Koa Action Plan

Management and research priorities for *Acacia koa* forestry in Hawai‘i
State of Hawai‘i Department of Land and Natural Resources
Division of Forestry and Wildlife

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Enhance, protect, conserve and manage Hawaiʻi's unique and limited natural, cultural and historic resources held in public trust for current and future generations of the people of Hawaiʻi nei, and its visitors, in partnership with others from the public and private sectors.

DIVISION OF FORESTRY & WILDLIFE (DOFAW) MISSION STATEMENT

The mission of DLNR's Division of Forestry and Wildlife is to responsibly manage and protect watersheds, native ecosystems, and cultural resources and provide outdoor recreation and sustainable forest products opportunities, while facilitating partnerships, community involvement and education. DOFAW's motto is "*Malama i ka aina*" (respecting the land).

DLNR AND DOFAW STATUTORY MANDATES

Portions of the following Hawaiʻi Revised Statues require native forest management including koa forested lands:
Ch. 171, Ch. 183, Ch. 183C, Ch.183D, Ch. 185, Ch. 195, Ch. 195D, and Ch. 195F.

DIVISION OF FORESTRY & WILDLIFE VISION FOR KOA

Abundant, healthy koa forests that connect people to Hawai'i's culture and natural resources while providing sustainable economic opportunities that promote forest conservation.

KOA IN HAWAIIAN CULTURE

Koa is an important part of traditional and modern Hawaiian culture. The plants and animals found in Hawaiʻi, many of which are found nowhere else, have shaped this unique culture. Koa is regarded as an important tree that represents strength and the warrior spirit. The Hawaiian moʻolelo (saying or story), *e ola koa* (live like a koa tree), suggesting to have a long life and live with strength reflects the importance of koa in Hawaiian culture. Many Hawaiian children are named after the koa tree.

Another Hawaiian saying is *ua ʻelepaio ʻia ka waʻa* (the ʻelepaio has marked the canoe). Traditionally, Hawaiian canoe makers determined whether a koa tree would be suitable to use for a canoe based on whether the ʻelepaio, an endemic insectivorous bird, pecked at the tree. Koa is the traditional wood for making Hawaiian canoes, but few trees large enough to make canoes remain in the forests. Ancient and modern Hawaiians also use koa wood for making paddles, bowls, and many other items. The wood is particularly prized because of it brilliant color and figure. Koa is widely used for making musical instruments, especially guitars and ukuleles. It is also used to make high-value furniture, surfboards, ornaments, and art. Koa trees are an important part of the recreational, spiritual, utilitarian, and aesthetic value of native forests, and serve to connect people to native Hawaiian species.

INTRODUCTION

Purpose

The purpose of this Koa Action Plan (KAP) is to describe the actions needed to achieve DOFAW's vision for *Acacia koa* (koa) forests. Koa is the second-most abundant native tree species in the Hawaiian Islands (in terms of areas covered, **Figure 1**) and provides the largest economic value of any species for the Hawaiian wood products industry. The United States Forest Service (USFS) State and Private Forestry (S&PF) agency provided the impetus for a more detailed strategy for this important forest species as a supplement to the 2010 Hawai‘i Statewide Assessment of Forest Conditions and Trends (SWARS).

DOFAW has a special role in recognizing and addressing koa-related issues. DOFAW is the single largest landowner of koa-dominated forests in Hawai‘i (**Figure 2** and **Figure 3**) and is charged with managing this important resource for the long-term benefit of the people of Hawai‘i. Additionally, DOFAW provides financial and technical assistance for landowners to manage and plant forests on private lands.

This document includes short and long term goals for koa forestry statewide. It also provides koa forest land owners and managers information about koa research, management, and utilization. The recommendations in this plan will be used by state and federal agencies to strategically allocate funding and leverage investments and will serve as an action plan for those working on koa forestry so that resources can be most effectively targeted to achieve priority goals on state, federal, and private lands. It is important to recognize that the objectives described herein can only be accomplished with adequate, long-term funding and partnerships.

Relation to Other Plans

Several other plans have been written that pertain to koa forest management. In 1992, the U.S. Congress passed the Hawai‘i Tropical Forest Recovery Act (HTFRA, Public Law 102-574, 106 Stat. 4593) sponsored by Senator Akaka. This law established the Hawai‘i Experimental Tropical Forest (HETF) to model sustainable harvest, research, and outreach. This Bill also established a Hawai‘i Tropical Forest Recovery Task Force, which was comprised of representatives from federal, state, and private organizations. In 1994, the Task Force created a state plan, the Hawai‘i Tropical Forest Recovery Action Plan (Hawaii Tropical Forest Recovery Task Force 1994). In 2005, the Hawai‘i State DLNR created Hawai‘i’s Comprehensive Wildlife Conservation Strategy (HCWCS; also known as the Hawai‘i Wildlife Action Plan and the Statewide Wildlife Action Plan) (Mitchell et al. 2005). Although the HCWCS focuses on wildlife, it emphasizes that native plants, especially koa, are essential to conservation of native biodiversity. Additionally, many of the primary challenges to conserving wildlife listed in this plan also apply to koa forest management (

Tables

Table 1). In 2009, the USFS State and Private Forestry agency developed Forestry National Themes to guide strategic directions for National Forests (**Table 2**) and required that all states receiving federal assistance create forest action plans to highlight state-wide issues related to these national themes for state and private lands. In 2010, under guidance in the 2008 Farm Bill, the State of Hawai‘i created the Hawai‘i Statewide Assessment of Forest Conditions and Resource Strategy (also known as the Hawai‘i Forest Action Plan FAP). The FAP describes strategic directions for nine issues concerning Hawaiian forestry (**Table 3**). Between 2010 and 2013, USFS has funded DOFAW over $2.6 M for eleven projects related to forest health, invasive species management, wildlife conservation, forest tree production, and watershed protection based on needs detailed in FAP. The State and Private Forestry National Themes (**Table 2**) and State Issues from the FAP (**Table 3**) that relate to each area are listed under each section header. In 2011, the Hawai‘i State DLNR wrote a plan for watershed improvement known as The Rain Follows the Forest plan (Department of Land and Natural Resources 2011). Further, management plans for several Watershed Alliances, Forest Reserves, and Natural Area Reserves include koa reforestation as a key objective. The KAP takes into account recommendations from many of these plans where they relate specifically to koa.

Koa biology and value

Acacia koa A Gray (koa) is the second most common tree species in Hawai‘i and is a dominant and co-dominant canopy tree in many native forests across the Hawaiian Islands. Endemic to Hawai‘i, it is closely related to *Acacia* species from Reunion (Le Roux et al. 2014). Koa is a member of the legume family (Leguminoseae/Fabaceae) and forms a symbiotic relationship with nitrogen-fixing bacteria. It bears bi-pinnately compound "true" leaves that transition to sickle-shaped phyllodes. Under ideal conditions, it is a tall tree that grows to over 115 ft (35 m). Koa has a wide distribution in Hawai‘i, currently occurring on four of the main islands (Hawai‘i, Maui, Oahu and Kauai). According to habitat models based on past occurrence records, koa once ranged from near sea level to over 7000 ft (2100 m) and on the wet and dry sides of all the large Hawaiian islands (**Figure 1**). However, over 90% of the remaining koa forests occur on Hawai‘i Island (Baker et al. 2009). Additional detail on koa biology and ecology can be found in the USDA publication, Koa (*Acacia koa*) Ecology and Silviculture (Baker et al. 2009)[1].

Koa has substantial ecological, economic, and cultural value. Koa forests provide habitat to 30 of Hawai‘i's remaining 35 native bird species, many of which are threatened or endangered with extinction (Mitchell et al. 2005). Koa forests also provide habitat for native plant and invertebrate species and for the Hawaiian hoary bat (Mitchell et al. 2005). In addition, koa forests enhance watersheds, ameliorate degraded soil conditions, and store carbon. It also forms an important structural component of native forests (Asner et al. 2011). Koa is Hawai‘i's premier timber species, contributing the majority of the state's $30 million/year forest products industry (Yanagida et al. 2004). It also provides one of the most valuable woods in the world, with prices typically ranging from $3 to $15 per board foot and up to $125 per board foot for the highest quality pieces (Baker, Scowcroft, and Ewel 2009). Given these varied uses and values, the goal for sustainable forestry is to provide a win-win-win situation by simultaneously promoting conservation, economic development, and cultural enhancement.

[1] http://www.fs.fed.us/psw/publications/documents/psw_gtr211/psw_gtr211.pdf

Social and ecological context
Over the past 150 years, substantial amounts of koa forest have been destroyed or degraded by conversion of upland forest to pasture and lowland forest to sugar cane or other food crops. Combined with limited regeneration due to invasive plant and animal species, koa has been locally extirpated from the majority of its previous range. With the demise of the sugar cane industry and low profitability of cattle ranching, tens of thousands of acres in Hawai‘i of abandoned agricultural land may be available for reforestation. Koa may be the ideal native tree to restore these degraded lands because it is a fast-growing tree that thrives in full sun, is widely adaptable, and is easy to propagate. As the monetary value of koa has increased dramatically over the past few decades (Yanagida *et al.* 2004), so has both demand for the wood and interest in planting koa as a timber species. Additionally, societal values increasingly recognize the importance of native species and the ecosystem services they provide, from recreational opportunities to carbon sequestration. Thus, the current societal and ecological context provides the opportunity and the impetus to reforest large areas with this important native species.

Stakeholder input methods summary
Inclusion of stakeholder input into this plan was of primary importance to DOFAW. To solicit stakeholder input, categories were defined of groups expected to be interested in, knowledgeable about, and/or affected by actions related to koa (e.g., public land managers, private landowners, and cultural practitioners). The goal of the survey was to acquire input to identify the most pressing koa-related issues and actions from a broad cross-section of stakeholders. To obtain a variety of ideas from a diversity of sources, several representative stakeholder groups and individuals in each category were identified. Stakeholders in each category completed electronic surveys. Details of the survey and summary results are in **Appendix 1**. Thus, this plan includes ideas and recommendations from landowners (small and large, private and public), scientists, educators, cultural practitioners, foresters, the wood products and nursery industries, and others. The content of the plan is largely based on these responses and subsequent stakeholder discussions and reviews. Three major objectives were identified from the survey responses, each with several specific actions related to that objective. The percent of stakeholder survey responses that referred to each objective, which is reflective of stakeholder prioritization, is summarized in the appendix. Responses to our survey indicate that stakeholders see demonstration of sustainable forest management as an extremely important action, with over half of responses (51%) referring to the need for improved management for existing forests and restoration to create future forests. A major take-home message was that the state should take a strong leadership role and show the way by sustainably managing their existing forests and restoring degraded lands.

Organization of the plan
Following this introduction, there are two sections that list major objectives and describe several actions related to these objectives. For each objective, a specific goal, a general problem statement, brief background, primary knowledge gaps, suggested project ideas, and some metrics of success are listed. Given the nature of the topics covered, there is some overlap in the text of each section to make it possible for readers to peruse each section without reading the entire document. The project ideas listed are intended to be suggestions to illustrate some of the projects that could be undertaken, given the availability of funding and other resources. These ideas are not a comprehensive list, and others may propose equally or more viable ideas in the future. However, it is hoped that these ideas will provide the starting point for developed

proposals by students, scientists, and managers that will bring us closer to achieving the major objectives. The objectives and actions listed in this plan are not hierarchically ranked as all are considered important and the order in which they are done will depend on available funding and capacity. Indeed, lack of funding and limited professional capacity may be the single largest impediment to progress towards attaining DOFAW's vision for koa.

1. MANAGE EXISTING KOA FOREST

State FAP issues addressed: 1, 2, 3, 5, 6, 7, 8
National themes addressed: 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 3.4, 3.5, 3.7

1.1. Manage existing koa forests for conservation and sustainable production of forest products

Goal

- Develop and implement active management plans for natural forests to balance conservation, social values, and economic values.
- Provide a sustainable supply of forest products to support the forest products industry and cultural practitioners while maintaining or increasing the conservation value of native forests.

Problem statement

- The demand for koa wood for the forest products industry exceeds demand, but harvesting must be carefully managed to ensure that ecological and cultural values are not compromised. Based on stakeholder surveys, there is substantial concern that old-growth trees may be overharvested and that actions to ensure forest regeneration following harvest are not uniformly applied. Further, there are large knowledge gaps in understanding koa forest dynamics to support the creation of sustainable harvesting plans.

Background

Sustainable management of natural koa forests can balance conservation, social values, and economic goals. As commented by one stakeholder: "Balance reflects the sustainability model of the 3 legged stool: environment, economy, and social equity. Too much emphasis on one or more legs at the expense of other legs results in the stool tipping over, and thus is not sustainable. [All legs do not] need to be equal, but [they do] need enough “balance” to keep the stool upright." Although it is possible to manage koa forests for multiple purposes, not all needs must be met in all locations at all times. Rather, management practices should be appropriate to the objectives for a given land management unit. Whether the goals are wildlife habitat or timber production, it is essential to take a long-term view of forest management to ensure the health of the ecosystem and the trees.

Koa is an important component of native forests, providing structure and habitat for native plants and animals. It is also important for improving watersheds, enriching soils, and storing carbon. Thus, management of natural forest stands should not reduce the ability of forests to provide these and other important ecosystem services.

As the base of Hawai‘i's forest products industry, koa from natural stands has been harvested to provide wood for the forest products industry. In most cases, harvesting has been done without ensuring stand regeneration. Sustainable harvesting of koa requires foresters to carefully develop harvest plans and manage regeneration or replanting with an eye towards the long-term future health and productivity of the forest. This requires knowledge about stand dynamics, growth rates, regeneration methods, and access/hauling plans. To ensure sustainability of a forest, at a minimum, the number of trees established should equal or exceed those that were harvested. Currently, we have sparse information on many of the factors that determine whether a harvest is sustainable, as no koa plantation has ever been managed through a full rotation. Standards for sustainable forest management are well-developed for many timber species

nationally, but do not include Hawaiian species (e.g., National Report on Sustainable Forests-2010, (USDA Forest Service 2010)). However, substantial amounts of growth data for koa are available from a number of long-term measurement plots (Baker, Scowcroft, and Ewel 2009). The standards and criteria for other species and forest types could potentially be used in conjunction with data on koa growth and regeneration to develop models for sustainable harvest. This would serve as an important first step towards creating a sustainable forestry industry in Hawai‘i and should be a high priority.

Knowledge gaps

To fill knowledge gaps about forest management, we require information on the ecology and dynamics of natural forests containing koa. To date, there has been little data collected on active management of koa forests (Baker, Scowcroft, and Ewel 2009). Further studies are needed to understand the role of koa in supporting native wildlife, including invertebrate species and native plants, and how harvesting affects forest dynamics and native species.

A primary knowledge gap for conducting sustainable harvest is that we do not currently have accurate growth and yield models. Data on growth rates across a diversity of ecosystem types (e.g., wet v. dry forest, high v. low elevation) are needed to develop such models. Data collected from long-term native forest plots, such as those managed by researchers at the University of Hawai‘i (UH) and the USDA-FS Institute of Pacific Islands Forestry (IPIF) are providing essential data to this effect. Continued support for long-term forest measurement plots will supply data on growth, mortality, and recruitment needed to make informed decisions. Additionally, we require better information on regeneration methods and how silvicultural practices affect growth rates (described in section 2.2). Until more data are available, applying models that are successful with similar species could be explored and tested (Baker, Scowcroft, and Ewel 2009). Up-to-date maps of the extent and condition of koa forest are also essential for accurate planning of sustainable management and harvest. Improving harvest and utilization methods and equipment would increase the efficiency of harvest operations and the usable yield of harvested trees. The institutional knowledge to conduct timber sales should also be improved (described in section 3.6).

Project ideas

- Continue to write and implement koa management plans for koa-dominated forest lands to maintain and increase ecosystem services (e.g., wildlife habitat, cultural value, economic benefit).
- Measure growth across ecosystem types and create growth models to inform plans for sustainable harvesting.
- Study ecology of koa-dominated forests.
- Map extent and condition of all koa forests using remote sensing and field data.
- Identify and prioritize areas for regenerating koa for generating forest products.

Metrics of success

- Acres of native forest either preserved or managed for sustainable harvesting.
- Forest health and productivity.
- Diversity of native species in preserved forest.

Metrics of success

- Establishment of demonstration forest to model forest stewardship.

- Successful harvest followed by high-quality stand re-establishment.
- Enhanced ecological, economic, and cultural value of koa forests.

1.2. Control grazing animals, invasive plants, and insect pests on koa lands

Goal

- Expand and improve koa forest by removing ungulates and controlling invasive plant species.

Problem statement

- Domestic and feral ungulates and invasive weeds degrade koa forests and prevent natural regeneration by suppressing seedlings.
- Invasive plants reduce the productivity of koa forests by competing with trees.

Background

Active management to remove ungulates and control invasive species is needed to encourage koa forest regeneration, especially in existing and degraded koa forest on state land. Feral and domestic ungulates are common in many areas that were once koa forest. Cattle, sheep, and goats eat koa seedlings and root sprouts, preventing natural regeneration. Feral pigs disturb the soil, reducing natural regeneration of native trees in heavily infested areas (Cole et al. 2012). The adverse effects of ungulates on koa are well-reviewed in Baker et al. (2009). Invasive plant species, especially grasses, suppress seedling growth and survival (Scowcroft and Adee 1991). The result of ungulate and weed presence is degraded natural forest and pastures with remnant, senescent koa trees and little to no regeneration (**Figure 4**). Removing ungulates and controlling invasive plant species is also consistent with the state-wide fencing plan to preserve intact forest and allow for restoration of deforested high rainfall areas developed as part of the Rain Follows the Forest program (Department of Land and Natural Resources 2011)[2]. Specific methods to remove grazing animals from fenced areas have been well developed and used in Hawai‘i by several agencies (e.g., DOFAW, the National Park Service (NPS), and The Nature Conservancy (TNC)).

