidesma platyphyllum</i>	4,649	2,447	2,002	961	961	2,377	1,319	—	—	—	—	—
<i>Myrsine lessertiana</i>	5,428	2,030	1,109	673	673	2,398	1,413	50	55	—	—	—
<i>Morella faya</i>	—	—	—	—	—	8,276	6,660	24	27	—	—	—
<i>Syzygium jambos</i>	—	—	52	51	51	7,654	6,238	—	—	—	—	—
<i>Spathodea campanulata</i>	—	—	680	347	347	5,508	3,171	—	—	—	—	—

Table A2-4—Number of live trees^a on forest land by species and forest community (continued)

Scientific name	Forest community types													
	Montane rainforest		Lowland tropical rainforest		Moist forest		Dry forest		Cloud forest		Strand vegetation		Plantations	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
----- Number of trees (thousand trees) -----														
<i>Myrsine sandwicensis</i>	5,812	3,917	361	370	—	—	—	—	—	—	—	—	—	—
<i>Melicope clusifolia</i>	5,037	2,755	643	501	466	402	—	—	—	—	—	—	—	—
<i>Hedyotis hillebrandii</i>	1,450	695	3,255	2,334	828	800	—	—	—	—	—	—	—	—
<i>Psychotria hawaiiensis</i>	445	196	2,396	1,202	1,509	1,058	—	—	—	—	—	—	966	1,091
<i>Melaleuca</i> ssp.	—	—	4,982	4,891	—	—	—	—	—	—	—	—	—	—
<i>Citharexylum caudatum</i>	—	—	4,919	3,171	—	—	—	—	—	—	—	—	—	—
<i>Psychotria mariniana</i>	—	—	—	—	4,225	3,866	—	—	—	—	—	—	—	—
<i>Falcataria moluccana</i>	255	217	3,807	2,350	—	—	—	—	—	—	—	—	—	—
<i>Coprosma</i> ssp.	1,740	1,201	—	—	2,071	1,999	—	—	—	—	—	—	—	—
Unknown tree ssp.	394	247	283	132	314	354	627	709	—	—	1,986	2,075	—	—
<i>Grevillea robusta</i>	1,930	993	62	54	789	624	746	650	—	—	—	—	—	—
<i>Cinnamomum burmannii</i>	—	—	3,412	3,013	—	—	—	—	—	—	—	—	—	—
<i>Coprosma longifolia</i>	2,016	979	430	410	361	370	—	—	411	405	—	—	—	—
<i>Pisonia brunoniana</i>	—	—	—	—	3,088	2,693	—	—	—	—	—	—	—	—
<i>Pandanus tectorius</i>	—	—	3,039	1,465	—	—	—	—	—	—	—	—	—	—
<i>Psydrax odorata</i>	—	—	649	629	—	—	2,220	2,508	—	—	—	—	—	—
<i>Dillenia suffruticosa</i>	—	—	643	501	2,085	1,908	100	109	—	—	—	—	—	—
<i>Nestegis sandwicensis</i>	2,681	2,219	—	—	—	—	—	—	—	—	—	—	—	—
<i>Cheirodendron forbesii</i>	—	—	—	—	—	—	—	—	2,612	2,161	—	—	—	—
<i>Wikstroemia</i> ssp.	2,612	2,161	—	—	—	—	—	—	—	—	—	—	—	—
<i>Perrottetia sandwicensis</i>	1,717	1,413	859	821	—	—	—	—	—	—	—	—	—	—
<i>Myoporum sandwicense</i>	371	372	—	—	1,576	1,016	240	172	—	—	—	—	—	—
<i>Sequoia sempervirens</i>	—	—	—	—	2,126	1,759	—	—	—	—	—	—	—	—
<i>Ficus microcarpa</i>	—	—	1,339	1,043	772	673	—	—	—	—	—	—	—	—
<i>Santalum paniculatum</i>	—	—	—	—	2,000	2,455	—	—	—	—	—	—	—	—
<i>Myrsine</i> ssp.	1,107	699	722	739	—	—	—	—	—	—	—	—	—	—
<i>Xylosma hawaiiensis</i>	1,741	1,441	—	—	—	—	—	—	—	—	—	—	—	—
<i>Coprosma rhynchocarpa</i>	1,630	1,700	—	—	—	—	—	—	—	—	—	—	—	—
<i>Melochia umbellata</i>	—	—	104	70	1,524	1,453	—	—	—	—	—	—	—	—

Table A2-4—Number of live trees^a on forest land by species and forest community (continued)

Scientific name	Forest community types											
	Montane rainforest		Lowland tropical rainforest		Moist forest		Dry forest		Cloud forest		Strand vegetation	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
-----Number of trees (thousand trees)-----												
<i>Aleurites moluccana</i>	205	127	1,028	794	243	167	124	108	—	—	—	—
<i>Cibotium chamissoi</i>	922	613	199	130	457	390	—	—	—	—	—	—
<i>Leptospermum scoparium</i>	—	—	—	—	1,544	1,347	—	—	—	—	—	—
<i>Heliocarpus popayanensis</i>	—	—	1,531	1,345	—	—	—	—	—	—	—	—
<i>Bobea sandwicensis</i>	—	—	87	62	1,390	1,272	—	—	—	—	—	—
<i>Cinnamomum verum</i>	—	—	1,456	1,270	—	—	—	—	—	—	—	—
<i>Pithecellobium dulce</i>	—	—	—	—	—	—	1,350	1,073	—	—	—	—
<i>Sophora chrysophylla</i>	—	—	—	—	50	55	1,242	851	—	—	—	—
<i>Syzygium sandwicense</i>	—	—	1,172	774	—	—	—	—	—	—	—	—
<i>Fraxinus uhdei</i>	741	622	—	—	349	288	—	—	—	—	—	—
<i>Tetraplasandra oahuensis</i>	1,085	778	—	—	—	—	—	—	—	—	—	—
<i>Melochia</i> ssp.	—	—	961	928	—	—	—	—	—	—	—	—
<i>Pinus patula</i>	—	—	—	—	209	173	—	—	—	—	576	627
<i>Melaleuca quinquenervia</i>	—	—	553	506	221	202	—	—	—	—	—	—
<i>Psychotria grandiflora</i>	—	—	—	—	772	673	—	—	—	—	—	—
<i>Psychotria kaduana</i>	—	—	55	51	674	751	—	—	—	—	—	—
<i>Chrysophyllum oliviforme</i>	—	—	695	636	—	—	—	—	—	—	—	—
<i>Eucalyptus deglupta</i>	680	657	—	—	—	—	—	—	—	—	—	—
<i>Macaranga mappa</i>	—	—	655	712	—	—	—	—	—	—	—	—
<i>Rhodomyrtus tomentosa</i>	—	—	649	629	—	—	—	—	—	—	—	—
<i>Acacia</i> ssp.	—	—	621	542	—	—	—	—	—	—	—	—
<i>Toona ciliata</i>	66	64	159	127	—	—	249	217	—	—	75	85
<i>Melicope kalaensis</i>	435	445	—	—	—	—	—	—	—	—	—	—
<i>Hedyotis terminalis</i>	414	400	—	—	—	—	—	—	—	—	—	—
<i>Melicope</i> ssp.	411	405	—	—	—	—	—	—	—	—	—	—
<i>Psychotria fauriei</i>	—	—	—	—	—	—	411	405	—	—	—	—
<i>Chenopodium oahuense</i>	324	361	—	—	66	64	—	—	—	—	—	—
<i>Cocos nucifera</i>	—	—	373	229	—	—	—	—	—	—	—	—
<i>Coprosma montana</i>	361	370	—	—	—	—	—	—	—	—	—	—

Table A2-4—Number of live trees^a on forest land by species and forest community (continued)

Scientific name	Forest community types											
	Montane rainforest		Lowland tropical rainforest		Moist forest		Dry forest		Cloud forest		Strand vegetation	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
-----Number of trees (thousand trees)-----												
<i>Antidesma pulvinatum</i>	—	—	—	—	324	361	—	—	—	—	—	—
<i>Cryptomeria</i> ssp.	—	—	—	—	311	271	—	—	—	—	—	—
<i>Trema orientalis</i>	—	—	241	178	34	33	—	—	—	—	—	—
<i>Swietenia macrophylla</i>	—	—	—	—	—	—	—	—	—	—	250	282
<i>Schefflera actinophylla</i>	—	—	173	115	52	40	—	—	—	—	—	—
<i>Persea americana</i>	—	—	191	122	—	—	—	—	—	—	—	—
<i>Diospyros sandwicensis</i>	70	58	—	—	120	105	—	—	—	—	—	—
<i>Acacia koa</i>	—	—	—	—	181	158	—	—	—	—	—	—
<i>Eucalyptus</i> ssp.	—	—	166	160	—	—	—	—	—	—	—	—
<i>Syzygium</i> ssp.	—	—	—	—	—	—	140	130	—	—	—	—
<i>Archontophoenix alexandrae</i>	—	—	128	79	—	—	—	—	—	—	—	—
<i>Casuarina glauca</i>	—	—	105	102	—	—	—	—	—	—	—	—
<i>Samanea saman</i>	—	—	52	40	—	—	49	55	—	—	—	—
<i>Mangifera</i> ssp.	—	—	67	65	—	—	—	—	—	—	—	—
<i>Psychotria</i> ssp.	—	—	67	65	—	—	—	—	—	—	—	—
<i>Clusia rosea</i>	—	—	—	—	62	54	—	—	—	—	—	—
<i>Erythrina sandwicensis</i>	—	—	—	—	—	—	62	54	—	—	—	—
<i>Casuarina cunninghamiana</i>	—	—	—	—	52	51	—	—	—	—	—	—
<i>Pritchardia</i> ssp.	26	29	26	30	—	—	—	—	—	—	—	—
<i>Pittosporum</i> ssp.	45	38	—	—	—	—	—	—	—	—	—	—
<i>Pritchardia munroi</i>	45	38	—	—	—	—	—	—	—	—	—	—
<i>Ilex paraguariensis</i>	—	—	—	—	30	30	—	—	—	—	—	—
<i>Coprosma ochracea</i>	26	29	—	—	—	—	—	—	—	—	—	—
<i>Eucalyptus saligna</i>	—	—	—	—	—	—	—	—	—	—	25	27
<i>Pinus pinaster</i>	—	—	—	—	—	—	—	—	—	—	25	27
Total	498,528	80,662	636,242	106,861	479,866	90,503	98,192	29,539	42,398	20,325	8,028	8,342
											16,596	6,125

Note: Totals may be off because of rounding; estimates are subject to sampling error; SE = sampling error; — = less than 50 trees were estimated.
^a Includes all live trees ≥ 1 inches in diameter at breast height.

