

# Trees in the landscape, Part 5:

## *Metrosideros polymorpha*

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### *Metrosideros polymorpha* Gaud.

Perhaps the most beloved and popular native Hawaiian tree, *Metrosideros polymorpha*, called 'ōhi'a lehua in the Hawaiian language, is an unusually variable but highly adaptable and splendid ornamental tree for a variety of uses in the Islands and probably also in the coastal plains and valleys in southern and central California. It occurs in a wide range of ecological situations in Hawai'i, is the most common tree in lowland to montane, dry to wet forests, subalpine shrublands, bogs, swamps, and recent lava flows, and has the ability to survive harsh conditions.

Famous for its dazzling array of flower colors, intriguing newly emerging leaves, attractive bark, and rugged-looking, often picturesque habit, 'ōhi'a lehua is a handsome and superb tree for park, residential, and flowering accent and, with proper training, makes an excellent shade and street tree.

Despite its popularity in Hawai'i, 'ōhi'a lehua is often overlooked in the Islands and is deserving of much wider use in the landscape and urban forest there, and is a prime candidate for evaluation in certain parts of California.

#### Taxonomy and history

**Synonyms:** *Metrosideros collina* (J. R. and G. Forster) A. Gray subsp. *polymorpha* (Gaud.) Rock. Dawson and Stemmerman (1990) list a multitude of other synonyms, nearly all of which are varieties or subspecies of *M. polymorpha* or *M. collina*, the latter of which is a species occurring in French Polynesia, Fiji, and Vanuatu.

**Common names:** 'ōhi'a, 'ōhi'a lehua, lehua.

**Etymology:** The genus name *Metrosideros* is derived from the Greek *metra*, meaning core or heartwood, and *sideros*, meaning iron, and alludes to the unusually hard wood of the genus. The specific epithet *polymorpha* is derived from the Greek *poly*, meaning many, and *morphe*, meaning form or

with several trunks or low, narrow-angled, upright branches appearing as trunks, slow-growing, long-lived, broad-leaf evergreen, unarmed prostrate shrub to lofty tree, 1-100 feet tall (Figs. 1, 18-19), 2-50 feet wide, canopy of trees irregular but mostly upright and narrowly columnar to broadly columnar or elliptic or sometimes rounded, dense to open, irregularly branched.

*A handsome and superb tree for park, residential, and flowering accent... an excellent shade and street tree.*

shape, and alludes to vast variation of this species that is manifested in innumerable growth habits; size, shape, color, and surface of leaves; and color of flowers.

**History:** French botanist and naturalist, Charles Gaudichaud-Beaupré (1789-1854), who served on the circumglobal expedition of the *l'Uranie* from 1817 to 1820, named and described this species in 1830 based on material he had collected in Hawai'i during the voyage.

#### Description

The description is from several sources (Dawson and Stemmerman 1990, Friday and Herbert 2006, Lamb 1981, Rock 1974, Staples and Herbst 2005) and from cultivated and wild trees in Hawai'i.

**Habit/conformation:** extremely variable, often rugged- and picturesque-looking, dwarf to large, solitary or

**Figure 1.** Under the right conditions of deep, well drained soil and adequate moisture, 'ōhi'a lehua can grow into a tall tree. Moist forest, Ka'ōhe, South Kona, Hawai'i.





Figure 2. (Left) Richard Missler provides scale for this 'ōhi'a lehua with a trunk six feet DBH, which is enveloped in a tangle of *Freycinetia* and *Hibiscus tiliaceus*. Moist forest, Waikāku'u, South Kona, Hawai'i.



Figure 3. (Center) This 'ōhi'a lehua has a stilt root supporting the base of the trunk. Moist forest, Waikāku'u, South Kona, Hawai'i.



Figure 4. (Right) Branching on forest trees of 'ōhi'a lehua typically begins at mid trunk or higher. Moist forest, Waikāku'u, South Kona, Hawai'i.

**Trunk(s):** straight or twisted, cylindrical, often deeply fluted, to 7 feet DBH (Fig. 2), sometimes with stilt roots at base (Fig. 3), branching beginning at mid trunk or higher on forest trees (Fig. 4) but near the ground on trees in the open; trunk and branches sometimes with pendant, elongate masses or reddish brown, hair-like aerial roots (Fig. 5).

**Bark:** tan to grayish tan, rough, flaky (Fig. 6), fissured, separating in thick flakes, sometimes smooth and separating in long, thin strips.

**Leaves:** simple, opposite, variably dark glossy green to gray-green (Fig. 7); petiole short, 0.05-0.6 inch long, without hairs or densely covered with silvery white, short, appressed, felt-like or woolly hairs; blade 0.4-3.25 × 0.4-2.2 inches, obovate to circular or elliptic, thick, leathery, without hairs adaxially and abaxially or abaxially densely covered with silvery white,

Figure 5. (Left) Under the right conditions, conspicuous, pendant, elongate masses of reddish brown, hair-like aerial roots form on the trunks and/or branches of 'ōhi'a lehua. Moist forest, Ka'ohe, South Kona, Hawai'i.

Figure 6. (Right) Bark of 'ōhi'a lehua is typically tan to grayish tan, rough, and flaky. Moist forest, Waikāku'u, South Kona, Hawai'i.





Figure 7. (Left) Leaves of 'ōhi'a lehua are simple, opposite, and variably dark glossy green to gray-green and often densely covered abaxially with silvery white, short, appressed, felt-like hairs. Waimea, Hawai'i.

Figure 8. (Center) New, emerging leaves of 'ōhi'a lehua, called liko, are sometimes mostly hairless and greenish or reddish. Waimea, Hawai'i.

Figure 9. (Right) Sometimes new, emerging leaves of 'ōhi'a lehua are densely covered with short, appressed, felt-like hairs and then are pink, gray, or nearly black. Waimea, Hawai'i.

