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Metrosideros polymorpha (ʻōhiʻa lehua)

Myrtaceae (myrtle family)

***ʻōhiʻa, ʻōhiʻa lehua, lehua* (Hawaiʻi)**

J. B. Friday and Darrell A. Herbert

IN BRIEF

Distribution Endemic to the six largest Hawaiian islands.

Size Greatly variable, typically reaches 20–24 m (66–79 ft) in height; may be much smaller on lava rock or boggy soils.

Habitat Wide range, 1–2500 m (1–8200 ft) elevation with rainfall of 400–10,000 mm (16–400 in). Largest component of lowland and montane wet and mesic forests, dry forests, subalpine shrublands, and new lava flows.

Vegetation Associated with dozens of other native species.

Soils Very widely adapted, occurring on medium and heavy clay uplands; tolerates rocky soils and organic soils forming on recent lava flows.

Growth rate Slow growing, 0.3–0.6 m (12–24 in) per year in height, and 1–3 mm (0.04–0.12 in) in stem diameter per year.

Main agroforestry uses Windbreak, shade, ornamental.

Main products Pole wood, fuelwood, honey source

Yields High-volume, old-growth stands may yield 70–84 m^3/ha (1000–1200 ft^3/ac or 5000–6000 bf/ac); stands on poor soils such as lava rock may yield much less.

Intercropping Used in farm cultivation only when naturally present due to very slow establishment and growth.

Invasive potential Poses a serious risk of being invasive if introduced outside of Hawaiʻi.

PHOTO: J. B. FRIDAY

Huge old ʻōhiʻa tree at Kīpuka Puaulu, Hawaiʻi Volcanoes National Park. Note the deeply fluted bole and the sparse crown.

INTRODUCTION

The native Hawaiian ʻōhiʻa (*Metrosideros polymorpha*) is the most abundant tree in the Hawaiian Islands. The name *Metrosideros* is derived from the Greek *metra*, heartwood, and *sideron*, iron, in reference to the hard wood of the genus (Dawson and Stemmermann 1999). Known locally by its Hawaiian name, ʻōhiʻa lehua, the species is found on all the major islands and in a variety of habitats. Distributed from near sea level to the tree line (2500 m [8200 ft]), the species exhibits tolerances of frost, volcanic vapors, and excesses or deficiencies in moisture. It is found across a rainfall gradient having extremes of less than 400 mm (16 in) to over 10,000 mm (400 in) on Mt. Waiʻaleʻale, Kauaʻi, one of the wettest places on earth. ʻŌhiʻa is found growing on a broad range of substrates including those as young as recent lava flows or as old as highly weathered Oxisols. Dominant in cloud forests and most rainforests above 400 m (1300 ft), often with a tree fern understory, the species is also common in seasonally wet forests, where it may be dominant or in mixtures with the native *Acacia koa* or the invasive species *Morella faya* (formerly *Myrica*) (Mueller-Dombois and Fosberg 1998).

ʻŌhiʻa is a slow-growing broad leaf evergreen whose form, foliage, and flower color can vary greatly from site to site. Representatives of the species can reach a stature as great as 30 m (100 ft) on well drained soils with sufficient moisture, while others in boggy sites can be fully mature when only a few cm tall. This phenotypic variation, affected by environment, allows the species to adjust to the extreme range of conditions listed above (St. John 1979, Stemmermann 1983, Aradhya et al. 1991). The resulting expressions of morphological variation lie at the heart of the species name *polymorpha* (meaning "many forms") and have prompted investigations into the genetic variations. The species is thought to be an example of how one ancestral species can begin to diversify and evolve into many species when isolated in an island environment (incipient speciation). It may also be that ʻōhiʻa remains a generalist with broad plasticity.

There are many modern and ancient uses for the flowers, leaves, and wood of ʻōhiʻa, but the forests are perhaps most highly valued for aesthetics, watershed protection, and as habitat for Hawaiʻi's native and endemic biota. The species itself is a critical food source to endemic nectivorous and insectivorous birds (Berger 1981, Smith et al. 1995), and critical specific habitat to endemic *Achatinella* and *Partulina* tree snail species (Hadfield and Mountain 1980, Hadfield and Miller 1989). However, past land-use practices have resulted in the reduction of ʻōhiʻa's range, largely through land-use conversion to cattle pasture and agriculture. Because mature stands may experience canopy decline and dieback of age-cohorts (Mueller-Dombois 1983, 1985, 1987), Hawaiʻi's early foresters experimented with the replacement of some forest stands with introduced species for the purposes of maintaining watershed integrity and creating a potentially renewable timber industry. In recent years there have been efforts to restore some of these lost ranges.

DISTRIBUTION

The natural distribution is limited to the six largest islands in the Hawaiian archipelago: Hawaiʻi, Maui, Molokaʻi, Lānaʻi, Oʻahu, and Kauaʻi.

Location of introductions

ʻŌhiʻa is planted as an ornamental plant in New Zealand, where there are several other native species of *Metrosideros* (Adams 1967).

BOTANICAL DESCRIPTION

Preferred scientific name

Metrosideros polymorpha Gaud.

Family

Myrtaceae (myrtle family)

Non-preferred scientific names

Metrosideros collina (not itself a synonym, but several infraspecific taxa described under it are)
M. haleakalensis
M. lutea
Nania glabrifolia
N. lutea
N. polymorpha

Common names

ʻōhiʻa, *ʻōhiʻa lehua*, *lehua* (Hawaiʻi). The common names are often written without the Hawaiian diacritical marks, i.e., ohia or ohia lehua.

Growth, form, and size

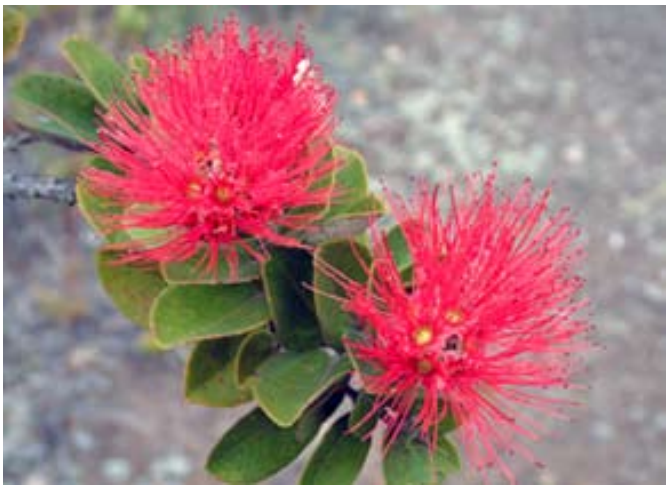
Growth form ranges from tall trees to small erect or prostrate shrubs. Crowns may be compact or open-branched. Height of crown base may be low when growing in open habitat, but branching begins at mid-stem or higher in closed canopy forest. On moist, deep soils, ʻōhiʻa grows to 20–24 m (66–79 ft) in height with a diameter at breast height (dbh) of 45–90 cm (18–36 in). Trees to 30 m (100 ft) in height and 216 cm (85 in) dbh have been recorded (Lamb 1981, Elevitch pers. obs.). The bole may be straight,

Top left: Flower buds close to opening. Top right: Ripening seed capsules; open capsules show tiny seeds within. Bottom left: Jack Jeffrey shows the common red flower, so familiar in the remaining native Hawaiian forests. Bottom right: Typical appearance of bark. PHOTOS: C. ELEVITCH

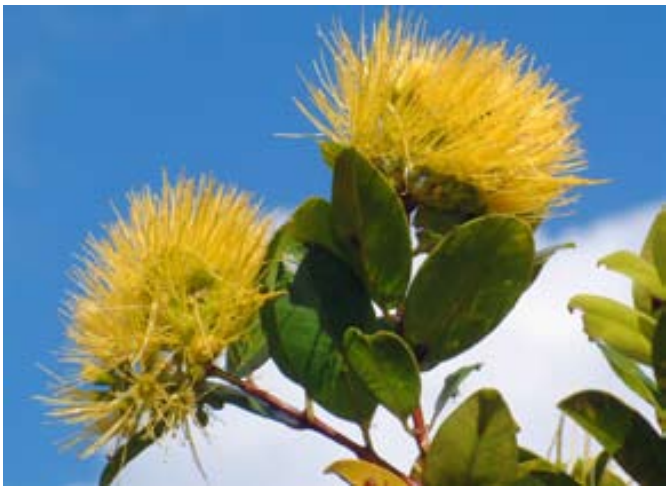
cylindrical and smooth, or twisted and deeply fluted. Forest trees may often have tall stilt roots, as these trees grow from seedlings that germinate on fallen logs or fallen hāpuʻu (*Cibotium* spp., tree fern) stems, which rot away by the time the tree matures. Some trees may sprout bunches of aerial roots. Shrub growth forms predominate on poorly drained, dry or rocky soils, and at high altitude (Skolmen 1974a, Little and Skolmen 1989, Adee and Conrad 1990, Mueller-Dombois and Fosberg 1998, Dawson and Stemmermann 1999).

Flowers

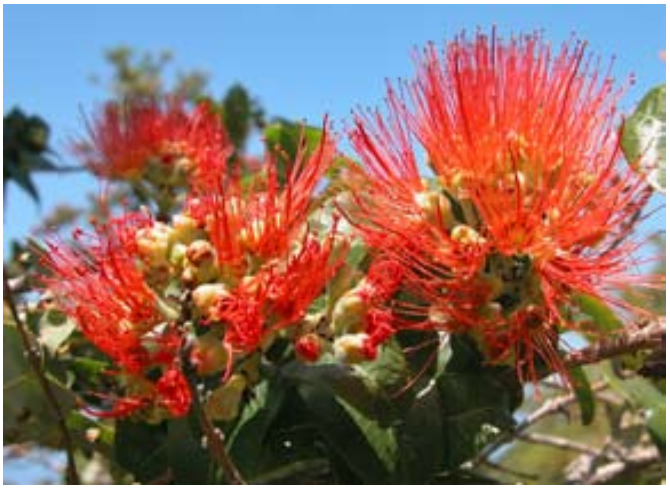
Flowers are usually red but sometimes salmon, pink, yellow, or orange. Clusters of flowers are about 5–8 cm (2–3 in) wide and are on the terminal ends of the branches. The bunches of stamens extend 1–3 cm (0.4–1.2 in) out from the flower and give the blossoms a pompom, brush, or hair-like appearance. The Hawaiian name *lehua* (from *ʻōhiʻa lehua*) refers to the hair-like appearance of the blossoms (Rock 1974). Flowers occur in inflorescences of 2–5 pairs of cymules; peduncles 7–18 mm (0.28–0.7 in) long; pedicels 2–8 mm (0.08–0.32 in) long; bracts ovate to suborbicular, 5–10 mm (0.2–0.4 in) long; sepals rounded to triangular, 1.5–4 mm (0.06–0.16 in) long; petals obovate to orbicular, 2.5–5 mm (0.1–0.2 in) long; stamens 10–30 mm (0.4–1.2 in) long; style 13–30 mm (0.5–1.2 in) long (Dawson and Stemmermann 1999). Each cluster of flowers lasts several days. Flowers are pollinated by both birds and insects. Yellow flowers have been shown to be self-compatible, while red flowers are partially self-incompatible and require a pollinator for good seed set (Carpenter 1976).