Table A2-5—Number of dead trees^a on forest land by species and forest community

Scientific name	Forest community types											
	Montane rainforest			Lowland tropical rainforest			Moist forest			Dry forest		
	Total	SE		Total	SE		Total	SE		Total	SE	
	-----Number of trees (thousand trees)-----											
<i>Metrosideros polymorpha</i>	6,134	1,299		2,776	605		1,661	432		440	298	
<i>Cibotium glaucum</i>	1,840	595		357	199		133	79		—	—	
<i>Acacia koa</i>	944	500		996	385		380	189		59	61	
<i>Cibotium menziesii</i>	1,231	363		520	198		350	211		—	—	
<i>Psidium cattleianum</i>	—	—		52	51		1,181	1,030		—	—	
<i>Schinus terebinthifolius</i>	—	—		458	263		470	297		124	108	
<i>Grevillea robusta</i>	60	53		—	—		243	133		559	488	
<i>Eucalyptus robusta</i>	198	195		70	58		582	368		—	—	
<i>Cibotium</i> ssp.	74	48		244	127		500	241		—	—	
<i>Melaleuca quinquenervia</i>	—	—		608	557		—	—		—	—	
<i>Leucaena leucocephala</i>	—	—		249	217		—	—		249	217	
<i>Cheirodendron trigynum</i>	254	98		34	33		63	44		—	—	
<i>Eucalyptus grandis</i>	—	—		—	—		—	—		29	30	
<i>Myoporum sandwicense</i>	50	55		—	—		50	55		—	—	
Unknown tree ssp.	45	38		52	40		101	55		138	105	
<i>Sophora chrysophylla</i>	—	—		—	—		251	273		66	65	
<i>Eucalyptus</i> ssp.	—	—		100	96		181	158		—	—	
<i>Fraxinus uhdei</i>	90	76		—	—		139	115		—	—	
<i>Pandanus tectorius</i>	—	—		168	125		—	—		—	—	
<i>Acacia confusa</i>	—	—		—	—		166	152		—	—	
<i>Falcataria moluccana</i>	—	—		155	121		—	—		—	—	
<i>Ilex anomala</i>	111	59		—	—		33	32		—	—	
<i>Myrsine lessertiana</i>	26	30		—	—		90	76		25	27	
<i>Pinus patula</i>	—	—		—	—		—	—		—	—	
<i>Syzygium cumini</i>	45	38		62	54		—	—		—	—	
<i>Melochia umbellata</i>	—	—		—	—		103	98		—	—	
<i>Cecropia obtusifolia</i>	—	—		85	52		—	—		—	—	

Table A2.5—Number of dead trees^a on forest land by species and forest community (continued)

Scientific name	Forest community types											
	Montane rainforest			Lowland tropical rainforest			Moist forest			Dry forest		
	Total	SE		Total	SE		Total	SE		Total	SE	
	-----Number of trees (thousand trees)-----											
<i>Cocos nucifera</i>	—	—	—	85	52	—	—	—	—	—	—	—
<i>Xylosma hawaiiensis</i>	70	58	—	—	—	—	—	—	—	—	—	—
<i>Aleurites moluccana</i>	—	—	—	—	—	—	62	54	—	—	—	—
<i>Erythrina sandwicensis</i>	—	—	—	—	—	62	54	—	—	—	—	—
<i>Acacia koaia</i>	—	—	—	—	—	60	53	—	—	—	—	—
<i>Cinnamomum burmannii</i>	—	—	—	55	51	—	—	—	—	—	—	—
<i>Heliocarpus popayanensis</i>	—	—	—	55	51	—	—	—	—	—	—	—
<i>Albizia chinensis</i>	—	—	—	52	51	—	—	—	—	—	—	—
<i>Psychotria hawaiiensis</i>	52	40	—	—	—	—	—	—	—	—	—	—
<i>Swietenia macrophylla</i>	—	—	—	—	—	—	—	—	—	—	50	56
<i>Antidesma platyphyllum</i>	33	33	—	—	—	—	—	—	—	—	—	—
<i>Eucalyptus deglupta</i>	33	32	—	—	—	—	—	—	—	—	—	—
<i>Coprosma</i> ssp.	29	30	—	—	—	—	—	—	—	—	—	—
<i>Dillenia suffruticosa</i>	—	—	—	—	—	—	25	27	—	—	—	—
<i>Pithecellobium dulce</i>	—	—	—	—	—	—	25	28	—	—	—	—
Total	11,319	1,795	7,234	1,215	6,799	1,775	1,953	734	516	428	750	386

Note: Dead trees were not inventoried in diameter classes <5 or >40 inches. Totals may be off because of rounding; estimates are subject to sampling error. SE = sampling error; — = fewer than 50 trees were estimated.

^a Includes all live trees ≥5 inches in diameter at breast height.

Scientific name	Diameter class (inches)																	
	5.0–9.9		10.0–14.9		15.0–19.9		20.0–24.9		25.0–29.9		30.0–34.9		35.0–39.9		40+		All classes	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
	----- Net volume (thousand cubic feet) -----																	
<i>Metrosideros polymorpha</i>	213,176	19,565	220,266	24,383	122,805	17,771	90,506	18,397	58,857	15,575	63,198	24,564	15,064	10,998	24,748	18,394	808,620	76,434
<i>Cibotium glaucum</i>	124,209	20,144	205,441	47,497	11,157	5,665	—	—	—	—	—	—	—	—	—	—	340,808	66,971
<i>Eucalyptus grandis</i>	61,060	27,762	121,347	49,984	50,563	27,301	11,135	10,749	—	—	—	—	8,976	10,141	—	—	253,081	101,214
<i>Eucalyptus robusta</i>	7,797	4,068	17,866	9,196	22,961	11,742	18,215	14,148	43,024	29,397	59,648	41,107	—	—	44,927	36,201	214,437	103,131
<i>Acacia koa</i>	24,656	14,935	23,144	7,034	16,672	4,400	22,953	8,785	4,066	3,170	22,549	12,010	6,104	6,246	12,707	13,003	132,851	33,355
<i>Cibotium menziesii</i>	72,969	11,277	40,392	7,829	10,728	3,855	—	—	—	—	—	—	—	—	—	—	124,090	19,995
<i>Sequoia sempervirens</i>	—	—	2,772	2,294	7,345	6,078	—	—	48,821	40,396	23,321	19,297	29,942	24,775	—	—	112,202	92,839
<i>Falcataria moluccana</i>	12,896	9,072	9,362	6,518	23,309	16,072	3,777	2,942	2,358	2,286	23,619	18,397	—	—	24,258	18,894	99,579	71,797
<i>Schinus terebinthifolius</i>	25,503	7,581	8,972	3,735	—	—	—	—	—	—	—	—	—	—	—	—	34,475	10,466
<i>Syzygium cumini</i>	8,244	2,829	7,912	3,561	9,818	4,580	2,090	1,602	—	—	—	—	—	—	—	—	28,064	8,985
<i>Grevillea robusta</i>	5,109	2,628	13,264	6,835	4,842	2,824	2,904	2,297	—	—	—	—	—	—	—	—	26,119	12,161
<i>Spathodea campanulata</i>	1,799	1,020	11,088	5,080	8,236	4,625	3,854	3,362	—	—	—	—	—	—	—	—	24,977	12,455
<i>Hibiscus tiliaceus</i>	7,832	3,856	8,377	6,208	3,032	2,546	3,756	3,154	—	—	—	—	—	—	—	—	22,998	14,841
<i>Psidium cattleianum</i>	20,594	6,581	1,983	1,035	124	120	—	—	—	—	—	—	—	—	—	—	22,701	7,542
<i>Casuarina equisetifolia</i>	9,210	5,151	5,790	3,820	3,235	3,176	1,604	1,574	—	—	—	—	—	—	—	—	19,840	12,734
<i>Melaleuca quinquenervia</i>	608	373	261	239	3,033	2,776	9,509	6,683	4,794	4,387	—	—	—	—	—	—	18,203	11,398
<i>Cheirodendron trigynum</i>	12,204	3,343	3,261	1,534	966	923	—	—	—	—	—	—	—	—	—	—	16,431	4,128
<i>Eucalyptus</i> ssp.	—	—	2,787	2,691	6,543	6,317	5,245	5,063	—	—	—	—	—	—	—	—	14,575	14,071
<i>Samanea saman</i>	—	—	—	—	—	—	1,115	1,239	11,481	8,407	—	—	—	—	—	—	12,595	8,617
<i>Cibotium chamissoi</i>	7,878	3,516	4,433	3,257	—	—	—	—	—	—	—	—	—	—	—	—	12,311	6,399
<i>Heliocarpus popayanensis</i>	2,901	2,546	2,401	2,197	4,337	3,969	—	—	—	—	—	—	—	—	—	—	9,639	8,711
<i>Syzygium jambos</i>	6,707	4,388	1,517	1,181	867	841	—	—	—	—	—	—	—	—	—	—	9,091	5,067
<i>Aleurites moluccana</i>	5,187	2,679	3,627	1,608	—	—	—	—	—	—	—	—	—	—	—	—	8,813	3,771
<i>Cecropia obtusifolia</i>	5,542	2,417	1,947	1,233	—	—	—	—	—	—	—	—	—	—	—	—	7,489	3,071
<i>Cryptomeria</i> ssp.	536	467	1,418	1,237	—	—	—	—	5,057	4,411	—	—	—	—	—	—	7,011	6,115
<i>Pandanus tectorius</i>	6,952	3,571	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6,952	3,571
<i>Ilex anomala</i>	5,237	1,502	1,584	984	—	—	—	—	—	—	—	—	—	—	—	—	6,821	1,901
<i>Cocos nucifera</i>	—	—	6,795	4,485	—	—	—	—	—	—	—	—	—	—	—	—	6,795	4,485
<i>Fraxinus uhdei</i>	337	279	4,177	3,009	2,243	1,883	—	—	—	—	—	—	—	—	—	—	6,757	4,912
<i>Pinus patula</i>	1,976	2,131	4,076	3,170	—	—	—	—	—	—	—	—	—	—	—	—	6,052	5,222
<i>Toona ciliata</i>	1,603	907	997	685	3,369	2,396	—	—	—	—	—	—	—	—	—	—	5,969	3,027
<i>Acacia</i> ssp.	3,179	2,773	1,096	956	1,275	1,112	—	—	—	—	—	—	—	—	—	—	5,549	4,840

Table A2-7—Estimated net volume of live trees^a on forest land by species and diameter class (continued)