Table 3. Hawaiian Names for 'Ōhi'a Lehua Flower Colors and Leaf Size and Arrangement.	
Flower/Leaf Color/Type	Hawaiian Name
flower red	'ōhi'a 'ula'ula, lehua 'ula'ula
flower dark red	'ōhi'a 'āpane, lehua 'āpane
flower orange	'ōhi'a 'ālan'i, lehua 'ālan'i
flower yellow	'ōhi'a mele mele, lehua mele mele
flower dark yellow	'ōhi'a mamo, lehua mamo
flower white	'ōhi'a kea, lehua kea
leaf very small	lehua lau li'i, 'ōhi'a lau li'i
leaf sessile and cordate	lehua kū ma kua, 'ōhi'a kū ma kua

Figure 10. (Left) Sometimes new, emerging leaves of 'ōhi'a lehua are densely covered with short, appressed, felt-like hairs and then are pink, gray, or nearly black. Ulu La'au Waimea Nature Park, Waimea, Hawai'i.

Figure 11. (Right) Flower buds of 'ōhi'a lehua are often showy because of the dense covering of silvery white, short, appressed, felt-like hairs. Waimea, Hawai'i.



short, appressed, felt-like or woolly hairs (Fig. 7), margins flat to revolute, apex rounded to short-pointed, new leaves (called liko in Hawaiian) emerging hairless and greenish or reddish (Fig. 8), or densely covered with short, appressed, felt-like or woolly hairs and then brown, pink, gray, or nearly black (Figs. 9-10).

**Flowers:** in terminal, showy, rather compact, conspicuous clusters 3-6 inches wide composed of multiple, few(2-3)-flowered cymes containing up to 40 flowers; buds (called 'ōpu'u in Hawaiian) without hairs or showy because of the dense covering of silvery white, short, appressed, felt-like hairs (Fig. 11); peduncle 0.25-0.7 inch long; individual flowers pin-cushion- or powder-puff-like, to 1.5 × 1 inches; pedicel 0.08-0.3 inch long; hypanthium 0.1-0.3 inch high and wide; sepals small and inconspicuous, 0.06-0.15 × 0.06-0.11 inch, rounded to triangular; petals small and mostly inconspicuous, 0.1-0.2 × 0.08-0.18 inch, obovate to rounded; stamens numerous, 0.4-1.2 inches long, red, orange, yellow, pink, salmon (Figs. 12-16), rarely white; style 0.5-1.2 inches long; nearly all parts of the inflorescence and flowers, including peduncle, pedicel, hypanthium, and abaxial surfaces of the sepals and petals without hairs or frequently and densely covered with silvery white, short, appressed, felt-like hairs; in spring and summer after vegetative flushes and/or sporadically throughout the year.



Figure 12. (Left) Flowers of 'ōhi'a lehua are variably colored and range from red, as shown here, to orange, yellow, pink, and salmon-colored. Ulu La'au Waimea Nature Park, Waimea, Hawai'i.



Figure 13. (Center) Orange flowers of 'ōhi'a lehua. Ulu La'au Waimea Nature Park, Waimea, Hawai'i.



Figure 14. (Right) Yellow flowers of 'ōhi'a lehua. Ulu La'au Waimea Nature Park, Waimea, Hawai'i.

**Fruits:** a capsule, 0.1-0.4 inch long and wide (Fig. 17), drying brown, without hairs or densely covered with short, appressed hairs; seeds brown, minute, ca. 50,000 per ounce.

#### Distribution and ecology

'Ōhi'a lehua occurs on all the main Hawaiian Islands except Ni'ihau and Kaho'olawe from near sea level to 9,000 feet elevation (Adee and Conrad 1990, Dawson and Stemmerman 1990, Friday and Herbert 2006, Rock 1974, Staples and Herbst 2005). It is the most common woody species in lowland to montane dry, mesic (Fig. 1), and wet forests, subalpine shrublands, bogs, swamps, and recent lava flows. It is the initial and mostly only woody-species colonizer on recent lava flows and/or disturbed sites and has the ability to survive harsh conditions (Figs. 18-19).

Annual rainfall over the range of 'ōhi'a lehua varies greatly and ranges

from 15 in dry, leeward areas to over 400 inches on Mt. Wai'ale'ale, Kaua'i. Relative humidity ranges from 70 to 80% in humid windward regions and 60 to 70% in more arid leeward areas (Adee and Conrad 1990). Mean annual temperatures range from 50 to 75 F and the mean maximum and minimum temperatures of warmest and coolest months are 84 F and 32 F respectively (Adee and Conrad 1990, Friday and Herbert 2006) although seasonal variation in mean monthly temperature does not exceed 9 F (Adee and Conrad 1990). The minimum temperature tolerated is 25 F and dry season duration (consecutive months with less than 1.6 inches of rain) tolerated is four months (Friday and Herbert 2006). Frost and occasional snow occur at the upper end of the elevation range (Adee and Conrad 1990). However, maximum biomass and optimal growth occur at temperatures between 61 F and

70 F and annual rainfall between 40 and 120 inches (Stemmerman 1983, Stemmerman and Ihsle 1993, Mueller-Dombois 1987, Adee and Conrad 1990), with rainfall distributed evenly throughout the year (Friday and Herbert 2006).

The wide range of soils upon which 'ōhi'a lehua grows is amazing, and includes excessively drained, recent lava flows to ancient, highly weathered, poorly drained, saturated clays around bogs and swamps (Mueller-Dombois 1994, Herbert and Fownes 1995). It occurs on nutrient-rich as well as nutrient-depleted soils (Crews et al. 1995, Herbert and Fownes 1999) and on soils suffering from aluminum toxicity (Moomaw et al. 1959, Mueller-Dombois 1994). Soil pH ranges from 3.6 to 7.4 (Crews et al. 1995). Best growth producing tall trees is on level or gently sloping, well structured, well drained, medium clays (Friday and Herbert

Figure 15. (Left) Pink flowers of 'ōhi'a lehua. Ulu La'au Waimea Nature Park, Waimea, Hawai'i.

Figure 16. (Center) Salmon-colored flowers of 'ōhi'a lehua. Ulu La'au Waimea Nature Park, Waimea, Hawai'i.

