

**Farm and Forestry
Production and Marketing Profile for**

Koa

(Acacia koa)

By James B. Friday

USES AND PRODUCTS

Unlike most of the crops in this series, koa is a wild tree of the native Hawaiian forest. People of Hawai'i have harvested koa for centuries, but koa forests have been taken for granted and continue to be lost. Although koa yields one of the most valuable timbers in the world, koa forests are worth more for watershed protection, wildlife habitat, and cultural connections than they are for wood. A healthy forest can be part of a sustainable and productive farm. This chapter is about more than managing a tree; it is about managing the forest.

The main economic product of koa is its beautiful wood, because of its color and figure considered one of the finest tropical timbers in the world. Koa lumber is the raw material for a high-end furniture industry worth tens of millions of dollars each year to Hawai'i. Koa wood is used for turned bowls, matched musical instrument sets, and picture frames. Rare low-defect koa logs achieve maximum utilization when sliced into veneer that can be laid up on a variety of substrates used in cabinetwork and on wall paneling. Flooring is also made from koa, although koa is softer than most hardwoods used for flooring. In ancient times, native Hawaiians carved seagoing canoes from koa logs, and koa canoes are still built today for racing, fishing, and recreational use.

BOTANICAL DESCRIPTION

Preferred scientific name

Acacia koa A. Gray; *Acacia koaia* Hillebr.



Left: A tall, straight koa growing in native forest on windward Mauna Kea. Right: An open-grown koa in a pasture on Mauna Kea. Photos: © J.B. Friday. Cover: Ten-year-old natural koa regeneration at Honokōhau Mauka in Kona, Hawai'i. Photo: © Craig Elevitch

Family

Fabaceae (Legume family)

Common names

koa (Hawai'i)

Botanical synonyms

Acacia hawaiiensis (Rock) Degener & I. Degener, *A. heterophylla* Willd. var. *latifolia* Benth., *A. kauaiensis* Hillebr., *Racosperma koa* (A. Gray) Pedley, *Racosperma kauaiense* (Hillebr.) Pedley. *Acacia koaia* is a closely related native Hawaiian species previously classified as a subspecies of *A. koa* (Wagner et al. 1999).

Description

Koa is one of the two large, dominant canopy trees of the Hawaiian forest; ʻōhiʻa (*Metrosideros polymorpha*) is the other. Large forest-grown koa trees commonly reach 25 m (82 ft) in height and the largest exceed 35 m (115 ft). Trunks of mature trees commonly grow to 1.5 m (5 ft) in diameter and the largest ones measured have reached twice that.

Koa is a member of the legume family, and when grown in the open it tends to display the spreading architecture of a legume, for example monkeypod (*Samanea saman*), rather than the tall, straight growth form of *Eucalyptus* species. Koa trees in pastures usually develop only a short, thick trunk and retain many branches. The form of open pasture trees is often also influenced by damage to terminal leaders caused by cattle or insects. In contrast, forest-grown koa on Maui and Hawai'i islands often develop tall, straight trunks. Koa populations on Kaua'i and O'ahu are usually restricted



Top left: Koa flowers. Top right: Narrow sickle-shaped phyllodes typical of koa growing on Kaua'i. Middle left: Koa seed. Middle right: Koa nodules. Bottom left: Newly sprouted koa seedlings with immature pinnate leaves. Bottom right: A branch with both immature (pinnate) true leaves and the mature phyllodes. Photos: © J.B. Friday

to windy ridges, and as a result koa trees on those islands tend to be lower and more spreading in architecture.

Mature koa “leaves” called phyllodes are actually flattened leaf stalks. Koa phyllodes are thick with parallel veins and range from 7.5–26 cm (3–6 in) in length and 0.5–2.5 cm (0.2–1 in) in width (Wagner et al. 1999). They may be slightly curved to crescent shaped. Immature koa trees develop true leaves which are twice pinnate (feather-shaped) and resemble the leaves of some *Leucaena* species. Stressed mature koa trees may also produce flushes of true leaves.

Koa produces bunches of pale yellow or cream-colored puff-ball-shaped balls of flowers. Each flowering head is about 8 mm ($\frac{1}{2}$ in) in diameter and is composed of many flowers, several of which may produce seedpods. Seedpods are 8–30 cm (3–12 in) long, flat, and contain several flat, shiny seeds, each of which is about 6–12 mm ($\frac{1}{4}$ – $\frac{1}{2}$ in) long.

Koa roots are shallow and spreading, especially in rocky soils. Suckers can develop from roots injured by foot traffic or livestock.

Koai’a (*Acacia koaia*) are usually low, spreading trees, smaller than *Acacia koa*. Mature trees seldom top 10 m (33 ft).

Leaves are usually narrower and seeds are arranged lengthwise in the seedpods whereas seeds of *Acacia koa* are arranged crosswise.

VARIETIES/RELATED SPECIES/GENETICS

Koa characteristics vary among islands and among populations within islands. Trees may have broad or thin curved leaves, seeds may be large or small, and trunks may be tall and straight, short and spreading, deeply fluted or relatively round. Wood color also seems to vary among populations, ranging from yellow to deep red to chocolate brown, indicating that color has a genetic component. Growth rates, stem form, and leaf shape have been shown to be heritable (Sun 1996). Tolerance to drought has been shown to be greater in koa from dry areas (Ares et al. 2000). *Acacia koaia* is now regarded as a separate species (Wagner et al. 1999), although it was previously classed as a subspecies of *Acacia koa*. Botanists in the 19th century called koa on Kaua’i a separate species (*Acacia kauaiensis* Hillebr.) *Acacia koa*, *Acacia koaia*, and koa of intermediate forms all exist on Kaua’i. Recent genetic studies using microsatellite markers have shown that koa on Kaua’i can be distinguished on a molecular level



Top left: Spreading canopy architecture and narrow phyllodes are typical of koa growing on O’ahu. Top right: Curved phyllodes typical of koa populations on Kaua’i. Bottom left: Comparison of koa (top) and koai’a seedpods. Koai’a tree planted in North Kohala. Photos: © J.B. Friday and Craig Elevitch (bottom left)



Left: A koa tree demonstrating a genetic tendency to grow straight even in an open setting. Top right: Continuous cattle grazing for decades has destroyed many koa forests. Bottom right: Most koa forests have been converted to cattle pastures. Skeletons of dead koa may still be seen. Photos: © J.B. Friday

from koa on the other islands and that genetically Kaua'i koa is more diverse than koa on any of the other islands (Fredua-Agyeman et al. 2008). An earlier study of isozymes showed differences between Hawai'i Island populations and populations on the other Hawaiian islands (Conkle 1996), however microsatellite markers give a more definitive picture of koa's genetic diversity.

Australian blackwood acacia (*Acacia melanoxylon*), a closely related species, has been planted in Hawai'i for reforestation and is regarded as a valuable timber species internationally, although it is considered an invasive species in Hawai'i. "Formosa koa" (*Acacia confusa*) is a common ornamental which has escaped cultivation and is commonly found in drier forested areas. Blackwood acacia may be distinguished because of its straight bole and smaller and less curved phyllodes whereas Formosa koa has bright yellow flowers and much smaller phyllodes than koa. Ends of phyllodes in both blackwood acacia and Formosa koa are rounded whereas koa phyllodes come to a point.

DISTRIBUTION

Koa is endemic to Hawai'i and does not grow naturally anywhere else. Most koa forests occur on the windward sides of Maui and Hawai'i Islands at elevations of 600–2,100 m (2,000–7,000 ft), although scattered populations can be found as low as 100 m (330 ft). The Kona districts on the leeward side of Hawai'i Island also support extensive koa forests. Koa does not naturally occur in the wettest forests on the windward sides of Maui and Hawai'i Islands, nor in Kohala. Koa forests grow on the leeward sides of the mountains of Kaua'i and O'ahu but are absent from the highest, wettest peaks. Koa grows on the upper elevations of Kaua'i and O'ahu but these forests are not as extensive as on Hawai'i and Maui. Few koa grow on Moloka'i or Lana'i.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Koa forests grow best in areas receiving 1,000–4,000 mm (40–160 in) rainfall annually. The wettest forests in Hawai'i may sometimes receive as much as 6,000 mm (240 in) of rainfall and are too wet for koa. Koa is replaced by koai'a on drier sites, for example the leeward side of the Kohala mountains on Hawai'i Island. At the highest elevations young koa seedlings are damaged by frost (Scowcroft and Jeffrey 1999). Koa seldom grows well at elevations lower than 300 m (1,000 ft), but this may be because the warmer temperatures at lower elevations facilitate the development of pests and diseases fatal to koa.

Soils

Koa is tolerant of a wide range of soil pH, but it needs well-drained soils. Koa stands which naturally regenerate on pāhoehoe (sheet lava) soils on windward Hawai'i Island tend to be short-lived. Koa forests reach their maximum growth on deep, ash-derived soils on windward Maui and Hawai'i Islands but also occur on organic soils on windward and leeward Mauna Loa and older soils on O'ahu and Kaua'i. Different koa populations have been shown to be adapted to

Table 1. Elevation, rainfall, and temperature for Hawai'i

Elevation range	lower: 100 m (330 ft) upper: 2,300 m (7,500 ft) Recommended for planting only above 610 m (2000 ft).
Mean annual rainfall	lower: 850 mm (34 in) upper: 5,000 mm (200 in)
Rainfall pattern	Koa tolerates a wide range of rainfall patterns including summer, winter, and uniform.
Dry season duration	0–5 months
Mean annual temperature	lower: 9°C (48°F) upper: 21°C (70°F)
Minimum temperature tolerated	–4°C (25°F). Koa seedlings may be killed by frost (Scowcroft and Jeffrey 1999).

their local soil conditions, at least in regard to acidity and nutrient availability (Scowcroft and Silva 2005).

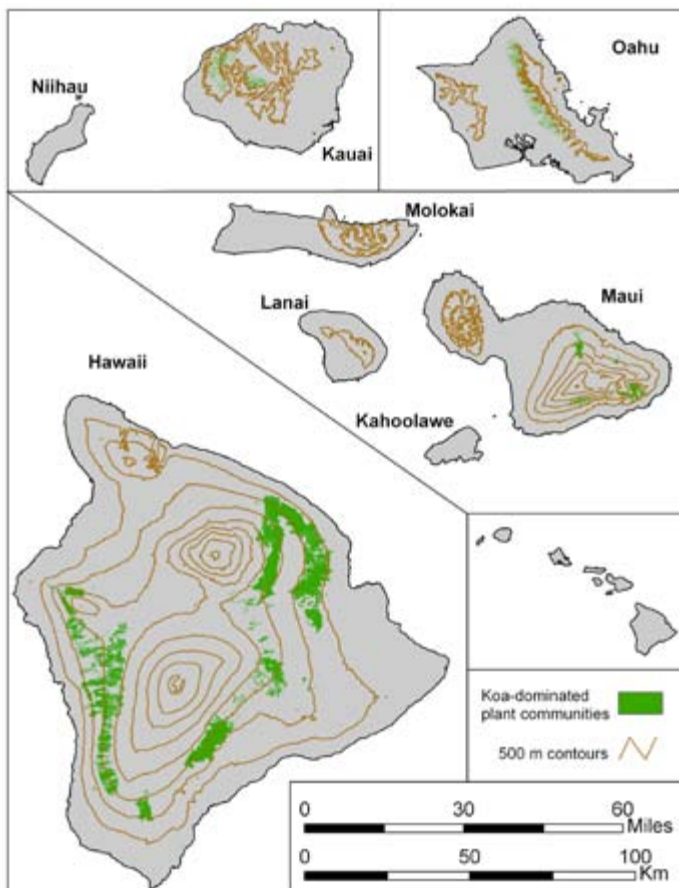
GROWTH AND DEVELOPMENT

Height and diameter

Young koa trees under good conditions grow rapidly. Dominant seedlings in natural stands can put on 1.5 m (5 ft) in height and 1 cm (0.4 in) in stem diameter each year for the first few years. Stands which naturally regenerated in the early 1970s along lower sections of Mauna Loa Strip Road (about 1,200 m or 4,000 ft elevation) were 18–25 m (60–82 ft) tall by 2008 (Martinez Morales, unpub. data) whereas upper elevation stands along the same road at about 2,000 m (6,500 ft) elevation had only reached 5–7 m (16–23 ft) in the roughly the same time. A plantation at 1,400 m (4,600 ft) on the windward side of Mauna Kea reached 16 m (52 ft) in 18 years while a plantation at 1,600 m (5,200 ft) at Keana-kolu reached the same height in 26 years (Scowcroft, unpub. data).