Scientific name	Diameter class (inches)													
	5.0–9.9		10.0–14.9		15.0–19.9		20.0–24.9		25.0–29.9		30.0–34.9		35.0–39.9	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
----- Net volume (thousand cubic feet) -----														
<i>Cinnamomum burmannii</i>	3,368	2,976	1,230	1,126	795	727	—	—	—	—	—	—	5,393	4,110
<i>Psidium guajava</i>	5,271	1,698	—	—	—	—	—	—	—	—	—	—	5,271	1,698
<i>Swietenia macrophylla</i>	1,879	2,122	1,550	1,751	1,649	1,862	—	—	—	—	—	—	5,077	5,736
<i>Syzygium malaccense</i>	1,465	1,212	3,478	2,878	—	—	—	—	—	—	—	—	4,943	4,090
<i>Acacia confusa</i>	4,399	3,071	324	296	—	—	—	—	—	—	—	—	4,723	3,349
<i>Trema orientalis</i>	—	—	2,581	1,882	2,087	1,420	—	—	—	—	—	—	4,668	3,239
<i>Eucalyptus deglupta</i>	1,442	1,393	1,743	1,683	—	—	—	—	—	—	—	—	3,185	3,075
<i>Prosopis pallida</i>	509	270	—	—	2,645	2,307	—	—	—	—	—	—	3,155	2,482
<i>Psychotria hawaiiensis</i>	2,477	1,041	542	422	—	—	—	—	—	—	—	—	3,019	1,121
<i>Melicope kaalaensis</i>	2,662	2,724	—	—	—	—	—	—	—	—	—	—	2,662	2,724
Unknown tree ssp.	1,861	873	649	413	—	—	—	—	—	—	—	—	2,510	942
<i>Morella faya</i>	923	691	1,323	1,353	—	—	—	—	—	—	—	—	2,246	2,016
<i>Leucaena leucocephala</i>	2,225	937	—	—	—	—	—	—	—	—	—	—	2,225	937
<i>Myrsine lessertiana</i>	1,462	529	746	478	—	—	—	—	—	—	—	—	2,209	774
<i>Persea americana</i>	490	280	1,622	1,342	—	—	—	—	—	—	—	—	2,112	1,524
<i>Cinnamomum verum</i>	1,885	1,644	—	—	—	—	—	—	—	—	—	—	1,885	1,644
<i>Acacia koa</i>	50	44	1,681	1,470	—	—	—	—	—	—	—	—	1,731	1,514
<i>Archontophoenix alexandrae</i>	—	—	1,581	989	—	—	—	—	—	—	—	—	1,581	989
<i>Melochia umbellata</i>	992	573	—	—	560	534	—	—	—	—	—	—	1,553	1,062
<i>Myoporum sandwicense</i>	1,368	672	—	—	—	—	—	—	—	—	—	—	1,368	672
<i>Ardisia elliptica</i>	226	151	—	—	883	856	—	—	—	—	—	—	1,109	959
<i>Hedyotis hillebrandii</i>	488	291	585	419	—	—	—	—	—	—	—	—	1,073	695
<i>Anidesma platyphyllum</i>	811	387	161	155	—	—	—	—	—	—	—	—	972	414
<i>Pithecellobium dulce</i>	822	877	102	116	—	—	—	—	—	—	—	—	924	993
<i>Bobea sandwicensis</i>	—	—	880	631	—	—	—	—	—	—	—	—	880	631
<i>Schefflera actinophylla</i>	873	715	—	—	—	—	—	—	—	—	—	—	873	715
<i>Mangifera</i> ssp.	106	104	—	—	683	670	—	—	—	—	—	—	789	774
<i>Eucalyptus saligna</i>	—	—	—	—	—	—	745	811	—	—	—	—	745	811
<i>Casuarina glauca</i>	278	269	425	412	—	—	—	—	—	—	—	—	703	682
<i>Melochia</i> ssp.	656	633	—	—	—	—	—	—	—	—	—	—	656	633
<i>Diospyros sandwicensis</i>	514	335	—	—	—	—	—	—	—	—	—	—	514	335

Table A2-7—Estimated net volume of live trees^a on forest land by species and diameter class (continued)

Scientific name	Diameter class (inches)																	
	5.0–9.9		10.0–14.9		15.0–19.9		20.0–24.9		25.0–29.9		30.0–34.9		35.0–39.9		40+		All classes	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
----- Net volume (thousand cubic feet) -----																		
<i>Pinus pinaster</i>	—	—	—	—	504	548	—	—	—	—	—	—	—	—	—	—	504	548
<i>Coprosma</i> ssp.	483	254	—	—	—	—	—	—	—	—	—	—	—	—	—	—	483	254
<i>Chenopodium oahuense</i>	444	429	—	—	—	—	—	—	—	—	—	—	—	—	—	—	444	429
<i>Syzygium</i> ssp.	386	358	—	—	—	—	—	—	—	—	—	—	—	—	—	—	386	358
<i>Pritchardia</i> ssp.	361	325	—	—	—	—	—	—	—	—	—	—	—	—	—	—	361	325
<i>Sophora chrysophylla</i>	289	172	—	—	—	—	—	—	—	—	—	—	—	—	—	—	289	172
<i>Broussaia arguta</i>	255	261	—	—	—	—	—	—	—	—	—	—	—	—	—	—	255	261
<i>Psychotria</i> ssp.	254	249	—	—	—	—	—	—	—	—	—	—	—	—	—	—	254	249
<i>Casuarina cunninghamiana</i>	205	199	—	—	—	—	—	—	—	—	—	—	—	—	—	—	205	199
<i>Citharexylum caudatum</i>	199	182	—	—	—	—	—	—	—	—	—	—	—	—	—	—	199	182
<i>Dillenia suffruticosa</i>	96	104	99	107	—	—	—	—	—	—	—	—	—	—	—	—	194	212
<i>Psychotria kahuana</i>	65	59	130	144	—	—	—	—	—	—	—	—	—	—	—	—	194	156
<i>Melicope clusifolia</i>	187	146	—	—	—	—	—	—	—	—	—	—	—	—	—	—	187	146
<i>Ilex paraguariensis</i>	—	—	169	168	—	—	—	—	—	—	—	—	—	—	—	—	169	168
<i>Pittosporum</i> ssp.	165	139	—	—	—	—	—	—	—	—	—	—	—	—	—	—	165	139
<i>Syzygium sandwicense</i>	162	116	—	—	—	—	—	—	—	—	—	—	—	—	—	—	162	116
<i>Ficus microcarpa</i>	157	122	—	—	—	—	—	—	—	—	—	—	—	—	—	—	157	122
<i>Perrottetia sandwicensis</i>	124	118	—	—	—	—	—	—	—	—	—	—	—	—	—	—	124	118
<i>Pritchardia munroi</i>	116	97	—	—	—	—	—	—	—	—	—	—	—	—	—	—	116	97
<i>Erythrina sandwicensis</i>	106	92	—	—	—	—	—	—	—	—	—	—	—	—	—	—	106	92
<i>Clusia rosea</i>	97	85	—	—	—	—	—	—	—	—	—	—	—	—	—	—	97	85
<i>Coprosma rhynchocarpa</i>	89	73	—	—	—	—	—	—	—	—	—	—	—	—	—	—	89	73
<i>Coprosma longifolia</i>	89	88	—	—	—	—	—	—	—	—	—	—	—	—	—	—	89	88
<i>Coprosma ochracea</i>	87	97	—	—	—	—	—	—	—	—	—	—	—	—	—	—	87	97
<i>Morinda citrifolia</i>	79	62	—	—	—	—	—	—	—	—	—	—	—	—	—	—	79	62
<i>Nestegis sandwicensis</i>	51	42	—	—	—	—	—	—	—	—	—	—	—	—	—	—	51	42
<i>Psychdrax odorata</i>	49	55	—	—	—	—	—	—	—	—	—	—	—	—	—	—	49	55
<i>Psychotria mariniana</i>	32	29	—	—	—	—	—	—	—	—	—	—	—	—	—	—	32	29
Total	700,028	46,604	759,956	73,472	327,266	39,620	177,406	27,855	178,457	51,691	192,335	54,784	60,086	29,607	106,640	46,636	2,502,174	216,192

Note: totals may be off because of rounding; estimates are subject to sampling error. SE = sampling error; — = less than 50 ft³ was estimated.

^a Includes all live trees ≥ 5 inches in diameter at breast height.

Table A2-8—Estimated net, sound, and gross volume of live trees^a on forest land by diameter class

Diameter class (inches)	Net volume		Sound volume		Gross volume	
	Total	SE	Total	SE	Total	SE
----- Thousand cubic feet -----						
5.0–9.9	700,028	46,604	708,789	47,057	710,647	47,152
10.0–14.9	759,956	73,472	771,499	73,760	773,038	73,820
15.0–19.9	327,266	39,620	336,465	40,134	336,800	40,170
20.0–24.9	177,406	27,855	183,936	28,915	183,936	28,915
25.0–29.9	178,457	51,691	183,468	52,021	183,468	52,021
30.0–34.9	192,335	54,784	193,121	54,875	193,121	54,875
35.0–39.9	60,086	29,607	60,497	29,709	60,497	29,709
40+	106,640	46,636	110,719	47,881	110,719	47,881
Total	2,502,174	216,192	2,548,493	217,713	2,552,225	217,829

SE = sampling error; descriptions of net, sound, and gross volume are available via: https://www.fia.fs.usda.gov/library/sampling/docs/supplement3_121704.pdf.^a Includes all live trees ≥ 5 inches in diameter at breast height.**Table A2-9— Aboveground biomass and carbon of live^a and dead^b trees on forest land by diameter class**

Diameter class (inches)	Live biomass		Dead biomass		Live carbon		Dead carbon	
	Total	SE	Total	SE	Total	SE	Total	SE
----- Thousand tons -----								
<5.0	17,768	1,734	—	—	8,884	867	—	—
5.0–9.9	20,731	1,387	2,791	324	10,365	693	1,395	162
10.0–14.9	19,499	1,742	2,490	378	9,750	871	1,245	189
15.0–19.9	10,319	1,188	1,218	259	5,160	594	609	129
20.0–24.9	6,975	981	703	215	3,488	490	351	108
25.0–29.9	5,685	1,431	425	203	2,842	715	213	102
30.0–34.9	6,070	1,829	255	186	3,035	915	127	93
35.0–39.9	1,562	721	234	226	781	361	117	113
40+	4,492	1,897	—	—	2,246	948	—	—
Total	93,102	6,622	8,115	955	46,551	3,311	4,058	478

Note: totals may be off because of rounding; estimates are subject to sampling error. SE = sampling error; — = less than 50 thousand tons was estimated.

^a Includes all live trees ≥ 1 inches in diameter at breast height [d.b.h.].^b Includes all dead trees ≥ 5 inches d.b.h.; dead trees <5 inches d.b.h. were not inventoried.