Figure 17. (Right) Fruits of 'ōhi'a lehua are small, brown capsules that split open to liberate the tiny seeds. Waimea, Hawai'i.



2006). Under harsh conditions, such as on steep slopes, exposed ridges, poorly drained, or especially rocky sites, growth is much retarded and the plants are typically reduced to small, dwarf, or even prostrate shrubs (Adee and Conrad 1990).

'*Ōhi'a lehua* is typically the dominant tree where it grows. Associated genera in wetter areas include *Acacia*, *Cheirodendron*, *Freycinetia*, *Gouldia*, *Pittosporum*, *Pritchardia*, *Psychotria*, and several ferns, especially the tree ferns *Cibotium*. In drier areas associated genera include *Diospyros*, *Dracaena*, *Erythrina*, *Myoporum*, *Osmanthus*, *Sophora*, and *Xylosma* (Adee and Conrad 1990). Endemic Hawaiian birds and insects are likely pollinators (Carpenter 1976).

Fruit maturation can take as long as 4 to 12 months (Porter 1973) although Allen (2002) reported 70 to 90 days. Germination is varied but typically less than 35% (Adee and Conrad 1990), probably because often less than 20% of the seeds are viable due to lack of embryos (Burton 1982,

**Figure 18. (Left)** '*Ōhi'a lehua* is able to colonize recent lava flows and/or disturbed sites and has the ability to survive harsh conditions. Dry forest, North Kona, Hawai'i.

**Figure 19. (Right)** This multi-trunked '*ōhi'a lehua* grows in harsh conditions in the Kau Desert in the rain shadow of Kīlauea Volcano, Hawai'i.



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Drake 1993). Most seeds germinate epiphytically on tree fern (*Cibotium* spp.) trunks or on moss-covered, fallen logs (Adee and Conrad 1990) where the roots grow over and down the "nurse" plant. These nurse plants eventually rot away, leaving a cavity under the tree and stilt roots at the base of the trunk (Fig. 3). Seedlings in habitat grow slowly, about four inches in height per year (Adee and Conrad 1990) and forest trees rarely grow

more than 0.08 inch stem diameter per year and 24 inches in height per year (Adee and Conrad 1990, Herbert and Fownes 1995, 1999, Raich et al. 1997, Vitousek and Farrington 1997, Gerrish and Mueller-Dombois 1999).

### Propagation and growth rate

'*Ōhi'a lehua* can be propagated by seeds, cuttings, and air-layers. Although it generally comes true from seeds (Stemmerman 1983), vegetative means are best for ensuring a particular flower color, leaf type, or even growth habit (Rauch and Hensley 1977). Digging plants from the wild is discouraged, difficult, and, in most instances, prohibited.

Collect whole, mature fruit capsules before they open (Allen 2002). Just prior to splitting capsules are swollen and have lines marking where they will split open. Place capsules in a paper bag or box to contain seeds when the capsules split. Seed storage reduces germination; thus, spread fresh, recently collected seeds on the surface of a moist, sterile, porous, well drained potting medium (Bornhorst 2005), for example two parts perlite and one part peat moss. Mist lightly so the seeds are not disturbed, cover with glass or plastic, and place the container in a shady location (UH CTAHR 2012). Fresh seeds germinate in 5 to 10 days (Corn 1979). Seeds germinate at temperatures from 50 F to 93 F although 72 to 77 F were best (Burton 1980, 1982, Drake 1993).

Transplant seedlings into two-inch

liners or rose pots in a sterile, porous, well drained potting medium when they are at least an inch tall and have four to six leaves (Bornhorst 2005, Bornhorst and Rauch 2003, NTBG 1993). Keep seedlings moist and gradually introduce them to a sunny location. When seedlings are 6 to 12 inches tall and growing vigorously plant them out into the landscape or pot them up into larger pots (Bornhorst 2005).

'*Ōhi'a lehua* is variable in its ability to root from cuttings (Bornhorst and Rauch 1994). For best results, use tip or stems about 0.25 inch diameter and four to six inches long (Bornhorst 2005, UH CTAHR 2012) from recently, matured growth (Criley 1998) and reduce leaf area by removing portions of the distal leaves. Cuttings will likely root best in full sun, with intermittent mist, and, at least in California, with bottom heat maintaining temperatures of 70 to 75 F in the root zone. Cuttings of yellow-flowered '*ōhi'a lehua* rooted best when dipped in a 2,000 ppm indolebutyric acid (IBA) solution of Dip 'N Grow and placed under intermittent mist of six seconds every two minutes (Rauch et al. 1997). Criley (1998) had similar results using rooting solutions of a 2:1 ratio of IBA to NAA (naphthaleneacetic acid) in the 2,000 to 4,000 ppm range. Bornhorst (2005) recommended cutting leaves in half, removing lower leaves, and dipping cuttings in a 10% solution of Dip 'N Grow for 10 seconds.

'*Ōhi'a lehua* can be grown from air layers but, similarly to cuttings, it is variable in its ability to root from this technique (Bornhorst 2005). Standard air-layer techniques and a strong rooting hormone are recommended (UH CTAHR 2012). Bornhorst (2005) recommended using a 10% solution of Dip 'N Grow. Tanabe and Frazier (1984) found that a 3% IBA talc dust (30,000 ppm) and the ring-girdle technique improved rooting percentage and root quality when air layering vigorously growing branches of younger plants. Plants that tend to produce aerial roots might be easier to air layer (Bornhorst 2005).