There are several native and introduced insects that predate koa, reducing its growth and survival and possibly causing poor tree form. Major pests include the acacia psyllid (*Acizzia uncatoids* Ferris & Klyver), twig borers (*Xylosandrus compactus* Eichhoff and *Xyloborus* spp.), and the koa moth (*Scotorythra paludicola* Butler). The acacia psyllid feeds on new growth at branch tips, which may damage the apical meristem and possibly result in multiple leaders (i.e., forked stems) in 1-3 year old seedlings (Friday 2010). Twig borers are primarily an issue at lower elevations (below 900 m) where they may kill young saplings by creating tunnels in the main stem (Daehler and Dudley 2002). Seed predators, including seed weevils (*Araecerus levipennis* Jordan and *Stator* spp.) and the koa seed worm (*Cryptophlebia illepida* Butler) also limit fecundity and may be problem for producing seed from seed orchards (see section 2.3). Chemical repellents and traps have been studied as a means to monitor and control twig borers on both coffee and koa (Burbano et al. 2012). There is some evidence that there is a genetic component to twig borer resistance (Daehler and Dudley 2002). The koa moth is an endemic species that specializes on koa. Koa moth populations occasionally increase to the point where

[2] http://dlnr.Hawai‘i.gov/rain

many acres of adult trees suffer severe defoliation, reducing their growth and survival (Stein and Scowcroft 1984; Haines et al. 2009). Many koa trees respond by flushing true leaves instead of phyllodes, which may be a defense response as koa moths have lower fitness on true leaves than on phyllodes (Barton and Haines 2013).

Knowledge gaps

The ability to fence and remove ungulates from high-value forest and restoration areas is not primarily restricted by lack of knowledge. Rather, lack of funding and public opposition to fencing and removing ungulates are the major impediments to this action. Methods to facilitate the creation of a social contract for forest management to increase consensus among diverse stakeholder groups, as implemented in Canada (Benner, Lertzman, and Pinkerton 2014), deserve further investigation to determine their applicability to Hawai‘i (see section 3.1). Additional information on land use would be helpful to identify lands outside of areas already slated for fencing that would be suitable for koa forests.

Although grazing animals are known to damage young koa trees, there may be potential for closely-managed silvopastoral systems to integrate grazing into stands of mature koa trees. Although widely used in the mainland U.S. and other tropical countries, there are no successful examples of silvopastoral systems with koa in Hawai‘i. Observation of koa trees in areas where grazing animals are present shows that animals often damage koa bark, causing wounds that allow rot and diseases to enter. However, with careful stock rotation, it may be possible to introduce limited grazing of smaller animals, such as sheep, without damaging koa mature trees (Friday 2011). Research to demonstrate these methods would be needed before this could be recommended to land owners.

Additional research and development of more effective management are necessary to cost-effectively reduce invasive weeds and pests, especially at large scales. Herbicide and pesticide trials are needed to refine application methods. In particular, methods for controlling weeds at a large scale prior to planting, such as using aerial spraying, should be further tested. For insect pests, the study and release of effective biocontrols may offer the best chance of control. Biocontrol methods for some invasive species have been developed (Trujillo 2005; Trujillo et al. 2001) and these efforts should be expanded to make koa forestry more cost-effective. New herbicides and pesticides may need to be registered for use once experimental trials are complete. Further investigation on the extent, consequences, and mechanisms of invasive plant species competition with koa is needed to prioritize control measures.

Project ideas

- Work with ranchers to repair existing fences separating forest reserves and ranches or grazing leases.
- Investigate the potential create silvo-pastoral systems that integrate grazing animals and koa.
- Identify and evaluate the threats posed by invasive weeds, pests, and animals.
- Develop more cost-effective strategies for controlling invasive plants and pests, especially at landscape scales.

Metrics of success

- Increased cattle-free acres where koa can regenerate.
- Reduction in cover and biomass of invasive species.
- Increased growth and survival of koa plantings and natural regeneration.

- Management methods for pest control developed.

2. ESTABLISH KOA FOR CONSERVATION AND FOREST PRODUCTS

State FAP issues addressed: 1, 2, 3, 5, 6, 7, 8
National themes addressed: 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 3.4, 3.5, 3.7

2.1. Undertake reforestation with koa on degraded lands within koa's range

Goal

- Restore degraded lands by supporting and undertaking large-scale reforestation with koa.

Problem statement

- Large areas of koa forest have been converted to pastures or sparse woodlands and are now dominated by invasive species, especially invasive grasses. Reforestation with koa could help to restore ecosystem services of degraded lands, and serve as a first step towards returning them to native forests.

Background

Removing ungulates and weeds from lands that were once dominated by koa forests is necessary to promote regeneration, but in many areas active reforestation, such as scarification or planting, will also be necessary. Where adult koa populations persist, there may be a koa seed bank that can be stimulated to germinate by mechanical scarification of the soil, usually by tilling or bulldozing (Baker, Scowcroft, and Ewel 2009). If plantations are intended for specific purposes (e.g., timber production) planting of improved stock may be desirable. Restoring koa forests from pasture will provide ecosystem services including enhanced soil fertility (Scowcroft and Jeffrey 1999), carbon storage (Conte et al. 2009), ground water recharge (Brauman, Freyberg, and Daily 2010; Giambelluca et al. 2011), and wildlife habitat (Pejchar, Holl, and Lockwood 2005). Strategies for developing cost-effective policies to promote and fund reforestation have been proposed and this information may serve as a basis for initiating such policies (Goldstein et al. 2006; Goldstein, Pejchar, and Daily 2008). When planning koa reforestation on agricultural land, it is important to consider and minimize potential conflicts with food production. Models of the climatic range of koa based on past and present occurrence data (Price et al. 2012) show that over half of the land area where koa could potentially grow is owned by state and federal agencies (State 40% and Federal 9%; **Figure 2** and **Figure 3**). Thus, DOFAW has a unique opportunity to provide a model for koa reforestation. Two areas identified by Rain Follows the forest for prioritizing forest restoration include leeward Haleakala and Mauna Kea. However, accomplishing large-scale reforestation will require additional financial and other resources to be allocated to this effort.

Knowledge gaps

A primary question that should be answered as part of a long-term reforestation strategy is where to focus reforestation efforts. It is necessary to define areas where koa reforestation could most contribute to overarching management goals. For example, priority reforestation areas for wildlife conservation may be situated adjacent to intact native-dominated forests or designed to provide migration corridors as is being done by the Department of Hawaiian Home Lands

(DHHL) via their membership in the Mauna Kea Watershed Alliance (MKWA)[3]. Where the management goal is water infiltration or decreased erosion, koa reforestation could be focused in areas within koa's actual or potential range that have been previously identified as priority watersheds for groundwater recharge (**Figure 5**) or restoration (**Figure 6**).

In prioritizing reforestation, efficient use of resources should be considered. In general, improving semi-intact areas will be more cost-effective than reforestation highly invaded or deforested lands (Goldstein, Pejchar, and Daily 2008). For example, low-cost large-scale reforestation of degraded koa forest could be accomplished using soil scarification. A recent study showed that where at least one adult koa persisted after many years of cattle grazing, scarification resulted in abundant natural regeneration, but that areas without nearby koa had little regeneration (Scowcroft 2013). More study of seed longevity in soil and the effects of distance from mature koa trees are needed for planning large-scale reforestation by helping to define in which areas scarification could be used to stimulate koa regeneration and which areas would require planting seedlings.

The contribution of koa reforestation to other ecosystem services, especially soil amelioration, watershed hydrology, and carbon sequestration should be rigorously quantified to fully understand benefits of koa forests and to aid in management decisions. The capacity of koa reforestation to enhance ecosystem services has not been assessed at a large scale. Koa plantations have been shown to provide habitat for native birds (Pejchar, Holl, and Lockwood 2005). However, the level of native biodiversity supported by koa plantations, versus multi-species stands of native forest, should be determined for different forest types and considered in comparison with current uses.

To accomplish the landscape-level reforestation that is urgently needed, techniques are needed to scale up existing practices to cost-effectively plant large areas. Large-scale reforestation will require a greater supply of propagules (seeds and seedlings) than currently available and improved silvicultural practices. Once areas for reforestation are defined, an assessment of propagule needs should be conducted and efforts should be made by private and state nurseries to increase production as needed. Refer to section 2.4 on seed and seedling availability, section 2.2 on developing silvicultural guidelines, and section 2.3 on seed sourcing.

Project ideas

- Map areas appropriate for koa restoration.
- Improve technology and approaches for more efficient and successful large-scale reforestation.
- Create guidelines for best management practices for establishing koa.
- Restore large areas using best-management practices to demonstrate success.
- Quantify enhancements to ecosystem services resulting from reforestation (e.g., wildlife use of reforested areas, watershed hydrology, and carbon storage).

Metrics of success

- Acres reforested with koa.
- Survival and growth rate of koa in reforestation areas.
- Increase in economic and ecosystem value of reforested land.

2.2. Develop and improve silvicultural guidelines

[3] maunakeawatershed.org

Goal

- Develop silvicultural prescriptions to ensure success of reforestation efforts and long-term forest health.
- Develop silvicultural protocols for growing commercial grade koa, especially for improving growth form.

Problem statement

- Lack of silvicultural information limits reforestation success and discourages planting.
- Poor growth form limits commercial value of koa plantations and silvicultural methods should be developed for how to improve form.

Background

Current silvicultural recommendations are largely based on a basic understanding of koa's biology and a number of small scale experiments (Baker, Scowcroft, and Ewel 2009). Much of the available information on koa silviculture is reviewed in Baker *et al.* (2009), with more detailed information in Specialty Crops for Pacific Islands (Friday 2010)[4], Traditional Trees of Pacific Islands (Elevitch, Wilkinson, and Friday 2006), and in the useful book Growing Koa: A Hawaiian Legacy Tree (Wilkinson and Elevitch 2003). Key topics and more recent research are summarized below.

Koa has a wide environmental range. However, the optimal range for planting koa is between 2950-5900 ft (900-1800 m) (Baker, Scowcroft, and Ewel 2009). This range is above the elevation where wilt causes high mortality and below the frost zone.

Koa can be planted as seeds or seedlings or, if seeds persist in the soil seed bank, can be induced to germinate by mechanical scarification of the soil such as ploughing or disking which is most effective in the vicinity of live koa trees (Scowcroft 2013). Koa has an extensive shallow rooting system and root sprouts are common near koa growing in open areas. This characteristic could be used as part of cost-effective "passive restoration" strategies (Scowcroft and Yeh 2013). Koa does best in full sun and does not grow well in shade (Craven, Gulamhussein, and Berlyn 2010). As discussed in other sections, grazing animals must be excluded and controlling weeds and insect pests is essential for good koa growth (refer to section 1.2). Protection from wind may also be necessary in some areas.

Koa grows quickly under the right conditions, but rotation length for commercial production are expected to be long; harvest ages may be 30-80 years depending on site conditions and desired tree size (Baker, Scowcroft, and Ewel 2009). Thinning and fertilization at appropriates time increases growth (Baker, Scowcroft, and St 2005; Scowcroft et al. 2007). High stand density does not appear to improve form; after 21 years high-density stands did not have a lower proportion of forked stems than low-density stands (Scowcroft 2013). Preparation of planting sites is vital to the survival and growth of planted koa. Recent studies have found that substantial gains can be obtained by application of appropriate treatments. For example, researchers found that placing shade-cloth structures near koa seedlings planted at high elevations dramatically increased survival (Scowcroft and Jeffrey 1999). Additionally, complete weed control substantially increases growth rates (Scowcroft et al. 2007; Scowcroft and Adee 1991).

Knowledge gaps

[4] http://www.traditionaltree.org/

New experiments, and follow up on established experiments, are needed to refine techniques for controlling weeds, fertilization, soil preparation, and other factors. Expert knowledge from researchers and the private forestry sector should also be used to enlarge the information base. The results should be synthesized into a working manual for koa planting. The "best" silvicultural methods will necessarily vary with site conditions, thus experiments should be conducted across a diversity of conditions.

Despite decades of study, many questions remain regarding koa planting; this limits successful restoration and commercial production. For example, it is unknown how long koa seeds persist in soil seed banks. This information is needed to delineate areas where mechanical scarification may be most effective. More information on the efficacy of direct seeding is also needed, as this method has the potential to lower planting costs (Baker, Scowcroft, and Ewel 2009). Depending on the region, the timing of planting may have a substantial effect on planting success; though this aspect of koa planting has not been studied. The optimal initial density for planting koa has likewise not been well-studied. Fertilization of koa increases growth rates (Baker, Scowcroft, and St 2005; Scowcroft et al. 2007), and may ameliorate poor soil conditions or poor seed sources (Cole et al. 1996), though the physiological mechanisms of growth responses to fertilizer are poorly understood (Scowcroft and Silva 2005).

Once established, continued management can improve the growth, health, and form of young koa trees. Thinning koa stands at appropriate ages can increase the growth of the remaining trees (Scowcroft et al. 2007). However, more information regarding timing and intensity of thinning is needed to develop specific thinning prescriptions. Pruning koa to improve form was previously not recommended because koa often heals poorly from wounds (Baker, Scowcroft, and Ewel 2009). Recently, koa researchers and private landowners have found some success with pruning to improve koa form. More work is needed to test pruning techniques and determine the long-term effects on form and wood quality.

The development of accurate models has been hampered by the fact that no koa plantation has been through a full rotation of establishment, thinning, harvest, and reestablishment (Friday 2010). The rotation age and expected yield for koa plantations across a variety of environmental conditions must be determined to develop accurate economic models. These models are essential to promote private investment in koa forestry and develop carbon markets.

There is growing interest in using koa as part of mixed-species plantings both for commercial production (e.g., as shade for coffee[5], or as overstory for native plants). Established koa can provide some benefits to other species. For example, at high elevations, ohia (*Metrosideros polymorpha*) planted under koa canopies suffered less frost damage and survived better than ohia planted in the open (Scowcroft et al. 2000). Additionally, interplanting short-rotation crops, such as coffee or Christmas trees, could provide landowners with rapid returns on investments, making koa forestry more economically attractive. However, koa may compete with other plants and its shade may reduce growth of understory plants. More studies to test methods for mixed-species plantings should be conducted.

Project ideas

- Planting trials to test the benefits of different planting densities, planting timing, thinning schedules, and mixed species planting.

[5] http://agroforestry.net/projects/Hawai‘i-coffee-agroforestry-systems

- Conduct planting studies to create a planting calendar by region with optimal times for seed collecting, sowing, and outplanting.
- Develop predictive models of koa stand growth and yield.
- Harvest planted stands that have reached adequate size to refine yield estimates and increase our understanding of how to sustainably manage koa as a timber crop.

Metrics of success
- Survival, growth, and health of natural and planted koa.
- Increased number of commercially successful plantations.
- Silvicultural best management practices (BMPs) guide written for koa reforestation.

2.3. Develop seed source, handling, and storage guidelines

Goal
- Clear guidelines for collecting, handling and storing seeds from appropriate sources based on an understanding of koa's adaptive range and genetic structure.

Problem statement
- Lack of data on koa's adaptive range and genetic structure makes it impossible to adequately define seeds zones, creating confusion about the proper sources for seeds for a given site and the ranges across which collected seeds can be planted.
- Koa processing can be laborious and time consuming without effective tools.
- Lack of information on koa seed storage methods to optimize long-term viability and information management system to track seed accessions.

Background
For every planting operation, landowners must select the source of propagules to plant into a given site. To ensure growth and survival of planted seedlings, landowners are usually advised to source propagules from sources as near to the planting area as possible so that the trees will be adapted to site conditions (Baker, Scowcroft, and Ewel 2009). However, seedling performance in a given site may be due to a number of factors including rainfall, temperature, and soils. Performance differences among source populations may be due to genetic differences resulting from past reproductive isolation. Thus, it is unknown whether the best sources are those that are "near" to the planting site in terms of environmental conditions or "near" in terms geographic distance. For example, do plants sourced from low-elevation sites do best at other low-elevation sites, or is it more important to select sources with similar rainfall or soils? Alternately, we may find that adaptive differences across populations are primarily linked to geographic distance (e.g., trees from Oahu do better on Oahu than on other islands). Where differences between source and site conditions are important, how much difference can be tolerated?

The genetic structure of koa within and across populations will provide clues about eco-region boundaries. Isozyme studies revealed that trees from Oahu, Kauai, and Maui were genetically similar but that they differed from trees from Hawai‘i Island (Conkle 1996). This finding was supported by analysis of morphological traits which found that leaves, seed, and pod characteristics of trees from Oahu and Kauai were similar but differed substantially from trees from Hawai‘i Island (Daehler et al. 1999).

However, genetic differences among populations may indicate adaptive differences or they may be an artifact of demographic history or of genetic drift due to habitat fragmentation or

founder effects (Sork et al. 2013; Savolainen, Lascoux, and Merila 2013). Thus, it is necessary to directly evaluate potential negative or positive genetic consequences for crossing ecoregion boundaries. For example, planting genotypes from other ecoregions could lead to outbreeding depression (i.e., reduction in fitness of offspring resulting from cross pollination of genetically *dissimilar* trees), which may reduce the fitness of local populations (Thomas et al. 2014; Kettenring et al. 20147). Alternately, introducing new genotypes to small, isolated populations may "rescue" them from inbreeding depression (i.e., reduction in fitness of offspring resulting from cross pollination of genetically *similar* trees), and may be an important conservation tool (Thomas et al. 2014; Kettenring et al. 20147). However, this practice is controversial among some who fear deleterious ecological effects of mixing koa genes among regions and islands. Ultimately, rapidly changing climates and the need to reforest areas from which koa has been extirpated will require us to make decisions about where to source propagules from outside local areas (Andrew et al. 2013).