Pink flowers. PHOTO: J. B. FRIDAY



Yellow flowers. PHOTO: J. B. FRIDAY



Salmon flowers. PHOTO: C. ELEVITCH

Leaves

Foliage varies from thick, dark greenish-gray with dense surface fuzziness, primarily on the lower surface of the leaf, to thin, bright green, and smooth. Leaves are opposite and clustered at the ends of the branches. Leaf shape is highly variable, ranging from round to oval to egg-shaped, 1–8 cm (0.4–3.1 in) long, 1–5.5 cm (0.4–2.2 in) wide. Several pairs of raised veins radiate from the base. Upper surface is smooth, lower surface smooth or woolly or fuzzy. Margins are flat to turned under, apex rounded or sometimes pointed, base wedge-shaped or heart-shaped. Petioles are 1–16 mm (0.04–0.63 in) long, 1–3 mm (0.04–0.1 in) wide, but can be sessile, especially at high elevation (Dawson and Stemmermann 1999).

Fruit

Fruiting capsules are 3–10 mm (0.1–0.4 in) long and wide, smooth or fuzzy (Dawson and Stemmermann 1999).

Seeds

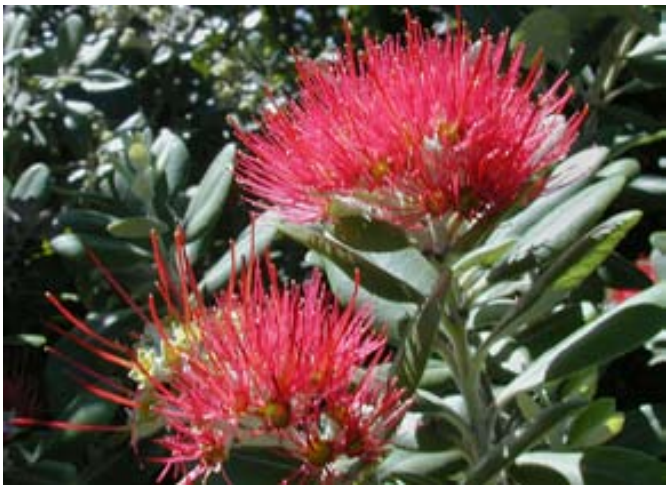
The seed capsules contain many minute seeds. There are approximately 1750 seeds per gram (50,000 seeds/oz).

Similar or look-alike species

There are about 50 species in the genus *Metrosideros* in Southeast Asia and the Pacific (Wagner et al. 1999). *Metrosideros kermadecensis*, from the Kermadec Islands off of New Zealand, has escaped from cultivation on Maui and may be considered a pest species (Evenhuis and Eldredge 2004). The pohutukawa tree of New Zealand, *Metrosideros excelsa* (syn. *M. tomentosa*), is sometimes planted as an ornamental in Hawai‘i but is not reported to have escaped from cultivation (Kinsey, undated). Several cultivars of *M. excelsa* are grown. ‘Ōhi‘a was originally classified as a variety of *Metrosideros collina,* a related tree of Tahiti, Rarotonga, and other islands in the South Pacific, but now is seen as a species endemic to Hawai‘i (Little and Skolmen 1989).

How to distinguish from similar species/look-alikes

The flowers of *Metrosideros excelsa* and *M. kermadecensis* are dark crimson in color, as opposed to the more orange-red of *M. polymorpha,* and the young buds and undersides of leaves are covered in a silvery-white felt. *Metrosideros kermadecensis* is a smaller tree with brighter red flowers than *M. excelsa*. A variegated leaf variety of *M. kermadecensis* is also cultivated. *Metrosideros polymorpha* has not been reported to naturalize elsewhere in the Pacific, although it has been introduced to New Zealand as an ornamental plant. The Hawaiian species of *Metrosideros* are characterized by the presence of bud scales and a frequently forking branching pattern.



***Metrosideros kermadecensis*, an exotic to Hawai'i not recommended for planting, has darker crimson leaves than 'ōhi'a, and a silvery-white felt on the underside of the leaves.** PHOTO: FOREST AND KIM STARR, USGS

GENETICS

Eight varieties of the Hawaiian *Metrosideros polymorpha* complex are recognized on the basis of classical taxonomy (Wagner et al. 1999). In addition to the *M. polymorpha* varieties, four distinct species are also recognized: *M. macropus, M. rugosa*, *M. tremuloides*, and *M. waialealae*. Genetic distinctions between varieties are not clear, but isozyme analyses suggest variability between populations are a likely case of incipient speciation (Aradhya et al. 1991). Altitudinal, soil-based, and successional ecotypes have been proposed on the basis of morphological variations, especially in leaves (Corn and Hiesey 1973, Stemmermann 1983, Stemmermann and Ihsle 1993, Adee and Conrad 1990, Mueller-Dombois 1994, Kitayama et al. 1997). Intraspecific hybridization has been demonstrated (Corn 1979). Genetic differences correlate with environmental differences, although in some cases differences within phenotypic varieties may be greater than between varieties, and many intermediate phenotypes exist (James et al. 2004).

Variability of species

The species occurs in a range of forms from prostrate shrubs to tall trees. Leaves range greatly in both size and shape and may be smooth to fuzzy or woolly. Flowers may be red, pink, salmon, orange, yellow, and many shades in between.

Known varieties

There are eight known varieties (see table), some of which are restricted in geographic distribution across the main Hawaiian islands.

Table. *Metrosideros polymorpha* varieties

dieteri	Middle to high elevations on Kaua'i. Small trees. Leaves with raised veins.
glaberrima	Middle to high elevations on O'ahu, Moloka'i, Lāna'i, Maui, Kaua'i, and Hawai'i. Shrubs to tall trees.
incana	Low to middle elevations on O'ahu, Moloka'i, Lāna'i, Maui, and Hawai'i. Shrubs to tall trees.
macrophylla	Middle elevations on Hawai'i. Small to tall trees. Relatively large leaves.
newelli	Low to middle elevations on Hawai'i, usually along watercourses. Small to large trees.
polymorpha	Middle to high elevations on O'ahu, Moloka'i, Lāna'i, Maui, and Hawai'i. Small to large trees. Leaves usually with dense woolly pubescence on lower surface.
pumila	Middle to higher elevation swamps on Kaua'i, Moloka'i, and Maui. Prostrate shrubs.
pseudorugosa	Higher elevation bogs on West Maui. Prostrate shrubs.

ASSOCIATED PLANT SPECIES

'Ōhi'a is by far the dominant forest tree in Hawai'i and makes up most of the biomass in most lowland and montane wet and mesic forests. 'Ōhi'a also occurs as a major component of the vegetation in dry forests, subalpine shrublands, and on new lava flows. 'Ōhi'a forests in wet areas with deep soil are tall in stature with a continuous canopy, whereas scattered 'ōhi'a trees occur on new or little-weathered lava flows and in dry areas. Small 'ōhi'a trees grow with other shrub species at high-elevation sites above 2000 m (6500 ft). Open stands occupy young lava flows in wet areas on Hawai'i island, while swampy areas may be occupied by dwarf 'ōhi'a trees, especially on the island of Kaua'i (Adee and Conrad 1990, Wagner et al. 1999).

Associated species commonly found in native habitats

ʻŌhiʻa forms almost pure stands on new lava flows. In older forests it grows as huge old specimens along with up to 40 other tree species (Lamb 1981). In wet and mesic areas above 800 m (2600 ft), where most remaining native forests occur, the next most common tree after ʻōhiʻa is koa (*Acacia koa*). ʻŌhiʻa and koa share the montane forests with smaller tree species such as naio (*Myoporum sandwicense*), kōlea (*Myrsine lessertiana*), ʻōlapa (*Cheirodendron* spp.), pilo (*Coprosma* spp.), kāwaʻu (*Ilex anomala*), manono (*Hedyotis* spp.), alani (*Melicope* spp.), kōpiko (*Psychotria* spp.), and ʻōhiʻa hā (*Syzygium sandwicensis*). The understory is dominated by ferns, including the tree ferns hāpuʻu (*Cibotium* spp.) and ʻamaʻu (*Sadleria* spp.), and shrubs such the native Hawaiian raspberry or ʻākala (*Rubus hawaiensis*) and ʻōhelo (*Vaccinium* spp.). Dryland ʻōhiʻa forests are interspersed with native trees such as lama (*Diospyros sandwicensis*), alaheʻe (*Psydrax odorata*), kauila (*Colubrina oppositifolia*), olopua (*Nestegis sandwicensis*), wiliwili (*Erythrina sandwicensis*), and naio. Lama, alaheʻe, and hala (*Pandanus tectorius*) are also common in the few remaining lowland wet ʻōhiʻa forests, where the understory is frequently the uluhe fern (*Dicranopteris linearis*). At high elevations, above about 2000 m (6500 ft), ʻōhiʻa forms scattered stands and shrublands with māmane (*Sophora chrysophylla*), koa, and naio (Adee and Conrad 1990, Wagner et al. 1999).

Heidi Johansen stands next to a centuries-old ʻōhiʻa lehua tree that has a circumference at breast height of 6.8 m (22.3 ft) and diameter of 2.16 m (7.08 ft). Manukā, South Kona, Hawaiʻi. PHOTO: C. ELEVITCH

Species commonly associated as aboriginal introductions in Pacific islands

Few coastal ʻōhiʻa forests remain, and ʻōhiʻa is rarely seen in cultivated areas in Hawaiʻi, which were originally cleared for agriculture and now support the Polynesian-introduced trees such as coconut, breadfruit (*Artocarpus altilis*), and milo (*Thespesia populnea*).