**Table 2. Varieties of *Metrosideros polymorpha* ('*Ōhi'a Lehua*) in Hawai'i.**

Variety	Characteristics
<i>dieteri</i>	small tree, bark rough; leaves broadly obovate, without hairs, apex broadly rounded, margins flat; middle and high elevations, Kaua'i.
<i>glaberrima</i>	shrub to tall tree; bark rough but separating in thin strips; leaves ovate to obovate or elliptic, without hairs, apex rounded to short-pointed, margins mostly flat; middle to high elevations, all islands except Ni'ihau and Kaho'olawe.
<i>incana</i>	shrub to tree; bark separating in thin strips; leaves ovate to suborbicular, abaxially hairy, apex rounded to retuse (rounded with central depression), margins flat; low to middle elevations, O'ahu, Moloka'i, Lāna'i, Maui, and Hawai'i.
<i>macrophylla</i>	small to tall tree; bark separating in thin strips; leaves without hairs, large, broadly ovate, apex rounded, margins flat; middle elevations, Hawai'i.
<i>newellii</i>	shrub to small tree; bark unknown; leaves elliptic, without hairs, apex rounded to short pointed, margins flat; along streams, middle elevations, Hawai'i.
<i>polymorpha</i>	shrub to small tree; bark rough; leaves ovate to suborbicular, abaxially hairy, apex rounded to retuse, margins revolute (rolled under); middle to high elevations, O'ahu, Moloka'i, Lāna'i, Maui, and Hawai'i.
<i>pseudorugosa</i>	prostrate shrub; bark unknown; leaves small, less than 0.6 inch long, broadly ovate to suborbicular, abaxially hairy, apex rounded, margins revolute; high elevation bogs, w. Maui.
<i>pumila</i>	prostrate shrub; branches ascending; bark separating in thin flakes; leaves without hairs or abaxially with hairs, apex rounded, margins slightly revolute; middle and high elevation swamps, Kaua'i, Moloka'i, and Maui.

'*Ōhi'a lehua* often reproduces vegetatively from stem sprouts on fallen trees. These stem sprouts produce adventitious roots and eventually live on their own, and have been used for propagation (Conrad et al. 1988).

Pot up seedlings, rooted cuttings, and air layers regularly in a clean, porous, well drained medium to avoid circling, girdling, and/or kinked roots. When repotting and planting out in the landscape, take

care not to disturb the roots. Such disturbance can damage the roots and result in poor growth (D. Kim per. comm.). Place plants in full sun. Fertilize regularly and do not allow plants to dry out. Plants seem especially sensitive to drying out when young and/or in containers and daily irrigation might be necessary in some instances (Bornhorst 2005, Bornhorst and Rauch 1994).

Under optimal conditions cultivated plants grow more rapidly than their wild counterparts. Seedlings can grow to 28 inches tall after one year from seed (Friday and Herbert 2006). Young plants in the 5 to 15 feet-tall range grow more quickly than older trees (Bornhorst 2005), and 24 to 36 inches of growth annually might be expected under optimal conditions in the nursery and landscape (Friday and Herbert 2006). Growth slows as plants age and become larger.

#### Environmental tolerances

'*Ōhi'a lehua* is well adapted to nearly all of Hawai'i, but especially cooler and wetter areas, and, based on its natural distribution and ecology, is

likely suitable for the coastal plains and valleys of southern and central California. Although not listed in *Sunset* (Brenzel 1995), it appears adapted to Sunset Zones 16-17, and 21-24 and should be tried in Zones 14-15 and 18-20. Much of this area falls within USDA Zones 9 to 11. Hawaiian provenance likely plays a role in the adaptability of '*ōhi'a lehua* to California; plants from higher elevations and/or drier sites in the Islands are likely more appropriate for California, especially the non-coastal areas.

'*Ōhi'a lehua* can tolerate temperatures as low as 25 F for brief periods (Friday and Herbert 2006) but temperatures below 18 F can permanently damage tissue (Cordell et al. 2000, Scowcroft et al. 2000). It tolerates nearly all soil types, including shallow, rocky, nutrient-poor, extremely acid or slightly alkaline, and light or heavy; the only requirement is that they be well drained.

Old, well established '*ōhi'a lehua* with deep root systems can survive in areas receiving less than 16 inches of rain annually and can tolerate extended periods, up to four months,

with little or no water (Friday and Herbert 2006). However, regular irrigation in the nursery and landscape in California and drier areas of Hawai'i promotes best growth. It is intolerant of heavy shade (Friday and Herbert 2006), fire (Smith and Tunison 1992), constantly saturated soil (Hodges et al. 1986), and salt spray (Rauch and Hensley 1997). However, '*ōhi'a lehua* has good wind tolerance (Herbert et al. 1999) and is tolerant of volcanic fumes (Friday and Herbert 2006), indicating it might be somewhat tolerant of air pollution.

The forms of '*ōhi'a lehua* with leaves covered with silvery white, short, appressed, felt-like or woolly hairs are better suited to hot, dry, windy, and sunny situations, are more resistant to '*ōhi'a* rust (see below under Pests and Diseases), and have a faster growth rate than the forms lacking hairs on the leaves (D. Kim per. comm.).

#### Uses

'*Ōhi'a lehua* is an exceptional ornamental and has numerous features that make it a prized and splendid

Figure 20. (Left) '*Ōhi'a lehua* makes a fine small to medium tree in turf grass in parks. Ulu La'au Waimea Nature Park, Waimea, Hawai'i.

Figure 21. (Right) This '*ōhi'a lehua* is doing well in turf grass near an athletic field. Waimea, Hawai'i.





**Figure 22. (Left) 'Ōhi'a lehua can be a spectacular flowering accent. Ulu La'au Waimea Nature Park, Waimea, Hawai'i.**



**Figure 23. (Right) This red-flowered 'ōhi'a lehua is a spectacular flowering accent. Ulu La'au Waimea Nature Park, Waimea, Hawai'i.**

small to medium tree for the landscape and urban forest. Its conspicuous, showy, variably colored flowers and new leaves are especially appealing. Some appropriate uses include park tree (Figs. 20-21), shade tree, specimen, and flowering accent (Figs. 22-23). For street tree use it would do best in at least a six-foot median, parkway, or cutout (Figs. 24-25) and trees must have lower branches removed to raise the canopy for vehicular and pedestrian clearance (Figs. 26-27). Maintaining an elevated canopy also allows the handsome trunk and bark to be easily admired and appreciated.