The few available provenance studies suggest that seed source affects tree performance across sites. In one experiment, seed sources from eight locations from four islands ranging widely in elevation (500-6200 ft) and rainfall (40-140 in. mean annual precipitation (MAP)) throughout the state were planted into a single site on Oahu (Conrad, M., and H. 1995). This study found that trees sourced from elevations similar to the planting site and from the Kauai and Oahu sources performed best (Conrad, M., and H. 1995). Another experiment at this site explored the relationships between P fertilization, soil type, and seed source (Scowcroft and Silva 2005). This study also found that the local source performed better, probably due to adaptation to poor soils (Scowcroft and Silva 2005). A separate experiment tested seeds sourced from two wet sites on Hawai‘i Island (elevation range: 2200-3800 ft; MAP range: 120-140 in) at three dryer sites on Maui (elevation range: 1000-3500 ft; MAP range: 61-86 in) (Conrad 1996). This study found that seedlings from the lower-elevation source grew faster at all sites, and that seedlings from both sources grew fastest at the higher-elevation site (Conrad 1996). Unfortunately, both of Conrad's experiments were limited in extent and duration, suffered from pest and disease problems, and the data were not analyzed to ascertain whether observed differences were statistically significant. Provenance tests conducted on Hawai‘i Island of seed sources from throughout the state found that families from Kauai and Maui grew better than families from Hawai‘i Island (Sun, Brewbaker, and Austin 1996). However, koa wilt disease reduced the survival and vigor of many trees in this planting trial, and the environmental conditions of the source locations were not evaluated.

Knowledge gaps

Seed source guidelines should be based on data about long-term growth and survival rates from reciprocal transplanting experiments (i.e., provenance trials), information about the genetic structure and "gene flow" of koa populations, and evidence of inbreeding and outbreeding depression. The methodologies for defining seed zones using provenance trials have been developed for other species and could be applied to koa (Zobel and Talbert 1984). However, defining appropriate seed zones for koa is complicated by the large natural variation in climates across the Hawaiian Islands and the wide environmental and geographic range of koa. To define koa "ecoregions" and koa "ecotypes" that are best adapted to each region, a number of well-designed koa provenance studies are needed. Where differences are found among populations, studies should be conducted to determine the physiological mechanisms of differential performance across sites. Studies on the genetic structure of koa populations across environmental gradients are in progress as of this writing (S. Lawson and C. Liang, *pers.*

comm.). Additional studies of gene flow could be used to understand reproductive isolation of populations (Falk and Holsinger 1991). The degree of inbreeding versus outbreeding depression can be measured using cross-pollination studies in conjunction with common garden planting trials (Falk and Holsinger 1991). Defining koa seed zones is fundamental to a breeding program and for making decisions about where to obtain planting stock for restoration.

Project ideas

- Reciprocal transplanting provenance trials to test the interaction between seed source and site.
- Studies of physiological responses to site conditions of seed sources from a variety of populations.
- Genetic studies to measure genetic similarities and differences within and among populations and to measure gene flow among populations.
- Studies of genetic inbreeding and outbreeding depression using cross pollination and genetic markers.
- Information technologies for tracking seed provenances and outplantings.

Metrics of success

- Clearly defined seed zones to guide commercial and conservation planting.
- Optimized performance of planted koa across a range of sites.

2.4. Improve seedling quality & availability

Goal

- Produce a sufficient supply of high-quality seedlings that have high survival and growth across a range of site conditions to support reforestation projects.
- Develop techniques to vegetatively propagate koa.

Problem statement

- The availability of high-quality seedlings is limited due to inadequate seedling production. Scientifically-proven methods to produce high-quality seedlings are often not used by nurseries, resulting in poor-quality seedlings and reducing outplanting success.
- Low success with vegetatively propagating koa limits research and breeding efforts.

Background

In a workshop on koa tree improvement, the opening remarks stated that the most pressing need for koa tree improvement is a comprehensive seed collection and genetic conservation program (Brewbaker 1991). Availability of high quality seedlings and vegetative propagules is essential to support reforestation efforts. However, such a program has not yet been developed.

Koa is usually propagated from seed, but flowering and seed set are highly variable across sites and years (Lanner 1965). Koa flowers later at higher elevations and some in years trees produce abundant seeds, while in other years seeds are scarce, with a large number of seed pods predated by insects (Lanner 1965). Although koa can self-pollinate, cross pollination probably improves seed set (Brewbaker 1974 *in* (Baker, Scowcroft, and Ewel 2009). Honey bees have been observed to visit koa flowers, but there are no published studies of their importance as pollinators or of the identity of native pollinator species.

Techniques for propagating koa from seed are well-developed. Koa seeds can remain viable for several years, or possibly decades, after harvesting. However, germination rates decline after long storage. Seed storage guidelines recommend storing seeds at low temperatures and humidity in airtight containers (Elevitch and Wilkinson 2005). Koa seeds germinate best following scarification. Several methods to scarify seeds are used, including mechanical scarification by nicking the seed coat or by pouring boiling water over the seeds (Elevitch and Wilkinson 2005).

Although the ability to vegetatively propagate koa will be useful for genetic research and to replicate desirable genotypes, little research has been conducted and even less has been published on this topic (Skolmen and Mapes 1976; Skolmen 1978). In the 1970's Roger Skolmen experimented with vegetative propagation from cuttings and air layers of root and shoot sprouts (Skolmen 1978). He tried several treatments and obtained from 0% to 50% rooting success, depending on the treatment. Skolmen also attempted micro-propagation of koa, but was unsuccessful(Skolmen and Mapes 1976). More recently researchers at HARC have found moderate success with rooting cuttings taken from young seedlings (Dudley, *unpub. data*). In addition, researchers at HARC and Purdue University have successfully grown plantlets using micropropagation techniques (Paula Pujit, *pers. comm.*). Grafting of very small koa seedlings onto *A. koa*, *A. mangium* Willd., and *A. confusa* Merr. has had a success rate as high as of 20% to 70% (Nelson 2006).

Producing vigorous seedlings in the nursery that grow quickly and can compete with invasive grasses can substantially increase growth and survival rates. Experimental trials have found that koa grown in larger containers grew significantly larger both in the nursery and the field and produced more phyllodes during the first year after outplanting (Jacobs, Davis, and Dumroese 2007; Dumroese, Davis, and Jacobs 2011). Higher rates of fertilization in the nursery produces larger plants and inoculation with *Bradyrhizobium* spp. increased formation of root nodules for nitrogen-fixation (Dumroese et al. 2009). Higher fertilization rates in the field also significantly increased growth during the first year after outplanting (Jacobs, Davis, and Dumroese 2007). Increased fertilizer can be more efficiently applied to nursery seedlings using subirrigation, which produces koa seedlings that grow as well as or better than other methods of fertilizer application (Davis, Pinto, and Jacobs 2011; Schmal et al. 2011).

Knowledge gaps

Improving seed availability would best be accomplished by establishing a network of seed orchards that are managed to produce abundant, easily-collected, improved seed for a variety of uses and suitable for a wide range of environmental conditions. In seed orchards (and possibly for wild plants), techniques to increase set should be investigated. This will require a better understanding of koa reproductive biology, which has thus far been poorly studied. Honeybees and flies have been observed on koa flowers, but koa's native pollinator is unknown and the effectiveness of honeybee and fly pollination has not been studied (Baker, Scowcroft, and Ewel 2009). The identity of koa's pollinators, and the extent to which pollination contributes to seed production, should be investigated. The timing of flower and seed production (i.e., phenology) of koa trees, and its variability within and across sites and years should be studied to aid seed collection and production. Other than temperature, it is unknown what environmental variables may influence flowering and seed set, and this topic has received only limited attention (Lanner 1965). The causes of poor seed set should be studied and options for control of seed predators should be developed; preliminary work has been conducted by US Forest Service and Hawai‘i Agriculture Research Center (HARC).

Vegetative propagation of koa is difficult. Further studies should be done to develop methods to increase success of propagation from cuttings and air layering, especially from mature trees. Studies to test methods to root cuttings from root sprouts of mature trees are being conducted by University of Hawai‘i (UH) researchers. Long-term survival of micro-propagated and grafted plants remains to be tested.

Although substantial progress has been made to develop nursery production techniques, additional studies are needed to refine methods. It is also essential to conduct extension and trainings to ensure that nursery managers are knowledgeable about and adopt improved techniques as they are developed, as well as to educate landowners about the importance of using high-quality planting material. This will substantially improve the success of future outplantings.

Project ideas

- Establish seed orchards in accessible locations to facilitate maintenance for seed production (e.g., thinning, fertilization, and pruning to encourage low branches).
- Study koa reproductive biology (e.g., phenology and pollination) across environments to determine the biotic and abiotic drivers of seed production.
- Establish a koa seed bank to support large-scale restoration efforts following fire or other catastrophic events.
- Establish treatments for seed predators in seed orchards.
- Continue to test nursery production techniques to reduce costs and increase seedling quality.
- Organize workshops and trainings to improve adoption of science-based nursery techniques that improve seedling quality.
- Study vegetative propagation techniques to develop techniques that provide consistently good results.

Metrics of success

- Abundant supply of high quality seeds and seedlings for reforestation and research.
- Success in vegetative propagation.
- Secure seed reserves stored in koa seed banks.
- Growth and survival of planted koa in reforestation projects.
- Information technologies for tracking seed storage and sources.

2.5. Selectively breed for survival, growth, form, disease resistance, and wood quality across koa's environmental range

Goal

- Develop improved koa with traits that meet the needs of landowners, including better growth rates, form, disease and insect resistance, drought and cold tolerance, and wood quality.

Problem statement

Poor survival, growth, form, and wood quality reduces reforestation success and the value of trees planted for timber, thereby reducing interest in planting this native species.

Background

To increase the success and value of koa plantings, we need to breed trees with improved traits for a variety of applications. The most important traits to select for will depend on the site conditions and the goals of the land owner/manager.

Koa trees bred to be adapted to site conditions would increase planting success and long-term survival of plantations. For planting in dry environments, trees should be selected for drought-tolerance. This may become increasingly important as dry locations in Hawai‘i are predicted to become even dryer with climate change (Timm et al. 2011). For planting in high-elevation sites, trees should be selected for cold tolerance. Koa seedlings planted at elevations above 6000 ft (1800 m) suffer high mortality and stunted growth from frost damage due to low nighttime temperatures (Scowcroft and Jeffrey 1999).

In areas where koa wilt disease occurs, it is essential to breed for tolerance to koa wilt disease (Gardner 1980). Koa wilt disease is caused by a fungal infection with a pathogenic strain of *Fusarium oxysporum* (Gardner 1980; Shiraishi et al. 2012). In wilt-prone areas, planted koa seedlings suffer high mortality within the first 4 years; adult trees may lose their leaves on major branches and often die. For more information and images of koa wilt symptoms, see the Hawai‘i Forestry Pests & Disease Website[6] maintained by the College of Tropical Agriculture and Human Resources (CTAHR) forestry extension program. Koa infected with *F. oxysporum* have been found on all the major islands in tree nurseries, plantations, and natural forests (Dudley et al. 2012). Wilt disease commonly at elevations below 2500 ft (750 m), but has been found up to 5400 ft (1650 m) in naturally regenerated forest (Anderson et al. 2002). Field trials have shown substantial genetic variation in seedling mortality due to *F. oxysporum* (Dudley et al. 2007). Thus, there appears to be a genetic basis for disease resistance which could be used to breed resistant varieties (Shi and Brewbaker 2004). As of this writing, HARC has operationalized a method for screening family-level resistance to *F. oxysporum* by inoculating seedlings with the disease in replicated experiments to quantify the percent survival by family and have installed several field trials to test the long-term tolerance of the best families (Dudley et al. 2012). These field trials will also serve as seed orchards to provide improved seed for reforestation. Another line of research is to identify molecular markers for wilt-tolerance. Researchers at UH and HARC had achieved some success in using chitenase, an enzyme that degrades fungi, as a molecular marker for *Fusarium* resistance (Rushanaedy et al. 2012). This discovery could potentially lead to a genetic screening method for disease resistance. UH researchers in the CTAHR-Plant and Environmental Protection Sciences (PEPS) department are conducting experiments to find genetic markers in resistant and susceptible koa populations (S. Miyasaka, *pers. comm.*).

Selective breeding for form, wood quality and other traits may provide substantial benefits for commercial production. Breeding for stem form is especially important for commercial plantations, as poor stem form discourages private investment in koa by reducing the amount of merchantable lumber produced (Scowcroft et al. 2010). Limited data suggest that the offspring of trees with excellent form have less forking than unselected trees (Sun 1996; Scowcroft et al. 2010). Finally, wood quality (e.g., color, density, and figure), largely determines the commercial value of koa, with figured koa wood, especially "curly" koa, fetching much higher prices than unfigured wood ($80 to $150/board foot) (Yanagida et al. 2004; Lowell, Wiedenbeck, and Porterfield 2013). Based on studies of other species, it is likely that wood quality (e.g., figure, color, density, and sapwood:heartwood ratio) is under genetic control (Simmons 1991). In addition, reduction in defects through selection of trees that better tolerate injury may be an important source of improvement for koa wood quality (Lowell, Wiedenbeck, and Porterfield 2013).

[6]http:// www.ctahr.Hawaii.edu/forestry/disease/koa_wilt.html

Breeding for faster growth rates is likely to be successful and would be beneficial for a diversity of users. Data from progeny trials show that diameter and height growth rate are moderately to highly heritable (Shi and Brewbaker 2004; Sun 1996; Rueda-Krauss et al. 2013), indicating that selective breeding for this trait may result in substantial gains. For landowners interested in commercial harvests, faster-growing trees may reduce rotations times, thereby increasing economic returns. The few data we have for koa suggest that growth rates and wood density are uncorrelated, so fast growth will not reduce wood quality (Rueda-Krauss et al. 2013). For those interested in reforestation for conservation, faster growth means better ability to outcompete invasive plants, a shorter time to canopy closure, and a quicker return to native forest cover. As carbon markets develop and the state moves towards balancing carbon emissions with sequestration, fast-growing native trees that reach taller heights would be increasingly valuable (see section 3.4).

Knowledge gaps

Despite decades of work, there are substantial knowledge gaps remaining in developing a selective breeding program for koa. This is largely due to limited resources to support a long term tree improvement program. Most importantly, the degree of genetic control of most traits remains unknown. Although koa trees vary genetically in many morphological traits (Daehler et al. 1999), few data are available on the heritability of most important ecological and economic traits. For example, it is unknown to what extent wood quality is heritable or driven by environmental conditions. Further, the selection age for valuable traits, a key factor for tree a breeding program, is currently unknown. Selective breeding for koa is complicated by the wide diversity of habitats in which it grows, which may necessitate breeding separate improved lines for each "ecoregion" (see section 2.3).

Many of these questions can be answered using planting trials designed to test the genetic component of morphological traits (i.e., progeny trials) (Zobel and Talbert 1984). Early progeny trials to evaluate genetics of koa growth and form suffered high mortality due to koa wilt disease or lack of continued management (Shi and Brewbaker 2004). New trials should be established using rigorous experimental design based on the successful progeny trails used for other species (Zobel and Talbert 1984). In addition, marker-assisted and genomics-assisted selection using modern genetic tools has the potential to drastically reduce the time needed to breed improved koa (e.g., (Varshney, Graner, and Sorrells 2005; Jannink, Lorenz, and Iwata 2010; Pérez-de-Castro et al. 2012)). Thus, it will be beneficial to discover the genetic regions that are associated with traits of interest.

Breeding for tolerance to koa wilt disease has progressed substantially over the past decades, but major questions remain. To effectively manage for this disease, more work is needed to discover the origins, vectors, and environmental tolerances of the disease. Additional testing is necessary to determine the long-term survival of families identified in seedling screening. Continued investigation to find molecular and/or genetic markers is a promising avenue of research that may provide a method to rapidly screen large numbers of families for wilt-tolerance. Finally, researchers should explore silvicultural management options for disease control. For example, seedling inoculation with beneficial fungi and soil fungicide treatments has been successful for other species. It is possible that a combined approach, using both disease-resistant stock and silvicultural procedures to reduce risk, will be most effective.

Project ideas

- Replicated progeny trials across a variety of environments to evaluate genetic variability and to identify superior families for continued selection and as seed sources for planting.
- Studies of molecular genetics to identify markers for desirable traits.
- Long-term studies of the relationship between rankings over time for important characteristics (*e.g.*, growth and form) to identify suitable selection age.
- Study of the extent of genetic and environmental control over wood quality characteristics.
- Expand field trials to test the durability of wilt-resistance as identified by seedling screening and to develop resistant varieties for all affected ecotypes. Once mature, these field trials will serve as seed orchards to provide propagules for further selection and outplanting.
- Expand previous remote sensing work to cover a wider area to assess environmental correlates of koa wilt. The availability of higher resolution satellite data and more accurate maps of precipitation and evapotranspiration will result in better predictions for koa wilt extent.
- Model how wilt disease extent may be affected by climate change using understanding of koa environmental constraints in conjunction with downscaled regional climate models.
- Investigate other mechanisms of resistance. It may be possible to reduce or control wilt using silvicultural methods, as described above. Multiple approaches should be considered wherever possible.
- Continue and expand studies to identify molecular markers for wilt-resistance.

Metrics of success

- Number of acres planted with improved stock
- Number of improved lines producing seeds available for planting
- Increase in survival, growth, form, and/or wood quality of improved families (i.e., genetic gain)
- Increased value of plantations planted with improved stock
- Number of wilt-resistant families available for planting.
- Acres of healthy koa in wilt-prone areas.
- Increased understanding and management of koa wilt disease.

2.6. Manage wildfire risk on koa lands

Goal

- Manage lands where koa occurs to reduce wildfire risk and plant koa to reduce wildfire risk and increase ecosystem resilience in wildfire-prone areas.
- Improve post-fire treatments in koa growing areas.

Problem statement

- Wildfire is a costly and damaging problem that affects thousands of acres of Hawai‘i and is predicted to worsen with climate change.