Table A2-10—Aboveground biomass of live trees^a on forest land by species and diameter class

Scientific name	Diameter class (inches)															
	<5.0		5.0–9.9		10.0–14.9		15.0–19.9		20.0–24.9		25.0–29.9		30.0–34.9		35.0–39.9	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
----- Thousand tons -----																
<i>Metrosideros polymorpha</i>	4,307.1	548.0	9,691.2	824.9	9,085.1	879.1	4,702.8	691.2	4,043.2	763.2	2,568.3	690.7	2,110.4	791.0	486.2	352.6
<i>Psidium cattleianum</i>	8,739.2	1,617.6	1,606.6	502.4	141.1	76.8	49.9	48.4	—	—	—	—	—	—	—	—
<i>Eucalyptus robusta</i>	144.0	102.5	302.5	167.0	608.9	282.9	770.3	394.4	551.2	436.2	1,507.0	1,054.0	2,227.5	1,534.8	—	—
<i>Eucalyptus grandis</i>	37.1	28.9	1,834.7	803.8	3,511.9	1,444.8	1,408.8	759.2	322.1	311.0	—	—	—	—	361.8	408.7
<i>Acacia koa</i>	222.7	125.4	871.8	517.6	739.7	231.6	577.4	152.9	808.3	299.3	162.5	129.7	707.0	352.9	182.0	186.2
<i>Falcataria moluccana</i>	53.2	36.7	281.9	202.2	201.3	137.1	552.0	373.5	95.0	74.0	102.9	99.8	610.8	475.7	—	—
<i>Cibotium glaucum</i>	—	—	857.6	138.8	1,419.5	326.6	77.0	39.1	—	—	—	—	—	—	—	—
<i>Sequoia sempervirens</i>	4.6	3.8	—	—	47.3	39.1	125.4	103.7	—	—	866.1	716.6	414.5	343.0	532.1	440.3
<i>Schinus terebinthifolius</i>	472.7	170.1	734.4	215.5	311.0	136.6	—	—	—	—	—	—	—	—	—	—
<i>Syzygium cumini</i>	89.7	57.4	254.1	92.9	265.7	116.2	360.0	164.4	96.9	74.4	—	—	—	—	—	—
<i>Grevillea robusta</i>	1.6	1.1	169.5	88.0	435.7	213.9	238.8	153.6	130.1	90.8	—	—	—	—	—	—
<i>Casuarina equisetifolia</i>	180.7	126.5	363.5	219.8	225.4	153.5	110.1	108.1	89.6	87.9	—	—	—	—	—	—
<i>Hibiscus tiliaceus</i>	99.5	68.8	280.7	142.1	286.0	196.8	93.6	78.6	177.1	148.7	—	—	—	—	—	—
<i>Cibotium menziesii</i>	1.2	1.4	489.2	75.6	267.1	51.8	74.3	26.5	—	—	—	—	—	—	—	—
<i>Cheirodendron trigynum</i>	318.5	61.6	341.8	81.3	89.0	39.4	22.1	21.1	—	—	—	—	—	—	—	—
<i>Spathodea campanulata</i>	16.4	10.0	65.3	38.9	275.0	146.8	192.4	107.4	130.5	113.8	—	—	—	—	—	—
<i>Melaleuca quinquenervia</i>	—	—	18.2	11.1	6.6	6.1	91.3	83.6	290.4	203.6	149.8	137.1	—	—	—	—
<i>Ardisia elliptica</i>	478.9	285.9	10.6	7.5	—	—	65.7	63.7	—	—	—	—	—	—	—	—
<i>Leucaena leucocephala</i>	485.3	183.6	66.8	26.8	—	—	—	—	—	—	—	—	—	—	—	—
<i>Acacia confusa</i>	254.9	157.6	205.8	138.5	15.1	13.8	—	—	—	—	—	—	—	—	—	—
<i>Syzygium jambos</i>	133.0	121.7	228.9	145.8	56.1	43.7	53.4	51.8	—	—	—	—	—	—	—	—
<i>Eucalyptus</i> ssp.	—	—	—	—	89.4	86.3	205.6	198.5	154.8	149.5	—	—	—	—	—	—
<i>Psidium guajava</i>	235.2	86.3	192.7	61.6	—	—	—	—	—	—	—	—	—	—	—	—
<i>Syzygium malaccense</i>	217.1	179.6	42.5	35.2	114.8	95.0	—	—	—	—	—	—	—	—	—	—
<i>Ilex anomala</i>	121.3	47.9	155.4	44.4	51.1	29.9	—	—	—	—	—	—	—	—	—	—
<i>Fraxinus uhdei</i>	2.8	2.4	53.3	44.1	172.3	102.3	61.6	51.7	—	—	—	—	—	—	—	—
<i>Samanea saman</i>	—	—	—	—	—	—	—	—	37.2	41.3	220.3	145.6	—	—	—	—
<i>Aleurites moluccana</i>	—	—	131.2	68.5	105.2	49.0	—	—	—	—	—	—	—	—	—	—
<i>Cecropia obtusifolia</i>	107.6	71.5	79.9	38.6	16.5	10.5	—	—	—	—	—	—	—	—	—	—
<i>Toona ciliata</i>	—	—	56.6	30.6	29.6	20.5	104.6	75.2	—	—	—	—	—	—	—	—

Table A2-10—Aboveground biomass of live trees^a on forest land by species and diameter class (continued)

Scientific name	Diameter class (inches)															
	<5.0		5.0–9.9		10.0–14.9		15.0–19.9		20.0–24.9		25.0–29.9		30.0–34.9		35.0–39.9	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
----- Thousand tons -----																
<i>Cocos nucifera</i>	—	—	—	—	169.8	115.6	—	—	—	—	—	—	—	—	169.8	115.6
<i>Psychotria hawaiiensis</i>	75.1	33.9	81.3	30.4	11.7	9.1	—	—	—	—	—	—	—	—	168.2	57.5
<i>Acacia</i> spp.	—	—	86.5	75.4	31.6	27.5	48.7	42.5	—	—	—	—	—	—	166.8	145.5
<i>Pandanus tectorius</i>	11.6	11.4	141.6	71.5	—	—	—	—	—	—	—	—	—	—	153.2	73.6
<i>Bambusa</i> spp.	152.9	151.0	—	—	—	—	—	—	—	—	—	—	—	—	152.9	151.0
<i>Heliotropis popayanensis</i>	7.0	6.4	46.8	41.0	31.8	29.1	66.2	60.6	—	—	—	—	—	—	151.9	137.1
<i>Myrsine lessertiana</i>	72.8	27.5	45.4	15.1	33.1	22.7	—	—	—	—	—	—	—	—	151.3	51.0
<i>Pinus patula</i>	—	—	61.1	57.0	87.8	67.9	—	—	—	—	—	—	—	—	148.8	124.0
<i>Cinnamomum burmannii</i>	13.2	12.1	81.2	71.6	25.9	23.7	24.2	22.2	—	—	—	—	—	—	144.5	107.9
<i>Myoporum sandwicense</i>	42.0	27.1	98.7	53.3	—	—	—	—	—	—	—	—	—	—	140.8	78.1
<i>Cryptomeria</i> spp.	—	—	8.4	7.4	24.1	21.0	—	—	—	—	108.0	94.2	—	—	140.5	122.5
<i>Eucalyptus deglupta</i>	18.0	17.4	49.3	47.6	72.7	70.2	—	—	—	—	—	—	—	—	140.0	135.2
<i>Morella faya</i>	37.2	30.8	38.3	25.1	62.4	63.8	—	—	—	—	—	—	—	—	138.0	95.7
<i>Prosopis pallida</i>	19.1	14.9	15.2	8.2	—	—	97.9	85.4	—	—	—	—	—	—	132.1	94.0
Unknown tree spp.	19.5	16.0	61.7	27.1	28.2	19.1	—	—	—	—	—	—	—	—	109.5	35.7
<i>Swietenia macrophylla</i>	—	—	42.2	47.7	32.3	36.4	32.5	36.7	—	—	—	—	—	—	107.0	120.8
<i>Trema orientalis</i>	—	—	—	—	50.2	35.8	56.6	35.6	—	—	—	—	—	—	106.8	67.2
<i>Antidesma platyphyllum</i>	66.9	30.0	24.2	11.0	6.3	6.1	—	—	—	—	—	—	—	—	97.4	34.9
<i>Acacia koaia</i>	—	—	7.8	6.8	67.3	58.9	—	—	—	—	—	—	—	—	75.1	65.7
<i>Cibotium chamissoi</i>	—	—	47.4	21.2	27.6	19.5	—	—	—	—	—	—	—	—	75.0	38.9
<i>Cinnamomum verum</i>	14.2	12.4	59.0	51.5	—	—	—	—	—	—	—	—	—	—	73.2	63.9
<i>Archontophoenix alexandrae</i>	—	—	—	—	70.0	45.8	—	—	—	—	—	—	—	—	70.0	45.8
<i>Coprosma</i> spp.	38.4	32.9	20.2	10.7	—	—	—	—	—	—	—	—	—	—	58.6	34.7
<i>Melochia umbellata</i>	12.8	12.2	23.2	16.2	—	—	18.6	17.7	—	—	—	—	—	—	54.5	45.6
<i>Melicope kaalaensis</i>	—	—	52.6	53.8	—	—	—	—	—	—	—	—	—	—	52.6	53.8
<i>Eucalyptus saligna</i>	—	—	—	—	—	—	—	—	48.9	53.2	—	—	—	—	48.9	53.2
<i>Broussaia arguta</i>	39.6	16.9	4.4	4.5	—	—	—	—	—	—	—	—	—	—	43.9	20.5
<i>Pithecellobium dulce</i>	8.3	6.7	29.8	26.4	4.6	5.2	—	—	—	—	—	—	—	—	42.7	36.7
<i>Dillenia suffruticosa</i>	29.0	17.5	1.8	1.9	9.3	10.1	—	—	—	—	—	—	—	—	40.1	21.2
<i>Morinda citrifolia</i>	37.5	28.3	2.0	1.6	—	—	—	—	—	—	—	—	—	—	39.6	29.9

[illegible]

[illegible]

Table A2-11—Aboveground biomass of dead trees^a on forest land by species and diameter class (continued)

Scientific name	5.0–9.9		10.0–14.9		15.0–19.9		20.0–24.9		25.0–29.9		30.0–34.9		35.0–39.9		All classes	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
-----Thousand tons-----																
<i>Chinese albizia</i>	—	—	12	11	—	—	—	—	—	—	—	—	—	—	12	11
<i>Syzygium cumini</i>	11	9	—	—	—	—	—	—	—	—	—	—	—	—	11	9
<i>Acacia confusa</i>	11	10	—	—	—	—	—	—	—	—	—	—	—	—	11	10
<i>Pandanus tectorius</i>	9	7	—	—	—	—	—	—	—	—	—	—	—	—	9	7
<i>Aleurites moluccana</i>	9	8	—	—	—	—	—	—	—	—	—	—	—	—	9	8
<i>Cinnamomum burmannii</i>	4	4	—	—	—	—	—	—	—	—	—	—	—	—	4	4
<i>Xylosma hawaiiensis</i>	3	3	—	—	—	—	—	—	—	—	—	—	—	—	3	3
<i>Psychotria hawaiiensis</i>	3	2	—	—	—	—	—	—	—	—	—	—	—	—	3	2
<i>Eucalyptus deglupta</i>	2	2	—	—	—	—	—	—	—	—	—	—	—	—	2	2
<i>Pithecellobium dulce</i>	2	2	—	—	—	—	—	—	—	—	—	—	—	—	2	2
<i>Antidesma platyphyllum</i>	1	1	—	—	—	—	—	—	—	—	—	—	—	—	1	1
<i>Coprosma</i> ssp.	1	1	—	—	—	—	—	—	—	—	—	—	—	—	1	1
<i>Dillenia suffruticosa</i>	1	1	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Total	2,791	324	2,490	378	1,218	259	703	215	425	203	255	186	234	226	8,115	955

Note: Totals may be off because of rounding; estimates are subject to sampling error. SE = sampling error; — = less than 50,000 tons was estimated.

^a Includes all dead trees ≥5 inches diameter at breast height [d.b.h.]; dead trees ≤5 inches d.b.h. were not inventoried.