Experience in Hawai'i shows that, while 'ōhi'a lehua can grow as fast or faster in cultivation than in the wild, cultivated trees typically are smaller than their wild forest counterparts, and usually grow 15 to 50 feet tall and 5 to 30 feet wide (Friday and Herbert 2006). Trees can live for well over 100 years in the forest but its life span in cultivation is likely shorter because of human-caused stress and injury, including root damage, soil compaction, improper irrigation, and poor general

care (Friday and Herbert 2006). Its slow growth rate, while a disadvantage for growers, is an advantage once

**Figure 24. (Left) When properly trained, 'ōhi'a lehua is suitable for medians. Waimea, Hawai'i.**

**Figure 25. (Right) Properly trained 'ōhi'a lehua make excellent small trees for parking lot medians. Waimea, Hawai'i.**



the plant is in the landscape because it would reduce maintenance pruning and generate less green waste. Its relatively small size make it a wise choice for ever-diminishing residential yards (Fig. 28)

'Ōhi'a lehua could be used in much the same manner and sites in California as its New Zealand relative, *Metrosideros excelsa* (New Zealand Christmas tree), but the dizzying array of eye-catching flower and leaf colors of the Hawaiian native make it more versatile and are a distinct advantage in the landscape. However, its intolerance of salt spray and salt-laden wind likely preclude its use in first-exposure seacoast in California.

In addition to its exceptional ornamental value, 'ōhi'a lehua can be used for a wind break, living fence, or a visual/noise barrier (Friday and Herbert 2006). Its flowers attract birds and bees, and the honey produced from them is much prized in Hawai'i. Its wood is very hard, dense, pale brown to reddish or purplish brown, and exceedingly handsome (Friday and Herbert 2006, Rock 1974). Al-







**Figure 26. (Left)** For street-tree use, 'ōhi'a lehua must have lower branches removed to raise the canopy for vehicular and pedestrian clearance. Waimea, Hawai'i.



**Figure 27. (Right)** 'Ōhi'a lehua must have lower branches removed for street-tree use to raise the canopy for vehicular and pedestrian clearance. Waimea, Hawai'i.

though difficult to work because of its hardness, its wood is much prized for furniture, cabinetry, flooring and decking, craft boxes, and decorative posts (Abbott 1992, Skolmen 1974, Little and Skolmen 1989). It finds utilitarian use as fence posts and firewood (Friday and Herbert 2006).

'Ōhi'a lehua is of major cultural significance to Hawaiian people and their culture. It is probably most famous and prized for its colorful flowers and colorful, new, juvenile leaves (called *liko* or *liko lehua*) used for personal adornment, primarily in garlands and leis (Krauss 1993, McDonald 1989, McDonald and Weissich 2003, Neal 1965, Pukui 1972). Its wood was used for carving sacred images, spears, mallets, household items, construction, and decking, gunwales, and seats in canoes (Abbott 1992, Gon and Pang 1998, Kirch 1985, Little and Skolmen 1989, Rock 1974). Because of its connection to the Hawaiian deities *Ku*, *Pele*, and *Laka*, 'ōhi'a lehua has special symbolic and spiritual significance and Hawaiian lore is re-

plete with references to it (Loope and La Rosa 2008). For example, because 'ōhi'a lehua is the symbolic plant of *Laka*, the deity of *hula*, it is central to numerous chants and dances. A common and popular myth is that the act of picking a red 'ōhi'a lehua flower will surely result in rain.

### Pruning/management

'Ōhi'a lehua has a tendency for mostly straight, upright, multi-trunked growth and retention of lower branches in the nursery and landscape. Provide adequate space in the nursery and retain lower branches to encourage maximum trunk caliper. However, for street or other use where a single trunk is desired, removal of competing lateral trunks or upright basal branches is likely necessary in nursery production or early in the landscape. To encourage a broader, more rounded canopy, structural pruning and/or heading back of the upright leader and selection of lateral scaffold branches are probably necessary.

Because of a tendency for straight, upright growth, staking is probably mostly unnecessary if trees are given adequate nursery space. Nursery trees might only need light pruning to reduce canopy density and, when nearing readiness for sale, to remove lower branches to elevate the canopy if desired. Once in the landscape only judicious thinning out to reduce canopy density, if desired, and pruning to encourage or maintain structure might be required. However, because 'ōhi'a lehua mostly lacks self-pruning capabilities and retains dead twigs and small branches (Friday and Herbert 2006), consider thinning out this dead growth for esthetic reasons.

Trees would benefit from regular irrigation in California and drier areas of Hawai'i. Mulch and judicious use of controlled-release or organic fertilizers are also beneficial in the landscape. However, 'ōhi'a lehua evolved on nutrient-poor soils and excessive fertilizer could cause weak growth that is susceptible to pests (Friday and Herbert 2006).

### Problems/litter

'Ōhi'a lehua is largely problem free. Its major limitation might be its slow growth rate, which, as mentioned earlier, has its landscape advantages. Landscape maintenance machinery, like mowers, edgers, and string trimmers, easily damage its bark.

Roots of 'ōhi'a lehua are very susceptible to disturbance, such as cutting and compaction. Even very small trees are difficult to transplant. As residential development extends into forested areas many developers and residents sometimes desire to retain and incorporate native 'ōhi'a lehua trees on the site. However, roots systems are typically disturbed and damaged during construction, especially on trees growing on new lava flows with shallow soils producing wide-spreading, shallow roots. Later, residents are surprised and dismayed when the tree inevitably declines and dies. Such unsightly trees are a hazard and in danger of falling over in high winds (Friday and Herbert 2006). If

**Table 1. Species of *Metrosideros* in Hawai'i (not including *M. polymorpha*).**

Species	Characteristics
<i>macropus</i>	small tree; bark fissured, flaky; flowers yellow-red; Ko'olau Mountains, O'ahu.
<i>rugosa</i>	shrub or rarely a small tree; bark separating in thin flakes; leaves with nerves impressed adaxially, prominently raised abaxially; flowers red; Ko'olau Mountains, O'ahu.
<i>tremuloides</i>	semi-weeping shrub to small tree; bark fissured, flaky; leaves small, elliptic; flowers red; Ko'olau and Wai'anae Mountains, O'ahu.
<i>waialealae</i>	shrub to small tree; bark fissured, flaky; flowers red; Kaua'i, Moloka'i, Lāna'i.

native, naturally occurring 'ōhi'a lehua are desired and retained at construction sites, a non-disturbed protective zone must be established, maintained, and enforced around each tree. When considering the fragile nature and susceptibility of 'ōhi'a lehua roots to disturbance and damage, a protective zone extending out from the trunk for a minimum of five feet per inch of trunk diameter seems prudent although no research-based information exists on this subject. Even larger protective zones might be necessary for trees on unusually shallow soils.