Background

Koa is both at risk from fire and has the potential to reduce fire risk and facilitate post-fire restoration. Wildfire in Hawaiian ecosystems reduces native species cover and increases non-native grass cover, which in turn increases the risk of wildfire; this pattern is often termed the

grass-wildfire cycle (Ellsworth et al. 2014). As temperatures rise and drought becomes more severe with climate change, wildfires are predicted to become larger, more intense and more frequent. Koa is commonly planted for post-wildfire restoration because it quickly establishes a closed canopy. Koa is also fire-resilient because wildfire stimulates germination of buried koa seeds (Scowcroft and Wood 1976) and established trees often resprout after wildfire (Loh et al. 2007). Having koa seeds immediately available after fires offer a unique opportunity to reforest with koa (also refered to in section 2.3). Additionally, koa plantations may reduce wildfire risk (*i.e.*, lower ignition probability and lower intensity of wildfire behavior) by reducing fuel loading of shade-intolerant, highly flammable grass species and maintaining higher fuel moisture through canopy shade (Grace 1995).

Knowledge gaps

Despite the potential to use koa as a wildfire-management tool, fundamental knowledge gaps remain. Critical questions include:1) Is koa a cost-effective tool for reducing wildfire risk in wildfire-prone ecosystems? 2) Is it possible to selectively breed koa with desired characteristics to improve establishment and regeneration in wildfire-prone areas? 3) Can we develop management practices that promote post-wildfire germination of koa seed banks? 4) Under what circumstances can koa trees resprout following wildfire?

Project ideas

- Use remote sensing data to assess the wildfire-risk index due to replacing invasive grasses koa. Measure changes in wildfire risk (e.g., flammability, fuel-loading, and fire behavior) that occur after restoring grasslands to koa in wildfire-prone areas.
- Create cost-benefit model to use as management tool for deciding how to incorporate koa plantations into wildfire management plans.
- Explore the potential to select and breed koa for wildfire management (e.g., high drought-tolerance, ability to resprout, and low flammability).
- Study the conditions and mechanisms of koa seed germination and resprouting associated with wildfire.
- Establish koa seed bank for post-wildfire restoration, with seed sources appropriate for high-risk areas (see section 2.3).

Metrics of success

- Fewer acres of koa forest burned annually.
- Reduced cost of fire suppression and increased ecosystem services (e.g., erosion control and water infiltration) due to increased native forest cover in wildfire-prone areas.
- Reduced contiguous areas of fine fuel cover from invasive grasses.
- Increased cover of native forest in wildfire-prone areas.
- Percentage of land area with reduced wildfire-risk index due to native forest cover.
- Adequate stored seed resources for post-wildfire restoration.

3. HUMAN DIMENSIONS OF KOA FORESTRY

State issues addressed: 7
National themes addressed: 3.4, 3.6

3.1. Support education, extension, and outreach

Goal

- Widespread public awareness of koa's value, uses, silviculture, and economics.

Problem statement

- The general public and landowners lack sufficient and accurate information on the economic and ecological benefits of koa forestry, resulting in divided public opinion on harvesting and inhibiting action and investment in koa forestry. Lack of education about silvicultural practices reduces planting success.

Background

Education can be an important component of an effective conservation and utilization strategy (Ardoin and Heimlich 2013). This is because political will and public support are essential for the long-term success of forestry initiatives. One purpose of education is to build support for sustainable forestry, including harvesting on appropriate state lands. Outreach to the general public and stakeholders could potentially reduce ambivalent attitudes and conflict over forest management options.

A number of education, extension, and outreach programs have been initiated in the past 15 years by several organizations to provide information to landowners, students, scientists, and the general public. The Hawai‘i Forestry and Communities Initiative (HFCI) provided initial funding and coordination to create and implement education/extension programs with, UH-CTAHR, the Hawai‘i Community College (HCC), and Hawai‘i Forest Industry Association (HFIA). In 1998, CTAHR established the forestry extension program to supply stakeholders with up-to-date science-based information of forestry in Hawai‘i, for koa and other viable species[7]. One exceptionally successful education project was the Tropical Forest Ecosystem and Agroforestry Management (TEAM) program[8] administered by HCC as a two year program to teach students native plant identification and propagation, GIS, mapping, surveying, and other forestry topics. From 1999 to 2001, HFIA conducted a Hawai‘i Forest Industry Training Project funded by the State of Hawai‘i Department of Labor and Industrial Relations’ Workforce Development Division Employment and Training Fund to provide training for Hawai‘i's forest industry[9]. Activities included courses in logging and harvesting, nursery skills, road maintenance, tree farm establishment, superior tree identification, and seed collection. In 2000, UH Manoa established the Natural Resources and Environmental Management (NREM) department with faculty in applied forest ecology, remote sensing, geographic information systems (GIS), watershed management, and other forest management specialties. In 2007, UH Hilo created the first faculty position in forestry. In 2011, DOFAW initiated the Rain Follows the Forest program which includes continued support for teacher training in environmental issues and the Youth Conservation Corps (YCC). The HFIA has sponsored three symposiums on koa

[7] http://www.ctahr.Hawaii.edu/forestry
[8] http://www.hawcc.Hawaii.edu/forestteam
[9] http://www.Hawaiiforest.org/index.php/article/forestry_training_project

forestry over the past three decades. These koa symposia brought together scientists, managers, and landowners to update stakeholders on recent advances (e.g., in research, silviculture, etc.) and to set goals for the next decade while evaluating whether the last decade's goals were achieved. The HFIA also sponsors an annual wood show to feature high-quality Hawaiian-made wood products and raise awareness of the wood products industry in Hawai'i (woodshow.Hawai'iforest.org). In 2013, DOFAW forestry consultants led workshops on Oahu and Hawai'i Island. Several more information sharing programs and organizations exist to educate the public about Hawaiian forests in general and koa in particular, including the Waikoloa Dry Forest Future Forester's program, Friends of Hakalau Teaching Change program, Kupulehu, and the Hawai'i Environment Education Association. This list is not exhaustive; more programs are conducted in Hawai'i and by partners from other states.

Knowledge Gaps

To be successful, it is important to plan and evaluate education and outreach programs to ensure their effectiveness. A clear understanding of the objectives of information sharing programs is essential. First, we must define how lack of knowledge by the general public and/or specific user-groups prevents DOFAW from achieving its vision for koa. Then evaluate the importance of these issues, the extent to which they hinder progress, and how information sharing programs could best be used to address these issues. For example, education of the general public about sustainable forestry could potentially reduce ambivalent attitudes towards koa harvesting and ease conflict over forest management options. The identification of the key stakeholder groups that should be targeted by such programs is essential. Once identified, the knowledge needs of the stakeholders can be assessed to develop suitable curriculum. Once the purpose, target groups, and messages have been developed, then exploration of the most effective means of reaching target audiences (e.g., through online resources, workshops, etc.) enables efficient use of resources. Given real budget constraints, the overall cost-effectiveness of information sharing programs should be compared to other actions to determine how best to allocate resources (i.e., How much does spending money/time on information sharing programs move DOFAW towards its vision versus the same expenditures in other areas, such as management or research?). DOFAW must also assess its role in conducting or supporting educational and outreach programs (i.e., Should DOFAW manage programs itself or support other organizations to do the work?) Further, the organizational capacity for information sharing programs should be assessed (i.e., Does the demand for information about koa exceed the ability of existing institutions to supply it?). Finally, analysis of education needs should consider that the importance of public information sharing may change when wilt-resistant koa is developed, allowing more land on smaller low-elevation privately-owned parcels to be successfully planted.

Project ideas

- Develop clear information sharing objectives, identify, assess the information needs of target groups, and develop appropriate curriculum.
- Conduct information sharing projects as appropriate given above analysis.
- Provide opportunities for youth to visit state nurseries and to engage in growing and planting koa.

Metrics of success

- Increased knowledge and awareness of koa value and uses.

- Improved communication with the hunting community and agreement of priority areas for hunting and growing koa/native forests.

3.2. Develop economic models and refine policies to encourage investment in koa plantations and to promote large-scale reforestation

Goal

- Regulations, policies, and plans that promote koa planting and sustainable harvest

Problem statement

- High costs and economic uncertainties inhibit investment in koa plantations. Current perceptions, policies and regulations create impediments to sustainable harvest of koa on state lands. State forest management plans should do more to promote planting.

Background

Uncertainty about the economic value of koa plantations was cited as one of the major limitations to private investment in koa plantations (Pejchar and Press 2006). Koa economic models that estimate costs and potential yields have been developed by Kevin Grace (Grace 1995) , Josh Goldstein (Stanford) (Goldstein, Pejchar, and Daily 2008), and Forest Solutions, Inc. However, these models are hypothetical given that there has never been a commercial harvest of a koa plantation to correctly estimate yields and values. In the future, improved silvicultural techniques and planting selected koa may decrease time to harvest and improve yield and value.

Incentives, such as tax benefits, that would make it more profitable to plant koa by reducing the large upfront costs have been suggested to make koa forestry more attractive to private landowners (Pejchar and Press 2006). Fencing, preparing land and planting koa are expensive, prohibitively so for some landowners. Given that koa has long rotations times (estimated at 30-80 years), landowners must be willing and able to make a long term investment and to defer economic returns on their land for many years. For ranchers or farmers, they must also factor in the lost economic value of the land for raising cattle or food crops. However, the low value of cattle ranching and the high value of koa present an opportunity to shift from destructive land uses to those that enhance the conservation value of the land. Appropriate incentives can tip the cost-benefit balance in favor of forestry.

There are currently several incentives for landowners to plant koa. For example, the Forest Stewardship Program provides a 50% cost-share and effectively creates public-private partnerships for conservation. For example, the Forest Legacy Program pays for conservation easements to prevent forest from being converted to non-forest. There are property tax incentives in Hawai‘i that reduce taxes for land designated for tree farming or conservation of native forest. In addition, income from timber sales is treated as capital gain, not regular income for federal taxes (USDA Forest Service Timber Tax website[10]). Development of new market opportunities, such as payments for carbon sequestration (section 3.4), may also provide economic incentives for koa forestry. More incentive programs are listed on the Hawai‘i Forestry Extension website[11].

[10] http://www.timbertax.org

[11] http://www.ctahr.Hawaii.edu/forestry/incentive.html

However, some policies and regulations discourage koa planting. For example, restrictions required by the Endangered Species Act (ESA) have been cited as a major disincentive for restoring forests due to fears that attracting endangered species will limit landowners' ability to harvest in the future. Although Safe Harbor Agreements (SHAs) are a mechanism to protect landowners from this, SHAs have been criticized as difficult to obtain and potentially unreliable. State and Federal laws for threatened and endangered species that classify tree harvesting as an "irreversible action" requiring an Environmental Impact Statement (EIS) (as opposed to a less-burdensome Environmental Assessment (EA)) may be a major component of deterring koa harvest on DLNR lands.

Effective management requires good planning. Good planning helps to provide focus and direction and provide a framework for future actions. Reforestation and timber harvesting plans should be written with public input to provide transparency and build public support. Plans could build on existing plans for watershed management and salvage sales.

Knowledge gaps

Better estimates of the overall value of koa forests, both natural and planted, would promote conservation and aid management decisions. For example, an estimate of the number of jobs produced by koa forestry would be useful in lobbying the legislature for additional funding for koa projects. The economic value of the koa wood products industry was estimated in 2007 from surveys of woodworkers (Yanagida et al. 2004), but an expanded and updated study is needed to provide a more precise and current estimate. Further development of economic models for koa investment is needed to reduce the uncertainty about the economic value of koa plantations for private landowners. These will require additional growth and harvest data of planted koa. The potential for improved trees and silvicultural methods to decrease costs and increase yields should be quantified. Valuation of koa should include an evaluation of the economics of reforestation that includes timber value and economic valuation of ecosystem services (Daily et al. 2000; Goldstein et al. 2006; Conte et al. 2009). Ecosystem services models should be explicit about the trade-offs between production and biodiversity to optimize all potential benefits (Nelson et al. 2009).

Economic incentives and disincentives (e.g., taxes) can strongly affect behavior when properly applied. The objectives of incentive programs should be clearly stated and programs should be designed to achieve the greatest gain for resources used. This requires evaluating the changes in behavior resulting from incentives thus far, and their potential to change behavior in the future. An understanding of which groups should be targeted is essential (e.g., large versus small landowners). An examination of the potential effects of increasing the availability and/or flexibility of cost-share programs is also needed. This would enable further refinement of incentives. For example, incentives that value ecosystem and social benefits, such as water, biodiversity, and recreation may better encourage koa forestry. Similar incentives such as the State's Right to Harvest law could ensure koa growers that their investments in growing koa could generate a return on that investment. Study of the best methods to achieve objectives could examine effective programs in other places to determine what methods they use that could be applied in Hawai‘i.

Project ideas

- Quantify the current and future market value of koa products and the number of jobs created by koa forestry.

- Quantify value of ecosystem services for koa forest restoration.
- Develop economic model of koa plantations using additional data from market and forest growth/yield models (see section 2.2).
- Evaluate the success of current incentive programs (e.g., using Model Return on Investment, ROI) to identify ways to improve effectiveness and to minimize disincentives to grow koa.
- Investigate value added from 'sustainably raised koa'.
- Write strategic plan for large-scale reforestation with koa.
- Write timber management plans for sustainable harvesting.

Metrics of success
- Economic viability of koa plantations.
- Understanding of the value of ecosystem services from koa reforestation.
- Efficiency of incentive funds in achieving objectives.
- Incentives that make it economically attractive to plant koa.
- Clear policies that promote planting of koa trees.
- Plans are implemented and successful in achieving goals and objectives.
- Reforestation projects funded by sustainable timber sales.

3.3. Develop markets and infrastructure for koa wood products industry

Goal
- Markets and infrastructure to support a thriving and sustainable wood products industry.

Problem statement
- Dwindling supply of high-quality old-growth timber and uncertain future market for plantation koa.

Background
Koa is renowned for the beauty of its wood, especially "curly" koa, which is one of the most expensive woods in the world. In the 1970's, koa wood was worth little and koa trees were commonly bulldozed to make way for cattle pasture. Today, koa enjoys excellent brand recognition and many consumers place a premium on native-Hawaiian wood products. In 2007, the koa wood products industry in Hawai'i was valued at $29 million (Yanagida et al. 2004). Koa is used for high-value products locally and internationally, including furniture, musical instruments, bowls, picture frames, artwork, canoes, and canoe paddles. The market for Hawaiian wood products, including koa, is promoted and supported by the HFIA.

There is a limited supply and high demand for koa wood. The koa wood market is currently based entirely on timber harvested from old-growth forests, especially downed and diseased trees harvested from private land. The number of old-growth trees available for harvest is rapidly being depleted, as is the supply of high-quality wood from these trees. Sawyers and woodworkers have adapted to the dwindling supply of large trees by accepting timber of smaller dimensions.

Although there has not yet been a commercial harvest of plantation koa, there are concerns that plantation koa, especially from early harvests (i.e., 20-25 yrs) will be worth little. However, some woodworkers believe that the market will adapt or that lower-value products

could be made from young koa, such as flooring and cabinetry. One experimental harvest of 25-33 year old trees shows that "young" koa has lighter-colored heartwood and substantially more light-colored sapwood versus dark-colored heartwood than old-growth trees (J.B. Friday, *pers. comm.*). Informal woodworker surveys suggests that objects made from this young plantation koa may be worth only about one third of those made from medium-quality old growth koa (J.B. Friday, *pers. comm.*). However, harvests of other trees of similar age have shown that some young trees have attractive dark wood (Nick Dudley, *pers. comm.*). One concern has been raised that plantation koa will flood the market and result in lower prices. Given the global shortage of high-value hardwood from both tropical and temperate forests, the value of koa may continue to be high even as plantation-grown koa supplies increase.

Adequate infrastructure for processing and exporting koa is essential to support the koa wood products industry. A report on the potential for forestry in Hawai‘i noted that, compared with most tropical locations, Hawai‘i is unusually well-endowed with the necessary infrastructure, such as roads and ports, to support a timber industry (Groome 1994). However, he advised that facilities for processing wood were needed to develop vertically-integrated markets. For example, he suggested that biofuel plants and chip mills would provide a use for wood from pre-commercial thinning. To date, these facilities have not been constructed. The situation in Hawaiian forestry has been compared that of a cattle market that can only sell steaks, not hamburger. In other words, there are markets for fine koa wood objects, but not for lower-value forest products; both are needed to make koa forest plantations economically viable.

Knowledge gaps

Studies of koa markets and supply should include an assessment of the availability, accessibility, and appropriateness of koa supply. For example, there is currently no published information on how long the supply of wood from old-growth trees will last or how much wood planted koa trees may supply and when. Further, it is essential to evaluate where it is appropriate to harvest trees based on zoning, roadways and/or access, and management goals for a given site. These market studies would aid in the development of an economic model for koa investment.

As the supply of old-growth koa dwindles, it is unknown whether markets will adapt or if values will fall sharply. For example, the quality and value of koa wood harvested from planted stands is unknown. Although experimentally-harvested "young" koa wood had low quality, it is unknown whether wood quality improves as trees age. A study of the relationship between tree age and wood quality should be conducted. Further, as plantation koa has never been marketed, it is unknown how consumers will respond to it. Additionally, planting selected trees that have been bred to have better wood quality may increase the wood quality of planted koa in the future (see tree breeding section 2.5). The potential for forest certification to apply to koa forests should be investigated (e.g., Forest Stewardship Council certification[12]). In addition to promoting sound forest management practices, it is possible at consumers will be willing to pay more for wood that is certified to be sustainably raised and harvested.

An assessment of the market for lower-value and smaller-dimensional wood should be conducted. Although a wide-variety of products are made from small pieces of wood, it is unknown how much value can be generated from this market.

Although it has been much discussed, a grading system for koa wood has never been developed. One workshop sponsored by the HFIA brought together forest industry representatives to discuss a grading system, but did not develop a complete system (J.B. Friday,

[12] https://us.fsc.org/

pers. comm.). Such a system would be useful to ensure quality control. This task may be complicated by the high variability of color and figure in koa wood.

To effectively invest in infrastructure development, we must first assess current and projected needs and resources. For example, what is the current state of roads, mills, and ports? Where is investment most needed? How much would improved or larger-scale technology increase production efficiency?