As is the case with all forest trees, the rate of koa stem diameter growth depends on the density of the stand and how many trees are competing for the same resources. While young, open-grown koa trees can grow more than 2.5 cm (1 in) in diameter per year, managed plantation trees usually average 1–1.5 cm (0.4–0.6 in) diameter growth per year, with the future crop trees doing better. While the dominant trees in very dense, unthinned natural stands may grow as much as 1 cm (0.4 in) per year, most trees will grow as little as 0.2–0.4 cm (0.08–0.16 in) per year.

Generally speaking, sapwood tends to be proportionally thicker on trees when they are young and fast growing, although sapwood thickness also seems to vary greatly among trees and among different populations of koa. Juvenile wood forms in the section of the bole that still has branches attached. The log from an open-grown tree with a full crown that grew quickly in its first few years will have more juve-



Distribution of koa in Hawai'i (Map developed from Gon, 2006 and Jacobi, 1990 by Baker et al., 2009. Used with permission.)

nile wood in the pith than the same sized log from a tree that grew more slowly. However, once the tree sheds its lower branches and starts growing clear wood, there is no known relationship between growth rate and wood density.

Phenology

Koa seedlings initially produce true pinnate (feathery) leaves for the first year or two of growth and produce phyllodes thereafter. The transition time from true leaves to phyllodes is different for different populations of koa. Koa seedlings may flower as soon as 3 years after planting but more commonly flower after 5 years. Koa flowers December until June; seeds usually ripen in September and October. No one knows how long koa can live, but trees more than about 100 years old are usually affected by heart rot and it is unlikely that koa trees can live more than a couple of hundred years. Since koa is not deciduous, it does not produce annual rings.

SILVICULTURE

Regeneration in natural forests

Most koa trees in Hawaiian forests today have regenerated naturally from seed buried in the soil. Koa's hard, shiny seeds can remain viable for decades in the soil and germinate only when the soil is disturbed and warmth and light can reach the seeds. In nature this can occur when a large tree falls in the forest and opens up a gap in the canopy. More commonly today, koa seedlings regenerate when the soil is scraped by bulldozers constructing roads, building fences, or skidding logs. Koa seedlings may also germinate after fires. Many pastures with scattered koa trees have abundant koa seed in the soil, but these can only germinate when grazing animals are excluded and the grass mat mechanically removed.

Koa also sprouts from root suckers, especially in areas where rocky soils force the roots to grow at the surface and the roots are injured by human or livestock traffic. Many of these clonal stands of trees which regenerated from root suckers can be seen along Mauna Loa Strip Road in Hawai'i Volcanoes National Park. Feral goats injured roots of remnant trees growing in pastures, and after the goats were removed in the 1970s the root suckers developed into the stands seen today (Tunison et al. 1995).

Koa seedlings need full sunlight to grow and flourish. Hundreds of seeds may germinate after a large tree falls in the forest and tears up the soil, but only

one or two seedlings may eventually reach mature size due to lack of light. If the gap is too small, the overstory trees will close canopy and not enough light will reach the forest floor for koa seedlings to survive. Small seedlings can sometimes be observed growing along fence lines or other small disturbances in the forest, but these do not receive enough light to reach the canopy and they eventually die.

In most Hawaiian forests, koa has failed to regenerate well after harvesting because of invasive animal and plant species. Both feral and domestic cattle roam the forests and destroy any regeneration. Invasive plant species such as strawberry



Top left: Koa growing at low elevation (750 m or 2,460 ft) on windward Mauna Kea. Note the strawberry guava understory. Top right: A young koa seedling showing the transition from immature, pinnate leaves to phyllodes. The large phyllodes are typical of Hawai'i Island populations of koa. Bottom: Although koa seedlings (with pinnate leaves) are sprouting in the gap caused by the fallen parent tree, there are many more tropical ash seedlings, and ash will eventually dominate the site. Photos: © J.B. Friday



Top left: A large, senescent koa falls over and creates a gap in the forest canopy for other trees to take over. Here, tropical ash are taking advantage of the growing space. Top right: No young koa trees will replace this old, fallen giant, since strawberry guava has taken over the understory. Middle left: Healthy young koa seedlings regenerating in a canopy gap created by a dying koa tree that later fell. Middle right: A koa seedling is able to survive only because it is protected from feral cattle by logging slash. Bottom left: Clonal stands of koa growing from root sprouts on Mauna Loa. The different growth forms of the parent trees result in drastically different stands. Bottom right: Koa regenerates prolifically from buried seeds after the soil is scraped with a bulldozer blade. Photos: © J.B. Friday

guava (*Psidium cattleianum*) and tropical ash (*Fraxinus uhdei*) reproduce far more prolifically than koa and choke out any koa regenerating after logging or a disturbance (Friday et al. 2008). While there are few examples of sustainable koa harvests in natural forests, some new management ideas are emerging. Since the seed of strawberry guava is only viable for a few months after the fruit falls to the ground (Uowolo and Denslow 2008), harvests in guava-infested stands could be scheduled 6 months after the fruiting season to minimize strawberry guava germination. Resprouting cut guava would still compete with koa regeneration, however. Koa has also been shown to be tolerant of the herbicide imazapyr, and targeted applications of this herbicide might kill invasive species such as tropical ash while leaving koa relatively unaffected. In forests infested with feral cattle, the piled branches of harvested koa can be used to protect seedlings, but this is only feasible for a small area.

Some trees can be harvested and regenerated by “coppicing,” cutting the tree and allowing new shoots to develop from

the cut stump. While young koa trees coppice readily, this method is more likely to result in multi-stemmed shrubs than trees of good form.

Regeneration of koa in pastures

Most upland pastures in Hawai'i were once koa forests, and where scattered koa trees can still be seen it is likely that a seed bank still exists. The first step in regenerating a koa forest in a pasture is to graze the area heavily to reduce the density of the grass sward, then exclude the cattle entirely. The soil surface is then scarified with a small bulldozer with a brush rake attached, with care being taken to move as little soil as possible. Grazing the area first makes scarification much easier; otherwise the typically thick kikuyu grass mat clogs the brush rake. Since complete scarification usually results in a stand that is much denser than desired (as much as 20,000 seedlings/ha or 8,000 seedlings/ac) and may lead to erosion, managers have experimented with other methods. One recommendation is to lower the bulldozer blade every 10 m (30 ft) or so and scarify a small patch. Another method



Top left: An 8-year-old koa stand regenerated from scarification in a fenced cattle pasture on Mauna Kea. Top right: A 15-year-old koa stand that naturally regenerated in an area cleared for sugarcane production in Ka'u. Bottom left: Healthy young koa trees established after salvage logging of senescent pasture koa trees on windward Mauna Kea. Cattle have been excluded from the area. Bottom right: A koa stand regenerated from soil scarification on Mauna Kea. Cattle have been excluded from the reforestation area while the pasture to the right of the fence line is still grazed. Photos: © J.B. Friday and Dean Meason (top left)

is to scarify lines across the landscape, leaving undisturbed grass in between. Lines should be wide enough so that the grass does not re-colonize the area under the seedlings too quickly. The overall goal is to regenerate a closed-canopy stand of trees, which are widely spaced enough to allow good growth, at minimum cost to the landowner.

Plantation establishment

Plantation koa has at best a mixed record. While koa was the fourth most planted tree in Hawai'i reforestation projects, with more than a million seedlings planted from 1908–1960 (Nelson 1965), few if any of those plantations can be located today. More recent plantings have been successful in growing koa trees but less successful in producing timber. Hundreds of thousands of trees have been established over the past 20 years at the Hakalau Forest National Wildlife Refuge for habitat for Hawai'i's native forest birds. Few planted stands, though, have trees with the superior form needed to produce quality timber (Scowcroft et al. 2010). In addition to suffering losses from cattle, plantations are also attacked by various insects (see the sections on pests and diseases below).

Propagation

Koa is not difficult to propagate in the nursery, and detailed descriptions of koa propagation have been published elsewhere (Wilkinson and Elevitch 2003, 2004; Elevitch, Wilkinson, and Friday 2006). Seed collection needs to be scheduled well ahead of time so that seeds may be collected during times of peak seeding. Tree architecture (straightness, branchiness) and probably wood color are strongly inherited, so it makes sense to collect seed from superior

trees in wild populations (Friday 2000). Large, spreading trees growing in open pastures may be easy to collect from but may produce spreading, branchy progeny. Different populations are also adapted to different climates and soil conditions, so it is usually best to collect seed from trees growing in the same general area as they are to be planted. A good rule of thumb is to collect seed from at least two dozen trees. Wild populations of koa have suffered from decades of selective harvesting straight trees for lumber and centuries of harvesting the largest trees for canoe building, so superior trees may be less common in the wild than they once were. Territorial foresters in Hawai'i used to plant koa from mixed seed lots all over the state, so wild populations of koa in some locations may come from planted stock rather than natural stock. Resistance to disease is also partly genetic (Shi and Brewbaker, 2004), and koa currently thriving in highly disease-prone environments may already have some resistance. Research to select and propagate disease-resistant koa is currently under way in several locations in Hawai'i but no disease-resistant seed is commercially available as of 2009.

Seed

Seed need to be scarified before planting, either with a hot water treatment, by clipping, or by soaking in sulfuric acid (Wilkinson and Elevitch 2003, 2004; Friday 2000). There are usually between 5,300 and 16,500 seeds/kg (2,400–7,500 seeds/lb), although some seeds may be smaller.

In the nursery

Most koa grown for reforestation is raised in dibble tubes with a soil-less mix containing peat moss, perlite, and/or vermiculite. Standard practice is to grow koa in tubes con-



Left: Dibble tubes train roots to grow downward and not spiral. Right: Larger dibble tubes can be used to produce larger seedlings, which may grow faster in weedy sites. Photos: © J.B. Friday



Left: The herbicide imazapyr is effective in killing kikuyu grass but does not seem to affect koa. Right: One-year growth of a koa seedling at the Hakalau Forest National Wildlife Refuge. For this tree, weeds were controlled pre-planting and post-planting with herbicides and the seedling was fertilized with a complete fertilizer. Photos: © J.B. Friday

taining 164 cm³ (10 in³) or even only 49 cm³ (3 in³) of potting mix, but koa seedlings grown in even larger tubes of 656 cm³ (40 in³) grow to a larger size in the same amount of time and would be able to grow above competing grasses more quickly (Jacobs et al., no date). The trade-off is that larger seedlings are more expensive to raise and more difficult to plant. Forestry dibble tubes or other root trainers force roots to air-prune and branch in the container and result in a healthy root plug when the seedling is planted. Koa should not be grown in round pots or plastic bags, as the tap root will spiral at the bottom of the bag and result in a crooked or “J-rooted” seedling which will never grow into a healthy tree.