Because trees tend to produce growth, flowers, and fruits in flushes, an abundance of fallen leaves, flowers (stamens), and subsequent fruits could be problematic.

### Pests and diseases

Few pests and diseases plague 'ōhi'a lehua. The most conspicuous pest is probably a psyllid that causes galls on new leaves of young plants but otherwise does not significantly affect growth and trees seem to grow out of this pest as they age (Friday and Herbert 2006). Perhaps the most serious pest is an endemic cerambycid borer, *Plagithmysus bilineatus*, that can

become epidemic on weakened, forest trees (Adee and Conrad 1990, Mueller-Dombois 1985, Papp et al. 1979). Little is known of its occurrence on landscape trees.

Dennis Kim, native Hawaiian plant grower and aficionado, discovered a new rust disease caused by the fungus *Puccinia psidii* on potted 'ōhi'a lehua plants in his nursery on O'ahu in 2005 (D. Kim per. comm., Killgore and Heu 2007). It is a major pest of *Eucalyptus*, guava, paperbark, and other Myrtaceae in Florida and South and Central America, where it is commonly called *Eucalyptus* or guava rust. It quickly spread to all the major Hawaiian Islands, attacking 'ōhi'a lehua and other indigenous and exotic Myrtaceae. Symptoms, mostly restricted to new, young leaves, are yellow, powdery spots and deformed growth. Little is known about its management but cutting and destroying infected foliage and keeping foliage dry might be beneficial.

'Ōhi'a decline is a condition that affected large portions of wet 'ōhi'a lehua forest on the windward slopes of Mauna Kea and Mauna Loa on the Big Island in the 1960s and early 1970s (Hodges et al. 1986). It is a typi-

cal decline disease where tree decline and death result from a sequence of events starting with tree stress, in this case excessively wet, saturated soils of poor drainage. The stressed tree is then susceptible to attack from pests and disease, in this instance the endemic cerambycid borer, *Plagithmysus bilineatus*, and two disease-causing fungi, *Phytophthora cinnamomi* and *Armillaria mellea* (both fungi are present in California).

However, because soils do not abruptly become poorly drained, there are other factors that likely played a role in 'ōhi'a decline. The most likely explanation is that particular stands of 'ōhi'a lehua, because they regenerated after a specific disturbance event, are even aged and predisposed to decline due to age and cohort senescence, leaving them vulnerable to stress and attacks of pests and disease (Mueller-Dombois et al. 1980, Mueller-Dombois 1983).

Whatever the cause of 'ōhi'a decline, the importance of providing proper culture and maintaining stress-free trees in the landscape cannot be over emphasized.

### Weed/invasive species risk

'Ōhi'a lehua is potentially an invasive-species risk in suitable climates outside of Hawai'i because of its prolific, wind-blown seeds and ability to colonize and survive on harsh sites (Friday and Herbert 2006). California, especially the southern region, mostly lacks a suitable climate so the risk of 'ōhi'a lehua being invasive is probably low. There is the danger that 'ōhi'a lehua could hybridize with other species of *Metrosideros* on other Pacific Islands (Friday and Herbert 2006) although research-based information on the subject is lacking.

### Availability

'Ōhi'a lehua is readily available in nurseries in Hawai'i. Many of the offered plants were selected and vegetatively propagated for a particular growth habit or trait, especially flower or *liko* color. Unfortunately, it is little offered in California if at all.



**Figure 28.** Its relatively slow growth rate and small size make 'ōhi'a lehua a wise choice for ever-diminishing residential yards. Kāne'ohe, Honolulu, Hawai'i.

Seeds can be procured from trees in Hawai'i (see below) or from mail-order suppliers.

Several nurseries in California sell a mostly shrubby *Metrosideros*, *M. collina* 'Springfire', with the common name 'ōhi'a lehua or lehua but it is unclear if this is a Hawaiian native, one of the New Zealand or other Pacific Island species, or a hybrid of them; indeed, images on the web seem to depict a plant from New Zealand rather than one from Hawai'i. A nurseryman in New South Wales, Australia made the original selection from a plant purportedly indentified as *M. collina* but it never gained popularity until another nurseryman in Auckland, New Zealand propagated and marketed it. Because many Hawaiian *Metrosideros* once were considered *M. collina*, it was likely just assumed that this selection must have been from a plant of Hawaiian origin. However, *M. collina* is now considered indigenous to several Pacific islands but not Hawai'i.

Randy Baldwin of San Marcos Growers in Santa Barbara, Califor-

nia, which sells *Metrosideros collina* 'Springfire', stated (per. comm.) that a plant on their property is over 25 feet tall, is growing vigorously, and was unharmed in January, 2007 when temperatures dipped to 25 F on three successive nights.

Another *Metrosideros* offered in California and originating from a nursery in New Zealand is *M. kermadecensis* 'Tahiti' and, while of somewhat obscure parentage (sometimes listed as a cultivar of *M. collina*), it, too, is unlikely to be of Hawaiian parentage. However, see below under Notes about the difficulty of distinguishing among the various species of *Metrosideros*.

#### Trees in California and Hawai'i

Despite being a Hawaiian native, 'ōhi'a lehua is still not used as extensively as it should be in the Island landscape. The best place to see 'ōhi'a lehua in the landscape in Hawai'i is in Waimea (Kamuela) on the Big Island, where it is used extensively as a street, park, and home landscape tree. Indeed, it is the unofficial tree of the city.

Also in Waimea, Ulu La'au Waimea Nature Park is home to an extensive collection of 'ōhi'a lehua. Nearly all the flower and liko color forms can be found in Waimea.