Species commonly associated in modern times or as recent introductions

Native ʻōhiʻa forests in Hawaiʻi suffer from an onslaught of invasive alien species. Chief among these in the wet forests are strawberry guava (*Psidium cattleianum*), albizia (*Falcataria moluccana*), and various melastomes (for example, *Melastoma* spp., *Clidemia hirta*, and *Miconia calvescens*). ʻŌhiʻa forests in mesic areas suffer invasions from *Morella faya* (formerly *Myrica*), *M. cerifera,* and Christmas berry (*Schinus terebinthifolius*). The understory of ʻōhiʻa forests is often composed of alien grasses, in particular meadow rice grass (*Ehrharta stipoides*), which inhibits regeneration of the trees. Dryland ʻōhiʻa forests are invaded by silk oak (*Grevillea robusta*) and threatened by fires encouraged by invasion of the introduced fountain grass (*Pennisetum setaceum*).

LEGENDARY ʻŌHIʻA LEHUA

Many Hawaiians believe that ʻōhiʻa forests are sacred to Pele, the goddess of volcanoes. When angry, Pele destroys the ʻōhiʻa with streams of lava. It is one of five plants sacred to Laka, the goddess of hula. Many Hawaiian legends include ʻōhiʻa.

In one legend Ka-ehu, the yellow shark of Pearl Harbor, homesick for the beauty of Puna, chanted:

O my land of rustling lehua-trees!
Rain is treading on your budding flowers,
It carries them to the sea.
They meet the fish in the sea.
This is the day when love meets love,
My longings are stirring within me
For the spirit friends of my land.
They call me back to my home, I must return.

(Westervelt 1916)

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

ʻŌhiʻa has a wide environmental amplitude. The species occurs from just above sea level to the tree line (above 2500 m [8200 ft]), where such high-altitude forests are exposed to frost and ephemeral snows. Along moisture gradients ʻōhiʻa can be found distributed between sites as extreme as dry forests with less than 400 mm (16 in) annual rainfall to wet forests and bogs with more than 10,000 mm (33 ft) annual rainfall (Stemmermann and Ihsle 1993, Dawson and Stemmermann 1999). Maximum biomass and optimal growth form occur at mean annual temperatures between 16°C (61°F) and 21°C (70°F) and rainfall between 1000 (40 in) and 3000 mm (120 in) annually (Stemmermann 1983; Stemmermann and Ihsle 1993; Mueller-Dombois 1987, 1994; Adee and Conrad 1990).

Elevation range

1–2500 m (3–8200 ft)

Mean annual rainfall

400–10,000 mm (16–400 in); 1000–3000 mm (40–120 in) preferred

Rainfall pattern

Prefers year-round rainfall, although it grows in areas with seasonal precipitation.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

4 months

Mean annual temperature

10–24°C (50–75°F); 16–21°C (61–70°F) preferred

Mean maximum temperature of hottest month

29°C (84°F)

Mean minimum temperature of coldest month

0°C (32°F)

Minimum temperature tolerated

-4°C (25°F)

Soils

The range of soil types tolerated includes Histosols, Mollisols, Spodosols, Oxisols, Ultisols, and Alfisols (Adee and Conrad 1990, Crews et al. 1995). ʻŌhiʻa is the dominant tree on new, excessively drained lava flows as well as on ancient and water-saturated soils surrounding the Alakaʻi bogs on Kauaʻi (Mueller-Dombois 1994, Herbert and Fownes 1995). ʻŌhiʻa is also dominant on both nutrient-rich and nutrient-depleted soils (Crews et al. 1995, Herbert and Fownes 1999), as well as soils suffering from aluminum toxicity problems (Moomaw et al. 1959, Mueller-Dombois 1994). On exposed ridges, steep slopes, or poorly drained sites ʻōhiʻa does not reach large size and may be reduced to dwarf shrub stature (Adee and Conrad 1990).

Soil texture

ʻŌhiʻa usually grows on medium and heavy clay soils of the Hawaiian uplands. It also tolerates rocky soils and organic soils forming on new lava flows.

Soil drainage

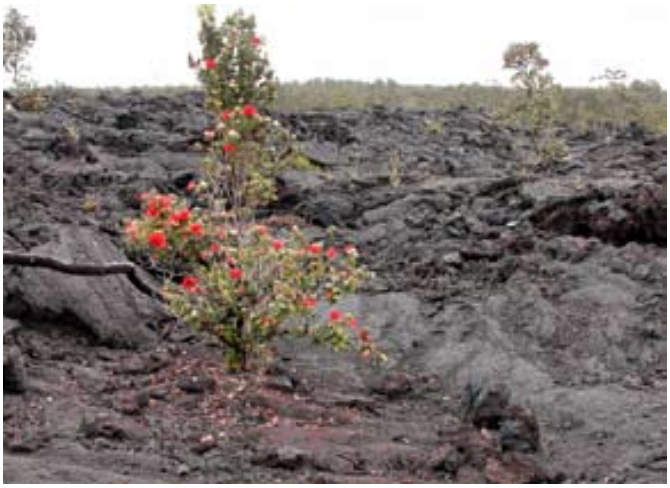
The species develops best on relatively level well drained sites. ʻŌhiʻa does not tolerate poor drainage well and may die out on very poorly drained pāhoehoe (sheet) lava.

Soil acidity

pH 3.6–7.4. ʻŌhiʻa generally grows in acid, weathered soils where the pH may reach as low as 3.6 (Crews et al. 1995). In drier areas ʻōhiʻa may grow in soils that are neutral to mildly alkaline.

Special soil tolerances

ʻŌhiʻa tolerates shallow, rocky soils, and young trees may be found on all but the very freshest lava flows. In other sites, ʻōhiʻa will grow in extremely acid, infertile soils.



ʻŌhiʻa is often one of the first plants to colonize new lava flows. PHOTO: C. ELEVITCH

Dwarf ʻōhiʻa near the Alakaʻi swamp, Kauaʻi, Hawaiʻi. In harsh conditions, or on poorly drained sites, ʻōhiʻa is dwarfed. PHOTO: D. HERBERT

Tolerances

Drought

Well established ʻōhiʻa with deep root systems can persist in extremely dry areas receiving less than 400 mm (16 in) of rain annually. On older substrates in dry areas, ʻōhiʻa forests are replaced by other native dryland species such as lama (*Diospyros sandwicensis*) and alaheʻe (*Psydrax odorata*) (Stemmermann and Ihsle 1993). Droughts in these areas commonly last for 4 months. However, trees growing on shallow lava soils in wetter areas can be killed by droughts of a few weeks.

Full sun

ʻŌhiʻa prefers to grow in full sun.

Shade

The tree tolerates only light shade. It can grow underneath a koa canopy but does not regenerate in its own shade or under other understory trees, relying on treefall gaps in the mature forest.

Fire

ʻŌhiʻa is killed by intense fires, although it may resprout after light fires. Dryland ʻōhiʻa forests are threatened by alien invasive grasses, which allow fires to spread and kill the native trees (Smith and Tunison 1992).

Frost

ʻŌhiʻa tolerates light frosts, but temperatures below –8°C (18°F) permanently damage tissue (Scowcroft et al. 2000, Cordell et al. 2000).

Waterlogging

It does not tolerate waterlogging. Forest dieback is common in high-rainfall areas with underlying heavy clay soils or pāhoehoe (sheet) lava (Hodges et al. 1986).

Salt spray

The species has low salt tolerance and is seldom found where exposed to salt spray, although it is found in sheltered areas down to sea level (Rauch and Hensley 1997).

Wind

ʻŌhiʻa has good wind tolerance and is wind-firm in hurricanes (Herbert et al. 1999), although strong winds may snap isolated trees.

Other

The tree is tolerant of volcanic fumes.

Abilities

Regenerate rapidly

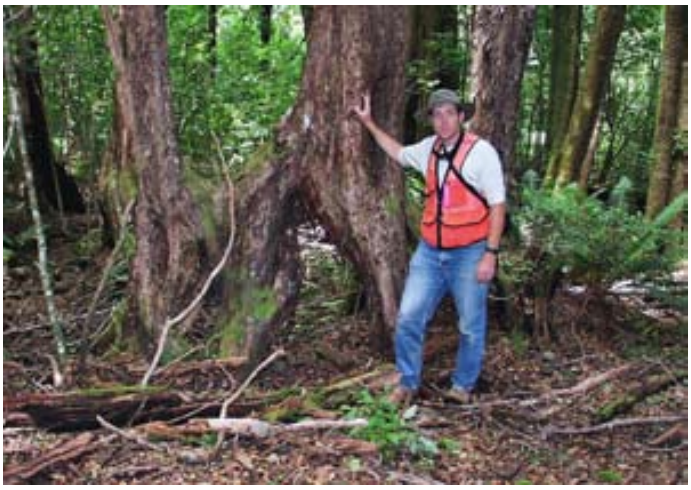
ʻŌhiʻa regenerates prolifically from windblown seeds after disturbances, if the site is not taken over by alien vegetation. ʻŌhiʻa is the only native tree to regenerate on recent lava flows for the first few years or even decades.

Self-prune

The tree self-prunes only slowly. Tall trees may retain scraggly lower branches for years.

Coppice

Sometimes ʻōhiʻa coppices thickly, but at other times the tree is killed by coppicing or pollarding. New growth after trees are coppiced is fragile and easily broken. Fallen trees

ʻŌhiʻa trees often start out growing on nurse logs on the forest floor (left)… leaving a cavity under the tree after the substrate decays (right). Pictured: co-author J.B. Friday. PHOTOS: J. B. FRIDAY, T. MCEVOY

in the forest, however, may send up new vertical shoots that in time develop into trees.

GROWTH AND DEVELOPMENT

ʻŌhiʻa trees seed prolifically but grow slowly. They survive by colonizing lava flows or fallen logs in forest gaps where other vegetation cannot compete. Growth of mature forest trees may be imperceptibly slow.

Growth rate

In optimal conditions, seedlings 60–70 cm (24–28 in) tall can be grown from seed in a year. This relatively fast rate of growth may continue through the pole stage, after which growth is typically slow.

Stem diameter growth rates are especially slow, in the range of 1–3 mm (0.04–0.12 in) per year. Saplings and poles may have relatively fast growth rates (Bornhorst 2005), but forest trees rarely grow more than 2 mm (0.08 in) in diameter per year (Adee and Conrad 1990, Herbert and Fownes 1995, 1999, Raich et al. 1997, Vitousek and Farrington 1997, Gerrish and Mueller-Dombois 1999). Annual height growth is up to 0.3–0.6 m (12–24 in).