Fertilization is important, as seedlings need sufficient nutrients to reach their full potential. Seedlings grown in larger containers require more nutrients. One study found an optimum rate of 2.3 kg/m³ potting mix (2.3 oz/ft³) of a slow-release fertilizer with 15N-9P-12K (Dumerose et al. 2009). Koa is a nitrogen-fixing tree and in nature forms an association with the bacteria *Bradyrhizobium* in the soil. Seedlings grown in a soil-less mix should be inoculated with *Bradyrhizobium* so that the bacteria can establish colonies on the seedlings’ roots (called nodules) and the process of nitrogen fixation can begin. Commercial preparations of *Bradyrhizobium* inoculum are not available in Hawai‘i, so growers need to collect nodules from forest trees to inoculate seedlings in the nursery. Nodules can be collected from young koa trees or from koa roots growing in rotten logs. They should then be washed and then crushed in distilled or bottled water (because chlorine can kill the bacteria) or mixed with water in a blender and the solution used to water the young koa

seedlings 2 weeks after the seedlings have sprouted (Wilkinson and Elevitch 2003). Inoculating with this suspension of nodules in water is better than attempting to inoculate with soil from koa forests, because introducing soil into the potting mix can introduce pathogens. Koa trees in nature also form associations with mycorrhizal fungi in the soil, which aid in the tree’s uptake of phosphorus and other nutrients (Miyasaka et al. 1993). However, most forest and pasture soils have good populations of mycorrhizal fungi and seedlings naturally form associations with them shortly after they are planted. No long-term benefits of inoculating with mycorrhizal fungi have been shown.

Planting

Seedlings are ready to outplant when they are 20–30 cm (8–12 in) tall, usually in 12–18 weeks. Only healthy stock should be planted, and slow-growing, root bound, or diseased seedlings should be culled. It is a waste of time and effort to try to nurse a sick tree back into health once it is planted. Although koa fixes nitrogen, a complete fertilizer high in phosphorus is beneficial to get seedlings off to a good start. Standard practice is to apply 100 g (4 oz) of complete fertilizer such as 10-30-10 per seedling in a hole adjacent to the seedling at planting time. Different soils require different fertilizers, and it is a good idea to have soil tested before planting (Silva and Uchida 2000). Koa planted in low phosphorus soils such as the Oxisols and Ultisols on O‘ahu and Kaua‘i may benefit from extra phosphorus application at planting. A study on an Oxisol on O‘ahu showed good initial growth when seedlings were fertilized with 35 g (1.2 oz) triple super phosphate (0-45-0) per seedling (Scowcroft and

Silva 2005). Since phosphorus cycles through the ecosystem, phosphorus fertilization can have long-term positive effects in P deficient soils (Meason et al., 2009).

Tree crowns will expand to take advantage of whatever growing space is available, so different planting designs are possible. Trees planted at a higher density will close canopies sooner, shading out understory weeds and beginning the process of self-pruning. On the other hand, denser plantings will cost more per area in terms of seedlings and planting costs, without necessarily yielding more in the end. Trees do not need to be planted on a square spacing, and rectangular spacings might make weed control between rows easier. Typically trees are planted at spacings of between 2.5–3 m (8–10 ft), creating densities of 1,600–1,100 trees/ha (650–450 trees/ac). Any plantation will need to be thinned before harvest, and the first possible timber harvests would only

occur when the plantation has been reduced to about 10 m (33 ft) between trees.

Mixed plantings of koa and other species such as ‘ōhi‘a would be more similar to natural forests and might have some silvicultural benefits. ‘Ōhi‘a grows more slowly than koa and so would not compete much with koa for light but might help koa self-prune by shading side branches. A mixed koa-‘ōhi‘a stand might not require pre-commercial thinning the way a pure koa stand would. Understory plantings of native species such as ‘ākala (*Rubus hawaiiensis*), pilo (*Coprosma* spp.), ‘ōlapa (*Cheirodendron* spp.), and ‘ōhelo (*Vaccinium* spp.) help improve habitat for native birds. Interplanting koa with faster-growing trees such as *Eucalyptus* does not work, as koa needs ample light in order to thrive and the faster growing trees are also aggressive competitors for available nutrients and water.



Top left: Koa and ‘ōhi‘a interplanted in a 8-year-old mixed stand on old sugarcane land on windward Mauna Kea. Top right: This tree grew 51 cm (20 in) in diameter in 18 years but much of the wood was sapwood. Heart rot had begun in a fork in the trunk and progressed through the stem. Bottom left: A 7-year-old koa plantation at low elevation on the Hāmākua coast. Bottom right: A 28-year-old koa plantation at a high elevation grown from seed collected beneath superior forest trees. Photos: © J.B. Friday and Dan Adamski (top right)



A dense young koa stand thinned to release a crop tree with superior form. Photo: © J.B. Friday

Protection

It cannot be stated strongly enough that livestock need to be excluded 100% of the time from young koa plantings. A few stray cattle can nip the tops off of all the trees in a new planting in a few hours, ensuring that the grower is left with a stand of short branchy trees that look like apple trees. Horses, goats, and sheep can do even more damage. Even after seedlings are a meter tall, competition from grass and weeds can rob them of nutrients and moisture. A study conducted in dense kikuyu grass on Mauna Kea showed that seedlings grew almost twice as tall 8 months after planting when the grass was controlled with herbicides (James Leary pers. comm.). While the broad-spectrum herbicide glyphosate can provide good pre-plant grass suppression it should not be used after planting, as koa is highly susceptible. Grass-selective herbicides such as fluzafop-p-butyl can be used to control grasses during establishment. Koa seems to be highly tolerant to the broad-spectrum herbicide imazapyr, although research is still on-going. Mechanical weed control with string weed trimmers or other tools is costly and risky because koa seedlings are easily injured.

Stand management

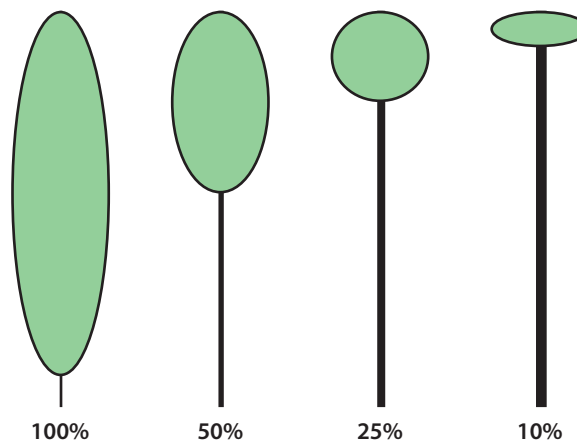
Thinning

Koa stands, either natural or planted, thin themselves out as larger trees grow by overtopping smaller trees. A natural stand can go from 20,000 trees/ha to 1,000 trees/ha in a couple of decades. Individual trees in dense stands grow slowly, though, because of all the competition. Managers can both speed up the process and select for the best trees in the stand by thinning. Releasing selected crop trees from competition can increase their diameter increment by 50–100%, greatly shortening the time to harvest (Baker et al. 2008; Scowcroft et al. 2007). Thinning will also increase the potential yield of a stand if forked or unhealthy trees are culled and straight, vigorous trees take their place. A good crop tree thinning strategy is to select and mark potential crop trees based on their size, health, vigor, and form. Crop trees need to have

reasonably full crowns in order to respond to thinning. One rule of thumb is to select crop trees that have at least 25–30% live crown ratio. The live crown ratio is the percent of the height of the tree that supports a live crown, thus a 9 m (30 ft) tall tree that had a live crown 3 m (10 ft) deep would have a 30% live crown ratio (Figure 1). The larger the live crown ratio the more the selected crop trees will respond to thinning. Suppressed trees that only have a small live crown remaining will not respond well, if at all.

Competing trees out to a given radius are culled or harvested if they are large enough. Koa trees can be killed by double-ring chain saw girdling or by notching and herbicide application (Motooka et al. 2002). Some herbicides may translocate from treated trees to non-target trees through root grafts. Triclopyr has been used in thinning koa stands without showing any signs of translocation, but other herbicides should be tested locally before being applied on a large scale. Koa trees will grow faster when given more room, and a wide enough radius should be cleared so that thinning will not need to be done again for years (Baker et al. 2008). Fertilization combined with thinning can give released trees a boost (Scowcroft et al. 2007). In an 8-year-old stand on

Figure 1. Live crown ratio. The response to thinning increases with the live crown ratio of remaining trees.



Mauna Kea, potential crop trees in a dense natural stand were released when all competing trees within a 4.5 m (15 ft) radius of selected trees were cut. The released trees grew almost twice as fast as the selected control trees, increasing an average of 1.7 cm (0.7 in) in diameter at breast height per year over the next 2 years. The next planned thinning for that stand will come when the stand closes canopies, when it is hoped that some trees will be merchantable. A final harvest is planned with trees at a 10 m (33 ft) spacing or an average stocking density of 100 trees/ha (40 trees/ac). Better sites with more rainfall and more fertile soil will support a higher stocking, that is more trees per area of the same diameters than poorer sites (Ares and Fownes 1999, Baker and Scowcroft 2005, Baker et al. 2009). The butt log of a hardwood tree such as koa is where most of the timber value lies, and even better formed young koa trees fork within 5–10 m (16–33 ft) of the ground or lower. Once a tree has forked, there is little value in the upper branches. Forest managers should maintain high stand density or high stocking until the butt logs of the koa develop and are relatively branch free, then thin aggressively to maximize diameter growth on the valuable butt log. Pre-commercial thinnings where no logs are sold are an up-front cost and investment in the stand, but while there are no hard economic data available the improved growth and quality observed immediately after thinning indicate that thinning operations will be economically advantageous.

Singling and pruning

Young koa leaders are sometimes killed by pests and trees develop multiple leaders. If one goal is to produce timber, these should be reduced to a single leader. Multiple leaders can be pruned with hand clippers as long as they are smaller than a pencil. Pruning of larger branches with a saw has not been successful. Wounds from pruning larger branches invariably develop rot that goes into the stem of the tree, weakening it and rendering it useless for timber. Tree form should be managed by selecting for the best trees in the stand and giving them space to grow rather than trying to improve the form of branchy or forked trees.

Group selection systems

Foresters define a stand as a group of trees growing in a similar environment and sharing a similar history. A forest contains many stands, each of which may have regenerated at a different time or may be growing on a different soil or at a different elevation. Koa stands that have grown up in old pastures are likely to be all of the same age, since young koa trees do not regenerate under older trees. Native forests often contain many small koa stands, each of which has regenerated during disturbances such as windfalls or logging. A silvicultural system that might work in mixed native forest would be a group selection system, where harvesters cre-



Pruning large branches leaves wounds that enable rot to enter the tree. Photo: © J.B. Friday

ate small gaps in the forest large enough for small, healthy stands of koa to regenerate. Group selection has not yet been tried in Hawai'i, and no studies exist on how large such gaps should be, but they should be larger than individual treefall gaps and small enough that the resulting koa stands do not attract outbreaks of insects or other pests. Invasive species such as tropical ash or strawberry guava would need to be controlled. Over the forest landscape, many small harvests over time would allow many small stands of different ages to regenerate and grow, mimicking the structure of the natural forest. A group selection system would differ from the destructive but sadly common practice of high-grading, where the best trees in the forest are cut, poorly-formed and diseased trees are left, and no provision is made for regeneration. Harvesting a single tree usually will not open up the forest canopy to let enough light in to get good koa regeneration. High-grading often goes by the environmentally-friendly sounding name of "selective logging," but without a silvicultural plan, the end result is the same. While high-grading can turn a quick profit, over the long term it de-



Top left: Potential future crop trees (blue ribbons) and cull trees (pink ribbons) in a young koa stand marked for thinning. Top right: A 2-year-old koa planted into a gap in a eucalyptus forest. Bottom left: A koa tree released from competition in a thinned stand. Bottom right: A straight 8-year-old koa tree which grew in a dense, naturally regenerated stand on Mauna Kea and was released by thinning. Photos: © J.B. Friday and Paul Scowcroft (bottom right)

stroys the productivity and health of the forest. In a valid silvicultural system, the focus is on regeneration and growth of the next generation of trees.