Table A2-12—Estimated area of understory vegetation cover by life form, land owner group, and number of Forest Inventory and Analysis subplots where the species occurred

Scientific name	Common or Hawaiian name	Native (n)/endemic (e)/ Polynesian introduced (p)/ introduced (i)	Owner group						Number of subplots		
			Federal			State and local government				Private	
			Total	SE	Total	SE	Total	SE		Total	SE
			-----Area (acres)-----								
Forbs											
<i>Dicranopteris linearis</i> (Burm.) Underw.	Uluhe	N	30,767	13,883	121,839	18,726	61,919	12,211	79		
<i>Hedychium gardnerianum</i> Shepard ex Ker Gawl.	Kahili Ginger	I*	162	157	15,644	6,858	322	183	12		
<i>Hedychium coronarium</i> J. Koenig	White garland-lily	I	—	—	13,612	8,033	115	105	4		
<i>Sadleria pallida</i> Hook. & Arn.	‘Ama‘u ‘i‘i	E	—	—	10,840	5,768	1,131	608	6		
<i>Diplazium sandwichianum</i> (C. Presl) Diels	Ho‘i‘o	E	—	—	10,431	6,208	109	78	4		
<i>Diplopterygium pinnatum</i> (Kunze) Nakai	Uluhe lau nui	E	244	233	6,461	3,851	3,399	1,810	15		
<i>Sadleria souleyetiana</i> (Gaudich.) T. Moore	‘Āma‘uma‘u	E	2,149	1,113	4,505	2,010	247	130	17		
<i>Nephrolepis exaltata</i> (L.) Schott	Kupukupu	N	—	—	3,975	2,533	1,468	552	19		
<i>Zingiber zerumbet</i> (L.) Sm.	Awapuhi	P	—	—	3,877	1,835	1,524	1,187	4		
Forb (herbaceous, not grass nor grass- like)	Unknown forb	N/A	697	392	860	433	3,811	2,374	15		
<i>Polygonum punctatum</i> Elliott	Dotted smartweed	I	—	—	3,309	1,637	1,633	956	7		
<i>Senecio madagascariensis</i> Poir.	Madagascar ragwort	I	37	37	3,117	3,062	614	493	5		
<i>Sphagneticola trilobata</i> (L.) Pruski	Bay Biscayne creeping-oxeye	I	—	—	69	68	3,558	2,164	3		
<i>Thelypteris parasitica</i> (L.) Fosberg	Parasitic maiden fern	I	—	—	2,045	1,423	1,340	687	6		
<i>Nephrolepis multiflora</i>	Asian swordfern	I	434	265	217	156	2,610	2,385	6		
<i>Arundina graminifolia</i> (D. Don) Hochr.	Bamboo orchid	I	—	—	2,291	1,953	645	378	6		
<i>Justicia betonica</i> L.	Squirrel's tail	I	2,917	2,544	—	—	—	—	1		
<i>Blechnum occidentale</i> L.	Hammock fern	I	—	—	870	417	1,960	1,035	8		
<i>Blechnum appendiculatum</i> Willd.	Palm fern	I	—	—	1,962	1,642	860	935	4		
<i>Pneumatopteris sandwicensis</i> (Brack.) Holtum	Ho‘i‘o kula	E	—	—	2,624	1,595	—	—	3		
<i>Nephrolepis cordifolia</i> (L.) C. Presl	Kupukupu	N	—	—	484	226	1,895	1,819	8		

Table A2-12—Estimated area of understory vegetation cover by life form, land owner group, and number of Forest Inventory and Analysis subplots where the species occurred (continued)

Scientific name	Common or Hawaiian name	Native (n)/endemic (e)/ Polynesian introduced (p)/ introduced (i)	Owner group						Number of subplots		
			Federal			State and local government				Private	
			Total	SE		Total	SE			Total	SE
-----Area (acres)-----											
<i>Sadleria</i> Kaulf.	‘Ama‘u	E	41	39	1,972	1,036	333	363	6		
<i>Diplazium esculentum</i> (Retz.) Sw.	Ho‘i‘o	E	—	—	—	—	2,338	1,551	2		
<i>Commelina diffusa</i> Burm. f.	Climbing dayflower	I	—	—	—	—	2,205	1,906	3		
<i>Sticherus owhyensis</i> (Hook.) Ching	"	uluhe"	E	516	351	1,438	819	—	—		
<i>Dryopteris wallichiana</i> (Spreng.) Hyl.	Laukahi	N	—	—	1,893	1,102	—	—	3		
<i>Nephrolepis falcata</i> (Cav.) C. Chr.	Fishtail swordfern	I	—	—	—	—	1,888	1,471	1		
<i>Agave sisalana</i> Perrine	Sisal hemp	I	—	—	1,550	1,356	—	—	1		
<i>Dicranopteris emarginata</i> (T. Moore) W.J. Rob.	Uluhe	E	—	—	1,420	1,543	—	—	1		
<i>Angiopteris evecta</i> (J.R. Forst.) Hoffm.	Oriental vessel fern	I	1,189	1,136	181	130	—	—	2		
<i>Tibouchina herbacea</i> (DC.) Cogn.	Herbaceous glorytree	I	—	—	782	380	539	295	5		
Fern or Fern Ally	Unknown forb (fern)	N/A	—	—	1,317	798	—	—	3		
<i>Athyrium microphyllum</i> (J. Sm.) Alston	‘Ākōlea	E	43	41	832	597	434	311	3		
<i>Thelypteris cyatheoides</i> (Kaulf.) Fosberg	Kikawaio	N	—	—	1,300	1,138	—	—	1		
<i>Nephrolepis</i> Schott	kupukupu	N	—	—	1,202	577	75	63	8		
<i>Pteris excelsa</i> Gaudich.	Waimakanui	N	—	—	1,204	1,232	—	—	1		
<i>Microlepia strigosa</i> (Thunb.) C. Presl	Palapalai	N	—	—	932	827	258	201	4		
<i>Blechnum</i> L.	Midsorus fern	I	—	—	1,045	597	—	—	2		
<i>Odontosoria chinensis</i> (L.) J. Sm.	Chinese creepingfern	N	161	147	186	112	696	675	4		
<i>Paederia foetida</i> L.	Stinkvine	I	—	—	—	—	901	702	1		
<i>Phymatosorus grossus</i> (Langsd. & Fisch.) Brownlie	Laua’e	I	—	—	—	—	870	701	2		
<i>Lycopodiella cernua</i>	Wawa’e’iole	N	—	—	449	202	407	429	7		

Table A2-12—Estimated area of understory vegetation cover by life form, land owner group, and number of Forest Inventory and Analysis subplots where the species occurred (continued)

Scientific name	Common or Hawaiian name	Native (n)/endemic (e)/ Polynesian introduced (p)/ introduced (i)	Owner group						Number of subplots		
			Federal			State and local government				Private	
			Total	SE	Total	SE	Total	SE		Total	SE
			-----Area (acres)-----								
<i>Stachytarpheta urticifolia</i>	Oi	I	—	—	775	678	—	—	1		
<i>Asystasia gangetica</i> (L.) T. Anderson	Chinese violet	I	774	675	—	—	—	—	1		
<i>Rivina humilis</i> L.	Rougeplant	I	645	563	—	—	129	113	2		
<i>Ageratina adenophora</i> (Spreng.) R.M. King & H. Rob.	Sticky snakeroot	I	—	—	533	240	239	261	4		
<i>Monstera deliciosa</i> Liebm.	Tarovine	I	—	—	—	—	751	585	1		
<i>Leonotis nepetifolia</i> (L.) R. Br.	Christmas candlestick	I	—	—	—	—	749	653	1		
<i>Astelia menziesiana</i>	Pa'iniu	E	—	—	41	40	687	748	2		
<i>Adiantum hispidulum</i> Sm.	Rough maidenhair	I	—	—	225	197	429	334	2		
<i>Pteridium aquilinum</i> (L.) Kuhn	Kilau	E	645	616	—	—	—	—	1		
<i>Polygonum capitatum</i> Buch.-Ham. ex D. Don	Pinkhead smartweed	I	—	—	—	—	613	413	2		
<i>Phymatosorus scolopendria</i> (Burm. f.) Pic. Serm.	Monarch fern	I	—	—	600	525	—	—	1		
<i>Phytolacca sandwicensis</i> Endl.	Popolo ku mai	E	—	—	566	579	—	—	1		
<i>Momordica charantia</i> L.	Balsampear	I	—	—	—	—	496	383	2		
<i>Stachytarpheta cayennensis</i> (Rich.) Vahl	Cayenne porterweed	I	—	—	41	41	426	409	2		
<i>Desmodium</i> sp.	Ticktrefoil	I	465	405	—	—	—	—	1		
<i>Sadleria cyatheoides</i> Kaulf.	‘Ama‘u	E	—	—	—	—	439	383	1		
<i>Dryopteris fuscoatra</i> (Hillebr.) W.J. Rob.	‘I‘i	E	—	—	—	—	374	314	1		
<i>Phaius tancarvilleae</i> (Banks ex L'Hér.) Blume	Nun's-hood orchid	I	—	—	105	73	232	203	3		
<i>Kalanchoe pinnata</i> (Lam.) Pers.	Cathedral bells	I	—	—	300	263	—	—	1		
<i>Deparia petersenii</i> (Kunze) M. Kato	Petersen's-Spleenwort	I	—	—	300	263	—	—	1		
<i>Cibotium chamissoi</i> Kaulf.	hapu‘u	N	—	—	286	168	—	—	2		
<i>Elaphoglossum</i> sp.	‘Ēkaha	E	—	—	284	373	—	—	1		
<i>Passiflora edulis</i> Sims	Purple granadilla	I	—	—	—	—	281	236	1		

Table A2-12—Estimated area of understory vegetation cover by life form, land owner group, and number of Forest Inventory and Analysis subplots where the species occurred (continued)