Flowering and fruiting

The earliest flowering is 2 years after germination (Bornhorst 2003). Flowering occurs throughout the year but may be most abundant after seasonal rains, generally during and after the winter months and on into summer. The seed capsules may not release their seed for up to a year after flowering (Carpenter 1976).

Some trees form air roots that trap moisture droplets in the air. PHOTO: C. ELEVITCH

Timber yields

Timber volumes per unit area for mature forest are low in comparison for related trees such as *Eucalyptus* species because of ʻōhiʻa's tendency to grow in dense, pole-sized stands and the trees' irregularly shaped stems, which yield little lumber. Higher-volume stands may only yield 70–84 m^3/ha (1000–1200 ft^3/ac or 5000–6000 bf/ac) (Skolmen 1974a), whereas the average stands yield only half that. Basal area of ʻōhiʻa forests may be up to 40 m^2/ha (175 ft^2/ac), although again this may be composed of many small trees (Adee and Conrad 1990). A forest survey in 1970 estimated that stands on deep soils on the wetter parts of the island, which were described as "commercial" ʻōhiʻa stands, were increasing volume at a rate of 0.47 m^3/ha/yr (6.7 ft^3/ac/yr or 34 bf/ac/yr). Many other stands were composed of pole-sized timbers that were not increasing in volume at all (Metcalf et al. 1970).

Rooting habit

ʻŌhiʻa is shallow-rooted on pāhoehoe (sheet) lava or in poorly-drained areas but deeply rooted in dry sites and on ʻaʻā (rough) lava. Even on pāhoehoe lava, roots may find cracks and penetrate deeply.

Reaction to competition

ʻŌhiʻa does not tolerate shading from overstory trees and can easily be smothered or shaded out by exotic weedy grasses, vines, and trees.

PROPAGATION

ʻŌhiʻa is propagated by cuttings, air-layering, or by seeds. While seeds germinate readily and are true to type (Stemmermann 1983), cuttings or air-layers are perhaps the best way to achieve specific flower color for ornamentals (Rauch and Hensley 1997). The National Tropical Botanical Garden recommends that care be taken to select plants or seeds to be propagated from a nearby locale with similar environmental conditions to the outplanting site, because ʻōhiʻa exhibits a variety of growth patterns that are influenced by environment (NTBG 1993).

Propagation by seed

Seeds are easily collected and germinate readily. In natural settings seeds commonly germinate as epiphytes on tree ferns or moss-covered logs (Little and Skolmen 1989).

Seed collection

Whole fruit capsules are collected. Fruits mature 70–90 days after flowering and should be collected after maturity but before capsules open (Allen 2002). The mature capsules will be swollen, and lines will appear where the capsule will dehisce (Allen 2002). Capsules should be air-dried in a paper bag or cardboard box to prevent loss of seeds (NTBG 1993, Herring 2002). Viability ranges from less than 10% to more than 75% (Dawson 1970, Burton 1982, Drake 1993, Allen 2002).

ʻŌhiʻa can flower throughout the year but flowering generally peaks in spring or summer after vegetative flushing. Some varieties or populations peak in fall or winter. Individual trees or branches may produce flowers at any time during the year (Adee and Conrad 1990). Drake (1993) noted that on the island of Hawaiʻi (wet forests at 700 m [2300 ft] elevation), 75% of seeds were dispersed in December and January.

Capsules must be collected before they open, as shown here, or the seeds disappear into the wind. PHOTO: J. B. FRIDAY

Seed storage

For greatest viability, seeds should be sown as quickly as possible after collection (NTBG 1993). Seeds may be stored in a dry, cool location or under refrigeration (Allen 2002), but for greatest viability seeds should be sown within a month of capsule dehiscence. Viability may drop to less than 10% after a year of storage (Allen 2002) and may be near 0% within 3 years (Corn 1979).

Pre-planting treatments

No pretreatment of seeds is necessary.

Germination, media, and containers

Seeds should be spread onto germination trays filled with a moist, sterile potting medium, sterile compost, or cinder and left uncovered or covered by a very thin layer of soil (NTBG 1993, Bornhorst 2005). Fresh seeds germinate in 5–10 days, whereas stored seeds may take as long as 6 weeks

(Corn 1979). Seedlings should be transplanted into 5 cm (2 in) diameter containers with a well drained, loose substrate when 4–6 true leaves have formed (NTBG 1993, Bornhorst and Rauch 2003). The National Tropical Botanical Garden recommended a small amount of slow-release NPK 8–8–8 fertilizer with micronutrients be mixed with the media upon planting, and once-per-month applications of a liquid foliar fertilizer at half strength be applied thereafter (NTBG 1993). Bornhorst (2003) recommended daily watering of potted seedlings.

Time to outplanting

With good nursery practices, seedlings can be ready for outplanting in 6–12 months at a size of 25–30 cm (10–12 in) tall.

Outplanting

Seedlings are vulnerable to drought and should be well established before planting out (NTBG 1993, Bornhorst 2005, Allen 2002). Full sun, frequent watering, and avoidance of strong wind are recommended.

Other comments on propagation

Transplanting of wild seedlings seldom succeeds. If transplanting is attempted, plants should be as small as possible, not more than a few cm tall.

Potted seedlings have a tendency to send roots down into the ground through the bottom of their containers. Care should be taken that they do not form taproots into the ground while in the nursery. This is a particular problem in warm, humid environments.

Propagation by cuttings

Collecting vegetative material

Cuttings can be taken from the tips of vigorous and recently matured growth and should be 1 cm (0.4 in) diameter and 10–15 cm (4–6 in) long (Criley 1998, Bornhorst and Rauch 2003). Success can vary with material selected. Near 100% success is reported from some parent material, while other material is nearly impossible to propagate (Bornhorst and Rauch 2003).

Treatment

Bornhorst (2005) recommended cutting leaves

Top: A container that prevents root spiraling is recommended. Pictured: Baron Horiuchi. Bottom: For certain situations where early field maintenance is impractical, trees can be grown out in large containers and successfully transplanted. Pictured: Anya Tagawa. PHOTOS: C. ELEVITCH

in half, removing leaves from the lower 2.5 cm (1 in) of the stem, and dipping cuttings in a strong rooting hormone for ten seconds. Rauch and Hensley (1997) had 100% success with a 2000 ppm concentration indolbutyric acid (IBA) at a ratio of 2:1 with naphthaleneacetic acid (NAA). Criley (1998) reported success with rooting hormones having 2:1 IBA to NAA at concentrations of 2000–4000 ppm IBA. To grow ʻōhiʻa from cuttings, a misting system is strongly recommended.

Media

Sterile potting media such as pure perlite or vermiculite, 1:1 perlite to vermiculite, or 2:1 mixture of perlite to peat moss have been used (Bornhorst 2005, Rauch and Hensley 1997, Criley 1998, Herring 2002). Choice depends on climate and grower's preference.

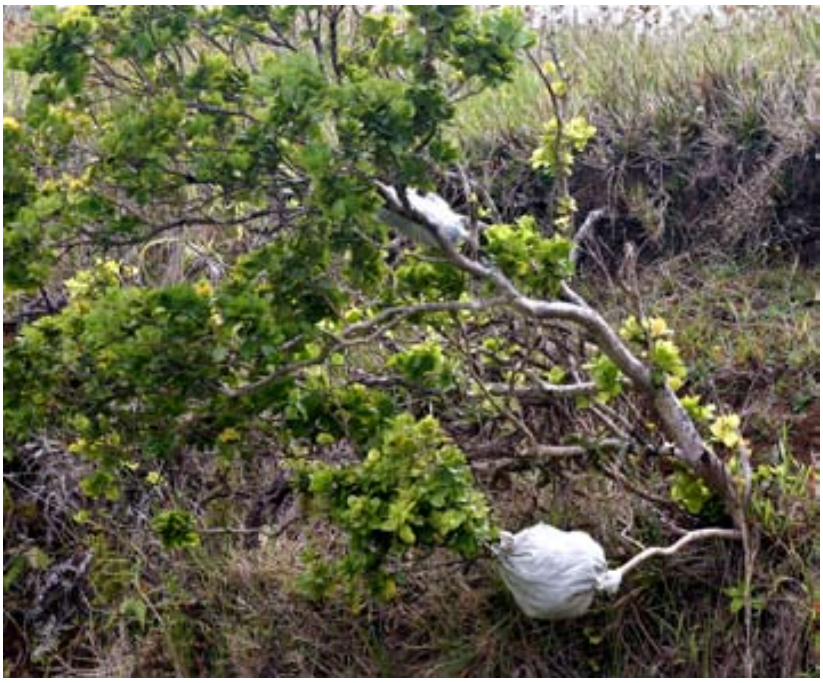
Propagation by air-layers

Vegetative material

Some individuals may air-layer easier than others (Herring 2002). Bornhorst (2005) suggested that the presence of aerial roots might indicate a plant that will air-layer easily.

Treatment

Herring (2002) recommended using a standard air-layering technique, while Bornhorst (2005) recommended using a strong rooting hormone. Tanabe and Frazier (1984) had good success with the ring-girdle technique and a range of indolbutyric acid IBA concentrations.