Salvage logging

“Salvage” logging connotes the harvest of trees that are dead or dying and would otherwise go to waste. In the past when koa forests were deliberately converted to pastures, it made sense to at least use the wood. Today, salvage logging can help a landowner finance forest restoration in degraded forest lands or pastures. Without a silvicultural plan in place to restore the forest, however, salvage logging is just unsustainable mining of timber.

PESTS AND DISEASES

Livestock

Most koa seedlings, whether planted or naturally regenerated, are destroyed by cattle. Larger seedlings are topped by cattle and then develop an “apple tree” form with multiple leaders, rendering them useless for timber. While managed cattle keep koa from growing up in pastures, thousands of un-owned feral cattle roam Hawai'i's forests and destroy regeneration of koa and other native plants. Sheep, goats, and horses also will browse koa foliage and strip bark from young koa seedlings and saplings. In any koa reforestation project, the first order of business is to construct solid fences to keep out the livestock. Feral pigs may uproot koa seedlings, but pigs probably do not preferentially browse koa seedlings, and koa seems to regenerate well in forests where pigs but not cattle are present. Boars may damage young trees by rubbing their tusks along the bark near the ground.

Koa wilt

Koa trees are susceptible to a vascular wilt disease commonly called koa wilt (Friday and Dudley, no date). While the fungus *Fusarium oxysporum* f. sp. *koae* is generally thought of as the pathogen causing koa wilt, several other pathogenic

species of *Fusarium* have been recovered from affected trees (Gardner 1980, Anderson et al. 2002, James 2004). The fungus blocks vascular tissue, causing leaves (phyllodes) to turn yellow, wilt, and fall off the tree. Cankers appear on the stem and the bark may ooze yellow sap. Dark staining spreads throughout the sapwood. Eventually whole branches or the entire tree becomes defoliated. Older trees often are able to isolate the infection and continue growing, but the disease is usually fatal to trees less than about 15 years old. Up to 95% of the trees at low elevation plantations can be affected (Shi and Brewbaker 2004), perhaps because the pathogen grows more rapidly at warmer site at lower elevations (below 750 m or 2,500 ft). A survey of koa stands along an elevation gradient of 600–1,000 m (2,000–3,300 ft) on Kaua'i showed that the proportion of diseased koa trees was higher at the warmer, lower elevations (Martinez-Morales, unpub. data). Symptoms are observed on trees at higher elevations, but the disease is much less commonly encountered and is not often fatal. *Fusarium* is a soil-borne fungus and common in Hawai'i's soils. Some individual koa trees seem to be resistant to wilt, and research to develop wilt-resistant strains of koa from these trees is ongoing. Until wilt-resistant koa strains are developed, growers should expect high mortality in koa plantations at low elevations (below 750 m or 2,500 ft). Koa grown from seed collected from healthy trees growing at low elevations might have increased resistance to wilt, as the parent trees have survived despite presumably having been exposed to the disease.

Other diseases

Two native rust fungi (*Atelocaula digitata* and *A. koae*) attack koa, forming rust-colored blisters on leaves and causing deformities or “witches’ brooms” on new shoots (Nelson 2009). While rusts are common and can deform young seedlings, they are rarely if ever fatal, and young trees usually recover. Many common root rot fungi such as *Armillaria* can attack koa trees (Gardner 1996). Large, old koa trees usually have advanced heart rot caused by various wood rot



Left: Cattle eat the growing leaders of young koa trees. Center: Koa roots are shallow and are easily damaged by livestock and machinery. Right: Typical damage to bark by horses. Photos: © Craig Elevitch and J.B. Friday (left)



Top left: The vascular disease kōa wilt (*Fusarium oxysporum*) often causes partial canopy dieback. While affected branches will not recover, older trees will often be able to isolate the infection and resume growth. Top center: Watersprouts of immature foliage are a sure sign of wilt. Top right: Canopy dieback and dead leaves remaining on the tree are symptoms of kōa wilt disease. Middle left: A two-year-old seedling which succumbed to kōa wilt disease. Middle right: A superior kōa tree growing in an experimental seed orchard composed of a second generation of kōa trees showing tolerance to kōa wilt. Bottom left: Typical staining of sapwood in a young tree caused by the kōa wilt fungus. Bottom center: Staining in roots caused by wilt. Bottom right: Diseased and injured trees may exude gums to ward off insects and pathogens. Photos: © J.B. Friday



Top left: Damage to terminal leaders caused by the *Acacia* psyllid. Top center: Entry hole of the black twig borer. Top right: The koa seed worm. Bottom left: Koa rust is a fungus disease that causes deformities of shoots and foliage. Bottom right: Hulumoa or Hawaiian mistletoe, a common parasite on koa. Photos: © J.B. Friday

fungi. Koa planted in old cane fields have been attacked by nematodes, which limit root growth. Older koa trees growing at higher elevations are often infested with native Hawaiian mistletoes or hulumoa (*Korthalsella* spp.) (Nelson and Friday 2009). Since mistletoes are parasites, heavy infestations are a sign of poor tree health. The mistletoes infest trees with low vigor and contribute to the tree's decline.

Insects

Insects usually cause fewer problems for koa growers than diseases but one insect in particular deserves increased attention. The koa psyllid, *Psylla uncatoides*, attacks growing shoots and terminal leaders of young koa trees, causing die-back and loss of apical dominance. Heavy attacks by this non-native insect may be the major reason that most koa plantations have multiple-stemmed trees even if livestock and grazing animals have been excluded. Large, open plantings of koa seem to be the most susceptible to attacks while koa growing up in gaps in mixed natural forests seem to be less affected. Biological controls have been introduced, but often the predators bring the psyllid under control after the

damage is done (Leeper and Beardsley, 1976). Singling, cutting back multiple leaders to get back to a single stem, is a promising management strategy, but only when the branches are pencil-sized or smaller and can be cut with a pair of hand clippers. Trees usually recover quickly after attacks, and if form is not a concern, for example when trees are being grown for wildlife habitat, the psyllid is not a major problem. Koa seedlings and twigs are also attacked by the black twig borer (*Xylosandrus compactus*) and other beetles such as *Xyloborus* spp. (Daehler and Dudley, 2002). While twig borers may kill young seedlings, especially at lower elevations, they do not seem to vector fungi that cause koa wilt. The koa moth, *Scotorythra paludicola*, a native species, occasionally explodes in spectacular outbreaks that can defoliate an entire koa forest, causing significant mortality (Haines et al., 2009). While severe, these outbreaks are rare, occurring only about once in a decade somewhere in Hawai'i. The koa seed worm (*Cryptophlebia illepidata*), actually a caterpillar, often attacks koa seed pods and destroys the seed. However, since koa is such a prolific seeder, seed loss to the koa seed worm does not harm koa populations. Because the use of

insecticides in forests in Hawai'i is problematic for both economic and ecological reasons, the best protection against loss to insects is maintenance of good tree health. Healthy trees are much less likely to be attacked by insects or to suffer mortality if they are infested.

DISADVANTAGES

Koa's main disadvantages to being included in farming systems are the tree's susceptibility to injury and diseases. Diseases limit koa to higher elevations, whereas most farms in Hawai'i are below 600 m (2,000 ft) in elevation, the minimum elevation recommended for koa forestry. Shallow soils and rocky, poorly drained soils also limit where koa can be grown. Koa is also easily wounded by farm animals such as cattle, goats, horses, and sheep and is not suitable for planting on farms if grazing animals are unconfined or if feral animals are a problem. Even where livestock are confined, a strong fence is required, as even in a few hours a young koa planting can be decimated. Insect pests, especially the black twig borer and acacia psyllid, can devastate koa plantings. As a forestry plantation tree, koa has poor stem form and lower per-hectare yields than other tropical plantation species such as teak (*Tectona grandis*), mahogany (*Swietenia* or *Khaya* spp.), or *Eucalyptus*. Low yields, however, may be made up for by the high value of koa timber.

INVASIVE POTENTIAL

Koa exhibits many characteristics of an invasive species: it grows rapidly and seeds prolifically, seeds can live for decades in the soil before sprouting, and the tree fixes nitrogen. Some other *Acacia* species have spread rapidly in Hawai'i and the Pacific Islands. However, *A. mangium* and *A. auriculiformis* seeds have bright orange fleshy tendrils, which attract birds to spread the seed. Koa seeds lack these tendrils and are unlikely to be spread by birds, wind, or water. Koa

is also susceptible to nematodes and fungal diseases and is highly palatable to livestock. There are no records of koa naturalizing outside its native range and the tree is unlikely to become an invasive species (Hawai'i Pacific Weed Risk Assessment 2009).

AGROFORESTRY USES

Silvopastoral systems

Cattle have been grazed under koa as long as cattle have been in Hawai'i, mostly to koa's detriment. Cattle devour young seedlings and will even knock down young trees to get at the leaves. Horses, too, will tear off young koa tree bark, wounding the trees and introducing infections that eventually lead to heart rot. On shallow, rocky soils, cattle can damage koa's shallow roots. It is possible that this damage can introduce diseases such as koa wilt. Despite these difficulties, many ranches in Hawai'i today are exploring ways to re-introduce koa, either by planting stands or by excluding cattle and allowing koa to regenerate naturally. Some ranches only graze wean-offs under koa trees, the theory being that wean-offs do not recognize koa and will concentrate on the grass. Certainly, it is essential to graze cattle only while there is an abundant supply of grass underneath. Cattle left too long in koa stands will invariably bark the trees once the grass is exhausted. Cattle may also serve a purpose in reducing fuel loads in open stands with heavy grass growth if they are managed well. Once koa trees have developed thick, scaly bark they are unlikely to be damaged by cattle or horses, but young trees with smooth bark are easily damaged.

Pasture grasses such as kikuyu grass (*Pennisetum clandestinum*) growing under koa trees often appear greener than the same grass growing out in the open. Grass under the trees may benefit from fog drip from the tree's crown or increased nitrogen from the tree's litter. Most cattle, however, seem to



Left: Cattle may be grazed under koa when trees are large enough that the cattle cannot knock them down to reach the foliage. Grazing cattle may damage roots, however. Right: Koa and mango used as coffee shade in Kona, Hawai'i Island. Photos: © J.B. Friday



Top left: A large koa growing in the forest on windward Mauna Kea. Top right: A koa tree collecting moisture from wind-blown precipitation and fog in a high pasture on Mauna Kea. Bottom left: 'Io (Hawaiian hawk) on a koa tree in Kona. Bottom right: 'Iwi on koa. Photos: © J.B. Friday and Jack Jeffrey (bottom right)

prefer grass grown in full sun, which may be higher in sugars and thus more palatable.

Coffee shade

Shade trees are traditionally used in coffee plantations and may help to reduce drought stress, reduce overbearing, and improve working conditions. Koa trees may be potentially good coffee shade trees, with some limitations. Most koa forests grow at higher elevations than coffee, so koa would only work as a shade tree at the higher end of the coffee belt (350–600 m or 1,200–2,000 ft). Even so, growers should

expect to lose significant numbers of koa from pests and diseases. Koa roots and boles are also easily wounded and may be damaged by operations in the plantation. On the positive side, koa's light canopy lets in sufficient light for coffee. A study in Kona, Hawai'i found that coffee yields were not depressed with shade levels under about 40% (Elevitch et al., 2009). Koa also fixes nitrogen, which might improve the coffee's nutrition. While coffee shade trees are likely to be poorly formed and unlikely to yield much timber, they could be a source of craft wood if they get too large for the coffee plantation.