Project ideas

- Quantify the supply of wood from old-growth trees that are available for harvest, and determine if continued harvests are appropriate.
- Conduct market research to investigate how to expand markets for plantation koa while maintaining prices.
- Conduct research on koa wood quality from planted stands.
- Develop grading system for koa wood quality.
- Assess the adequacy of local infrastructure for wood harvesting and processing.
- Work with canoe clubs and carvers to access koa canoe logs on State lands

Metrics of success

- Increased monetary value of koa's contribution to the wood products industry and state economy.
- More jobs in koa forestry and the koa wood products industry.
- Better markets and infrastructure for koa wood products.
- Coordination with forest products purchasers to support large and long-term investment into koa production.

3.4. Develop carbon markets for koa forestry

Goal

- Develop carbon markets for koa forestry to offset carbon emissions and to provide economic incentives for private investment in koa forestry and to fund forest management on public lands.

Problem statement

- Despite the potential for koa forestry to help reach Hawai‘i's carbon offset goals, carbon markets have not been developed in Hawai‘i.

Background

Greenhouse gas (GHG) emissions have caused substantial changes in global climate, and the changes are expected to increase in the coming decades as GHG levels in the atmosphere increase (Field et al. 2014). In response to the need to reduce GHG's, several countries and states have created GHG markets where carbon credits are sold to mitigate GHG emissions. Typically, projects that sequester carbon or reduce GHG emissions sell carbon credits to GHG emitters in compliance (legislatively required) or voluntary markets (Boxler et al. 2013). In many cases, carbon credits are sold through brokers that may consolidate credits from several producers and assist with developing projects and marketing carbon to buyers.

In Hawai‘i, the House of Representatives passed Hawai‘i House Bill 226 in 2007 which limits the state’s GHG emissions to 1990 levels by 2020. Recent analyses show that koa reforestation has the potential to help meet the state's emission reduction goals and that, under some circumstances, the sale of carbon credits could be used to offset costs of reforestations or provide a source of income to landowners (Conte et al. 2009; Boxler et al. 2013). Conte et al. (2009) concluded that reforestation of koa forest on only 30,000 acres would meet the state's carbon reduction goals. The most recent report also concluded that "many forestry management and reforestation projects in Hawai‘i would meet the standards accepted by most voluntary markets and by the Californian Compliance" (Boxler et al. 2013). Further, recently-developed allometric biomass models (Asner et al. 2011) are acceptable by some of the major carbon standards (Boxler et al. 2013). DOFAW is primarily interested in participation in carbon markets to fund forestry operations (Boxler et al. 2013). Other landowners and forestry companies are also interested in participating in carbon markets to fund forestry and provide income.

The profitability of selling carbon credits from forestry projects varies substantially depending on several factors, including the cost of reforestation, the availability of government subsidies, the productivity of the trees, the price that can be obtained for the carbon, and the time horizon over which returns are calculated. In general, establishing trees from scarification in already fenced areas greatly reduces costs, whereas planting seedlings in areas that require substantial maintenance and fencing is costlier, thus reducing the profitability of selling carbon. Several state and federal programs will pay some of the costs associated with forest establishment and fencing, which can make carbon projects more economical (see section 3.2). Koa trees that are selected for fast growth and/or that are grown in prime sites with good silvicultural practices will sequester more carbon at faster rate, providing more carbon credits to sell compared with unselected trees grown in poor sites with little management. Voluntary markets usually pay a higher price for carbon, especially when the project includes a substantial social or environmental benefit, such as providing native species habitat; this would be applicable to koa reforestation projects. When the return of investment is calculated over 40 years, the profitability of project increases relative to returns calculated over 10 or 20 years. Thus, carbon projects with low establishment costs and high growth that can take advantage of government subsidies and sell credits on the voluntary market over the long term are most likely to be profitable. Further, the cost-benefit analysis for carbon projects is more favorable when the value of other ecosystem services, such as biodiversity and watershed enhancement, is included.

Knowledge gaps

Given the number of variables that affect the profitability of participation in carbon markets, we need a more thorough analysis of the factors that primarily drive this variation (e.g., sensitivity analysis). Spatial analysis of the area where carbon projects may be most profitable (as done by Conte et al. 2009) should be expanded to a broader geographic area, potentially even statewide. This would provide useful information for determining where funds allocated to native forest restoration could generate the greatest return on investment for carbon plus co-benefits.

Calculations of carbon market economics should include several factors that will require additional research to properly quantify. For example, the opportunity cost for using the land as a carbon project instead of another use should be quantified. Other aspects that must be considered

include determining whether there are any laws that restrict the sale of carbon, the cost of hiring a company to assist with project development, and whether the personnel effort necessary to develop a carbon project and the resulting restrictions on land use is worth the potential returns. Protocols for returning money from the sale of carbon credits back to forestry projects also need to be clearly defined. Methods to adequately quantify the value added from ecosystem services such as watershed protection or providing habitat for native species should be further developed and standardized for koa forest carbon projects.

Measuring and verifying carbon sequestration is an important aspect of marketing carbon from forestry projects. Selecting an appropriate carbon standard (i.e., guidelines developed for measuring and verifying carbon sequestration) is an essential step in developing a carbon project. Several standards exist and, while similar, they have some differences that may make them more or less appropriate for reforestation/forest management projects in Hawai‘i. Most standards require accurate measurement of the GHGs that have been removed or reduced by a project. To do this for koa, more research is necessary to evaluate growth and sequestration in different environmental conditions, considering variations in elevation, temperature, and moisture regimes. Growth curves to predict aboveground biomass accumulation for some areas could possibly be modeled from existing data taken for other studies, but more data will be necessary to make a complete and reliable model. In particular, there is a dearth of data on belowground carbon sequestration, which is a substantial portion of overall sequestration.

Project ideas

- Conduct sensitivity analysis to determine the factors that most strongly influence the profitability of carbon projects.
- Develop koa growth models for a variety of environmental conditions.
- Map areas where carbon projects could be most economical using spatial analysis of productivity and reforestation costs.
- Quantify below-ground carbon storage in koa forests.
- Develop standard methods to include value from ecosystem services in economic model for carbon projects.
- Investigate legal and financial aspects of participation on carbon markets.

Metrics of success

- Successful and profitable carbon projects that return income to the state and private landowners and that encourage koa reforestation.
- Acres of koa forest in carbon projects.

3.5. Increase collaboration with partners

Goal

- Collaborative and coordinated research, management, and education/extension/outreach activities that increases efficient use of resources.

Problem statement

- Lack of coordinated activities results in duplicated effort, reduced efficiency and slowed progress.

Background

There are a large number of public and private organizations that are interested in koa forests and forest products for a variety of reasons. Public agencies and organizations include several of the watershed partnerships, the national parks, UH, DHHL, HFIA, Tropical Hardwood Tree Improvement and Regeneration Center (TropHTIRC), HARC, USDA-FS, US Fish and Wildlife, and Natural Resouces Conservation Service (NRCS). Many large and small private landowners are also interested in growing and/or using koa, including Kamehameha Schooles/Bishop Estates, and TNC. Several researchers from mainland institutions are also working on projects related to koa (e.g., Purdue University, the University of Idaho). Interest in koa of these organizations ranges from planting to selling finished wood products, as well as scientific research and cultural use. Collaboration among organizations and individuals may increase efficient use of limited funding for koa projects and may speed progress towards common goals. For example, researchers could reduce costs of planting experiments by coordinating with landowners who are already planting for other purposes. Likewise, landowners may benefit from experimental plantings on land they wish to reforest. There are several examples of this on state and private land. Such collaboration requires good communication, willingness to work together, and relationships based on trust. Leadership by the state in creating a framework for cooperation could potentially increase the number of synergistic projects. Providing examples of successful collaborations that are well-publicized and supported can often led to further success.

Knowledge Gaps

The primary hindrance limiting collaboration is the lack of awareness of what others are doing. This leads to duplicated efforts, missed opportunities for synergy, and wasted resources. Those working on koa-related projects need to know more about the interests of others to identify common goals. The state could potentially play a key leadership role in increasing collaboration, information sharing, and fostering relationships among key players. However, it is unclear exactly what could be done. What methods would best serve to increase collaboration? Effective methods to further this goal should be explored, such as establishing research/landowner networks or creating a searchable website of granted permits that would allow researchers to search for projects related to their interests.

Project ideas

- Review examples of activities that work to increase collaboration in other places or for other subjects and explore how they could be applied here.
- Expand and strengthen existing partnerships (e.g., by increasing communication, formalizing partnerships, or adding new partners).
- Improve coordination among and within funding agencies to strategically select projects for funding based on their contribution to overall objectives.
- Increase funding by collaborating on multi-disciplinary and multi-agency projects and seek new sources of funding (e.g., foundations or individual donations).

Metrics of success

- Number and scale of successful collaborative projects; efficiency of resource use.

3.6. Build human capacity in forestry

Goal

- Greater capacity of professional foresters in state and federal agencies for forest management and sufficient skilled labor for forestry operations.

Problem statement

- Hawai‘i lacks personnel and institutional capacity to conduct forestry management and operations.

Background

Capacity in forestry is essential to manage and restore healthy forests and to support a thriving forest industry. Forest management for conservation and production requires a diversity of specialized skills, including landscape planning, timber cruising, tree improvement, silviculture, horticulture, plant pathology, extension, ecology, wildlife biology, and cartography. Hawai‘i currently lacks trained professionals with permanent positions in tree improvement, silviculture, and conservation genetics. Capacity in plant pathology and forest management is also limited. Because timber harvesting on state land managed by DLNR has been restricted for decades, DLNR forestry professionals have little opportunity to develop their skills in this field. Additionally, lack of skilled workers may reduce the efficiency and quality of harvesting and reforestation operations. A forestry market review from 20 years ago concluded that workers displaced by the demise of the sugar industry could readily transition their skills to supply forestry needs (Groome 1994).

Long-term dedicated support is essential for a successful tree improvement program (Zobel and Talbert 1984). An important goal is to support the establishment of a permanent tree improvement position which is needed to achieve long-term goals. Lack of focus and continuity for tree improvement has hindered progress in tree improvement for the past 40 years, despite its potential. Past efforts include the planting of a plus tree seed orchard by Roger Skolmen of the USDA Forest Service in the 1980's. In the 1990's James Brewbaker established a two provenance trials, on the Hamakua coast of Hawai‘i Island and one on Oahu at Maunawilli (Sun 1996). More recently, HARC has established a network of wilt-resistant seed orchards on Hawai‘i, Maui, and Oahu. However, due to lack of reliable funding, many of the earlier plantings were not actively managed, reducing their usefulness.

Knowledge Gaps

The primary questions are whether the current capacity is adequate to fulfill current and future needs and, if not, in what areas should capacity be developed? Decisions about which areas to develop should be based on assessment of what areas are likely to provide the greatest short- and long-term benefits for achieving DOFAW's vision for koa forestry. To do this, DOFAW will need to consider what opportunities there are for building on existing programs, as well as funding availability, and a projection of future needs. DOFAW should also determine their role in building capacity in areas of koa forestry that they are interested in. For example, should

DOFAW provide training courses for loggers, or is this the purview of private industry? Should silviculture and tree improvement specialists be employed by DOFAW, or by other organizations such as UH or the Forest Service? If employed by other organizations, to what extent should DOFAW support these positions? DOFAW should also assess the effectiveness of existing training programs. For example, in the late 1990s HFCI funded programs to train labor for a forest industry. An initial step could be to evaluate whether these programs were effective, and if additional training programs of this type are needed, and when. For example, without an operating mill, it would not be sensible to train millworkers. Increased job opportunities in the forestry sector would be needed to justify a training program for forestry workers.

Project ideas

- Assess what areas in forestry and tree improvement are likely to grow and what skills will be needed to fill those positions.
- Assess effectiveness of existing educational and training programs to provide skilled labor for the forest industry.
- Establish needed training programs in collaboration with educational and industry partners.
- Update State "Forestry Series" minimum qualifications to encourage Hawai‘i educated students to apply for State jobs.
- Encourage the State to increase the pay scale for professional forestry jobs in Hawai‘i.

Metrics of success

- Local availability of adequate trained professionals to manage and restore healthy forests.
- Number of existing State Forestry jobs filled.

Non-Discrimination Statement

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TABLES

Table 1. Primary challenges and statewide objectives of Hawai‘i's Comprehensive Wildlife Conservation Strategy

Primary challenges to conserving wildlife in Hawai‘i • Loss and degradation of habitat resulting from human development, alteration of hydrology, wildfire, invasive species, recreational overuse, natural disaster, climate change, and other factors; • Introduced invasive species (e.g., habitat-modifiers, including weeds, ungulates, algae and corals, predators, competitors, disease carriers, and disease); • Limited information and insufficient information management; • Uneven compliance with existing conservation laws, rules and regulations; • Overharvesting and excessive extractive use; • Management constraints; and • Inadequate funding.
Statewide conservation objectives 1) Maintain, protect, manage, and restore native species and habitats in sufficient quantity and quality to allow native species to thrive; 2) Combat invasive species through a three-tiered approach combining prevention and interdiction, early detection and rapid response, and ongoing control or eradication; 3) Develop and implement programs to obtain, manage, and disseminate information needed to guide conservation management and recovery programs; 4) Strengthen existing and create new partnerships and cooperative efforts; 5) Expand and strengthen outreach and education to improve understanding of our native wildlife resources among the people of Hawai‘i; 6) Support policy changes aimed at improving and protecting native species and habitats; 7) Enhance funding opportunities to implement needed conservation actions.

Table 2. USDA Forest Service State and Private Forestry National Themes

1. Conserve working forest landscapes
1.1. Identify and conserve high-priority forest ecosystems and landscapes.
1.2. Actively and sustainably manage forests.
2. Protect forests from harm
2.1. Restore fire-adapted lands and reduce risk of wildfire impacts.
2.2. Identify, manage and reduce threats to forest and ecosystem health.
3. Enhance public benefits from trees and forests
3.1. Protect and enhance water quality and quantity.
3.2. Improve air quality and conserve energy.
3.3. Assist communities in planning for and reducing wildfire risks.
3.4. Maintain and enhance the economic benefits and values of trees and forests.
3.5. Protect, conserve and enhance wildlife and fish habitat.
3.6. Connect people to trees and forests.
3.7. Manage and restore trees and forests to mitigate and adapt to global climate change.

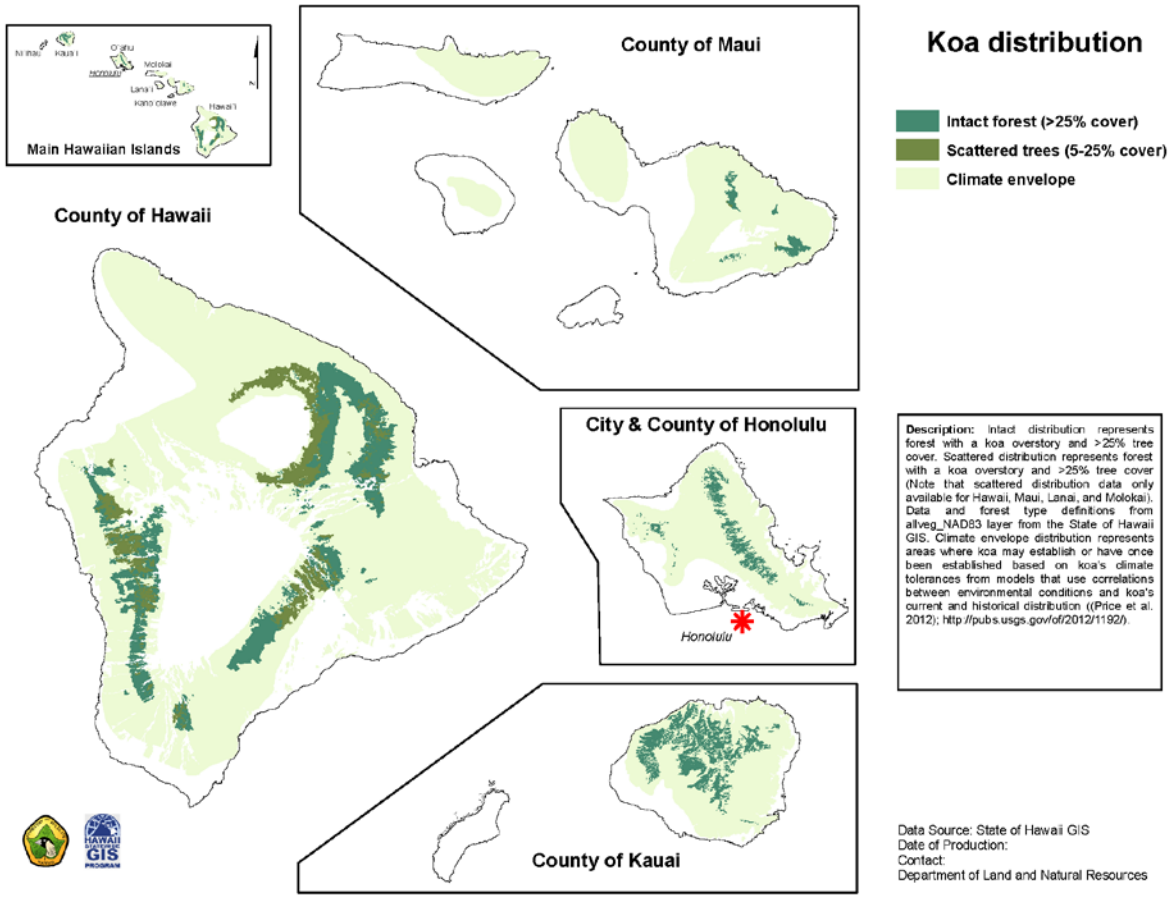
Table 3. State Issues from the 2010 Hawaii Statewide Assessment of Forest Conditions and Trends

Issue 1: Water Quality & Quantity
Issue 2: Forest Health: Invasive Species, Insects & Disease
Issue 3: Wildfire
Issue 4: Urban & Community Forestry
Issue 5: Climate Change/Sea Level Rise
Issue 6: Conservation of Native Biodiversity
Issue 7: Hunting, Nature-Based Recreation and Tourism
Issue 8: Forest Products and Carbon Sequestration
Issue 9: Multi-State Issues

Table 4. Definition of acronyms used in this document (in alphabetical order).