Several stretches of the Hawai'i Belt road along the Hāmākua coast from Waimea to Hilo have plantings of 'ōhi'a lehua as a windbreak (Friday and Herbert 2006). Botanical gardens, such as Ho'omaluhia Botanical Garden, Lyon Arboretum, and Waimea Valley Historical Nature Park, all on O'ahu, and the National Tropical Botanical Garden on Kaua'i, have good collections of 'ōhi'a lehua.

Several places in Hawai'i Volcanoes National Park on the Big Island, for instance Kīpuka Puauulu, have good examples of old, large 'ōhi'a lehua trees in habitat. Also on the Big Island, the intrepid explorer will encounter impressive specimens in some of the old, rich South Kona forests in places like Honomalino, Waikākū'u, and Manukā.

Unfortunately, typical 'ōhi'a lehua is little known in California. The San Francisco Botanical Garden at Strybing Arboretum in Golden Gate Park might have had the most extensive collection. Several specimens lived for up to 10 years there, grew strongly to five feet tall or more, flowered profusely, survived the January 1990 freeze with some or no damage when temperatures dipped to 26 F, but then died, likely from becoming too dry on the extremely porous, sandy soils (D. Mahoney, per. comm., J. Dewees per. comm.). However, some smaller plants, mostly in containers, are still alive and seem to do well in the foggy conditions that envelope Golden Gate Park from late May to late August (D. Mahoney per. comm.). See also above under Availability for an account of a plant grown in California that might be of Hawaiian origin.

#### Notes

*Metrosideros* includes about 50 species of shrubs and trees from the Philippines to New Guinea, New Caledonia, Fiji, and Polynesia with an outlier in South Africa. *Callistemon*

and *Melaleuca* are similar but differ in their flowers in cylindrical spikes. One species from New Zealand, *M. excelsa*, is a valuable, somewhat common landscape tree in coastal southern and central California but is an uncommon, slow-growing shrub in Hawai'i. Another species from New Zealand, *M. kermadecensis*, has become a pest on Maui (Friday and Herbert 2006).

Reliable, distinguishing characters among *Metrosideros polymorpha*, *M. excelsa*, *M. collina*, *M. keremedecensis*, and the various other Pacific Island species are weak and poorly documented. Indeed, many botanists feel that only one, extremely variable species of *Metrosideros* might exist among the Pacific Islands and it might be best to refer to it as a species complex.

Five species of *Metrosideros* have been recorded for Hawai'i (Table 1, page 53), including *M. polymorpha*, which has eight recognized varieties (Table 2, page 49) although these need further study (Dawson and Stemmerman 1990).

'*Ōhi'a lehua* is famous for its dazzling array of flower colors and leaf shapes and arrangements, each with a Hawaiian name (Dawson and Stemmerman 1990, M. McDonald per. comm.) (Table 3, page 46). Flowering tends to follow spring flushes of growth, up to three times a year (Weissich 1995), but also can be sporadic throughout the year. Sometimes one branch or part of a tree will be floriferous while the remaining part has few or no flowers. One tree in Hilo has two flower colors, each on a separate branch or trunk. Pure, white-flowered '*Ōhi'a lehua* has legendary status and is Hawaii's Bigfoot or Sasquatch: although many have claimed to have seen it, none can produce it.

The tremendous phenotypic variation in '*Ōhi'a lehua*, especially in habit and leaf size, shape, color, and indumenta, is environmentally driven and allows the species to colonize a wide range of often extreme or harsh habitats (Aradhya et al. 1991, St. John 1979, Stemmerman 1983). It is considered an example of incipient speciation where one ancestral species evolves

into many species and varieties in an isolated island environment (Friday and Herbert 2006).

### Acknowledgements

James E. Henrich, botanist at the Los Angeles County Arboretum and Botanic Garden in Arcadia; Matt Ritter, author and botany professor at California Polytechnic State University at San Luis Obispo; Ken Greby, an unusually knowledgeable arborist; and Dennis Kim, a native Hawaiian plant grower and landscape architect, critically reviewed the manuscript and offered valuable suggestions. Don Mahoney of San Francisco Botanical Garden at Strybing Arboretum, Jason Dewees of Forest Grubb Gardens nursery, and TAC members James DeVinny and Barrie Coate provided information about '*Ōhi'a lehua* in California. Patricia and Richard Missler of South Kona brought to my attention and showed me some magnificent '*Ōhi'a lehua* in their area.

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### Literature cited

- Abbott, I. A. 1992. *Lā'au Hawai'i: Traditional Hawaiian Uses of Plants*. Bishop Museum Press, Honolulu, HI.
- Adee, K. and C. E. Conrad. 1990. *Metrosideros polymorpha* Gaud., pp. 916-923 in: R. M. Burns and B. H. Honkala (eds.) *Silvics of North America. Agricultural Handbook 654*, USDA Forest Service, Washington, D. C. Online: [http://www.na.fs.fed.us/spfo/pubs/silvics\\_manual/volume\\_2/metrosideros/polymorpha.htm](http://www.na.fs.fed.us/spfo/pubs/silvics_manual/volume_2/metrosideros/polymorpha.htm).
- Allen, J. A. 2002. *Metrosideros polymorpha* Gaudich., pp. 569-571 in: J. A. Vozzo (ed.), *Tropical Tree Seed Manual. Agricultural Handbook 721*. USDA, Washington, D. C.
- Aradhya, K. M., DE. Mueller-Dombois, and T. A. Ranker. 1991. Genetic evidence for recent and incipient speciation in the evolution of Hawaiian *Metrosideros* (Myrtaceae). *Heredity* 67: 129-138.
- Bornhorst, H. L. 2005. *Growing Native Hawaiian Plants. A How-To Guide for Gardeners* (rev. ed.). Bess Press, Honolulu, HI.
- Bornhorst, H. L. and F. D. Rauch. 1994. *Native Hawaiian Plants for Landscaping, Conservation, and Reforestation*. HITAHR Res. Ext. Ser. 142, University of Hawai'i, Honolulu, HI.
- Bornhorst, H. L. and F. D. Rauch. 2003. *Native Hawaiian Plants for Landscaping, Conservation, and Reforestation. Ornamentals and Flowers Series No. 30*. CTAHR, University of Hawai'i, Honolulu, HI.
- Brenzel, K. N. 1995. *Sunset Western Garden Book*. Sunset Publishing Corp., Menlo Park, CA.
- Burton, P. J., 1980. Light regimes and *Metrosideros* regeneration in a Hawaiian montane rain forest, M.S. Thesis. University of Hawai'i, Honolulu, HI.