ENVIRONMENTAL SERVICES

Watershed protection

Reforestation of degraded grazing lands can improve watershed health. While healthy pastures can protect the soil and allow good rainfall infiltration, overgrazing can lead to soil compaction and increased runoff. Reforestation of overgrazed areas, especially in areas adjacent to watercourses, can increase infiltration and decrease runoff and erosion. The soil is protected not so much by the trees' canopy as by the thick litter layer that builds up under forest stands. Reforestation may increase or decrease stream flow in small streams at higher elevations. Koa trees planted in open pastures can intercept as much moisture in wind-blown fog as falls in precipitation. On the other hand, koa plantations probably use more water than the grasses they are replacing, which would tend to decrease average stream flow. Lastly, scale is important: reforestation of tens of hectares in a watershed of hundreds of thousands of hectares will likely not have much of an effect on downstream flow one way or the other.

Wildlife habitat

Koa trees provide habitat for Hawai'i's unique forest birds, including the common 'apapane (*Himatione sanguinea*), 'i'iwi (*Vestiaria coccinea*), and 'amakihi (*Loxops virens*), and the endangered 'akiapōlā'au (*Hemignathus munroi*), 'ākepa (*Loxops coccinea*), and Hawai'i creeper (*Oreomystis mana*). 'Elepaio (*Chasiempis sandwichensis*) have been observed foraging in young koa stands less than a decade old on Mauna Kea and the endangered 'akiapōlā'au nests successfully in stands only 15 years old (Pechjar et al. 2005). Dense young koa stands such as these include many dead branches and overtopped, dying trees, which support the insects the 'akiapōlā'au feed upon. The endangered 'ākepa, however, prefer large, old koa trees for nest sites (Freed 2001). The largest koa reforestation project in Hawai'i is being undertaken by the staff at the Hakalau Forest National Wildlife Refuge (Jeffrey and Horiuchi 2003). Managers and volunteers have planted hundreds of thousands of koa trees in an effort to extend the lower koa-ōhi'a forest across the upland pastures up to the high elevation māmane forest. The newly created habitat should give the forest birds an escape should malaria-bearing mosquitoes invade lower elevation forests. Few native forest birds are found at lower elevations, though, because of avian malaria and other mosquito-borne diseases, and koa plantations at elevations below 1,200 m (4,000 ft) are likely only to provide habitat for non-native birds such as cardinals, mynas, and Japanese white-eyes. Feral pigs are abundant in young koa stands and koa plantations where they have not been controlled, and deer inhabit koa forests on islands where there are deer populations.

Carbon sequestration

Growing trees take carbon dioxide out of the atmosphere and help slow the pace of global climate change. While there have been projects to plant trees to sequester carbon in other parts of the world, none have been funded in Hawai'i as of 2009. While koa grows rapidly, it does not produce the biomass of other tropical acacias or *Eucalyptus* species, and Hawai'i's high costs make it unlikely that growing koa primarily for carbon sequestration could be feasible. However, should a market for carbon from native Hawaiian forests develop, or should Hawai'i develop mechanisms to plant native trees to offset local greenhouse gas emissions, koa plantings could sequester significant amounts of carbon. Koa trees grow rapidly for the first 20 years or so, and on a good site a young koa stand could sequester carbon at the rate of 4 metric tons (MT) C/ha/yr (2.7 tons C/ac/year or 9.9 tons CO₂ equivalent/ac/year) in those first 20 years. As growth slows over the ensuing years, rates of carbon sequestration decrease, but old-growth koa forests contain large stocks of carbon. Whether a landowner would be ever able to harvest timber from a koa forest planted with funding from carbon credits would depend on the specific contract and time horizons included.

HARVESTING AND YIELD

Harvesting

Logging is a job best left to skilled professionals. Felling trees is dangerous work. It is also expensive. Professional loggers invest hundreds of thousands of dollars in trucks, loaders, and skidders (specialized trucks to pull logs out of the woods), not to mention chain saws. Professionals know how to fell trees to minimize breakage and damage and how to buck (cut up) logs to maximize value.

Working with a professional forester

Foresters are college-educated professionals with expertise in forest management. Private consulting foresters can work with landowners to develop a management plan, mark boundaries, mark a timber sale, market timber to local loggers, and monitor the sale. In a timber sale, the forester works for the landowner in selling the timber while the logger works for a mill and buys the timber. Many small private landowners sell timber only once or twice in lifetime and have no experience in drawing up logging contracts, developing silvicultural prescriptions, recognizing endangered species or sensitive habitats, or monitoring timber sales. Foresters will be able to determine how much timber can be harvested sustainably from the land and a fair price, and discuss with the landowner what the visual effect of a harvest on the land will be. Most landowners make more money from a timber sale if they work with a professional forester than if they market the timber on their own. They are also



Left: A koa tree marked with orange paint by a forester as a leave tree for wildlife habitat. Photo: © J.B. Friday. Right: A plank sawn from a 30-year-old cull koa tree in Kona. Markets for cull trees will need to be developed in order for stand management to become financially feasible. Photo: © Travis Idol

less likely to be surprised by problems such as boundary disputes and disagreements over which trees were to be harvested. Foresters are paid flat fees for each task or paid by a portion of the proceeds from a sale. State service foresters with the Hawai'i Division of Forestry and Wildlife can provide free advice on forestry for private landowners but do not develop individual management plans or monitor individual timber sales.

In contrast to consulting foresters who work for landowners, industry foresters work for timber companies. While they may provide free assistance to landowners, and are dedicated to sustainable management of forests, their mandate is to get the best possible deal for their employer.

The following sections are not designed to make a forester out of an inexperienced landowner, but to outline all the different considerations that go into a timber sale and improve communication among landowners, foresters, loggers, and millers for everyone's benefit.

Timber sales

Most landowners will sell timber "on the stump" to a logger, who will cut and mill the timber and pay the landowner a fee based on the amount of lumber recovered. These fees are called "stumpage" and are usually negotiated in terms of so many dollars per board foot of lumber (a board foot measures 12 in long by 12 in wide by 1 in thick). Stumpage fees vary based on the quantity and quality of wood, the terrain and ease of access, and any other stipulations added by the landowner.

Most Hawai'i timber businesses integrate a logging and a milling operation. Sometimes a miller simply keeps track of the amount of lumber produced by his sawmill and pays the landowner fees at regular intervals. Of course this system can become confusing when a mill is sawing logs from two or more areas. Sometimes logs are brought to a central location called a log deck, where they are scaled (measured) by the landowner or the landowner's representative, who estimates how much lumber will be produced when the logs are milled and how much the logger owes the landowner. In this system, the landowner gets paid earlier and has more control over his logs, while the miller bears the responsibility of maximizing yield out of the logs he has cut. Since koa logs are notoriously variable and prone to having heartrot and other defects that are not visible from the outside, sometimes the scalers over- or underestimate yield. In these cases, loggers and landowners may reach an agreement to settle up and pay for any extra lumber recovered (overrun) or receive credit for low recovery (underrun). Some landowners negotiate a premium for curly koa and some retain ownership of the logs and lumber with both logger and landowner receiving a percentage of the final sales.

Because it costs extra to mill low yield, short, small, or crooked logs, sometimes landowners or managers will negotiate tiered stumpage fees, with good quality logs selling at a premium and poor logs selling at a discount. Lower stumpage fees from low quality logs give the logger an incentive to maximize utilization and harvest trees that would otherwise be uneconomic to mill.

New landowners are sometimes surprised to find that stumpage rates are dramatically lower than prices per board foot for finished lumber. It should be borne in mind that only a small fraction of the timber from a sale has the color and figure to command premium prices. Most of the wood from a tree ends up in slabs, edging, and sawdust rather than high-quality lumber. Moving large logs out of the woods and milling lumber is also both capital and labor intensive. Harvesting and milling of koa in Hawai'i are also particularly expensive, due to the low volumes harvested and poor condition of most logs.

On the mainland, timber is often sold in "lump sum" contracts. In lump sum contracts, a forester estimates the volume of standing timber on a tract of land then different loggers bid lump sum fees based on that volume. This system of selling timber is not used in koa forestry in Hawai'i because of the difficulty of accurately estimating the volume and quality of timber to be recovered from standing trees.

Log rules

A log rule is a formula used to estimate how much actual lumber, in board feet, can be recovered from a log of given diameter and length. A board foot represents a unit a foot long, a foot wide, and an inch thick. While there are many different log rules in the U.S., including the "International" $\frac{1}{4}$ inch and the Doyle, the most common log rule used in Hawai'i is the Scribner. Different log rules come up with different estimations of lumber yield, so it is important for the buyer and seller to use the same log rule. In other countries, timber is sold by the cubic meter, which is a simple volume measurement. Timber may be sold by the cubic foot in the U.S., but it is important to realize that a cubic foot of roundwood usually only yields 5–8 board feet of sawn lumber, since the rest of the volume is lost to saw kerf, slabs, and edgings.

Contracts

Before any harvesting begins, a landowner or a consulting forester working on the landowner's behalf needs to negotiate a written contract with a logger. Contracts protect both the buyer and the seller of timber. Clarifying the details ahead of time can eliminate serious misunderstandings later (were the marked trees the ones to be cut or the ones to be left? Was the area to be logged to go up the second or the third fence line?) A good contract will specify:

- The area to be harvested, boundaries, how boundaries will be marked, and who is responsible if the logging show ends up on the neighbors forest. It is a good idea to include GPS locations on the property and good maps.
- The agreed-upon stumpage price and how it will be measured (how many dollars per board foot for firsts

and seconds, shorts, etc., and what log rules will be used).

- Deposits, performance bonds, and stumpage payment schedules.
- Insurance, indemnity, liability, and workman's compensation responsibilities.
- Location of roads, landings, and log decks and how they are to be constructed, what stream crossings will be allowed and how they will be maintained, and any bridges or culverts needed.
- Which trees are to be harvested, how they are to be marked, and penalties for harvesting or damaging the wrong trees.
- Adherence to Hawai'i's voluntary Best Management Practices (Hawai'i DLNR 1996).
- Time frames for harvesting and rights of land access by the landowner during the harvest.
- What is to be done with slash, logging waste, and refuse from the logging operation.
- How the contract can be terminated.

Many sample contracts are available on the Internet, although these usually have to be modified to fit Hawai'i conditions. Landowners need to understand that the more conditions and requirements they impose on a logger, the more it will cost to harvest the trees and the less stumpage the landowner will receive. Harvesters may choose not to bid on a contract with too many specifications or restrictions. Landowners may find it a good trade-off to accept a lower stumpage fee in exchange for a graveled road, a culvert on a stream, or clearing of invasive species from the land. Good stewardship of the forest costs money but it pays in the long run.

Legal requirements

Hawai'i does not have a Forest Practices Act as of 2009, and there are few legal restrictions to logging on agriculturally-zoned lands. Timber harvests may be permitted in the general or resource subzone of a conservation district but a Conservation District Use Application (CDUA) is required and an Environmental Assessment or Environmental Impact Statement may be required. Steep gulch sides and coastal areas as well as upland forest areas are often zoned conservation. Information on use of land in conservation zones and the CDUA process can be obtained from the Hawai'i Department of Land and Natural Resources Office of Conservation and Coastal Lands (<http://hawaii.gov/dlnr/occl/>). County public works offices should be contacted for permits for grubbing (removing vegetation) or grading (moving soil). Landowners may also want to develop conservation plans with the USDA Natural Resource Conservation Service through the local Soil and Water Conservation

Districts. An approved conservation plan may eliminate the need for a county grading permit.

Hawai'i has almost 300 species of endangered plants, many of which live in koa forests. Good stewardship, and state law, prohibits landowners from destroying endangered plants. Sufficient land around endangered plant populations should be left undisturbed so that the plants may flourish. Endangered mammals (for forests, the Hawaiian hoary bat) and birds receive more protection under the law. Forestry activities should neither affect the animals directly nor reduce the bat's or bird's habitat. Landowners who suspect that they have endangered birds or bats on their property, or who are considering reforestation projects that might increase habitat for endangered species, are encouraged to consider entering a "safe harbor" agreement with the Hawai'i Division of Forestry and Wildlife and the U.S. Department of the Interior Fish and Wildlife Service. Landowners with populations of threatened or endangered plants can work with the Hawai'i Division of Forestry and Wildlife. Staff from these agencies can work with the landowner to establish a baseline of populations of an endangered species on the property before a landowner starts work such as reforestation that might increase habitat for endangered species.