Scientific name	Common or Hawaiian name	Native (n)/endemic (e)/ Polynesian introduced (p)/ introduced (i)	Owner group						Number of subplots	
			Federal		State and local government		Private			
			Total	SE	Total	SE	Total	SE		
-----Area (acres)-----										
<i>Lindernia crustacea</i> (L.) F. Muell.	Malaysian false pimpnel	I	—	—	270	301	—	—	—	1
<i>Desmodium incanum</i> DC.	Ka'iimi	I	—	—	—	—	258	225	—	1
<i>Peperomia</i> sp.	Ala'ala wai nui	N/A	—	—	249	173	—	—	—	2
<i>Dicranopteris</i> sp.	Uluhe	N	—	—	—	—	230	210	—	1
<i>Hedychium</i> sp.	Garland-lily	I	—	—	227	253	—	—	—	1
<i>Peperomia hypoleuca</i> Miq.	Ala'ala wai nui	E	—	—	217	156	—	—	—	1
<i>Diplopterygium</i> sp.	Uluhe	E	—	—	208	204	—	—	—	1
<i>Thelypteris dentata</i> (Forssk.) E.P. St. John	Downy maiden fern	I	—	—	175	153	—	—	—	1
<i>Elephantopus mollis</i> Kunth	Elephants foot	I	—	—	174	144	—	—	—	1
<i>Asplenium nidus</i> L.	‘Ēkaha kuahiwi	N	—	—	—	—	172	134	—	1
<i>Hymenophyllum recurvum</i> Gaudich.	Ohiaku	E	—	—	42	41	129	100	—	2
<i>Anemone hupehensis</i> (hort. ex Lem.) Lem. ex Boynton	Japanese thimbleweed	I	—	—	—	—	168	141	—	1
<i>Polypodium pellucidum</i> Kaulf.	Dotted polypody	I	150	168	—	—	—	—	—	1
<i>Etilingera elatior</i> (Jack) R.M. Sm.	Torch-ginger	I	—	—	125	122	—	—	—	1
<i>Spathoglottis plicata</i> Blume	Philippine ground orchid	I	115	105	—	—	—	—	—	1
<i>Stellaria media</i> (L.) Vill.	Common chickweed	I	—	—	—	—	112	94	—	1
<i>Psilotum complanatum</i> Sw.	Moa	N	69	63	42	41	—	—	—	2
<i>Emilia fosbergii</i> Nicolson	Florida tasselflower	I	—	—	—	—	109	105	—	1
<i>Pityrogramma calomelanos</i> Domin	Silverback fern	I	—	—	108	111	—	—	—	1
<i>Ageratum conyzoides</i> L.	Tropical whiteweed	I	—	—	100	88	—	—	—	1
<i>Astelia</i> sp.	Kaluaha	E	—	—	97	93	—	—	—	1
<i>Passiflora tripartita</i> (Juss.) Poir. var. <i>mollissima</i> (Kunth) Holm-Niesen & P.M. Jørg.	Banana Poka	I*	—	—	96	99	—	—	—	1
<i>Microlepia speluncae</i> (L.) T. Moore	Palai nui	N	—	—	—	—	83	91	—	1

Table A2-12—Estimated area of understory vegetation cover by life form, land owner group, and number of Forest Inventory and Analysis subplots where the species occurred (continued)

Scientific name	Common or Hawaiian name	Native (n)/endemic (e)/ Polynesian introduced (p)/ introduced (i)	Owner group						Number of subplots	
			Federal			State and local government				Private
			Total		SE	Total		SE		
			-----Area (acres)-----							
<i>Amaranthus spinosus</i> L.	Spiny amaranth	I	—	—	—	77	68	1		
<i>Bidens alba</i> (L.) DC.	Beggar's tick	I	77	68	—	—	—	1		
<i>Bidens pilosa</i> L.	Hairy beggartick	I	77	68	—	—	—	1		
<i>Bidens torta</i> Sherff	Kō'oko'olau	E	—	—	—	77	68	1		
<i>Gomphrena globosa</i> L.	Globe amaranth	I	77	68	—	—	—	1		
<i>Hedychium flavescens</i> Carey ex Roscoe	Cream garland-lily	I	—	—	—	77	68	1		
<i>Ruellia caerulea</i> Morong	Britton's wild petunia	I	77	68	—	—	—	1		
<i>Selaginella arbuscula</i> (Kaulf.) Spring	Lelelepeamo	E	—	—	—	77	68	1		
<i>Ageratina riparia</i> (Regel) R.M. King & H. Rob.	Spreading snakeroot	I	—	—	76	86	—	1		
<i>Plantago lanceolata</i> L.	Lau kahi	I	—	—	75	66	—	1		
<i>Erigeron karvinskianus</i> DC.	Latin American fleabane	I	—	—	69	63	—	1		
<i>Waltheria indica</i> L.	'Uhaloa	N	—	—	—	65	63	1		
<i>Asparagus aethiopicus</i> L.	Sprenger's asparagus fern	I	—	—	—	65	63	1		
<i>Dicliptera chinensis</i> (L.) Juss.	Chinese foldwing	I	—	—	55	54	—	1		
<i>Hyptis pectinata</i> (L.) Poit.	Comb bushmint	I	—	—	—	52	59	1		
<i>Doodia kunthiana</i> Gaudich.	'Ōkupukupu	E	—	—	48	49	—	1		
<i>Elaphoglossum aemulum</i> (Kaulf.) Brack.	'Ēkaha	E	—	—	41	40	—	1		
<i>Mimosa pudica</i> L.	Shameplant	I	—	—	—	32	37	1		
<i>Rumex</i> sp.	Hu'ahu'ako	N/A	—	—	28	32	—	1		
Graminoids										
<i>Urochloa maxima</i> (Jacq.) R. Webster	Guineagrass	I	11,461	6,807	3,804	3,140	29,117	9,340	19	
<i>Pennisetum clandestinum</i> Hochst. ex Chiov.	Kikuyugrass	I	4,972	4,306	15,010	7,271	20,980	8,558	16	
<i>Microlaena stipoides</i>	Weeping grass	I	2,622	1,426	5,982	3,310	15,906	7,146	21	
Graminoid (grass or grass-like)	Unknown graminoid	N/A	2,142	2,355	3,802	2,528	10,686	5,881	16	

Table A2-12—Estimated area of understory vegetation cover by life form, land owner group, and number of Forest Inventory and Analysis subplots where the species occurred (continued)

Scientific name	Common or Hawaiian name	Native (n)/endemic (e)/ Polynesian introduced (p)/ introduced (i)	Owner group						Number of subplots		
			Federal			State and local government				Private	
			Total	SE	Total	SE	Total	SE		Total	SE
-----Area (acres)-----											
<i>Pennisetum setaceum</i> (Labill.) R. Br.	Crimson fountaingrass	I*	1,172	1,165	6,979	3,817	3,055	2,647	9		
<i>Setaria palmifolia</i>	Palmgrass	I	115	109	8,309	2,573	655	550	18		
Grass, perennial	Unknown graminoid	N/A	1,381	1,547	7,002	4,791	653	633	8		
<i>Oplismenus hirtellus</i> (L.) P. Beauv.	Basketgrass	I	—	—	5,382	3,059	2,530	1,505	7		
<i>Paspalum conjugatum</i> P.J. Bergius	Mau'u Hilo	I	—	—	5,352	3,167	1,267	620	14		
<i>Melinis minutiflora</i> P. Beauv.	Molassesgrass	I	1,261	1,378	1,442	990	3,844	1,796	13		
<i>Festuca</i> sp.	Fescue	N/A	400	448	4,568	3,212	1,264	1,294	6		
<i>Digitaria insularis</i> (L.) Mez ex Ekman	Sourgrass	I	2,788	2,432	—	—	2,416	2,411	3		
<i>Axonopus fissifolius</i> (Raddi) Kuhlman	Common carpetgrass	I	—	—	1,654	1,244	2,479	1,978	5		
<i>Vulpia myuros</i> (L.) C.C. Gmel.	Annual fescue	I	—	—	—	—	3,973	4,152	1		
<i>Holcus lanatus</i> L.	Common velvetgrass	I	473	408	1,474	853	1,882	1,688	8		
<i>Urochloa mutica</i> (Forssk.) T.Q. Nguyen	Para grass	I	—	—	42	41	3,783	2,939	4		
<i>Machaerina angustifolia</i> (Gaudich.) T. Koyama	‘Uki	N	—	—	2,215	1,443	1,177	1,435	4		
<i>Oplismenus compositus</i> (L.) P. Beauv.	Running mountaingrass	I	—	—	3,369	2,037	—	—	2		
<i>Andropogon virginicus</i> L.	Broomsedge bluestem	I	120	105	2,961	2,524	258	201	4		
<i>Pennisetum purpureum</i> Schumacher	Elephant grass	I	—	—	—	—	3,307	2,270	4		
<i>Sacciolepis indica</i> (L.) Chase	Glenwoodgrass	I	—	—	69	68	3,099	1,956	5		
<i>Juncus effusus</i> L.	Common rush	I	1,189	1,136	1,754	925	—	—	5		
<i>Digitaria</i> sp.	Crabgrass	I	—	—	—	—	2,899	2,435	1		
<i>Carex alligata</i> Boott	Hawai'i sedge	E	—	—	—	—	2,461	1,764	1		
<i>Panicum tenuifolium</i> Hook. & Arn.	Parkland panicgrass	I	—	—	—	—	2,134	2,323	1		
<i>Melinis repens</i> (Willd.) Zizka	Rose Natal grass	I	—	—	—	—	1,748	1,152	4		
<i>Paspalum urvillei</i> Steud.	Vasey's grass	I	—	—	1,376	918	257	221	5		
<i>Juncus planifolius</i> R. Br.	Broadleaf rush	I	344	328	—	—	1,086	778	2		
<i>Hyparrhenia</i> sp.	Thatching grass	I	—	—	—	—	1,414	1,371	1		

Table A2-12—Estimated area of understory vegetation cover by life form, land owner group, and number of Forest Inventory and Analysis subplots where the species occurred (continued)

Scientific name	Common or Hawaiian name	Native (n)/endemic (e)/ Polynesian introduced (p)/ introduced (i)	Owner group						Number of subplots		
			Federal			State and local government				Private	
			Total	SE	Total	SE	Total	SE		Total	SE
-----Area (acres)-----											
<i>Pennisetum ciliare</i> (L.) Link	Buffelgrass	I	37	37	—	—	—	1,322	1,036	3	
<i>Andropogon glomeratus</i> (Walter) Britton, Sterns & Poggenb.	Bushy bluestem	I	60	67	376	294	—	895	973	3	
<i>Pennisetum polystachion</i> (L.) Schult.	Mission grass	I	—	—	—	—	—	1,162	1,013	1	
<i>Coix lacryma-jobi</i>	Job's tears	I	—	—	574	434	—	567	451	4	
<i>Polygonum</i> sp.	Knotweed	I	—	—	—	—	—	1,029	864	1	
<i>Andropogon</i> sp.	Bluestem	I	—	—	—	—	—	1,017	1,166	1	
<i>Bambusa</i> sp.	Bamboo	I	—	—	1,014	839	—	—	—	1	
<i>Paspalum dilatatum</i> Poir.	Dallisgrass	I	903	862	—	—	—	65	63	2	
<i>Festuca hawaiiensis</i> Hitchc.	Hawai'i fescue	E	600	673	301	308	—	—	—	2	
<i>Panicum repens</i> L.	Torpedo grass	I	—	—	184	189	—	703	586	3	
<i>Bothriochloa pertusa</i> (L.) A. Camus	Pitted beardgrass	I	—	—	—	—	—	778	813	1	
<i>Morelotia gahniiformis</i>	Gaudichaud's sawsedge	E	—	—	—	—	—	578	663	1	
<i>Carex</i> sp.	Sedge	N/A	40	45	518	492	—	—	—	3	
<i>Carex meyenii</i> Nees	Meyen's sedge	N	480	538	—	—	—	—	—	1	
<i>Cyperus haspan</i> L.	Haspan flatsedge	I	258	246	42	41	—	171	139	4	
<i>Heteropogon contortus</i> (L.) P. Beauv. ex Roem. & Schult.	Pili	E	—	—	—	—	—	457	443	1	
<i>Digitaria ciliaris</i> (Retz.) Koeler	Southern crabgrass	I	—	—	184	168	—	437	406	1	
<i>Schizachyrium condensatum</i> (Kunth) Nees	Colombian bluestem	I	—	—	375	328	—	—	—	1	
<i>Sporobolus indicus</i> (L.) R. Br.	Smut grass	I	—	—	233	239	—	—	—	1	
<i>Paspalum paniculatum</i> L.	Arrocillo	I	—	—	—	—	—	204	189	1	
<i>Eleocharis obtusa</i> (Willd.) Schult.	Blunt spikerush	N	—	—	—	—	—	193	221	1	
<i>Machaerina mariscoides</i> (Gaudich.) J. Kern	'Ahaniau	E	—	—	145	104	—	—	—	1	
<i>Juncus</i> sp.	Rush	I	—	—	138	102	—	—	—	2	