Air-layering is frequently used to clone a desirable tree, such as this one with yellow blossoms. PHOTO: C. ELEVITCH

DISADVANTAGES

Potential for invasiveness

Because of its prolific, windblown seeds and ability to survive on harsh sites, ʻōhiʻa has the potential to become a serious pest if planted outside the Hawaiian islands. On other Pacific islands, there is the danger that ʻōhiʻa would hybridize with native populations of other species of *Metrosideros.*

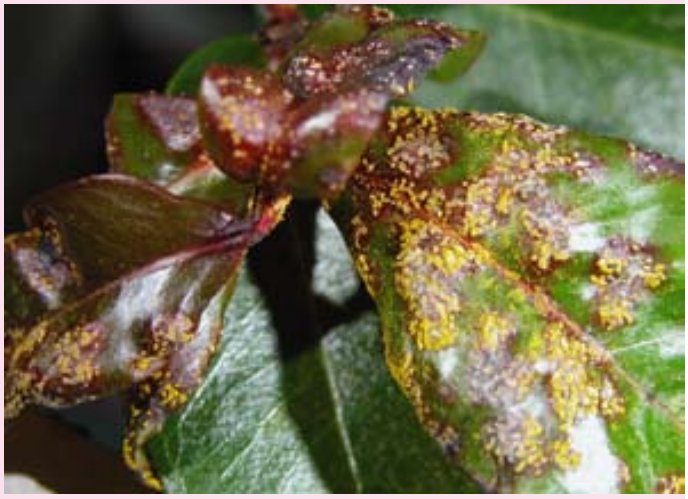
Diseases and pests

The National Tropical Botanical Garden (NTBG) notes problems with thrips and ants, which can transfer other pests such as scale and aphids to ʻōhiʻa (NTBG 1993). These pests mainly affect young, planted trees. Leaves on young trees are frequently affected by psyllid insects that cause galls. Mealybugs and sooty mold may affect seedlings in wet areas. A previously undescribed rust was found on ʻōhiʻa nursery seedlings in early 2005 (D. Ogata, pers. com.). The endemic cerambycid borer *Plagithmysus bilineatus* has the greatest potential for negative impact on ʻōhiʻa. It may become epidemic to weakened trees in cases of canopy dieback (Papp et al. 1979, Mueller-Dombois 1985, Adee and Conrad 1990). Other potentially damaging borers include *Ceresium unicolor*, *Xyleborus saxesensi*, and *X. simillimus* (Adee and Conrad 1990). ʻŌhiʻa is attacked by the two spotted leafhopper (*Sophonia rufofascia*), an exotic pest only discovered in Hawaiʻi in 1987 (Alyokhin et al. 2004). Forest trees are host to several species of native Hawaiian mistletoe (*Korthalsella* spp.) (Wagner et al. 1999). Root rots *Phytophthora cinnamomi*, *Pythium vexans,* and *Armillaria mellea* can also be damaging and are most often associated with weakened stands experiencing canopy decline (Corn 1972, Papp et al. 1979). ʻŌhiʻa forests on the windward side of the island of Hawaiʻi were observed to be undergoing massive canopy dieback in the 1960s and 70s. Five to seven types of decline have been identified, and no single uniform cause has been determined. Most of the area affected by ʻōhiʻa decline is wet and poorly drained, and the so-called "wetland dieback" and "bog formation dieback" make up more than 80% of the affected decline area (Hodges et al. 1986). While the fungal rots *Phytophthora cinnamomi* and *Armillaria mellea* and the borer

A NEW DISEASE OF ʻŌHIʻA

A new rust disease was discovered on potted ʻōhiʻa plants in a nursery on Oʻahu in April 2005. No previous rusts had been reported for ʻōhiʻa, thus this discovery was a cause for concern. The rust has been identified as *Puccinia psidii* and causes a common disease of eucalyptus, guava, allspice (*Pimenta dioica*), paperbark (*Melaleuca quinquenervia*), and other plants in the Myrtaceae in South and Central America to Florida, where it is called eucalyptus rust or guava rust. The rust quickly spread to all the major islands and on Oʻahu has been found infecting rose apple (*Syzygium jambos*) and common guava as well as the native trees *Eugenia koolauensis* and *E. reinwardtiana.*

The rust most commonly affects young shoots. Initial symptoms are yellow powdery spots growing individually or in a circular pattern on the leaf and shoot. Infected young tissue does not expand and leaves and shoots become deformed as normal tissue continues to expand. As this is a new disease in Hawaiʻi, it is unknown how severe the problem will be in natural forests or whether the rust can kill mature ʻōhiʻa trees. *Puccinia psidii* is considered a serious disease in the eucalyptus industry in Brazil. The Hawaiʻi Department of Agriculture is asking that growers avoid transporting ʻōhiʻa, eucalyptus, paperbark, guava, rose apple, or other seedlings in the family Myrtaceae inter-island to reduce the spread of the disease, although the rust spores are wind-borne and naturally spread rapidly within a community. For ornamental trees, cutting and destroying infected foliage and shoots may help reduce the infection. In nurseries, keeping the foliage dry may also help prevent infection (Killgore and Heu 2005).



Rust symptoms on new shoot. PHOTO: D. OGATA

Plagithmysus bilineatus have all been found attacking trees in areas affected by dieback, all probably only affect trees already stressed by poor soil drainage or other environmental factors. The most likely explanation of the ʻōhiʻa dieback phenomenon is that ʻōhiʻa stands are predisposed to decline because of age and cohort senescence (Mueller-Dombois et al. 1980, Mueller-Dombois 1983). Mature ʻōhiʻa stands are even-aged in nature, having been regenerated after a disturbance, and therefore reach senescence at the same time and are then vulnerable to attacks of pests and diseases. Prolific ʻōhiʻa regeneration under most dieback stands lends credence to the theory that ʻōhiʻa decline is age-related. In some areas, however, bogs are formed after the dieback of the ʻōhiʻa forest.

Other disadvantages or design considerations

ʻŌhiʻa's chief limitation is its slow growth. Timber plantations of ʻōhiʻa are unknown and would probably not be financially viable.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Soil stabilization

ʻŌhiʻa forests protect the upper reaches of most of Hawaiʻi's critical watersheds. On new lava flows, ʻōhiʻa forests help break down the rock and develop organic soils as well as providing sites for litter accumulation.

Crop shade/overstory

If some ʻōhiʻa trees are left when a forest is cleared for agricultural use, these can provide light shade for coffee, cacao, or other shade-loving understory crops. Alternatively, tree crops such as noni (*Morinda citrifolia*) may be planted in alleys cut in the ʻōhiʻa forest.

Shade or street tree

ʻŌhiʻa saplings and poles will grow quickly given an adequate water supply (Bornhorst 2005) but will not develop a significant canopy for many years. Trees are susceptible to dieback if the sites are badly compacted and often flooded and are susceptible to physical damage by people or careless weeding and maintenance.

Homegardens

Because of improved propagation success, ʻōhiʻa has in recent years become a popular garden ornamental. The flowers are most often red but are also found in yellow, orange, and salmon. Many garden shops and nurseries now carry ʻōhiʻa lehua (Bornhorst 2003, 2005). Unfortunately, some growers sell exotic species of *Metrosideros* as a type of ʻōhiʻa (e.g., "New Zealand ʻōhiʻa") when they are aliens such as pohutukawa (*M. excelsa*) and *M. kermadecensis.* Alien species in the same genus as ʻōhiʻa may pose a threat to the genetic pool of the native Hawaiian species if they escape from cultivation.

Windbreaks

Natural stands of ʻōhiʻa make fine windbreaks for moderately windy areas. Single trees or single rows of trees, if left after the surrounding forest is cut, are susceptible to wind breakage, so bands several meters wide should be left. Planted ʻōhiʻa trees could be part of a windbreak if planted along with other, faster growing trees.

Silvopasture

Isolated ʻōhiʻa trees are often found in high-elevation pastures in Hawaiʻi, remnants of the forests that were originally cleared. These trees are seldom healthy and suffer from soil compaction and root damage from grazing livestock. Eventually, if an area is grazed long enough, all the ʻōhiʻa trees except for individuals growing in protected locations die off. ʻŌhiʻa cannot regenerate through thick pasture grasses such as kikuyu grass (*Pennisetum clandestinum*), and cattle damage any young trees that get started.

ʻŌhiʻa can survive in pasture but will not regenerate. PHOTO: C. ELEVITCH

Dispersed ʻōhiʻa trees can provide light shade for crops such as coffee, as shown here, without interfering with most farm operations. PHOTO: C. ELEVITCH

Watershed and habitat for native species

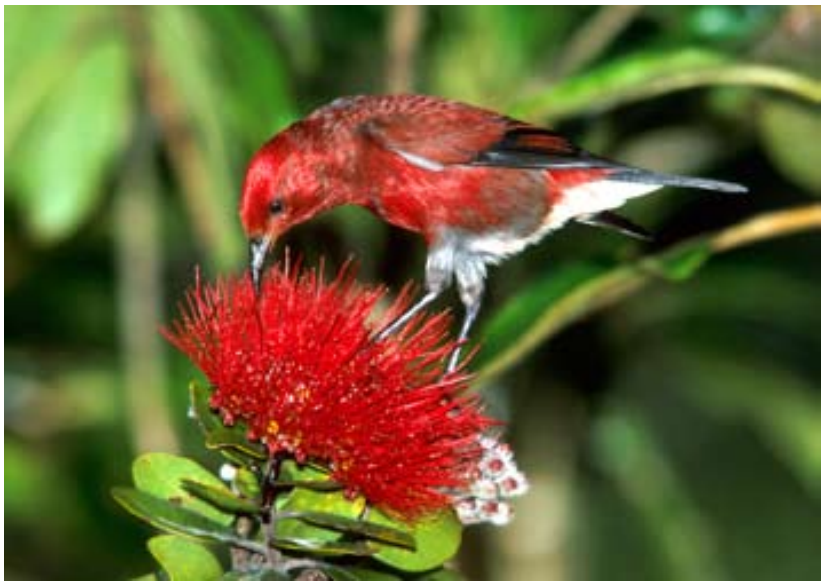
ʻŌhiʻa is more valuable for its environmental services than for products. ʻŌhiʻa forests are important habitat for Hawaiʻi's native and endemic species of birds, arthropods, mollusks, and plants, many of which have co-evolved with the ʻōhiʻa and endangered (Zimmerman 1948, Hadfield and Mountain 1980, Berger 1981, Hadfield and Miller 1989, Smith et al. 1995). The honeycreeper family of birds, in particular, has evolved into many endemic species in Hawaiʻi. Most of these, such as the common, bright red ʻapapane (*Himatione sanguinea*), the scarlet ʻiʻiwi (*Vestiaria coccinea*), and the yellow ʻamakihi (*Loxops virens*) inhabit the ʻōhiʻa forest and feed on the nectar of the ʻōhiʻa blossoms and insects in the trees (Carlquist 1980). ʻŌhiʻa and koa forests also provide habitat for Hawaiʻi's most endangered birds, such as the Hawaiʻi ʻākepa (*Loxops coccinea*), which nests in the cavities of the largest ʻōhiʻa trees (Freed 2001), and the Hawaiʻi creeper (*Oreomystis mana*). The endangered ʻakiapōlāʻau (*Hemignathus munroi*) has evolved a woodpecker-like lower bill and the ability to drill holes and

suck sap directly from certain individual ʻōhiʻa trees (Pejchar, pers. com.). ʻŌhiʻa also provides critical specific habitat for endemic *Achatinella* and *Partulina* tree snail species (Hadfield and Mountain 1980, Hadfield and Miller 1989). Understory plants in the forest germinate on fallen ʻōhiʻa logs or even on still-living ʻōhiʻa trees. The trees provide a growing surface above the alien grasses, which cover the forest floor and protect young plants against damage by feral pigs.

ʻŌhiʻa provides valuable watershed protection in Hawaiʻi because of its abundance and especially broad environmental amplitude. Most of the upper-elevation forests above Hawaiʻi's important agricultural and urban areas are covered with ʻōhiʻa forests.