A few private forest lands in Hawai'i may be designated "critical habitat" for endangered species by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 2005). These lands have been judged essential for these species to survive and recover and some activities may be restricted on the land. Even if the endangered species in question does not currently exist on the site, lands may be designated critical habitat if they are capable of supporting the species or if the species existed there in the past. Landowners with endangered species can find out if their lands are designated as critical habitat by contacting the Fish and Wildlife Service. Maps of critical habitat are also available on the Fish and Wildlife Service web site.

The presence of endangered species does not necessarily preclude any harvesting, but endangered species habitat needs to be taken into account if they are present. For example, the 'io or Hawaiian hawk is common in forests but generally nests in large 'ohi'a trees. A management plan for a forest where hawks are present should include a survey of hawk nesting sites and leave large 'ohi'a as nest trees. The U.S. Fish and Wildlife Service can work with landowners to protect endangered species yet allow economic use of the land through the Conservation Planning Program (<http://www.fws.gov/pacificislands/conservationplan.html>).

Landowners managing at least 4 ha (10 ac) of forest land can apply to have the land designed as a Tree Farm by submitting a management plan to the Division of Forestry and Wildlife. The property must be capable of sustained production of forest products in quantity sufficient to establish a

business. Once the plan is approved by the Land Board and the land is designated a Tree Farm, the landowner has the legal right to harvest trees he or she has planted.

Management of timber harvests

Timber harvests need to be carefully planned on the ground before any cutting starts. Boundaries should be clearly marked so that loggers do not inadvertently stray onto adjoining properties. Trees should be marked with a single color paint in accordance to the silvicultural plan for the stand. In most cases, trees to be cut will be marked, but in over-mature koa stands in degraded pastures it may work better to mark only trees to be left for bird habitat while the rest will be felled. Marks should be visible from any direction. An additional mark at the base of the tree below the cut serves to confirm that a particular tree was to be harvested in case of a dispute after the logging is done. Once a logging operation is underway, the landowner, her representative, or her consulting forester should visit the site frequently to be sure work is proceeding according to plan and that only the right trees are being harvested, leave trees and regeneration are not being damaged, roads and stream crossings are being maintained, and agreed-upon Best Management Practices are being observed. Good communication between the logger and the landowner during the harvest can forestall problems later.

In Hawai'i, land managers often contract with a logger to harvest timber on a rollover license rather than a contract to harvest a given area. If the land manager is pleased with the job being done on the ground the license is renewed periodically. This system makes it difficult for loggers to plan and invest in the necessary equipment, as they cannot know how long they will be able to work on a job.

Trees should be marked according to a silvicultural plan by the landowner or landowner's representative, preferably a professional forester working from a previous inventory. It is the landowner's or her forester's responsibility to decide which trees should be harvested and which are still growing rapidly and should be left for the next harvest. Landowners need to give loggers incentives to maximize utilization of timber to be harvested while ensuring sustainability of the forest. Lower stumpage fees for poorer quality logs can give the logger an incentive to harvest logs he would normally leave in the forest. Contracts can also be written to mandate harvest of all marked trees, but landowners should be aware that the logger might be taking a loss on some of these trees. Conversely, healthy trees which are still growing rapidly should be left to grow and increase in value. If a logger is required to leave valuable trees he would otherwise harvest in a normal logging job, he might be able to pay less for stumpage overall. The landowner is in a situation of giving up some financial return today for greater sustainability and higher returns tomorrow.

Best Management Practices

Best Management Practices (BMPs) are effective and practical steps to protect the forest and the environment, particularly water quality, during forestry operations. The most important rule is to “keep the soil out of the stream and on the hill.” The Hawai‘i Division of Forestry and Wildlife has developed a set of Best Management Practices (Hawai‘i DLNR, 1996) which are written into state contracts and are not legally binding but a good idea to follow on private lands as well. The BMPs include practices designed to:

- Keep sediment, nutrients, and pesticides out of streams.
- Minimize soil loss during site preparation before planting.
- Minimize soil loss from road construction, use, and maintenance, for example by controlling grade, covering road surfaces, and installing waterbars, culverts, and other drainage controls.
- Minimize soil compaction and productive forest land lost to landings and skid trails (the paths logs are dragged on when being pulled out of the woods).
- Minimize damage to the forest during felling, skidding, and bucking, for example by planning out skid trails.
- Ensure correct and effective use of pesticides.
- Make certain wastes are disposed of properly.
- Ensure special care in Streamside Management Zones (SMZs) including establishment of appropriate buffers.

While water quality is important everywhere, in Hawai‘i almost all lands are designated by the US Environmental Protection Agency as coastal zones and all streams empty out into the ocean in a short distance. What happens on the mountain affects the reef. The USDA Natural Resources Conservation Service and the Soil and Water Conservation Districts can help landowners develop conservation plans and implement Best Management Practices on private lands. Timber poaching, cutting trees without permission on someone else’s land, remains a problem for koa and other high-value trees in Hawai‘i. A landowner’s best defense is a good gate and well-marked boundaries. Property boundaries should be marked in the woods by painting marks on the sides of enough trees along the line so that from any point on the boundary four or five marked trees are visible. Koa millers can help discourage timber poaching by verifying that logs they are offered come from legitimate harvests, similar to the way that coffee mills ensure the coffee they purchase is not stolen. If there were no market for stolen goods, theft would disappear.

Milling and drying of koa lumber

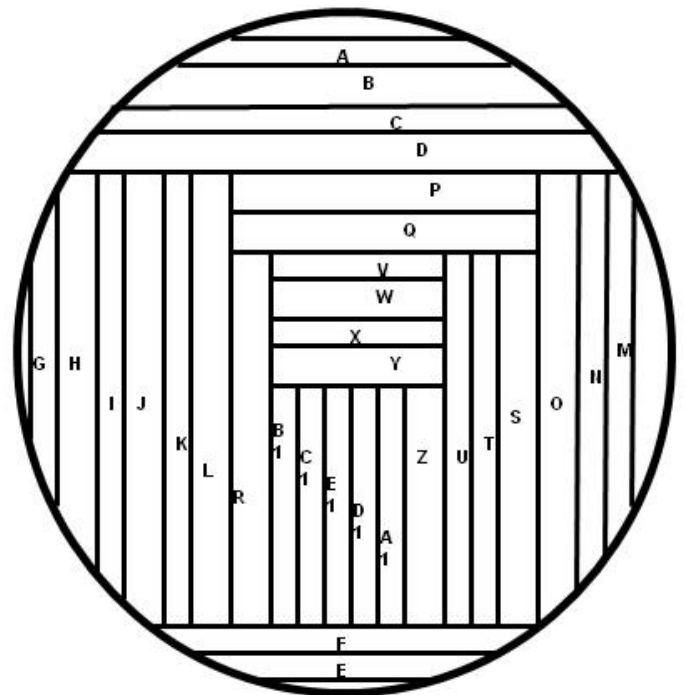
Most koa logs harvested in Hawai‘i today have significant amounts of defect such as heart rot, damage from fires and

livestock, sweep, and so on. The irregular shape of koa logs also makes them a challenge to saw. Most landowners leave milling to experts with years of experience. Skilled and experienced sawyers can get higher yields and more valuable lumber out of a log than less experienced sawyers. While landowners may consider buying an inexpensive portable mill, they should balance the savings obtained from doing the work themselves against the improved yield a larger mill and more experienced sawyer is likely to obtain. Good utilization of the wood resource is part of good forest stewardship.

Sawmills vary widely in efficiency. In general larger and more expensive mills are more efficient in terms of maximizing usable quality lumber from a given log. Band mills and circular sawmills are both common in Hawai‘i. Koa mills operating in Hawai‘i are relatively small and often portable. While processing tiny quantities by the standards of mainland hardwood mills, Hawai‘i mills seek to make up in value what they lack in volume.

Koa is generally flat sawn but occasionally quarter sawn. Since most koa logs are large, irregularly formed, and full of defects, sawyers will turn a log many times in order get most out of it (Figure 2). Many koa logs are more than 1.2 m (4 ft) across, but common band saws can only handle logs up to 90 cm (36 in) in diameter. Logs are therefore commonly split lengthwise with a chain saw before sawing. A dedicated

Figure 2. A sawing diagram of a large koa log showing how an experienced miller maximizes yield of both flat-sawn (boards A, B, and C) and quarter sawn (boards S, T, and U) lumber. Boards are lettered in the order they were sliced off the log. Note how often the sawyer rotated the log during sawing. Drawing by Eini Lowell, USDA Forest Service.



splitter can halve logs much more efficiently but is a big investment for the miller.

Koa lumber is both air and kiln dried. For sites on the wet, windward sides of the islands, kiln-drying is a necessity. Because the wood shrinks nearly equally in both radial and tangential directions, koa can be kiln dried more easily than many other Hawaiian species. Boards with end grain on the face of the wood, pith defect, rot, and other defects can warp, cup, or twist if drying is too rapid. The USDA Forest Service Forest Products lab publishes a drying schedule for koa (see Table 2). A simpler rule of thumb for kiln drying is to dry koa 30 days per each inch thickness of lumber.

Bowl turners prefer to turn green wood to save time drying. Koa cuts easily, although sharp tools are essential. Koa wood contains exudates that can build up behind the cutting edge of the tool and cause burn marks on freshly cut faces that are difficult to remove. Likewise, sandpaper needs to be clean

Table 2. Drying schedule for koa. For thicknesses of 1–1.5 inches, the recommended drying schedule is T6-D4

Step	Moisture content	Temperature in °F			Equilibrium moisture content	RH%
		Dry-bulb	Wet bulb depression	Wet-bulb		
1	Above 50	120	7	113	14.4	80
2	50 to 40	120	10	110	12.2	72
3	40 to 35	120	15	105	9.9	61
4	35 to 30	120	25	95	6.9	41
5	30 to 25	130	40	90	4.1	22
6	25 to 20	140	50	90	2.8	15
7	20 to 15	150	50	100	3.2	19
8	15 to final	180	50	130	3.6	26

For a thickness of 2 inches the recommended drying schedule is T3-D3

Step	Moisture content	Temperature in °F			Equilibrium moisture content	RH%
		Dry-bulb	Wet bulb depression	Wet-bulb		
1	Above 50	110	5	105	16.4	84
2	50 to 40	110	7	103	14.3	79
3	40 to 35	110	11	99	11.5	68
4	35 to 30	110	19	91	8.3	49
5	30 to 25	120	35	90*	5.7	32
6	25 to 20	130	50	90*	4.1	22
7	20 to 15	140	50	90	2.8	15
8	15 to final	160	50	110	3.4	22

* Wet bulb values below 90°F are set to 90°F.

Reference: USDA Forest Products Laboratory Hardwood Drying Schedules <http://www1.fpl.fs.fed.us/drying.html>

and grit sharp to avoid causing burn marks on the wood surface. Curly grain can tear out when planed, so sanding is preferred to planing for reducing the thickness of curly koa lumber.

Value added processing

Trained and experienced sawyers can greatly increase the value of a log by sawing with high value end products and markets in mind (Figure 2). Furniture manufacturers look for matched sets of boards for building custom furniture. Gun stocks and guitar or ukulele sets are other high value products a skilled sawyer can produce. Crotches can yield highly figured wood for bowl turning. Koa milling focuses on producing value from the wood rather than large volumes and catering to the needs of specific markets.