Acronym	**Definition**
BMPs	Best management practices
CTAHR	College of Tropical Agriculture and Human Resources
DHHL	Department of Hawaiian Home Lands
DLNR	Hawai‘i State Department of Land and Natural Resources
DOFAW	Division of Forestry & Wildlife
ESA	Endangered Species Act
GIS	Geographic information system
HARC	Hawai‘i Agriculture Research Center
HCC	Hawai‘i Community College
HCWCS	Hawai‘i Comprehensive Wildlife Conservation Strategy
HETF	Hawai‘i Experimental Tropical Forest
HFCI	Hawai‘i Forestry and Communities Initiative
HFIA	Hawai‘i Forest Industry Association
HTFRA	Hawai‘i Tropical Forest Recovery Act
IPIF	Institute of Pacific Islands Forestry
KAP	Koa Action Plan
NREM	Natural Resources and Environmental Management
MAP	Mean annual precipitation
MKWA	Mauna Kea Watershed Alliance
NPS	National Park Service
PEPS	Plant and Environmental Protection Sciences
S&PF	Forest Service State and Private Forestry
SWARS	Hawai‘i Statewide Assessment of Forest Conditions and Trends
TEAM	Tropical Forest Ecosystem and Agroforestry Management
TNC	The Nature Conservancy
UH	University of Hawai‘i
USDA	United States Department of Agriculture
USFS	United States Forest Service
YCC	Youth Conservation Corps
EA	Environmental Assessment
EIS	Environmental Impact Statement
ROI	Model Return on Investment
GHG	Greenhouse gas
TropHTIRC	Tropical Hardwood Tree Improvement and Regeneration Center
NRCS	Natural Resources Conservation Service

FIGURES



Island	Intact (ac)	Scattered (ac)	Climate envelope (ac)
Hawaii	178,406 (81%)	77,459 (99.8%)	1,526,586 (63%)
Kauai	27,409 (12%)	0	278,855 (11%)
Maui	6,955 (3%)	125 (0.2%)	298,867 (12%)
Oahu	7,494 (3%)	0	237,313 (10%)
Lanai	0	0	21,730 (1%)
Molokai	0	0	70,787 (3%)
All islands	220,264	77,585	2,434,137

Figure 1. Koa acreage and percent occurrence on each island across the Hawaiian Islands. Intact distribution represents forest with a koa overstory and >25% tree cover. Scattered distribution represents forest with a koa overstory and >25% tree cover (scattered distribution data are only available for Hawaii, Maui, Lanai, and Molokai). Data and forest type definitions from State of Hawaii GIS allveg_NAD83 layer developed from 1989 forest surveys (Jacobi 1989). Climate envelope distribution represents areas within koa's environmental tolerances based on models that use correlations between environmental conditions and koa's current and historical distribution (Price et al. 2012)[13].

[13] http://pubs.usgs.gov/of/2012/1192/

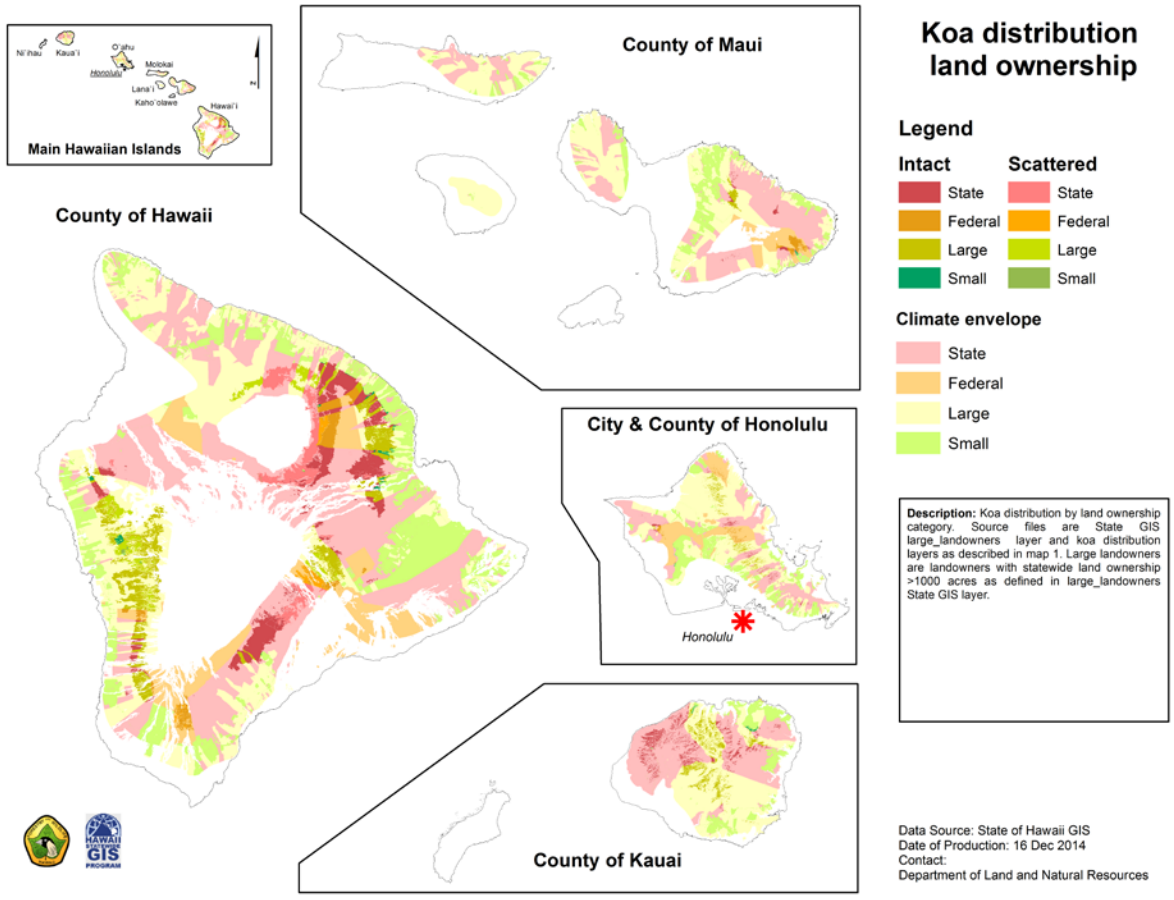


Figure 2. Map of koa distribution by land ownership category. Large landowners are defined as those owning >1000 acres statewide as per the State of Hawaii GIS large_landowners layer. Koa distribution layers as defined in Figure 1.

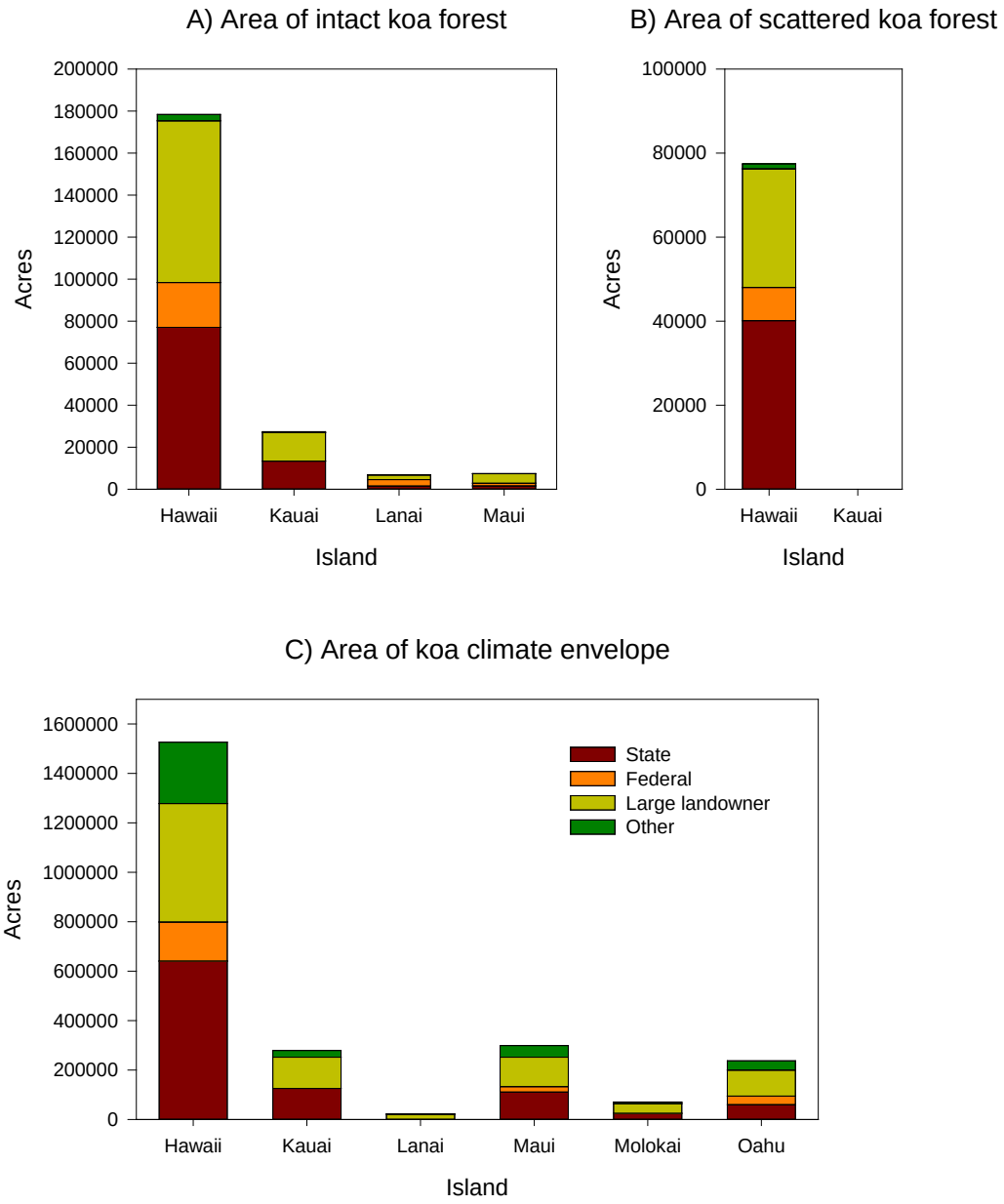


Figure 3. Koa acreage on each island by land ownership category as depicted in Figure 2. Large landowners are defined as those owning >1000 acres statewide as per the State of Hawaii GIS large_landowners layer. Koa distribution layers as defined in Figure 1.

Figure 4. Senescent koa surrounded by cattle pasture. Photo by J.B. Friday.

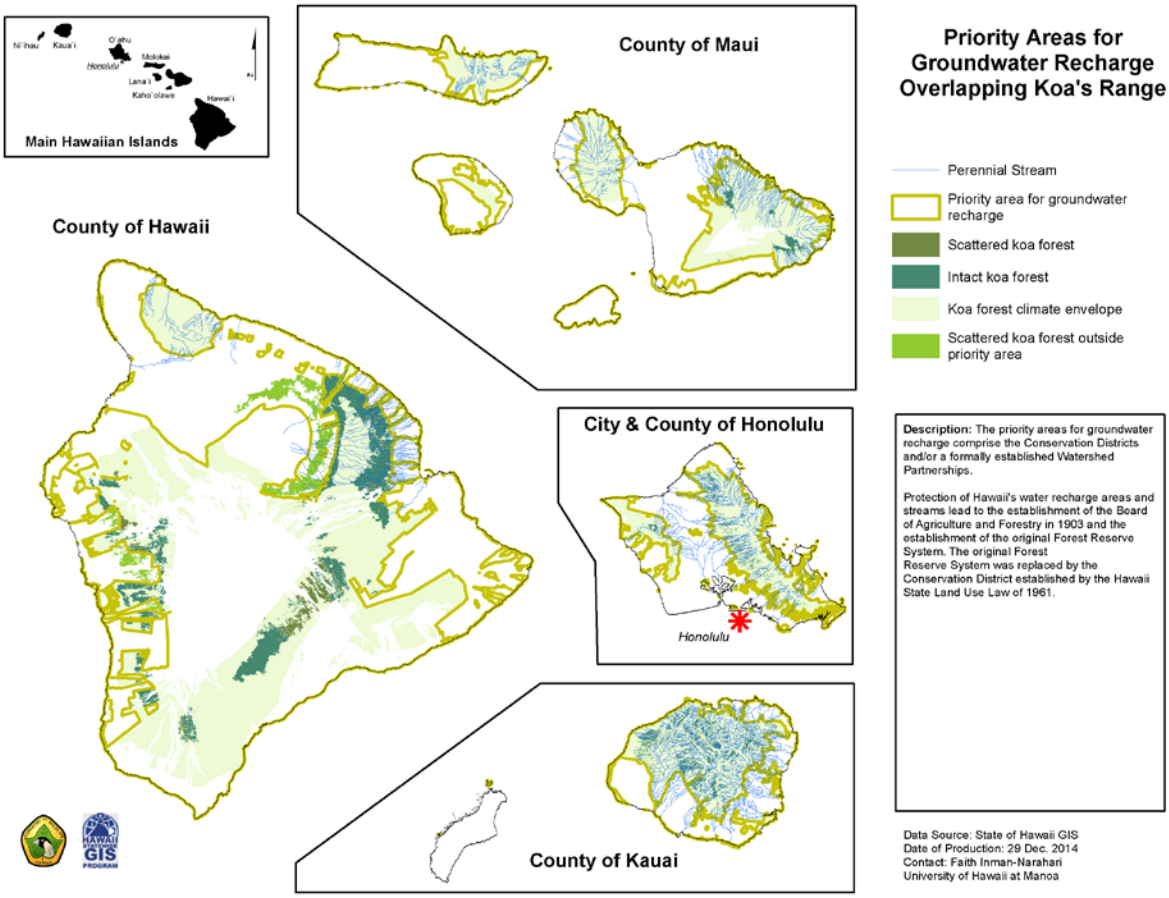


Figure 5. Map of priority areas for groundwater recharge overlapping koa's current and modeled range. Approximately 85% of koa's current range of intact forest (186,249 ac) and 85% of koa's modeled range (1,490,00 ac) fall within areas designated as priority areas for groundwater recharge. Priority groundwater recharge areas include only 0.4% (320 ac) of scattered koa forest which has been degraded to low canopy cover. The priority areas for groundwater recharge comprise the Conservation Districts and/or a formally established Watershed Partnerships. Protection of Hawai‘i's water recharge areas and streams lead to the establishment of the Board of Agriculture and Forestry in 1903 and the establishment of the original Forest Reserve System. The original Forest Reserve System was replaced by the Conservation District established by the Hawai‘i State Land Use Law of 1961.

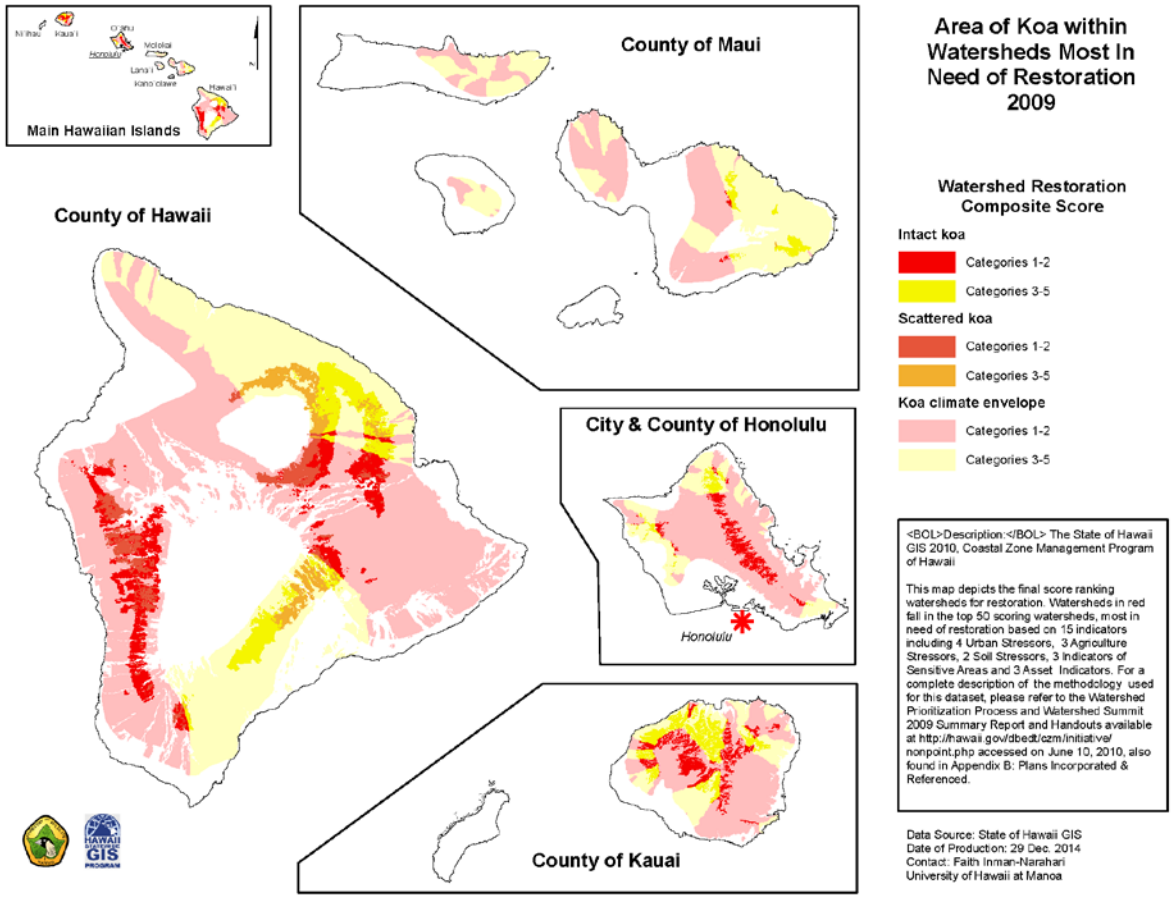


Figure 6. Map of areas identified as watersheds most in need of restoration that overlap koa's current and modeled range, with categories 1 and 2 representing the highest-priority watersheds and categories 3 and 4 representing the lower-priority watersheds. Of koa's current geographic distribution, 53% (117,788 ac) of intact forest and 51% (39,264 ac) of scattered forest occur within categories 1 and 2. Of koa's modeled range, 60% (1,466,00 ac) occurs within categories 1 and 2. Watersheds categories are based on 15 indicators including 4 Urban Stressors, 3 Agriculture Stressors, 2 Soil Stressors, 3 Indicators of Sensitive Areas and 3 Asset Indicators. For a complete description of the methodology used for this dataset, please refer to the Watershed Prioritization Process and Watershed Summit 2009 Summary Report and Handouts[14] also found in Appendix B: Plans Incorporated & Referenced of State FAP.