Table A2-12—Estimated area of understory vegetation cover by life form, land owner group, and number of Forest Inventory and Analysis subplots where the species occurred (continued)

Scientific name	Common or Hawaiian name	Native (n)/endemic (e)/ Polynesian introduced (p)/ introduced (i)	Owner group						Number of subplots		
			Federal			State and local government				Private	
			Total	SE	Total	SE	Total	SE		Total	SE
-----Area (acres)-----											
<i>Aira caryophyllea</i> L.	Silver hairgrass	I	—	—	—	—	—	129	113	1	
<i>Eragrostis variabilis</i> (Gaudich.) Steud.	Kāwelu	E	—	—	—	—	—	87	84	1	
<i>Isachne distichophylla</i> Munro ex Hillebr.	‘Ohe	E	43	41	—	—	—	—	—	1	
Shrubs											
<i>Clidemia hirta</i> (L.) D. Don	Koster's curse	I*	1,290	669	23,543	5,244	16,164	5,323	46		
<i>Syphelia tameiameiae</i> (Cham. & Schltdl.) F. Muell.	Pūkiawe	N	6,048	2,211	14,106	3,135	4,930	2,515	47		
<i>Melastoma candidum</i> D. Don	Asian melastome	I*	—	—	6,987	3,099	17,530	5,989	22		
<i>Dodonaea viscosa</i> (L.) Jacq.	‘A‘ali‘i	N	4,783	2,351	8,824	2,725	2,176	1,262	29		
<i>Freycinetia arborea</i> Gaudich.	‘Ie‘ie	N	—	—	6,299	2,740	8,146	3,480	21		
<i>Lantana camara</i> L.	Lantana	I*	358	211	5,784	2,827	4,352	2,615	18		
<i>Rubus hawaiiensis</i> A. Gray	‘Ākala	E	1,433	960	6,960	3,560	172	134	10		
<i>Osteomeles anthyllidifolia</i> (Sm.) Lindl.	‘Ūlei	N	1,637	1,278	41	41	6,880	3,891	11		
<i>Vaccinium calycinum</i> Sm.	‘Ōhelo kau la‘au	E	2,450	1,119	3,121	992	1,734	1,170	26		
<i>Desmodium tortuosum</i> (Sw.) DC.	Dixie ticktrefoil	I	—	—	—	—	4,809	4,465	1		
<i>Paederia foetida</i> L.	Stinkvine	I	—	—	2,531	1,698	1,643	814	6		
<i>Vaccinium reticulatum</i> Sm.	‘Ōhelo ‘ai	E	1,334	1,029	1,380	731	229	224	12		
<i>Ageratina riparia</i> (Regel) R. M. King & H. Rob.	Hamakua pamakani	I	—	—	2,876	2,516	—	—	1		
<i>Alyxia stellata</i> (J.R. Forst. & G. Forst.) Roem. & Schult.	Maile	N	138	126	2,585	1,364	64	50	8		
<i>Rubus argutus</i> Link	Sawtooth blackberry	I*	2,564	2,375	—	—	—	—	2		
<i>Plumbago zeylanica</i> L.	‘Ilie‘e	N	2,452	2,139	—	—	—	—	1		
<i>Passiflora tripartita</i> (Juss.) Poir. var. <i>mollissima</i> (Kunth) Holm-Niesen & P.M. Jørg.	Banana Poka	I*	—	—	2,074	1,505	160	126	6		
<i>Tibouchina urvilleana</i> (DC.) Cogn.	Princess-flower	I	—	—	—	—	1,554	1,011	2		

Table A2-12—Estimated area of understory vegetation cover by life form, land owner group, and number of Forest Inventory and Analysis subplots where the species occurred (continued)

Scientific name	Common or Hawaiian name	Native (n)/endemic (e)/ Polynesian introduced (p)/ introduced (i)	Owner group						Number of subplots		
			Federal			State and local government				Private	
			Total	SE		Total	SE			Total	SE
-----Area (acres)-----											
<i>Tibouchina herbacea</i> (DC.) Cogn.	Herbaceous glorytree	I*	—	—	1,011	623	387	338	4		
<i>Pluchea carolinensis</i>	Cure for all	I	138	126	975	853	—	—	2		
<i>Amaranthus spinosus</i> L.	Spiny amaranth	I	—	—	1,099	1,252	—	—	1		
<i>Passiflora edulis</i> Sims	Purple granadilla	I	—	—	—	—	1,044	1,013	1		
<i>Rubus rosifolius</i> Sm.	West Indian raspberry	I	—	—	607	290	436	212	9		
<i>Dioscorea bulbifera</i> L.	Pi`oi	P	—	—	—	—	966	752	1		
<i>Solanum pseudocapsicum</i> L.	Jerusalem cherry	I	946	903	—	—	—	—	1		
<i>Cestrum nocturnum</i> L.	Night jasmine	I*	—	—	855	875	—	—	1		
<i>Chenopodium oahuense</i> (Meyen) Aellen	‘Āweoweo	E	—	—	748	744	—	—	1		
<i>Passiflora ligularis</i> Juss.	Sweet granadilla	I	—	—	—	—	711	597	1		
<i>Lycopodiella cernua</i> (L.) Pic. Serm.	Wāwae`iole	N	—	—	651	467	—	—	1		
<i>Abutilon grandifolium</i>	Hairy Indian mallow	I	490	428	—	—	129	113	2		
<i>Leonotis nepetifolia</i> (L.) R. Br.	Christmas candlestick	I	—	—	606	691	—	—	1		
<i>Neonotonia wightii</i> (Wight & Arn.) Lackey	Perennial soybean	I	594	518	—	—	—	—	1		
<i>Coprosma ernodeoides</i>	Kūkaenē	E	—	—	141	120	428	419	3		
<i>Passiflora</i> sp.	Passionflower	I	490	428	—	—	—	—	1		
<i>Delairea odorata</i> Lem.	Cape-ivy	I	—	—	486	484	—	—	1		
<i>Philodendron hederaceum</i> (Jacq.) Schott var. oxycardium (Schott) Croat	Heartleaf philodendron	I	—	—	—	—	435	422	1		
<i>Passiflora suberosa</i> L.	Corkstem passionflower	I	284	248	—	—	103	90	2		
<i>Scaevola chamissoniana</i> Gaudich.	Naupaka kuahiwi	E	—	—	—	—	387	338	1		
<i>Rubus niveus</i> Thunb.	Snowpeaks raspberry	I*	—	—	—	—	350	228	2		
<i>Arthrostemma ciliatum</i> Pav. ex D. Don	Pinkfringe	I	—	—	—	—	345	315	1		
<i>Dicliptera</i> sp.	Foldwing	I	—	—	—	—	345	315	1		
<i>Ipomoea indica</i> (Burm. f.) Merr.	Oceanblue morning-glory	N	—	—	—	—	343	267	1		

Table A2-12—Estimated area of understory vegetation cover by life form, land owner group, and number of Forest Inventory and Analysis subplots where the species occurred (continued)

Scientific name	Common or Hawaiian name	Native (n)/endemic (e)/ Polynesian introduced (p)/ introduced (i)	Owner group						Number of subplots		
			Federal			State and local government				Private	
			Total	SE	Total	SE	Total	SE		Total	SE
-----Area (acres)-----											
<i>Rubus ellipticus</i> Sm. var. <i>obcordatus</i> Focke	Yellow blackberry	I	310	348	145	119	—	—	—	2	
<i>Stachytarpheta jamaicensis</i> (L.) Vahl	Light-blue snakeweed	I	77	68	—	—	218	211	2		
<i>Wikstroemia monticola</i> Skottsb.	Akia	E	—	—	275	241	—	—	1		
<i>Cyrtandra cordifolia</i> Gaudich.	Hahala	E	—	—	253	231	—	—	1		
<i>Caesalpinia decapetala</i> (Roth) Alston	Shoofly	I	232	203	—	—	—	—	1		
Vine, woody	Unknown shrub/vine	N/A	232	203	—	—	—	—	1		
<i>Cestrum</i> sp.	Jessamine	I	—	—	—	—	230	210	1		
<i>Stachytarpheta australis</i> Moldenke	Branched porterweed	I	—	—	75	66	129	100	2		
<i>Abutilon incanum</i> (Link) Sweet	Ma'o	N	—	—	—	—	199	208	1		
<i>Senna</i> sp.	Senna	N/A	—	—	—	—	199	208	1		
<i>Hedyotis centranthoides</i> (Hook. & Arn.) Steud.	Forest starviolet	E	—	—	—	—	187	204	1		
Shrub (>0.5m)	Unknown shrub	N/A	129	113	—	—	41	47	2		
<i>Monstera deliciosa</i> Liebm.	Tarovine	I	—	—	166	163	—	—	1		
<i>Solanum americanum</i> Mill.	Pōpolo	N	—	—	152	173	—	—	1		
<i>Sida acuta</i> Burm. f.	Common wireweed	I	—	—	150	131	—	—	1		
<i>Stachytarpheta cayennensis</i> (Rich.) Vahl	Cayenne porterweed	I	—	—	—	—	142	136	1		
<i>Pipturus albidus</i> (Hook. & Arn.) A. Gray	Māmaki	E	—	—	—	—	131	110	1		
<i>Desmodium</i> sp.	Ticktrefoil	I	—	—	125	109	—	—	1		
<i>Momordica charantia</i> L.	Balsam pear	I	—	—	114	130	—	—	1		
<i>Cyrtandra</i> sp.	Ha'i'wale	E	—	—	97	93	—	—	1		
<i>Rivina humilis</i> L.	Rougeplant	I	—	—	—	—	87	81	1		
<i>Chamaesyce celastroides</i> (Boiss.) Croizat & O. Deg.	Ekoko	E	—	—	—	—	87	84	1		
<i>Vaccinium dentatum</i> Sm.	‘Ōhelo	E	—	—	—	—	77	68	1		

Table A2-12—Estimated area of understory vegetation cover by life form, land owner group, and number of Forest Inventory and Analysis subplots where the species occurred (continued)

Scientific name	Common or Hawaiian name	Native (n)/endemic (e)/ Polynesian introduced (p)/ introduced (i)	Owner group						Number of subplots
			Federal		State and local government		Private		
			Total	SE	Total	SE	Total	SE	
			-----Area (acres)-----						
<i>Allenrolfea occidentalis</i> (S. Watson) Kuntze	Iodinebush	I	—	—	69	63	—	—	1
<i>Smilax melastomifolia</i> Sm.	Hoi kuahiwi	E	—	—	—	—	64	50	1
<i>Mucuna gigantea</i> (Willd.) DC.	Kāʻēʻe	N	—	—	53	66	—	—	1
<i>Sida</i> sp.	Fanpetals	I	—	—	—	—	49	51	1
<i>Cyrtandra platyphylla</i> A. Gray	Haʻiwale	E	—	—	41	40	—	—	1
<i>Stenogyne</i> sp.	Maohiʻohi	E	—	—	41	40	—	—	1
<i>Sadleria cyatheoides</i> Kaulf.	Puaʻa ʻehuʻehu	E	—	—	36	37	—	—	1
<i>Desmodium incanum</i> DC.	Kaʻimi	I	30	34	—	—	—	—	1

Note: Totals may be off because of rounding; estimates are subject to sampling error; SE = sampling error — = less than 50 thousand acres was estimated. N/A = unknown native status. Some species are listed under two growth habits as a result of field crew calls; this will be corrected in the next report. Most nomenclature follows PLANTS Database (NRCS 2022), but some species include names that are more accepted and recognized by Hawaiians, as recommended by coauthors and reviewers.