If a log can yield a 2.4 m (8 ft) long cant (a solid block of wood excluding the pith) at least 10 cm (4 in) wide, it can be saved for sale to a veneer mill. Koa cants are shipped to veneer mills on the mainland or in Asia, where they are sliced into thin veneers used in manufacturing plywood, picture frames, and specialty woodwork. Much koa veneer is re-imported into Hawai'i after being sliced overseas. Quality cants may also be re-sawn into relatively thick veneer 1.5–3 mm (1/16th–1/8th in) for use in door frames or other large pieces of woodwork. A veneer-quality cant may be worth significantly more per board foot than the equivalent volume of lumber.

Whereas short and imperfect boards were discarded in the past, today every bit of clear wood is utilized. Pieces under a foot in length are saved for making koa pens and other objects. Solid chunks are saved for bowl stock. However, the more defects there are in a log and the smaller the resulting lumber, the more it costs to mill per board foot. While a mill may be able to accept a mix of good and poor logs, it may not be economic to mill small logs or logs with too much defect.

Most koa today is harvested from large, old, and often senescent trees. While logs from such trees often suffer from substantial heart rot and other defects, the sound wood tends to be of excellent quality. Log diameters of 41–47 cm (16–18 in) are generally the minimum size that can be economically harvested in Hawai'i today. There is little if any market as of 2009 for small-diameter logs from second-growth koa trees. Young trees often have large proportions of unmerchantable sapwood and brash juvenile wood and all logs, large and small, have a crack associated with the pith that is more problematic the smaller the log. Although small diameter logs may contain substantial amounts of wood suitable for cabinets, boxes, and other small items, the cost of sawing to recover these items is prohibitively expensive in today's market, rendering the logs unmerchantable. Markets for small-diameter koa timber need to develop in Hawai'i in



A stack of koa shorts salvaged from downed trees from a previous logging operation. These will be used in furniture manufacture. Photo: © J.B. Friday

order for koa plantations and second-growth koa forests to become profitable.

Labeling

All koa lumber comes from Hawai'i, therefore it is superfluous to describe koa as "Hawai'i-grown." Hawaii Revised Statutes Volume 11 Chapter 0486-119.5 makes it illegal to represent and sell woods other than *Acacia koa* as another type of "koa." Before the passage of the law in 2002 some manufacturers had marketed furniture made of other *Acacia* species as "koala koa" or "kiwi koa." Of course, Hawai'i law does not hold outside Hawai'i, and other woods are sometimes falsely marketed as koa outside the state. Some fine furniture made from other *Acacia* species is marketed in Hawai'i as "koa-like." The Hawai'i Forest Industry Association promotes the "Hawai'i's Wood™" brand, which is given to wood products that are made in Hawai'i primarily out of woods grown in Hawai'i. When customers buy products bearing the Hawai'i's Wood™ brand, they can be sure they are supporting local crafts people and growers.

"Green" certification assures consumers that wood comes from sustainably managed forests. Certification schemes have rapidly grown in the past decade, but as of 2009 only one forest in Hawai'i was green-certified, Kamehameha Schools' Hōnaunau forest in Kona. The main problem for other Hawai'i landowners seeking individual certification is the up-front cost of certification and the lack of any local exclusive market or price premium for selling green-certified wood. The most popular certification system worldwide is run by the Forest Stewardship Council, who accredits two organizations in the U.S. to certify forests: Smartwood and Scientific Certification Systems. The other main green-certification system in the U.S. is the Sustainable Forestry Initiative of the American Forest & Paper Association. The American Tree Farm System offers group certification that is recognized by the Sustainable Forestry Initiative but not

the Forest Stewardship Council. The National Forestry Association and National Woodland Owners Association also offer their "Green Tag" certification program. Group certification may offer a way in the future for small landowners in Hawai'i to become certified. In addition to the cost, some landowners do not want to seek certification because of a perceived loss of autonomy on how they manage their land. Certification bodies may insist on limiting herbicide use, restricting harvest size, and allowing traditional rights of access by native groups. However, formal recognition of good forestry in the form of green certification, may be a powerful argument in the community where there is much misunderstanding of forestry issues.

SMALL SCALE PRODUCTION

Forestry and logging tend to involve large economies of scale. Most koa loggers operate on hundreds of hectares and for months or years at a time. There are considerable expenses involved in transporting logging equipment and portable sawmills to a new location, and the available resources must be large enough to justify these expenses. Smaller timber volumes could be profitable to harvest, depending on the ease of access and the value of the timber. For example, a logger might be able to send a crew from a neighboring ranch to harvest trees if he were already operating in the area. At some point, the value of the timber is less than the cost to the logger of setting up shop on site and harvesting the trees. Some harvesters also operate salvage operations, where they cut trees that need to be removed from farms and are paid in part by the value of the timber.

Hundreds of woodworkers in Hawai'i depend on koa lumber. The cost of the lumber is only a small part of the value of a finished rocking chair or dining room table. A few hundred thousand dollars worth of koa lumber supplies a diverse local industry worth tens of millions of dollars annually (Yanagida et al. 2004, Friday et al. 2006). Sustainable small-scale harvesting of koa ensures that Hawai'i woods continue to supply Hawai'i local industry, as opposed to shipping logs overseas to be processed elsewhere.

YIELDS

No koa plantations have yet been managed until harvest, so current yield estimates are based on projections rather than actual experience. Yield estimates are also based on minimum merchantable diameters, and as milling efficiency increases, smaller logs will become merchantable and stand yields will increase. While some estimates of koa yield have been fanciful, in general estimates have been about 140 m³ of sawlogs/ha (10,000 bf lumber/ac) in 40–50 years (Goldstein et al. 2006, Hensley 2001). However, these projections have been based on assumptions of good basal areas of 40 m²/ha (175 ft²/ac) and harvest of 5 m (16 ft) long logs. Grow-



Left: A koa table by John Gonczar made from sawn veneers. Middle: Butcher-block table tops made from small pieces of koa. Right: A jewelry box made by Gaylord Stadshaug from veneers sliced from highly figured koa. Photos: © John Gonczar (left), J.B. Friday (middle), and David Watersun (right)

ing experience with koa plantings has shown that while stands rapidly attain good basal areas, merchantable logs of 5 m are rare. Most planted koa trees, either because of herbivory or poor genetics, fork well below 5 m. In three 18 to 28-year-old plantations on the island of Hawai'i, only 5–20% of the dominant and co-dominant trees had merchantable boles longer than 3 m (10 ft) (Scowcroft 2010). Assuming good growth of these trees until age 45, these plantations would still only yield 10–90 m³ logs/ha (715–6,430 bf/ac) if only crop trees with 3 m long boles were harvested. Even if trees with boles of 2 m (6.5 ft) were judged merchantable, two of the plantations would have yielded 64 and 77 m³ logs/ha (4,570 and 5,500 bf/ac). The third plantation, the only one grown from selected seed, was projected to yield 260 m³ logs/ha (18,570 bf/ac) if trees with boles as short as 2 m were merchantable.

Yields from pure natural stands regenerated from scarification may be greater than yields from plantations if the dense spacing in naturally-regenerated stands causes trees to grow straighter with fewer forks. If stands are thinned for quality as well, it should be possible to select trees with reasonably long straight boles as crop trees. In one 8-year-old stand on Mauna Kea, butt logs of selected crop trees averaged 4.4 m (14.4 ft) in length, whereas the average tree in the stand had a clear bole of only 3.3 m (10.8 ft). However, natural regeneration in scarified pastures tends to be patchy and absent in some areas. Even if yield is good in pure stands on good sites, yields over the whole landscape are likely to be low if rocky outcrops, open glades, and area where trees did not regenerate are included. No koa stands regenerated from pasture scarification have yet been managed until harvest.

Estimates of rotation lengths (the time a tree is allowed to grow before harvest) and yields have been based on timber volumes. While volumes can be calculated from standing timber and predicted from growth rates, timber values depend as much on quality as yield. There have been too few

harvests of young trees to reliably assess how wood quality changes with age, although there is widespread belief that wood color darkens and thus timber value increases with age. Younger and smaller trees will of course have a greater percentage of juvenile wood and sapwood. Juvenile wood, developed when the bole is still supporting live branches, is unmerchantable and is discarded when the log is milled. Curl and figure are probably largely genetically determined and would be present in young as well as old trees, if at all. Older trees will begin to lose wood to heart rot. If wood quality increases with age, managers would have an incentive to increase rotation lengths to produce higher quality logs, even if volumes did not increase accordingly. Rotation lengths are also a function of the chosen discount rate in the financial analysis (Friday et al. 2000). Higher discount rates lead to shorter rotation lengths because of the high cost of capital.

CURRENT COMMERCIAL PRODUCTION

Estimates of commercial koa production are difficult to come by. Asking a logger where he gets koa and how much he harvests is sort of like asking a fisherman where his best spots are and how much he catches. A survey of industry experts in 2004 estimated that total production of koa lumber in that year was between 700 and 950 m³ (300,000–400,000 bf) (Dudley and Quinn 2004). If valued at an average stumpage price of \$3.50/bf, the value of revenue from koa harvests to landowners in the state would have been between \$1 million and \$1.4 million in 2004. Koa harvests, however, support a much larger forest industry producing cabinets, bowls, picture frames, and high-end furniture. An earlier survey in 2001 put the total retail value of finished products made from wood grown in Hawai'i at \$23.7 million/year (Yanagida et al. 2004), with koa products accounting for 75% of total sales (Friday et al. 2006).

MARKETS

What is sold

In Hawai'i, most sawmills also run logging operations to supply wood for the mills. There are also independent loggers who sell logs to the mills. Landowners usually sell stumpage to a logging/milling operation. The mill then sells green lumber to a kiln, or has a kiln dry the lumber for a price, before selling the dry lumber to builders, woodworkers, or manufacturers. Some mills are integrated with wood-working shops to process their own wood. Mill operators may work with furniture manufacturers to produce custom sets. Some larger furniture manufacturers purchase green wood and dry it in their own kilns.

Koa lumber is exported from Hawai'i to the mainland U.S., Asia, and Europe. Some local businesses have koa veneer produced outside of Hawai'i that is shipped back to Hawai'i laid up on plywood for use in cabinetwork and furniture or laid up on picture frames for sale in Hawai'i.

Grades

Koa grades are descriptive and not standardized across the state. Usually the darker the color and the more figure, the higher the price. Lumber is usually graded as common, select, and curly, with various descriptions added such as "light, medium, or heavy curl," "stress curl," "velvet curl," or "fiddleback." Lumber is commonly milled to 1 inch (4/4) or 2 inch (8/4) thicknesses. A 4/4 board needs to be surfaceable to a minimum thickness of 13/16 in. Longer pieces are relatively more expensive per board foot. Bowl stock and blanks for carving pens or other small items are also sold. Prices for lumber as of 2009 varied from \$8/bf for common stock to over \$100/bf instrument quality curly koa. Because of the great differences in value of koa based on size and quality of the wood, the key to maximizing value is to segregate by quality and market each product (shorts, bowl stock, curly lumber, matched sets) for maximum value.

ECONOMIC ANALYSIS

Koa stumpage prices

Stumpage prices depend on the volume of koa available, the size and quality of the trees, ease of access, and other conditions set by the landowner. Nonetheless, stumpage for koa in 2009 was generally \$4.00/bf or \$4,000/thousand board feet (mbf). Over the past 30 years, koa prices increased slowly from a low of \$100/mbf, rising sharply in the early 1990s, and increasing slowly since then (Figure 3). While it is impossible to predict future prices, increases in prices of koa cannot continue indefinitely, as woodworkers have the option of using other species such as walnut if koa becomes too expensive. On the other hand, Hawaiian-grown koa will always be a high-value specialty product, never a commod-

ity, and even with current efforts at reforestation, supply will be limited.

Financial analysis from landowner perspective

Establishment costs

Enough koa has been planted in Hawai'i that plantation establishment costs can be reasonably estimated. There are clear economies of scale in the cost of seedlings, costs of site preparation operations, and cost of fencing. Table 3 gives cost estimates for a larger plantation of about 40 ha (100 ac) established in open pasture. Clearing of woody brush such as strawberry guava would greatly increase establishment costs.