[14] Available at http://hawaii.gov/dbedt/czm/initiative/ nonpoint.php

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Appendix 1.

METHODS OF OBTAINING AND INCORPORATING STAKEHOLDER INPUT

Process

DOFAW foresters and consultants approached the process of writing of this KAP as an opportunity to increase alignment of stakeholders concerns and DOFAW's vision for koa and to open channels of communication among stakeholder groups. Prior to the survey, DOFAW foresters created a Koa Forestry Vision Statement to present to stakeholders for feedback. This in itself was an important step in developing a viable action plan. To ensure that a diversity of stakeholder views was considered in the KAP, a web-based stakeholder survey was conducted in March 2014. Following the review of the first draft of the Koa Action Plan by DOFAW foresters, additional feedback was solicited from key stakeholder groups including State and Private Forestry, the Tropical Hardwood Tree Improvement and Regeneration Center, the Forest Stewards Council, and the Natural Resources Conservation Service [*in progress*]. Following these reviews and subsequent revisions based on comments received, the KAP will be submitted to the general public for comment. The process for incorporating stakeholder input is summarized in Fig. A1.

Online survey methods

To develop online survey questions, a limited group of highly engaged stakeholders received a pre-survey to test and refine the survey questions prior to sending it to a broader audience. To encourage participation, it was a priority to keep the survey as short as possible (nine questions in total; full survey shown below). To obtain a balanced representation of important stakeholder categories, the survey was sent to a list of people belonging to a wide range of groups. The stakeholder categories and survey questions were developed in consultation with DOFAW foresters. Survey respondents self-categorized by checking one or more boxes of listed categories or supplying additional categories ("other").

The survey was sent to representatives of all stakeholder groups (~100 individuals), email lists of landowners and other stakeholders by DOFAW and UH-CTAHR Forestry Extension representatives, and members of the Hawaii Forest Industry Association. In total, the survey was sent to >100 people, the exact number is not known because recipients were encouraged to forward the survey to others. Approximately 68 respondents answered at least one question (summarized in figures).

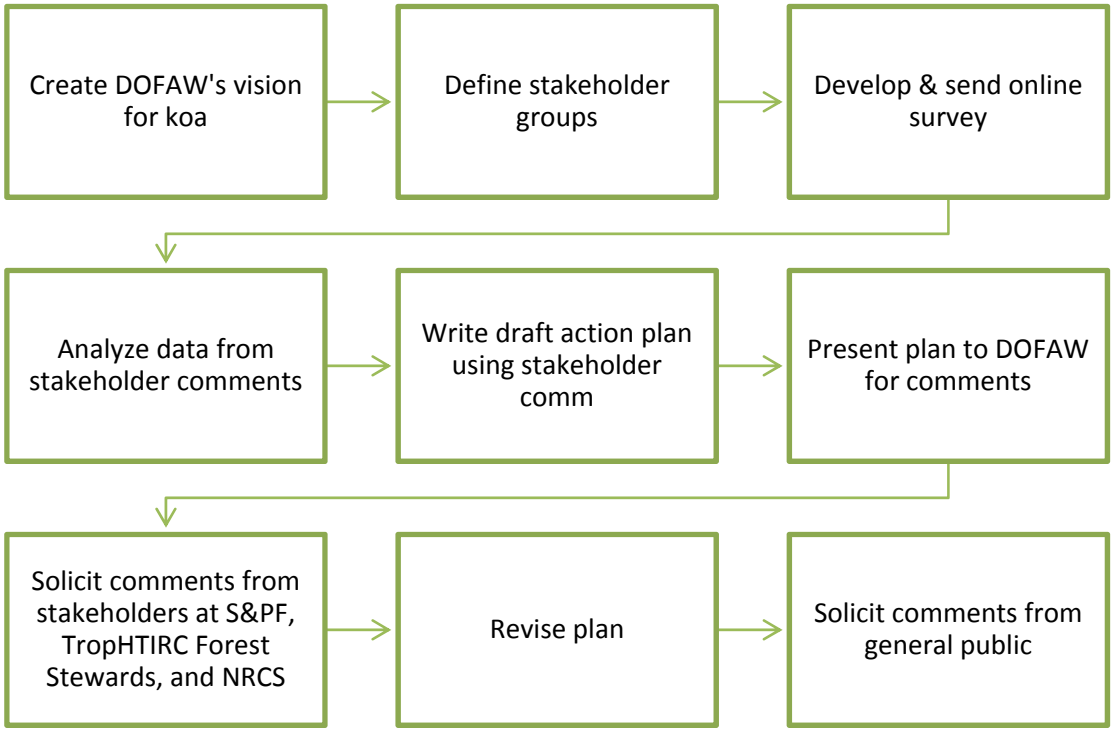
Questions about koa-related issues and actions solicited open-ended responses to encourage creative thinking and allow a diversity of opinions to be expressed. To sort out the information provided by these responses, responses were categorized under major themes identified after reviewing a majority (>75%) of the responses. The themes and sub-themes are intended to group actions or issues that might be taken by a particular project or a person with expertise in a particular field (*e.g.*, sustainable harvesting or market development). However, many actions taken under any given theme might affect another theme. For example, actions related to sustainable harvesting could also affect market development, and vice versa. Indeed, an integrated approach to sustainable harvesting and market development would be useful and

interdisciplinary teams may develop projects that address multiple themes. Each response was assigned a value of 1 if it referred to a particular theme and 0 if it did not (*e.g.*, harvesting, disease, and/or insect pests). As the content of the responses was similar for both issues and actions, responses to both questions were analyzed together. Non-responses were removed from the analysis. The proportion of responses referring to each theme was calculated as the sum for that theme divided by the total number of responses received (354, note that not all respondents answered all questions). Because many responses referred to more than one issue or action, the percentages do not sum to 100%. The stakeholder comments were then used to construct an outline of important issues and actions and direct the content of initial drafts of the Koa Action Plan.

Survey results

Responses were provided by stakeholders in all categories and from all islands (Figs. A2 & A3). Most respondents were interested or very interested in planting koa (Fig 4A). They also value koa for a number of uses (Fig. A5), with most valuing koa for 2-3 reasons (mean 2.75). The values were fairly equally balanced among uses, though conservation was more often valued than economic (possibly reflecting the large number of conservation practitioners that responded). An overwhelming majority agreed with DOFAW's vision for koa forestry (Fig. A6). A summary of stakeholder responses to each theme and sub theme is included here. Several ideas expressed by stakeholders relate to more than one theme, thus there is some overlap and redundancy in the summary of stakeholder input.

Figure A1. Process for inclusion of stakeholder input into Koa Action Plan



SUMMARY OF STAKEHOLDER INPUT FROM ONLINE SURVEY

Theme 1: Develop & demonstrate best management practices for existing koa forest, plantations, and natural regeneration (51%)

1.1. Control grazing animals and invasive plants to improve regeneration (17%)

Removing ungulates and controlling invasive plant species on koa lands is very important to stakeholders, with 17% of responses referring to this topic. Ungulates are a major threat to koa because grazing prevents koa regeneration. Stakeholders urge the state to fence state forest land, especially in high value conservation areas, and eradicate and keep out grazing animals (e.g., cows, sheep, and axis deer), as well as to use management plans and modify leases to reduce cattle grazing, especially where some forest remains. Some stakeholders suggested providing incentives to ranchers to keep cattle out of forests. Others suggest that the state begin a dialogue with ranchers and investigate the use of silvopastoral systems to allow ranching and forestry to coexist.

To control invasive plant species on koa lands, stakeholders suggested that the state should create and implement management plans to remove and control invasive plant species. Specific weed species mentioned were *Schefflera actinophylla*, *Clidemia hirta* (Koster's Curse) and *Tibouchina* spp., *Passiflora molissima* (banana poka), *Ulex europaeus* (gorse), *Rubus* spp. (blackberry), and *Miscanthus floridulus* (swordgrass). A few stakeholders recommended use of biocontrols and other less-toxic methods to control invasive plants.

1.2. Restore degraded lands (12%)

Stakeholders voiced emphatic support of large-scale reforestation to restore degraded lands for harvest and/or conservation. One comment that summed up many responses was simply "plant trees!" They also recognized the value of DOFAW's ongoing efforts ("keep up the good work") and encouraged the state to continue supporting restoration projects by collaborators such as Watershed Partnerships. The stated that planting trees should be done on former pasture and cane lands and also following harvest in natural forest. Reforestation was seen as important to both increase timber supply and to provide wildlife habitat, especially for endangered bird species. They suggested that DOFAW should develop a regeneration strategy to reforest large areas. One suggested approach was to encourage private landowners to plant koa by showing that growing koa for a commercial product is possible. Another idea was to use money from timber sales to finance large scale restoration. They emphasized the need to use the best genetic stock and best management practices, especially where it would increase survivorship on marginal lands. Stakeholders recognized the importance of reforestation in upper-elevation pasture to create contiguous forest and to replant at low elevations, noting the need to preserve genetic diversity to develop disease-resistant stock (covered in Selective Breeding for Disease Resistance section 2.1). They also suggested converting non-native plantations to koa. A couple caveats were expressed, such as the desire to plant diversified forest instead of monoculture and to be careful to only plant where appropriate (i.e., where koa is or was previously found naturally).

1.3. Conduct sustainable harvesting (11%)

Stakeholder responses to the survey indicated a desire to see the state to take the lead in demonstrating how to balance sustainable harvesting with restoration and habitat conservation.

Harvesting was mentioned in 40 responses (11%), both in questions about issues (6%) and about actions (5%). Of responses mentioning harvesting, the majority (58%) specifically referred to sustainable harvesting. Several respondents would like to see DOFAW establish a State Demonstration Forest in Timber Management Areas as a model for good forest stewardship. Stakeholders indicated that any harvesting be done in ways that are compatible with native plant and animal communities. They emphasized the importance of harvesting being done according to strict rules to ensure that regeneration is accomplished through planting or scarification to encourage stand reestablishment. One suggestion was to require a regeneration plan as a condition of obtaining a harvesting permit. Others proposed allowing increased salvage logging, especially on lands currently leased for cattle ranching. Some responses indicated that the scale of forestry in Hawai‘i should be taken into account to allow small producers to better participate. One response proposed that the state should harvest non-native species plantations and replant with native species. Best management practices should be used with the goal of establishing high quality stands. Many responses emphasized sustainability and the need to balance conservation with economic opportunity. A recurring idea was to use the income from timber sales to finance fencing, restoration, and improvement in forest health.

Reflecting the diversity of our community, a minority of responses referred negatively to harvesting (15% of responses that mentioned harvesting). The responses indicated a concern that old-growth trees were being over-harvested. A few expressed concern that "monoculture" plantations of koa could increase pest and disease problems, and possibly result in a loss of genetic diversity. Others indicated that they would support harvesting of koa plantations, but not old-growth trees. Several responses (15%) expressed the importance of preventing and punishing illegal harvesting (poaching) of trees from state lands. It is possible that the concerns of the minority could be addressed by clear rules regarding harvesting, and the enforcement of these rules to ensure long-term sustainability and ecosystem integrity. One respondent noted that restoration of forests will itself create economic opportunity, and this should be the focus of sustainable forest management. The diverging opinions regarding harvesting warrant further efforts to identify common ground and achieve consensus.

1.4. Manage existing forest (6%)

Stakeholders recommended that the state should develop and implement a koa management plan to conduct active management to preserve, improve, and restore public and private native forested areas which include koa, with a focus on productive koa-growing regions. They note that demonstrating good stewardship forest management will ensure healthy koa forests for future generations. Several respondents stated the need for a more complete inventory of koa forests to allow for more intensive/holistic management for sustainability of healthy native forests, protection of more land, and analysis of how changes in land use will affect koa forests. Stakeholders recognized that natural stands are a source of genetic diversity and seed for the future and that management plans should be compatible with conservation goals to preserve native species habitat. Respondents suggested that the state should monitor and track koa growth rates and associated changes in plant and animal communities in koa reforestation areas. One respondent stated that DOFAW should also "provide guiding principles of good forest

management to prevent abusive schemes". Providing standardized prescriptions for different management activities (e.g., watershed management or lumber production) would be helpful.

Theme 2: Support breeding, silviculture, and propagation

2.1. Breed disease-resistant koa (12%)

Stakeholders resoundingly stated the importance of dealing with koa disease, many specifically referring to wilt and the need to develop wilt-resistant varieties. They want to see DOFAW continue to support partners to do research and selection of disease-resistant koa. Others stated the need to figure out how to grow koa at lower elevations, presumably by finding ways to manage koa will disease. One respondent suggested exploring whether diseases are worse in monocultures. Another suggested that grafting onto resistant rootstock be evaluated as a possible solution.

2.2. Selectively breed for survival, growth, form and wood quality (4%)

Stakeholders indicated strong support for a research and selection program for Hawaiian koa tree improvement focused on survival, growth, form, and wood quality. In particular, research into wood quality (five of 12 responses) and form (four of 12 responses) was encouraged to increase the economic value of koa plantations.

2.3. Develop silvicultural guidelines (9%)

Stakeholders stated the importance of providing funding to support research to develop silvicultural systems to grow koa for reforestation and restoration. Responses suggested that it would be valuable to develop less toxic methods of weed control and to investigate the use of nurse trees. They noted the need to increase survivorship on degraded sites and improve forest productivity. They also indicated interest in research to measure differences in tree "quality" between koa planted in natural forests or in open areas such as pasture. Many stakeholders (6%) were particularly concerned about insect pests. They would like to see more information about the control and effects on insects, particularly the koa moth and the acacia psyllid. They are interested in the development of biological control and testing silvicultural control methods such as planting in mixed-species plantations.

2.4. Improve seed and seedling quality & availability (4%)

Stakeholders noted the importance of "improving availability and quality of seed stock and nurslings". They note that reliance on highly skilled nurseries would provide the highest quality seedlings for stand establishment. They would like to see the state fund efforts to improve existing stands for future seed collections. Further, they suggest that the state should fund and support koa seed storage efforts and that research is needed to understand the biology of koa seed set, such as what induces it.

Theme 3: Support human dimensions of koa forestry

3.1. Develop markets and infrastructure for koa wood products industry (8%)

Supporting the forest industry and developing the market were seen as essential activities by many stakeholders. They stated that research should be done to examine how to expand markets for planted koa and how to maintain prices so that plantations are profitable, giving consideration

to existing land tenure patterns, labor costs, and the likelihood that young koa will not have the same wood quality as old-growth.

To maintain the economic value of koa, some stakeholders stated the need for the creation of a grading system to help in pricing for both koa consumers and suppliers. The grading system should account for color as well as grain figure. Some felt that assistance with acquiring wood for local markets is needed because high prices driven by competition with export markets make it difficult for local woodworkers to access good quality koa.

Stakeholders felt that harvesting on state lands would improve market stability and help maintain a steady wood supply until plantations are harvestable. Opening state lands to harvesting would also reduce pressure on private lands, but should be done in concert with reforestation to ensure a sustainable supply. When designing timber sales, the state should support local producers by scaling the sales to accommodate smaller companies.

Stakeholders felt that more availability of improved infrastructure and technology for processing and sale of koa are needed to support the wood products industry. Some stated that developing the capacity for local mills to process trees and veneer would increase the value of the forest products industry. Other believed that improving ports and harbor infrastructure would facilitate export of wood products.

3.2. Develop economic models and refine incentives to encourage investment in koa plantations (10%)

Stakeholder responses indicated that better economic incentives are needed to encourage private investment in planting koa forests. Some stakeholders felt that there should be more incentives for landowners to plant and manage koa for economic and conservation benefits and for ranchers to keep cattle out of forests, although others note that many such programs exist. One suggestion was to create new state tax credits for koa establishment projects. Others note that more outreach is needed to educate landowners about existing incentives and the need to work with FWS to assist landowners when their lands are designated as critical habitat.

Several responses stated the need for accurate economic models for tree plantations to reduce uncertainty about investments in koa. They recognize that koa plantations are a long-term investment with large initial costs. One source of information for an economic model could come from carefully tracking the economics of timber harvests. Economic models should be realistic so as to not provide a "false sense of investment opportunity". One suggestion was to develop or adopt a forest sustainability certification to encourage sustainable management. To further these goals, stakeholders urged support for HFIA and HFI and investigation of the creation of a koa cooperative.

3.3. Adapt and policies to promote koa planting on private lands and create koa regeneration plans for state lands (11%)

Stakeholders proposed that DOFAW policies should provide a strong, consistent conservation message in alignment with DOFAW's mission. In particular, forestry policies should encourage "conservation in addition to economic benefit". While generally supportive of sustainable harvesting, some stakeholders suggested that regulations should be enacted to prevent harvesting of remnant native forests. Others wanted to see less regulation to remove restrictions to land uses, though no specific regulations were listed. Regulations relating to the Endangered Species Act (ESA) were of also of concern. Stakeholders urged the state to actively lobby for legislative

funding to support "conservation, including invasive species control, research, nursery/seed storage facilities, and outplanting".