Ornamental

ʻŌhiʻa trees, with their brightly colored flowers and silvery or reddish young foliage, make beautiful ornamental specimen plants.



The native Hawaiian honeycreeper ʻapapane on an ʻōhiʻa lehua blossom. PHOTO: J. JEFFREY

USES AND PRODUCTS

Honey

ʻŌhiʻa is an excellent honey plant, and ʻōhiʻa honey is one of the only truly native Hawaiian honeys. It is commonly sold in markets throughout Hawaiʻi.

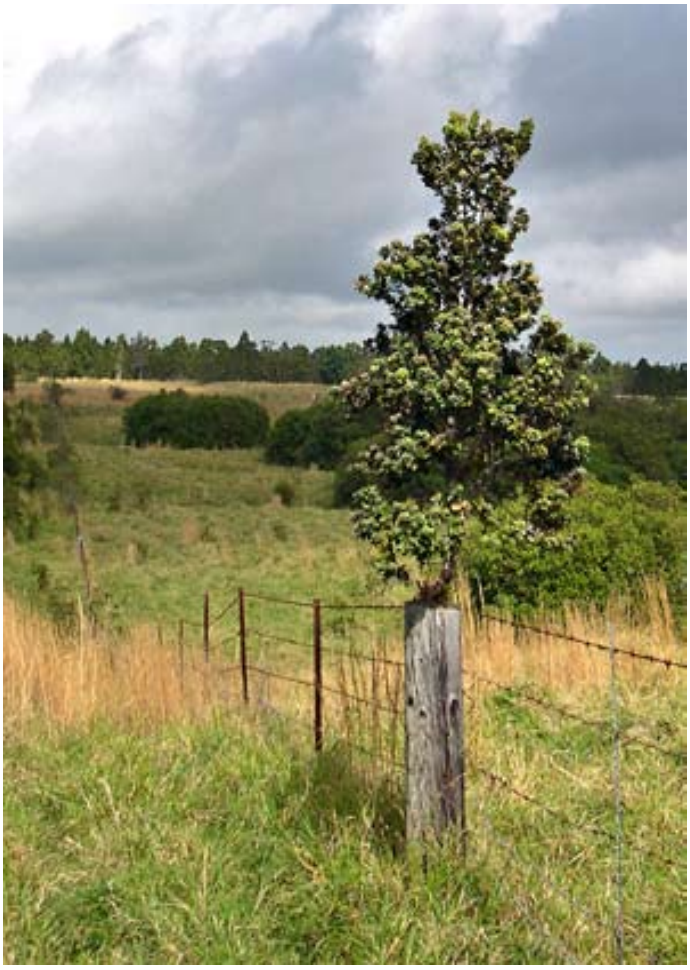
Although ʻōhiʻa is not considered feasible for commercial plantation forestry, existing ʻōhiʻa stands can be interplanted with other timber species such as koa. PHOTO: C. ELEVITCH

Medicinal

In ancient times extracts of ʻōhiʻa blossoms mixed with other herbs were used to treat childbirth pains and thrush (a fungal disease). In modern times flowers are still given to mothers for childbirth pains (Krauss 2001). New leaf shoots with a reddish color were chewed for numbing sore throats.

Wood

The wood is very hard and dense. A set of tests at the USDA Forest Service Forest Products Laboratory on wood from eleven trees from Kona and Puna found an average specific gravity of 0.81 (oven dry weight over green volume) (Youngs 1960). Weight averaged 0.91 g/cm^3 (57 lb/ft^3) for oven-dry wood and 1.17 g/cm^3 (73 lb/ft^3) for green wood. Shrinkage was 6.9% radial, 12.1% tangential, and 19.1% in volume. In color ʻōhiʻa has pale brown sapwood that merges indistinctly to the reddish to purplish brown heartwood, often streaked, and can develop a long curl. The interlocked grain and growth bands sometimes give the wood an attractive figure; at other times the wood is very plain. The texture is medium and the vessels are very fine and scattered throughout (Lamb 1981). The wood is not as strong as its density would suggest, though, probably because of its spiral grain (Youngs 1960). ʻŌhiʻa's hardness



Left: ʻŌhiʻa seedling that volunteered on fence post, showing how opportunistic the tree can be. Right: A mature ʻōhiʻa tree in upper Puna supporting epiphytic growth of paʻinu (*Astelia menziesiana*) and *Trematolobelia grandifolia*. PHOTOS: A. YEH

makes it difficult to work, and the wood is notorious for shrinking, warping, splitting, and checking during drying. Because of the wood's tendency to warp, boards should be air-dried before kiln-drying (Youngs 1960). The common spiral grain weakens the wood if sawn into timbers. Severe spiral grain and shrinkage during drying leads to instability of the wood and limits ʻōhiʻa's use in furniture making, cabinetry, and construction (Skolmen 1974a, Little and Skolmen 1989). Today the most common uses of the wood include wood strip flooring, decking, decorative posts, and round wood construction (Skolmen 1974a, Little and Skolmen 1989). While floors made of ʻōhiʻa in Hawaiʻi are generally stable, shrinking and swelling of the wood might cause problems in highly seasonal climates. Round posts are varnished to preserve the golden brown color of the sapwood; otherwise they weather to grey as does all exposed wood.

Heartwood is not resistant to attack by fungi when in contact with the ground. In tests in a wet area on Oʻahu, stakes cut from ʻōhiʻa heartwood lasted only about a third as long as redwood stakes and about half as long as stakes cut from *Eucalyptus robusta*. ʻŌhiʻa posts and rails exposed to the weather but not in contact with the soil were resistant to decay over the 9½ year test (Skolmen 1974a, 1974b). ʻŌhiʻa is only slightly resistant to termite attack (Grace et al. 1996).

Historically, ʻōhiʻa wood has been used as fence posts, furniture, veneer, ukulele keys, ship blocking in dry-docks, bracing stakes in agriculture and irrigation ditch construction, wharf fenders and marine construction, pallets, pile-driver cushions, and biofuel (Skolmen 1974a, Little and Skolmen 1989, Grossman 1992). A mill in Pāhoa on the island of Hawaiʻi sold millions of railroad ties made of ʻōhiʻa to the Santa Fe Railroad company in the early 1900s, until it was found that the ties were not durable in the desert climate.

Ancient Hawaiians used the wood in carving sacred images (kiʻi or tikis), spears, and mallets, and household items such as poi boards. Construction uses included structural poles, rafters, and temple walls (Abbott 1992, Gon and Pang 1998, Kirch 1985, Little and Skolmen 1989).

Fence posts

ʻŌhiʻa poles are traditionally used as fence posts in Hawaiʻi, although they are only moderately durable when in contact with the soil, and longer lasting woods such as kauila (*Colubrina oppositifolia* or *Alphitonia ponderosa*) were preferred before they became rare.

Fuelwood

ʻŌhiʻa has always been a favorite firewood, continuing to today. It burns with a hot, clean flame. The only disadvantage is the difficulty in splitting the cross-grained logs.

Craft wood

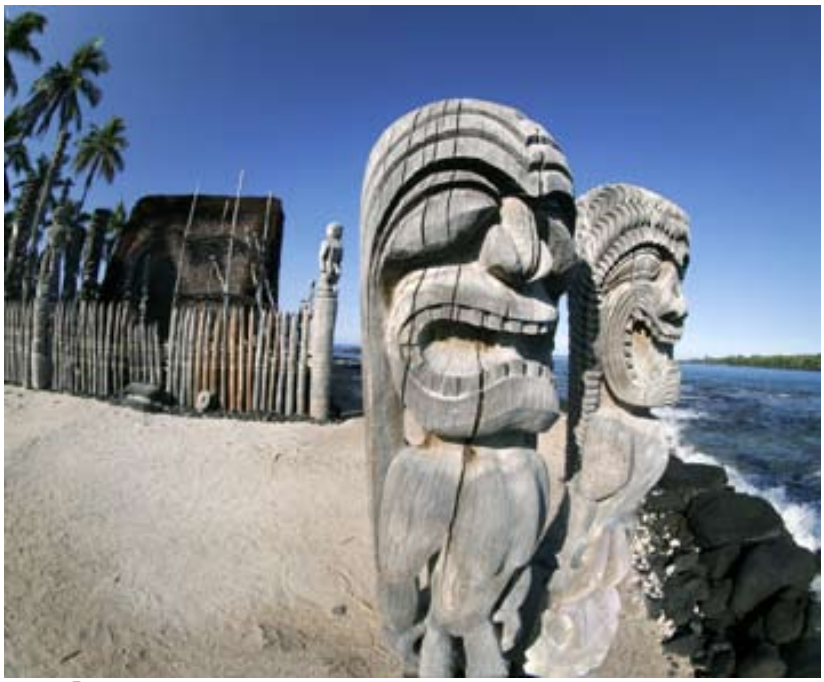
Jewelry, jewelry boxes, turned bowls, furniture, and cabinetry are among the many modern craft uses. ʻŌhiʻa was not used for carved wooden calabashes (ʻumeke lāʻau) in ancient times in Hawaiʻi due to its tendency to warp and crack (Abbott 1992).

Canoe/boat/raft making

Despite the large size of ʻōhiʻa trees, they were not used to build hulls for canoes (waʻa) in ancient times. Once a canoe's hull was carved from a koa tree, ʻōhiʻa wood was often used for the decking, gunwales, and seats (Abbott 1992). Spreaders for canoe hulls were carved from naturally curved ʻōhiʻa stilt roots (Krauss 1993). ʻŌhiʻa wood was also sometimes used for paddles and for the booms that connected the hulls of the great double-hulled voyaging canoes (waʻa kaulua).

Body ornamentation/garlands

The flowers are used in garlands and leis and in the traditional Hawaiian religion are considered sacred to the goddess Pele (Kirch 1985, Little and Skolmen 1989, Bornhorst 2005). The tips of young shoots known as liko are also commonly incorporated into leis.



Top: ʻŌhiʻa wood flooring. PHOTO: J. B. FRIDAY **Bottom: Hawaiians frequently use the wood for sacred images (kiʻi), which turn light gray when exposed to the elements. Puʻuhonua o Hōnaunau, Kona, Hawaiʻi.** PHOTO: C. ELEVITCH

Ceremonial/religious importance

The majority of the large carved wooden sacred images (kiʻi) in old Hawaiʻi were made from the wood of ʻōhiʻa. Along with lama (*Diospyros sandwicensis*), ʻieʻie (*Freycinetia arborea*), halapepe (*Pleomele aurea*), maile (*Alyxia oliviformis*), and the palapalai fern (*Microlepia strigosa*), ʻōhiʻa was one of the ritual plants associated with the hula. ʻŌhiʻa represented the god Kūkāʻōhiʻa Laka, who was named for a legendary ʻōhiʻa tree that bore both red and white flowers (Abbott 1992). In the traditional Hawaiian religion, the fire-red flowers are considered sacred to Pele, the volcano goddess.