If the area needs to be fenced against cattle, fencing costs could add \$2,070/ha (\$840/ac), based on a 40 ha (100 ac) rectangular area and linear costs of \$30/m (\$9/ft). The above costs also do not include planning and management. Intermediate costs would include weed control, fertilization, and pre-commercial thinning, if desired.

Where a viable seed bank exists, koa can be established much more cheaply by soil scarification. Costs for stand establishment by scarification would include the costs for soil scarification, weed control, fertilization, singling, and fencing but not planting or seedlings. Since most stands regenerated by scarification are extremely dense, an additional, early thinning might be necessary, adding to the cost. Costs for scarification, which usually only involves scraping off the grass mat, should be lower than for mechanical site preparation for planting. Goldstein et al. (2006) calculated that for a 200 ha (500 ac) property with a good seed bank koa could be regenerated for \$1,700/ha (\$700/ac), including fencing. Since the main cost to establish koa by scarification is fencing the area, larger areas are much less expensive per hectare because they are more efficient to fence.

Property taxes in Hawai'i are determined by the counties, and the property tax basis and rate may change if the land

Table 3. Koa plantation establishment costs (Idol et al., 2007)

Operation	Cost/ha	Cost/ac
Mechanical site preparation	\$1,430	\$580
Initial herbicide application for weed control	\$490	\$200
Seedlings	\$860	\$350
Planting	\$490	\$200
Fertilizer application	\$540	\$220
First post-plant herbicide application for weed control	\$430	\$175
Second post-plant herbicide application for weed control	\$430	\$175
Singling of multiple leaders	\$160	\$65
TOTAL	\$4,850	\$1,965

Figure 3. Koa stumpage prices. \$/board foot, not corrected for inflation.

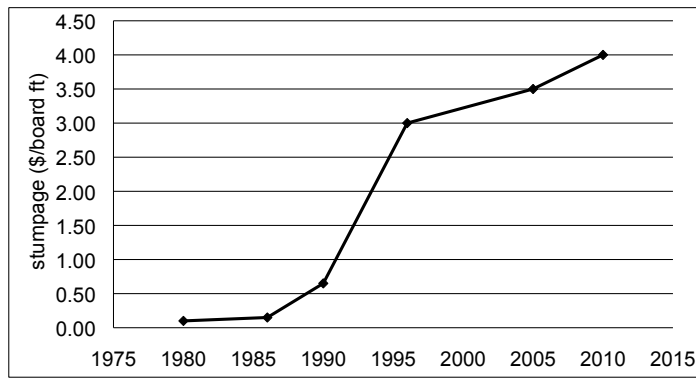


Table 4. Financial analysis. A simplified example of financial analysis of a koa plantation calculated from a spreadsheet (Friday et al., 2000). Costs do not include land costs, planning and management costs, or property taxes. Values are for a hypothetical example and could be higher or lower for a given project.

Item	Value or cost/ha	Value or cost/ac
Establishment	\$4,850	\$1,965
Annual maintenance (weeding and fertilization), years 2–4	\$704	\$285
Thinning (years 5 and 15)	\$803	\$325
Annual maintenance, years 5–40	\$25	\$10
Yield	40.2 m ³ sawn lumber	6,900 bf sawn lumber
Rotation age (years)	40	40
Stumpage, increasing 1% per year	\$1,700/m ³ sawn lumber	\$4.00/bf
Rate of return	6.8% above inflation	6.8% above inflation

use is changed from grazing or crops to forestry. Landowners should consult with the county property tax office about changes in taxes when the land use is changed.

Potential returns to a landowner from forestry depend on the time to harvest, the volume of wood harvested, the stumpage price, and the discount rate chosen. The choice of discount rate is critical, since most costs for forestry projects occur at the beginning and returns are not for decades. A spreadsheet is useful in analyzing all the different options, and a model spreadsheet for forestry financial analysis in Hawai'i is available from the University of Hawai'i (Friday et al. 2000). Each landowner will have a different tolerance for risk and thus a different effective discount rate. Spreadsheet models can help analyze the costs and benefits, contrast various different scenarios, and aid in decision making.

While many landowners expect to see a positive economic benefit from their koa plantations, hardly any plant trees solely for financial reasons. Almost all landowners in Hawai'i

also are restoring koa forests for wildlife habitat, watershed protection, recreation, and other environmental services.

EXAMPLE SUCCESS

Honokōhau Mauka, Kona, Hawai'i, Kelly Greenwell and Tai Lake

Honokōhau Mauka in Kona, Hawai'i, dedicated 100 acres to koa forestry in 1992. Their goals were to maximize the value of wood harvested from salvaged dead and dying old-growth koa while growing a new stand of koa to supply Hawai'i's woodworking industry in the future.

Although the ranch is on land that was once koa forest, cattle grazing had prevented any koa regeneration for decades. Weeds and vines covered the ground and the older koa trees were dying. Landowner Kelly Greenwell wanted to restore a sustainable koa forest to protect the watershed and supply timber for local woodworkers. He worked with Tai Lake, a Kona woodworker, to come up with a plan to manage the land for both economic and ecological sustainability. The keys to the project's success have been to control cattle so that they became a tool to be used in weed management, to allow koa to regenerate naturally, and to harvest small amounts of timber at a time, maximizing its value.

Initially several dead and downed koa per acre were harvested. Returns from the harvest were used to fence the area and temporarily exclude cattle. The soil disturbance from the harvest was enough to stimulate regrowth of young koa from the buried seed bank. Subsequent harvests have scarified additional areas, and the forest is developing multiple stands of different ages. Other native forest species are slowly coming in, creating a natural forest rather than a monoculture of koa and grass.

Only as much koa as could be sold in the local market is prepared at any one time. Rather than selling logs, a relatively low-value product, Greenwell and Lake market milled wood directly to Kona woodworkers, keeping the value of the timber in the local community. Lake himself uses much of the wood in his own shop. He is able to work with the loggers and sawyers to cut exactly the wood he needs for his projects, such as matched sets for larger projects. Close cooperation among the logger, sawyer, and craftsmen has allowed them to realize much more value from each log. At a time in the early 1990s when koa logs were selling for \$0.50 per board foot, they were able to sell matched sets of sawn lumber for \$9.00 per board foot. Subsequently, they produced 10,000 to 12,000 board feet of timber every 5 years, relatively little per unit area but enough to keep the project economically viable.

Since most of the young koa have become tall enough to avoid being browsed, cattle are occasionally pulse-grazed underneath to control grasses and vines, particularly ba-



Natural regeneration at Honokōhau Mauka in Kona, Hawai'i. Photo: © Craig Elevitch

nana poka. The cattle eat some of the smaller koa but do not browse on the larger trees. Areas where the regeneration is too dense for good tree growth are thinned by hand. In the future, thinnings may provide wood for small items such as boxes and bookmarks. Harvests of selected mature trees at 35–40 years old will provide timber and bowl stock while allowing the better trees to continue growing. Now that the older trees have been harvested, the ranch owners face challenges in producing an income stream from the land to pay for taxes and maintenance until the younger trees begin to produce timber. The 2010 drought and ongoing acid rain produced by the Kilauea eruption may also impact the health of the forest. Throughout the project, Greenwell and Lake have striven to create a healthy ecosystem that generates enough economic revenue to support itself and the local community.

FURTHER RESEARCH

Much more is known about koa ecology and management than was known a decade ago, but research invariably elicits new questions, and new management problems continue to emerge (Baker et al., 2009). Research into the following topics could improve the health of Hawai'i's native forests and increase koa production.

- Koa wilt has emerged as a major concern and limiting factor in establishing koa plantations. Is *Fusarium oxysporum* f. sp. *koae* the only causal organism or is the disease caused by several pathogenic fungi, or combinations of pathogens? Are pathogenic *F. oxysporum* native to Hawai'i or a new invasive species? How do site, elevation, and temperature affect the disease? Can improved management prevent the onset of disease in areas where the pathogens are present? Can resistant cultivars of koa be developed through a process of selection and breeding that will allow koa plantations in disease-rich environments?

- Molecular genetics work for koa has only begun. Researchers are discovering satellite markers that will help identify different koa populations. A better understanding of koa genetics will also be useful in identifying disease-resistant trees and trees with superior growth, form, and wood quality.
- Propagation of koa has until now been almost completely from seed. Can practical techniques for vegetative propagation or tissue culture be developed to allow growers to capture favorable properties such as superior wood quality or disease resistance?
- Pests such as the acacia psyllid and the koa moth can prevent trees from growing straight leaders and even kill trees. Are there ways to manage to prevent insect attacks or to mitigate the results of insect damage?
- Thinning has been shown to increase diameter increment in young koa trees growing in dense stands, and fertilization has increased diameter increment in some cases but not in others. What are the trade-offs in terms of costs and benefits to mid-rotation management of koa stands, and how do these vary by site?
- Native forests contain a mix of koa and other native tree species. What silvicultural systems could be designed to maintain mixed species stands? How large of a forest canopy gap is needed to ensure healthy koa regeneration? How would a group selections system work?
- Calculations for rotation ages for harvestable koa have been based on wood volumes and merchantable dimensions, but these calculations do not consider wood quality. Does wood color darken with age? Does figure increase in older trees? How does the percentage of sapwood and juvenile wood change with age?

GENETIC RESOURCES

Koa's genetic diversity is best preserved by planting seed from selected superior trees from local populations when available. In areas where no wild populations of koa exist, such as in most former sugar cane lands, seed orchards have begun to be developed by the University of Hawai'i and the Hawai'i Agriculture Research Center to supply seed from trees showing better form, faster growth, and increased disease resistance. Centuries of cutting the tallest, straightest koa in the forest have likely had a negative effect on the population genetics of koa (although any canoe trees would have had ample opportunities to reproduce before they were cut.) Modern day loggers could help ensure future genetics by making sure trees of good form and wood quality have the opportunity to reproduce, or even by collecting seed from exceptional trees for planting elsewhere. Clonal propagation of superior koa trees has shown promise but is not yet operational.

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RESOURCES: AGENCIES AND ASSOCIATIONS

U.S. Department of Agriculture Natural Resources Conservation Service Pacific Islands Area:

<http://www.pia.nrcs.usda.gov/>

U.S. Department of Agriculture Forest Service Institute of Pacific Islands Forestry:

<http://www.fs.fed.us/psw/programs/ipif/>

U.S. Department of the Interior Fish and Wildlife Service Pacific Islands: <http://www.fws.gov/pacificislands/>

Hawai'i State Department of Land and Natural Resources Division of Forestry and Wildlife:

<http://hawaii.gov/dlnr/dofaw>

University of Hawai'i Cooperative Extension Service: <http://www.ctahr.hawaii.edu/forestry>

Hawai'i Association of Conservation Districts: <http://www.hacdhawaii.org/>

Hawai'i Forest Industry Association: <http://www.hawaiiiforest.org>

Forest Stewardship Council: <http://www.fsc.org>

Smartwood: <http://www.smartwood.org>

Scientific Certification Systems: <http://www.scs-certified.com/forestry>

American Pulp and Paper Association: <http://www.afandpa.org>

American Tree Farm System: <http://www.treefarmssystem.org>

National Forestry Association: <http://www.nationalforestry.net>

National Woodland Owners Association: <http://www.woodlandowners.org>

NWOA "Green Tag" certification program: <http://www.greentag.org>

Smithsonian Flora of the Hawaiian Islands database: <http://botany.si.edu/pacificislandbiodiversity/hawaiian-flora/>

Specialty Crops for Pacific Island Agroforestry (<http://agroforestry.net/scps>)

Farm and Forestry Production and Marketing Profile for Koa (*Acacia koa*)

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