Glossary

aerial photography—Imagery acquired from an aerial platform (typically aircraft or helicopter) by means of a specialized large-format camera with well-defined optical characteristics. The geometry of the aircraft orientation at the time of image acquisition is also recorded. The resultant photograph will be of known scale, positional accuracy, and precision. Aerial photography for natural resource use is usually either natural color or color-infrared acquired using digital electronic sensors.

aspect—Compass direction that a slope faces.

biodiversity—Variety and variability among living organisms and the ecological complexes in which they occur. Biodiversity can include genetic, species, and ecosystem diversity, including the number of different items and their relative frequencies (Glowka et al. 1994).

biomass—The aboveground weight of wood and bark in live trees, that are ≥ 1 inch diameter at breast height (d.b.h.), from the ground to the tip of the tree, excluding all foliage. The weight of wood and bark in lateral limbs, secondary limbs, and twigs under 0.5 inch in diameter at the point of occurrence on sapling-size trees is included.

bole—Trunk or main stem of a tree.

condition class—For USDA Forest Service Forest Inventory and Analysis plots, a uniform area of accessible forest land that is delineated based on reserve status, owner group, forest community type, stand size class, regeneration status, and tree density.

damage—Damage to trees caused by biotic agents such as insects, diseases, and animals or abiotic agents such as weather, fire, or mechanical equipment.

diameter at breast height (d.b.h.)—The diameter of a tree stem 4.5 ft above the ground (breast height) on the uphill side of a tree. The point of diameter measurement may vary on abnormally formed trees (USDA FS 2016).

diameter class—A classification of trees based on diameter of outside bark, measured at 4.5 ft above the ground (see diameter at breast height) or if the tree has multiple stems, the diameter of each is taken and combined to establish total diameter for the tree. Woodland species diameters are measured at the ground line, or at the stem(s) diameter at root collar, whichever is higher. Diameter class increments may vary and are typically 5 to 10 inches (defined in tables and figures throughout this report).

disturbance—Any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment (Helms 1998).

ecosystem—A spatially explicit, relatively homogeneous unit of the Earth that includes all interacting organisms and components of the abiotic environment within its boundaries. An ecosystem can be of any size: a log, a pond, a field, a forest, or the Earth's biosphere (Helms 1998).

elevation—Height above a fixed reference point, often the mean sea level.

endemic—a species is unique to a defined geographical location, e.g., species only found in Hawai'i.

erosion—The wearing away of the land surface by running water, wind, ice, or other geological agents.

forb—A broad-leaved herbaceous plant, as distinguished from grasses, shrubs, and trees (USDA FS 2016).

forest land—The USDA Forest Service Forest Inventory and Analysis program defines forest land as an area currently or formerly (within 30 years) exhibiting at least 10 percent crown cover of trees of any size and which is not currently developed for nonforest use (USDA FS 2016). Forest land must occupy at least 1 ac and have a minimum continuous width of 120 ft.

graminoid—Grasses (family Gramineae or Poaceae) and grasslike plants, such as sedges (family Cyperaceae) and rushes (family Juncaceae).

grassland—Land on which the vegetation is dominated by grasses, grass-like plants, or forbs.

Hawaiian forest community type—The USDA Forest Service Forest Inventory and Analysis program categorized nine different vegetation community types in Hawai‘i: montane rainforest, lowland tropical rainforest, moist (mesophytic) forest, dry (xerophytic) forest, cloud forest, strand (halophytic) vegetation, mangrove swamps, plantations, and agroforestry. Field crews classified forest communities from dominant tree species both by tally and crown cover (canopy strata dominance), and from different topographical, climatic, and management characteristics (Mueller-Dombois and Fosberg 1998, USDA FS 2019a).

Hawai‘i State Conservation District lands—Hawai‘i State Conservation District lands are managed by the Department of Land and Natural Resources. The conservation district is divided into five subzones: protected, limited, resource, general, and special. The first four subzones are arranged in a hierarchy of environmental protection, ranging from priority resources that are most protected (protected) to those that are less environmentally sensitive (general) (Oswalt et al. 2014, DLNR 2020a). “Special” subzones are defined by unique land uses on a specific site location. Hawai‘i land use district boundary maps can be found here: <https://luc.hawaii.gov/maps/>, and rules and regulations for the use of conservation district lands are found here: <https://dlnr.hawaii.gov/occl/conservation-district/> (State of Hawai‘i 2022a, 2022b).

introduced species—species that are nonnative or naturalized and are introduced by humans and have established or expanded their populations (Imada 2012).

invasive species—Species that are nonnative to the ecosystem under consideration and that cause or are likely to cause economic or environmental harm or harm to human, animal, or plant health.

live trees—All living trees, including all size classes, all tree classes, and both commercial and noncommercial species listed in the USDA Forest Service Forest Inventory and Analysis field manual (USDA FS 2016).

mortality—The death of trees from natural causes, or after incidents, such as storms, wildfire, or insect and disease epidemics (Helms 1998).

native species—Plant species that were native to an American region prior to Euro-American settlement. Native plant status was determined by the USDA Plants Database (USDA NRCS 2019).

nonforest land—Land that has never supported forests or formerly was forested and currently is developed for non-forest uses. Included are lands used for agricultural crops, residential areas, and constructed roads. The area must be at least 1 ac and 120-ft wide.

nontimber forest products (NTFP)—Species harvested from forests for reasons other than production of timber commodities.

owner group—USDA Forest Service Forest Inventory and Analysis (FIA) defines landowner as an individual; a combination of persons such as a company, cooperation, partnership, club or trust; or a public agency that, as a legal entity has ownership interest on a parcel or group of parcels of land. In Hawai‘i, federal, state, county, and municipal government administered lands may include long-term lease agreements for the use and management of lands, and for FIA reporting purposes are grouped with other government “owned” lands managed in the public trust. This report further combines numerous land ownership classifications into three general owner groups: federal, state and county government, and private.

overstory—Uppermost canopy layer, including emergent, dominant and codominant trees.

pathogen—Parasitic organism directly capable of causing disease or mortality.

Polynesian-introduced species—also known as “canoe plants,” e.g., ti (*Cordyline fruticosa* (L.) A. Chev), niu (*Cocos nucifera* L.), and hau (*Hibiscus tiliaceus* L.), are nonnative and were historically introduced by Polynesian ancestors who arrived in Hawai‘i around 1200 CE.

poststratification—A statistical tool used to reduce the variance of the attributes of interest by partitioning the population into homogenous strata. This method uses the number of forest pixels in satellite imagery in combination with land management or owner groups, precipitation, and canopy cover to generate forest estimates at the jurisdictional level from the plot-level data (Bechtold and Patterson 2005).

regeneration—The established progeny from a parent plant, seedlings, or saplings in a stand, or the act of renewing tree cover by establishing young trees naturally or artificially. May be artificial (direct seeding or planting) or natural (natural seeding, coppice, or root suckers) (adapted from Helms 1998).

remote sensing—Capture of information about the Earth from a distant vantage point. The term is often associated with satellite imagery but also applies to aerial photography, airborne digital sensors, ground-based detectors, and other devices.

reserved forest land—USDA Forest Service Forest Inventory and Analysis (FIA) designates areas as “reserved” if the land prohibits, by law, the commercial production of wood products through statute or administrative designation (USDA FS 2016, 2019a). All private lands, including in-holdings, those owned by some conservation groups, those with conservation easements, and tribal protected areas, are considered not reserved, because it is difficult to determine legal status (USDA FS 2019b). FIA has adopted a default national list of federal land designations that are considered reserved (USDA FS 2019a). All federally owned lands managed by the National Park Service or U.S. Fish and Wildlife Service are considered reserved, and some

lands owned by state or county governments are considered reserved, even in the absence of specific laws covering them, if the agency mandate for that land designation precludes management to produce wood products (e.g., most state parks). In the absence of state-specific lists of reserved areas, any state or county government land area that includes “wilderness,” “wild river,” “reserve,” or “preserve” in the name is by default considered reserved. Note that harvests can occur in reserved areas, for example for restoration, safety, or recreation (USDA FS 2019a), or the rare possibility of commercial harvesting mainly with the goal of preserving an intact forest ecosystem. This FIA definition is used to summarize variables by reserved land status throughout this report.

sampling error—Difference between a population value and a sample estimate that is attributable to the sample, as distinct from errors due to bias in estimation, errors in observation, etc. Sampling error is measured as the standard error of the sample estimate (Helms 1998).

sapling—A live tree 1 to 4.9 inches in diameter (USDA FS 2016).

seedlings—Live trees <1 inch diameter and at least 6 inches in height (softwoods) or 12 inches in height (hardwoods) (USDA FS 2016).

shrub—Perennial, multistemmed woody plant, usually less than 13 to 16 ft in height, although under certain environmental conditions, shrubs may be single-stemmed or taller than 16 ft. This also includes succulents (e.g., cacti).

slope—Measure of change in surface value over distance, expressed in degrees or as a percentage (Helms 1998).

snag—A “standing dead tree.” To qualify as a snag, dead trees must be at least 5 inches diameter at breast height, have a bole that has an unbroken actual length of at least 4.5 ft, and have a lean angle that is less than 45 degrees from vertical.

stand size class—A classification of forest stands based on tree size. Large-diameter class refers to stands with a majority of trees ≥ 11 inches diameter at breast height (d.b.h.) for hardwoods and ≥ 9 inches d.b.h. for softwoods; medium-diameter class is a majority of trees 5 to < 11 inches d.b.h.; and small-diameter class is a majority of trees < 5 inches d.b.h.

succession—The gradual replacement of one community of plants by another (Helms 1998).

tree—The USDA Forest Service Forest Inventory and Analysis (FIA) program defines a tree as a woody perennial plant, usually with a single, well-defined stem supporting a crown of leaves, with a minimum diameter at breast height of 3 inches (7.6 cm) and a minimum height of 15 ft (4.6 m) at maturity. Tally trees are defined as all live and standing dead trees (i.e., snags in accessible forest land or measurable nonforest land condition classes (USDA FS 2016). Any plant species on FIA's tree list in the current field manual is measured as a tree.

understory—Lowermost canopy layer including shrubs, vines, and herbaceous vegetation such as forbs and graminoids.

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