Other

The red flowers are the official symbol of the island of

Liko (the new leaf tips) are found in a rainbow of colors and are a favorite component of leis. PHOTOS: C. ELEVITCH

Hawai'i. Some people believe that picking 'ōhi'a flowers will cause it to rain.

URBAN AND COMMUNITY FORESTRY

'Ōhi'a can be a splendid ornamental tree in cooler, wetter areas such as the Hilo and Puna districts on Hawai'i or in Mānoa or Wahiawā on O'ahu. Planting an 'ōhi'a tree in a yard or garden brings a bit of the forest home. A good example of this can be seen in Waimea on Hawai'i, where 'ōhi'a was planted along the roads and in many public landscapes. The tree grows slowly and needs to be well cared for. It cannot tolerate abuse as other popular landscape trees can. If forest areas are cleared for development, specimen 'ōhi'a trees can be left as a reminder of the forest that once was there.

Size

'Ōhi'a trees in landscape settings usually reach 3–12 m (10–40 ft) in height, smaller than trees in the forest. Some trees grow vertically and may only have a canopy spread of 1–2 m (3.3–6.6 ft); others may fork and spread their canopy over 10 m (33 ft).

Rate of growth in a landscape

In well watered areas, 'ōhi'a grows about 60 cm (2 ft) in height per year.

Roots

When grown on lava soils, 'ōhi'a has spreading surface roots. The tree may be killed if these roots are cut, and traffic and machinery can also damage roots. In deep soils or in porous lava, roots go deep and enable the tree to survive dry periods.

Products commonly used in a Hawaiian household

The red, yellow, and orange 'ōhi'a flowers are made into intricate leis in Hawai'i. The silvery, green, or reddish new shoots are also used. 'Ōhi'a wood was once used for housing and carving sacred images (ki'i) in old Hawai'i. Today 'ōhi'a wood is mostly used as round posts (unsawn) for architectural elements and for flooring.

Light requirements

'Ōhi'a trees prefer full sunlight but tolerate slight shading from surrounding plants.

Water/soil requirements

'Ōhi'a prefers wetter and cooler areas in Hawai'i. The tree can grow on various textures of soil and on organic soils formed over lava rock. 'Ōhi'a is killed by drying out and must be kept well watered, especially when first planted (Bornhorst 2005). 'Ōhi'a trees planted in shallow depressions in pāhoehoe (sheet) lava may flourish for several years but die from drying out when the trees grow larger and the

thin soil is no longer able to hold enough water to support them during dry spells. ʻŌhiʻa growing on pāhoehoe may also die from constant flooding, especially if water is diverted to the site because of nearby construction or development.

Expected life span in a homegarden

Huge old ʻōhiʻa trees in the forest are many centuries old, and even moderate-size trees may be a couple of hundred years old. However, trees grown near places where people live often succumb to injury, root damage, flooding, or soil compaction if care is not taken.

Varieties favored for use in a homegardens or for street trees

Many people favor the mamo (yellow-flowered) variety of ʻōhiʻa. Pink, orange, and red are also planted in landscaping. All colors may be propagated by air-layering.

Seasonality of leaf flush, flowering, fruiting

ʻŌhiʻa may flower at any time of year. Individual trees flower once or twice per year, and some individuals may flower almost continuously.

Exceptional ornamental values

ʻŌhiʻa is a favorite ornamental tree because of its showy blossoms. Trees with blossoms of exceptional color may be propagated by cutting or air-layer to ensure that the colors remain true.

Use as living fence, hedge, or visual/noise barrier

ʻŌhiʻa does not tolerate lopping or pollarding well, and this limits its use as a hedge. However, closely planted trees can form a thick barrier in open spaces.

Bird/bee/wildlife

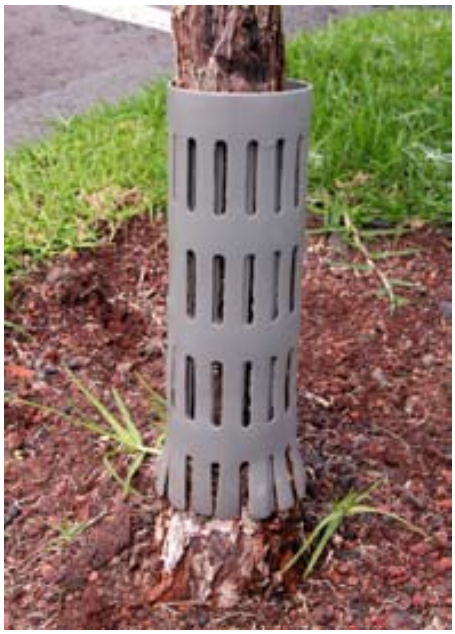
ʻŌhiʻa trees attract bees and other insects. While they are important nectar trees for native forest birds, few of these survive near inhabited areas, and ʻōhiʻa trees are more likely to attract alien bird species.

Maintenance requirements

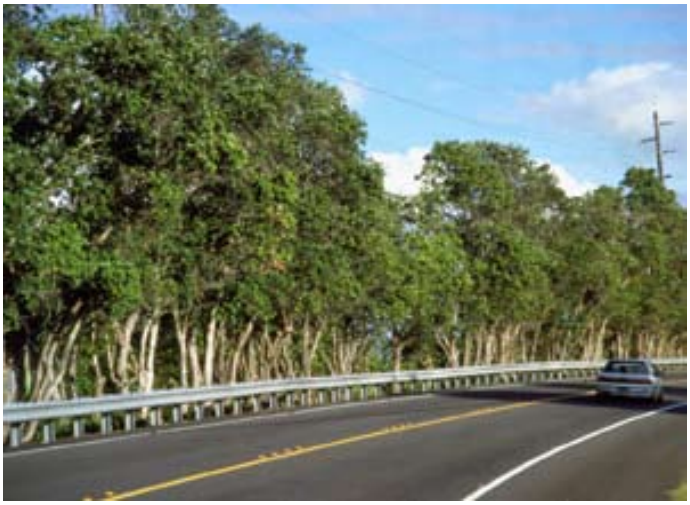
Trees should be mulched heavily and fertilized only sparingly. ʻŌhiʻa trees have evolved to survive in infertile soils; heavy fertilization causes sappy growth that may not be strong enough to bear its own weight and is prone to insect attack. Slow-release fertilizers or natural compost works best.

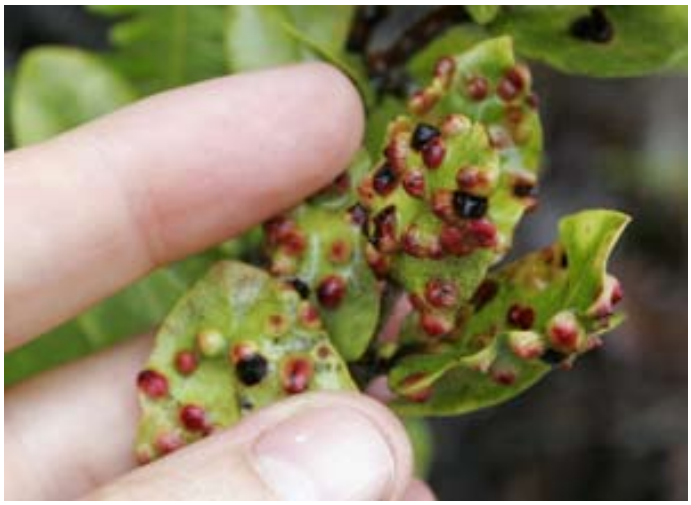
Drawbacks

In a landscape setting, ʻōhiʻa is limited by its slow growth. Trees over 22–30 cm (10–12 in) tall are not easily transplanted, and larger potted specimens may not survive. ʻŌhiʻa is also easily barked and damaged by machinery such as mowers and weed cutters. ʻŌhiʻa generally does not tolerate topping or pollarding. A drawback to using ʻōhiʻa in



Left: ʻŌhiʻa trunk and roots are easily de-barked by careless use of grass trimmers or other machinery. PHOTO: J. B. FRIDAY **Center and right: Plastic guards can help protect bark from damage during maintenance, although damage can still occur, as here above and below guard.** PHOTOS: C. ELEVITCH





Left: Stand of ʻōhiʻa serving as a windbreak for the Hawaiʻi Belt Road on the Hāmākua coast. PHOTOS: J. B. FRIDAY **Right: Gall insects commonly affect young trees, but the trees usually outgrow these pests.** PHOTO: C. ELEVITCH

agroforestry systems is that it is a host for the black twig borer (*Xylosandrus compactus*), a serious pest of coffee, cacao, and other tree crops.

Nuisance issues

None.

Common pest problems

Young ʻōhiʻa foliage may be attacked by Chinese rose beetles and gall insects. Usually the trees outgrow these pests without treatment. Aphids and their associated ants and sooty mold may be problems in wet areas. A rust disease probably caused by the fungus *Puccinia psidii* was discovered in Hawaiʻi in 2005 (see text box above).

Other

Developers in Hawaiʻi often leave a few token ʻōhiʻa when clearing native forest for building sites. Unfortunately, these usually die after a few months or years from having their root system damaged by bulldozers and other machinery. If ʻōhiʻa are desired as part of the landscape, an area at least as wide as the trees are tall must be left undisturbed. Since many building sites on Hawaiʻi are on relatively new lava flows with shallow soils, the trees' root systems are spreading and shallow. Cutting or trampling the roots will usually kill the trees. Compromised trees can become a hazard, especially in high winds, as the whole tree can come crashing down.

COMMERCIAL PRODUCTS

ʻŌhiʻa lehua has become a popular garden ornamental, and many nurseries and garden shops now carry the tree (Bornhorst 2003, 2005). For production of ornamental flowers it is recommended to start plants from cutting or air-layer because vegetative propagation ensures that the plants will be true to type (Rauch and Hensley 1997).

ʻŌhiʻa posts are sold in Hawaiʻi today for approximately US$1.00 per inch (2.5 cm) of diameter per lineal foot (30 cm). For example, a ten-foot long post of eight inches in diameter would sell for $80.00. Air-dried, rough-sawn lumber suitable for milling into flooring sells for $1.25/bf, while lumber of firsts and seconds grade sells for $3.50–$5.00 per board foot. Finished ʻōhiʻa flooring sells for $7.00–$9.00 per square foot.