The issue of permits was mentioned in a few contexts. Some stakeholders felt that the permitting process for building fences and planting was too onerous/expensive and that permitting difficulties prevented active management of koa on private lands zoned for both conservation and resource. Others exhorted the state to "uphold strict standards for harvesting permits for state or conservation lands, requiring demonstration of successful establishment of regeneration". Some stakeholders stated the need for more support of Division of Conservation and Resource Enforcement (DOCARE) to more strongly enforce illegal harvesting and fraud.

Stakeholders saw the need for more planning by DOFAW to provide direction for actions. They noted that "state foresters have a lot of constraints that hinder planning for active management" including opponents to harvesting. They believe that this has led to a lack forest stewardship activity. The need was expressed for an "action plan that tackles the issues head on"; which is what this document is intended to do. They also want the state to develop a "koa regeneration program and strategy" with clearly stated goals and objectives. This plan should focus on conservation and promote tree planting. It should include a review of the possibility of reducing grazing pressure on state lands where koa forest could be supported. They would also like the state to write a management plan for sustainable harvesting, the proceeds of which would then be used to finance fencing and restoration.

3.4. Support education, extension, and outreach (11%)

Stakeholders strongly emphasized the need for greater education of the general public. Education should increase awareness of the value of koa forests to conservation, culture, and economic growth. Respondent felt that outreach should provide a positive message that koa can simultaneously provide economic and ecological benefits. The educational messages should also make clear that koa regenerates easily and is not an endangered species. This would reduce ambiguity in public perception about koa harvesting. Working with Hawaiian cultural practitioners to inform the public about cultural traditions would help people to understand the significance of native Hawaiian plants and animals and "the connection of the people to Hawai‘i's culture and natural resources". Increased information sharing will facilitate the involvement of "a broad range of partners and the public in the management of public resources".

In addition to raising awareness of the value and status of koa, respondents felt that outreach and education should target landowners to promote planting and preservation of koa. This education should provide expertise and information about incentives for and benefits of planting koa and other native species. Education is also needed to prevent investment fraud related to koa forestry. Where wildlife habitat and other values are improved, the state should be sure to "publicize the benefits gained". As said by one stakeholder: "We have much to celebrate", pointing to the conservation activities of the watershed partnerships. Another stakeholder suggested that the state should: "Educate the public about the bright long-term future for koa forests and plantations if cattle are controlled." This message should then be backed up by actions demonstrating sustainable forest management that promotes conservation for future generations (as described in Action 1).

Stakeholders suggested that the state should sponsor public campaigns to inform the public about the ecological, cultural and economic value of koa forests using koa symposiums, workshops, and conferences. Engaging education programs with schools and youth organizations would also be helpful. They also urged the state to provide stable funding for koa extension.

3.5. Increase collaboration with partners (7%)

The importance of collaboration was noted by a number of stakeholders. They felt that the state should partner with a wide variety of stakeholders including other agencies, universities, private sector, news and media outlets, non-governmental organizations (NGO's), and land managers and owners with the goals of encouraging good management, advancing research priorities, and educating the public. Specific organizations named by stakeholders included UH, CTAHR, HARC, IPIF, HFIA, and DHHL. They felt that there should be increased effort to work together by coordinating, supporting, and funding (or continue funding) partner organizations. Stakeholders also wanted the state to work more with private landowners and communities. They felt that it was important to engage and continue to fund private landowners as forest stewardship partners, especially ranchers who wish to transition to forestry. One idea was to create a "network of koa growers" or "land managers coop" to "develop koa plantations with a research and monitoring component" and to create forest corridors on private lands.

3.6. Build capacity in forestry (3%)

Developing human capacity for forestry, silviculture, and tree breeding was seen as an important part of koa management. Stakeholders suggested that koa harvesting and restoration projects would also serve to improve DOFAW's institutional capacity by developing the skills of DOFAW staff to conduct timber sales. DOFAW foresters should focus on "leading, teaching and giving the best professional assessments" rather than being overly concerned with public perception. One respondent recognized the importance of stakeholders supporting DOFAW to move forward in this direction. They also suggested that the state should encourage IPIF and UH to create permanent positions in silviculture. Lack of skilled labor for "felling, yarding, milling, drying, and marketing Hawaiian woods" was also seen as a problem. Increasing capacity for management, research, and field operations was seen as a way to create career opportunities for young people in timber management and conservation.

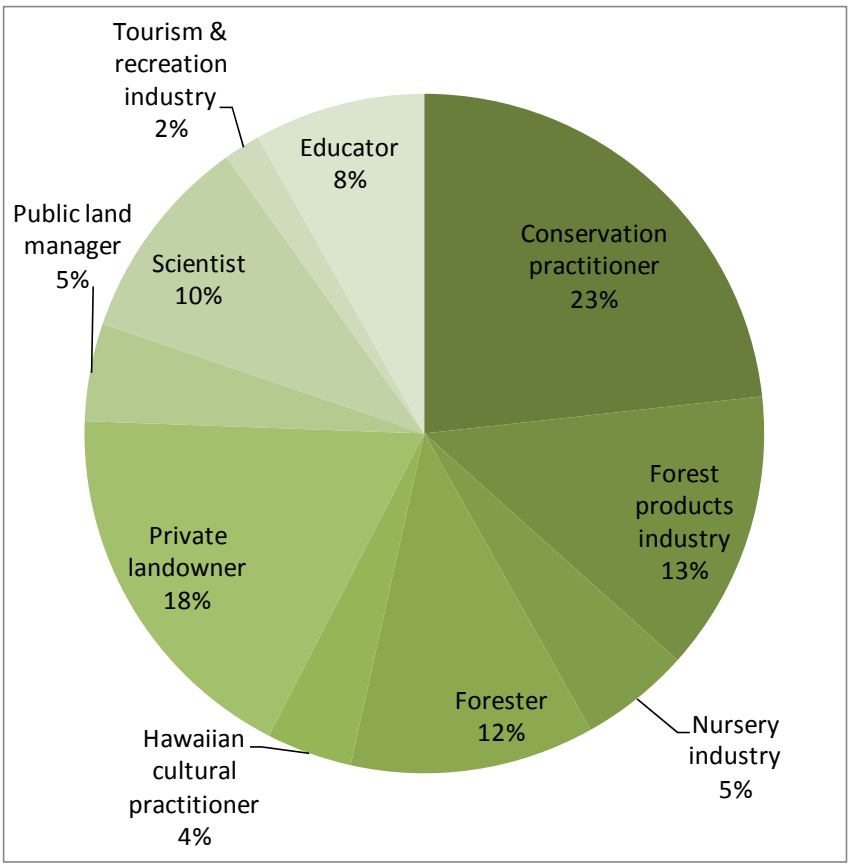


Figure A2. Representation of stakeholder groups showing proportion of respondents in each group. Respondents self-identified as belonging to one or more groups (*number of respondents* = 68).

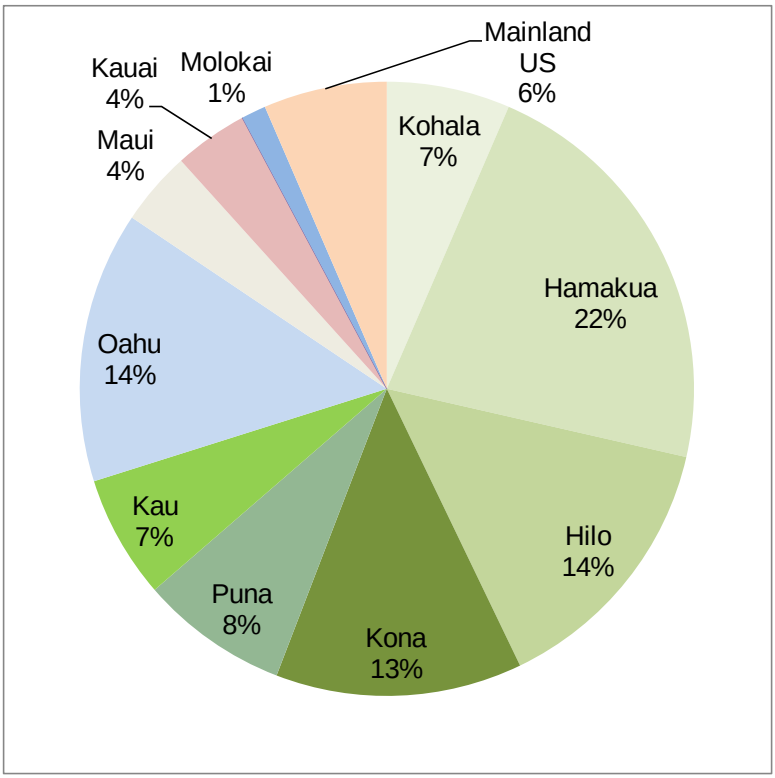


Figure A3. Representation of geographic regions showing proportion of respondents from each region. Respondents self-identified as living or owning land in one or more regions (*number of respondents* = 61).

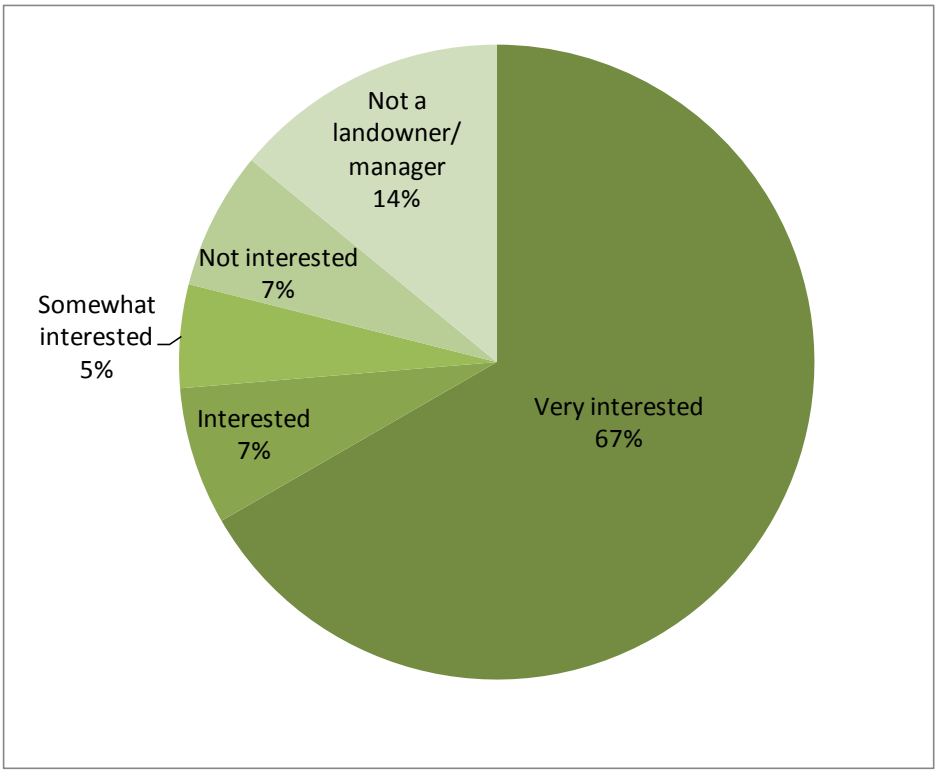


Figure A4. Interest level of growing koa showing that most respondents were either very interested (already growing koa) or interested (currently planning to plant koa) (*number of respondents* = 57).

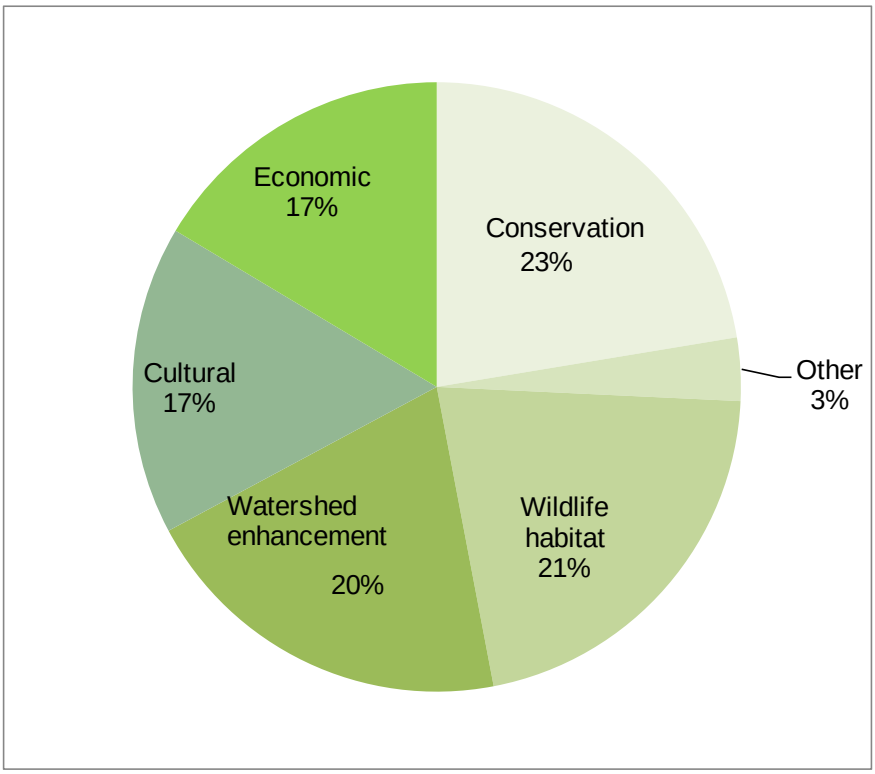


Figure A5. Ways in which koa is valuable to the community (*number of respondents* = 68). Responses in the other category included beauty, home use, native reforestation and enjoyment. On average, respondents listed four ways that koa was valuable to them.

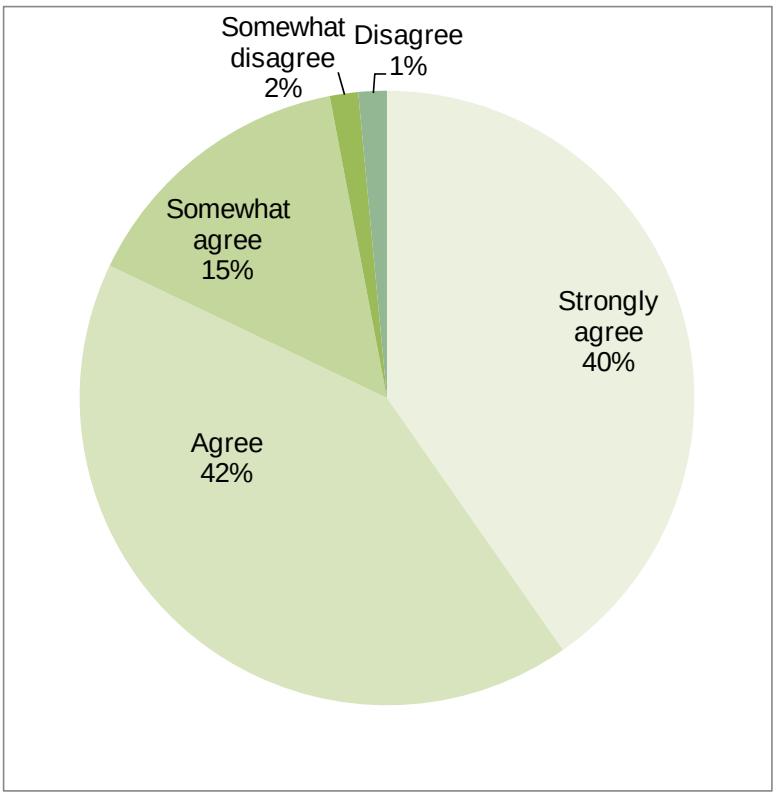


Figure A6. Agreement with DOFAW's vision for koa (*number of respondents* = 67).

Koa Action Plan Survey Form

1. Are you a member of the following groups or industries?

Please check all that apply

- ☐ Conservation practitioner
- ☐ Forest products industry
- ☐ Forester
- ☐ Hawaiian cultural practitioner
- ☐ Nursery industry
- ☐ Private landowner
- ☐ Public land manager
- ☐ Scientist
- ☐ Tourism & recreation industry
- ☐ Educator
- ☐ Other: _____

2. In which region(s) do live and/or own land?

Please check all that apply

- ☐ Kohala
- ☐ Hamakua
- ☐ Hilo
- ☐ Kona
- ☐ Puna
- ☐ Kau
- ☐ Oahu
- ☐ Maui
- ☐ Kauai
- ☐ Lanai
- ☐ Molokai
- ☐ Mainland US
- ☐ Other: _____

3. Email address _____

This is so we can keep track of who took the survey

4. If you are a landowner or land manager, how interested are you in planting koa?

- ☐ Very interested (I am already planting koa)
- ☐ Interested (I am currently planning to plant koa)
- ☐ Somewhat interested (I am considering the possibility of planting koa)
- ☐ Not interested (I am not considering planting koa)
- ☐ Not a landowner/manager

5. In what ways is koa valuable to you?

Please check all that apply.

- ☐ Conservation
- ☐ Wildlife habitat
- ☐ Watershed enhancement
- ☐ Cultural
- ☐ Economic
- ☐ Other: _____

6. Do you feel that DOFAW's vision statement resonates with your vision for koa?

"Abundant healthy koa forests that connect people to Hawai‘i's culture and natural resources while providing sustainable economic opportunities that promote forest conservation."

Select one.

- ☐ Strongly agree
- ☐ Somewhat agree
- ☐ Somewhat disagree
- ☐ Disagree

- Agree

7. **How would you amend the vision statement to better reflect your values?**

8. What do you think are the three most pressing koa-related issues?

Issue 1: _____
Issue 2: _____
Issue 3: _____

9. What do you think are the three most important actions DOFAW can take in the next ten years to address these issues?

Action 1: _____
Action 2: _____
Action 3: _____