Spacing

Because of its slow growth rate, ʻōhiʻa is not grown in timber plantations.

Management techniques

Timber management is seldom if ever undertaken in ʻōhiʻa forests because of the tree's perceived low value and slow rate of growth. Faster-growing pole stands might be managed for pole production for architectural elements. At a growth rate of 3 mm (0.12 in) diameter per year, it would take 50 years to grow a 15 cm (6 in) diameter pole. Natural forests might be extensively managed for a small return. However, continued pressure to clear lowland forests for agricultural crops makes the prospect of such sustainable, long-term silviculture unlikely.

Design considerations

While ʻōhiʻa itself is slow growing and unlikely to yield much return, ʻōhiʻa trees can be managed as part of a koa silvicultural system, as occurs in the native forests. The

faster-growing koa does not shade out the ʻōhiʻa, but the ʻōhiʻa can provide side shade for the koa and possibly reduce branchiness and encourage straight growth (Patrick Baker, pers. com.). ʻŌhiʻa could also provide habitat for native birds in such a mixed system. Koa trees may be planted into an existing scattered ʻōhiʻa forest, or ʻōhiʻa may be planted along with koa. ʻŌhiʻa is not shade tolerant and cannot be regenerated under its own canopy or in dense shade, although it does grow well under a light koa canopy.

On-farm processing methods required to access market

ʻŌhiʻa is often logged and milled using portable mills brought to the forest sites. Most ʻōhiʻa harvesting today occurs in conjunction with land clearing for coffee, papaya, pasture, or other agriculture or residential uses. Almost all ʻōhiʻa harvested is cut on the island of Hawaiʻi.

On-farm processing

ʻŌhiʻa logs often check badly at the ends. Brackets hammered into the ends of logs may help decrease losses due to splitting. Drying lumber should be done very slowly to minimize checking and splitting (Forest Products Laboratory, undated). Poles should be debarked when freshly cut.

Markets

ʻŌhiʻa flooring is produced locally on Oʻahu and Hawaiʻi. ʻŌhiʻa architectural elements are favored by builders on Hawaiʻi and upcountry areas on Maui and Kauaʻi.

INTERPLANTING/FARM APPLICATIONS

Example 1

Location

Hakalau National Wildlife Refuge, Hawaiʻi island. The refuge is located on the upper slopes on the windward side of Mauna Kea, in a cool, mesic area. Rainfall is 2000 mm (80 in) annually. The deep, acid soils are derived from volcanic ash and classified as Typic Hydrudands (USDA classification). Soils are silty clay loams and silt loams which contain high amounts of organic material but also fix available phosphorus. Temperatures at the higher elevations can dip below freezing during the winter months (Scowcroft and Jeffrey 1999). While originally forested, the upper parts of the refuge had been gradually converted by logging, burning, and grazing to pasture dominated by kikuyu grass (*Pennisetum clandestinum*), meadow rice grass (*Ehrharta stipoides*), and other alien grasses over the past century.

Description

The U.S. Department of the Interior's Fish and Wildlife Service has been restoring a native koa-ʻōhiʻa forest to the higher elevations (above 1800 m [6000 ft]) of the refuge since 1989. Their goal is to restore the habitat for the native bird life, including eight endangered species such as the ʻākepa (*Loxops coccinea*), the ʻakiapōlāʻau (*Hemignathus munroi*), and the Hawaiʻi creeper (*Oreomystis mana*). ʻŌhiʻa trees are grown from locally-collected seed in a nursery at the site. The seedlings, which are grown in dibble tubes

ʻŌhiʻa seedlings planted under 8- to 10-year-old koa trees at Hakalau National Wildlife Refuge are protected from frost damage. PHOTO: C. ELEVITCH

or root trainers, take 18–24 months to reach plantable height of 15–20 cm (6–8 in) tall. Planting sites are scalped to remove competing grasses, and trees are initially fertilized with 10–30–10 granular fertilizer. Older trees at the site are growing at a rate of approximately 1 mm (0.05 in) per year in diameter. Early reforestation efforts indicated that a major cause of mortality in young outplanted ʻōhiʻa seedlings was frost damage. Currently ʻōhiʻa seedlings are outplanted underneath the canopies of 8–10-year-old koa trees established on the site. The koa overstory decreases radiative cooling at ground level and keeps the ʻōhiʻa seedlings from being damaged (Scowcroft et al. 2000). Koa, being a nitrogen-fixing tree, also increases nitrogen availability in the soil. When planted under koa, ʻōhiʻa trees have shown close to 100% survival, whereas they showed almost no survival when planted on bare ground in the open.

An alternative successful planting technique is to plant seedlings onto fallen logs in the pastures, or even onto artificial planters made from wood and potting material. Elevating the seedlings above the ground by even 0.5 m (20 in) seems to help avoid frost damage.

Spacing

The ʻōhiʻa seedlings are planted at wide spacings, about 4 m (13 ft) apart, in a mixture of other native forest and understory trees including kōlea (*Myrsine lessertiana*), ʻōlapa (*Cheirodendron* spp.), and pilo (*Coprosma* spp.), and the shrubs ʻākala (*Rubus hawaiensis*), pūkiawe (*Leptecophylla tameiameiae*), and ʻōhelo (*Vaccinium* spp.).

Example 2

Location

Puna, Hawaiʻi.

Description

ʻŌhiʻa forests on lava rock soils in lower Puna are often cleared for planting horticultural crops such as papaya, noni, or ʻawa (kava). These crops all benefit from windbreaks. While planting ʻōhiʻa trees is not practical because of their slow growth, some landowners carefully lay out their fields so as to leave remnants of the ʻōhiʻa forest to serve as windbreaks.

Crop/tree interaction

The crops benefit from decreased moisture stress in dry periods and avoid physical damage from the wind. Windbreaks of ʻōhiʻa also serve as honey plants for nearby beekeepers and as forage for any native birds that remain in the area.

Spacing

Windbreaks generally protect areas ten times their height. ʻŌhiʻa forests in the lava rock lands of Puna may only be 10 m (40 ft) tall. To protect 3 m (10 ft) tall papaya or other tree crops, windbreaks should be left every 100 m (330 ft). Since ʻawa and noni tolerate some shade, windbreaks may be spaced even closer for better protection, or plantings may be done in alleys cleared in the native forest. Since a single row of ʻōhiʻa may not be windfirm, especially on shallow substrates, enough land needs to be left so that the trees can grow several rows deep.

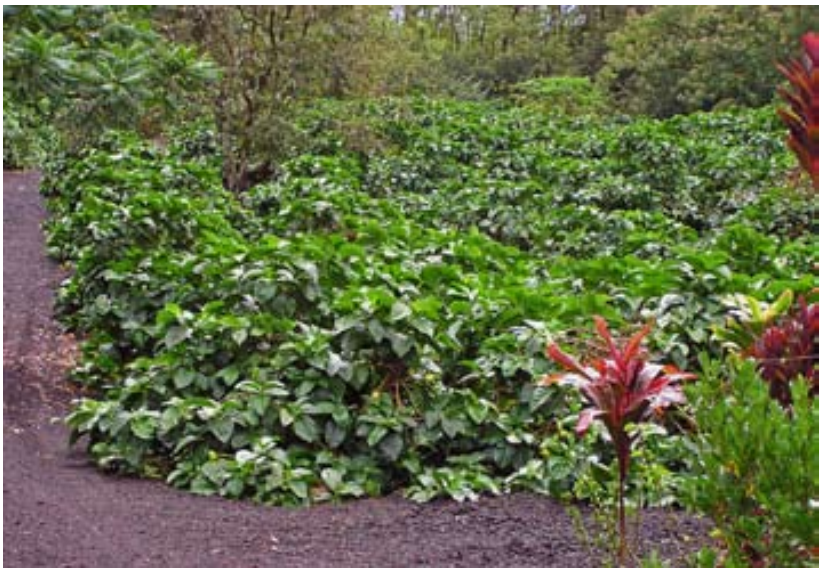
Example 3 (Contributed by Craig Elevitch)

Location

Kona, Hawaiʻi.

Description

Coffee is traditionally grown in full sun in Kona, but it can also be grown under light shade. Some landowners choose to leave some of the native forest trees such as ʻōhiʻa and lama (*Diospyros sandwicensis*) as shade trees in coffee farms. While both these trees are slow growing and it would not be practical to plant them along with the coffee, it is sometimes possible to leave some trees in place when the farm is cleared. These trees may provide habitat for native birds and serve as a reminder of the history of the farm. One disadvantage is that old ʻōhiʻa trees, as any nearby trees, may serve as a host for the black twig borer (*Xylosandrus compactus*), a serious pest of coffee.



Windbreak of ʻōhiʻa forest protecting a noni plantation in Puna, Hawaiʻi.
PHOTO: S. NELSON

Crop/tree interactions

Although coffee is a shade-tolerant plant, shading decreases the amount of the coffee produced. Light overstory shade is generally used in tropical countries to decrease overbearing and consequent nutrient stress (Bittenbender and Smith 2004). While growers in Hawai'i generally have avoided nutrient stress by fertilizing sufficiently and growing coffee in full sun, there may be a marketing premium or niche for "shade-grown" coffee.

Spacing

'Ōhi'a and other native overstory trees are left as they grow, scattered across the landscape.

PUBLIC ASSISTANCE

The Cooperative Extension Service (CES) of the University of Hawai'i can assist landowners with questions relating to 'ōhi'a. Their forestry web site includes many valuable publications, forestry news, and an extensive list of forestry links for Hawai'i.

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Web: http://www.ctahr.hawaii.edu/forestry

INTERNET

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

Hawaiian Native Plant Propagation Database–*Metrosideros polymorpha*: <http://www2.hawaii.edu/~eherring/hawnprop/met-poly.htm>.

Native Plant Network Propagation Protocol Database: <http://www.nativeplantnetwork.org/network/search.asp>.

The Flora of the Hawaiian Islands, a web site of the Smithsonian Institution, is a database of flowering plants and ferns in Hawai'i: <http://ravenel.si.edu/botany/pacificislandbiodiversity/hawaiianflora/index.htm>.

Coffee planted in the understory of native 'ōhi'a-lama-kolea forest, 'Ōhi'a Forest Farm, South Kona, Hawai'i. PHOTO: C. ELEVITCH

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Metrosideros polymorpha ('ōhi'a)

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