## Literature cited

- Burton, P. J. 1982. The effect of temperature and light on *Metrosideros polymorpha* seed germination. *Pac. Sci.* 36: 229-240.
- Carpenter, F. L. 1976. Plant-pollinator interactions in Hawai'i: Pollination energetics of *Metrosideros collina* (Myrtaceae). *Ecology* 57: 1125-1144.
- Conrad, C. E., P. G. Scowcroft, R. C. Wass, and D. S. Goo. 1988. Reforestation research in Hakalau Forest National Wildlife Refuge. *Trans. West. Sec. Wildlife Soc.* 24: 80-86.
- Cordell, S. C., G. Goldstein, P. J. Melcher, and F. C. Meinzer. 2000. Photosynthesis and freezing avoidance in 'ōhi'a (*Metrosideros polymorpha*) at treeline in Hawai'i. *Arctic Antarctic Alpine Res.* 32: 381-387. Online: <http://www.eeb.uconn.edu/courses/EEB302/EverythingInHereAsOfJan2006/Cordell%20et%20al.%201998.pdf>.
- Corn, C. A. 1979. Variation in Hawaiian *Metrosideros*. Ph.D. Dissertation. University of Hawai'i, Honolulu, HI.
- Crews, T. E., K. Kitayama, J. H. Fownes, R. H. Riley, D. A. Herbert, D. Mueller-Dombois, and P. M. Vitousek. 1995. Changes in soil phosphorus fractions and ecosystem dynamics across a long chronosequence in Hawai'i. *Ecology* 76: 1407-1424.
- Criley, R. A. 1998. Propagation of indigenous and endemic ornamental Hawaiian plants. *Comb. Proc. Int. Plant Prop. Soc.* 48: 669-674.
- Dawson, J. W. and L. Stemmerman. 1999. *Metrosideros* Banks ex Gaertn., pp. 964-970 in: W. L. Wagner, D. R. Herbst, and S. H. Sohmer. 1990. *Manual of the Flowering Plants of Hawai'i*. Bish. Mus. Spec. Pub. 83. University of Hawai'i Press and Bishop Museum Press, Honolulu, HI.
- Drake, D. R. 1993. Germination requirements of *Metrosideros polymorpha*, the dominant tree of Hawai'i lava flows and rain forests. *Biotrop.* 25: 461-467.
- Friday, J. B. and D. A. Herbert. 2006. *Metrosideros polymorpha* ('ōhi'a lehua). *Species Profiles for Pacific Island Agroforestry*, pp. 465-490 in: C. R. Elevitch (ed.), *Traditional Trees of Pacific Islands: Their Culture, Environment, and Use*. Permanent Agriculture Resources, Hōlualoa, HI. Online: <http://www.agroforestry.net/tti/Metrosideros-ohia.pdf>.
- Gerrish, G. and D. Mueller-Dombois. 1999. Measuring stem growth rates for determining age and cohort analysis of a tropical evergreen tree. *Pac. Sci.* 53: 418-429.
- Gon, S., III and B. K. Pang. 1998. The Forest Travels on the Wind. Moanalua Gardens Foundation Hawaiian Culture internet archive. Online: <http://www.pixi.com/~mgf/archive.html>.
- Herbert, D. A. and J. H. Fownes. 1995. Phosphorus limitation of forest leaf area and net primary productivity on a highly weathered soil. *Biogeochemistry* 29: 223-235.
- Herbert, D. A. and J. H. Fownes. 1999. Forest productivity and efficiency of resource use across a chronosequence of tropical montane soils. *Ecosystems* 2: 242-254.
- Herbert, D. A., J. H. Fownes, and P. M. Vitousek. 1999. Hurricane damage to a Hawaiian forest: nutrient supply rate affects resistance and resilience. *Ecology* 80: 908-920.
- Hodges, C. S., K. T. Adee, J. D. Stein, H. B. Wood, and R. B. Doty. 1986. Decline of 'Ōhi'a (*Metrosideros polymorpha*) in Hawai'i: A Review. Gen. Tech. Rep. PSW-86. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA. Online: [http://www.fs.fed.us/psw/publications/documents/psw\\_gtr086/psw\\_gtr086.pdf](http://www.fs.fed.us/psw/publications/documents/psw_gtr086/psw_gtr086.pdf).
- Kilgore, E. M. and R. A. Heu. 2007. 'Ōhi'a Rust. *Puccinia psidii* Winter. New Pest Advisory No. 05-04 (updated December 2007). State of Hawai'i Department of Agriculture, Honolulu, HI.
- Kirch, P. V. 1985. *Feathered Gods and Fishhooks*. University of Hawai'i Press, Honolulu, HI.
- Krauss, B. H. 1993. *Plants in Hawaiian Culture*. University of Hawai'i Press, Honolulu, HI.
- Lamb, S. H. 1981. *Native Trees and Shrubs of the Hawaiian Islands*. Sunstone Press, Santa Fe, NM.
- Little, E. L., Jr. and R. G. Skolmen. 1989. *Common Forest Trees of Hawai'i (Native and Introduced)*. Agric. Handbook 679. USDA Forest Service, Washington, D. C.
- Loope, L. and A. M. La Rosa. 2008. An Analysis of the Risk of Introduction of Additional Strains of the Rust *Puccinia psidii* Winter ('Ōhi'a Rust) to Hawai'i. U.S. Geological Survey Open File Report 2008-1008, Reston, VA.
- McDonald, M. A. 1989. *Ka Lei: the Leis of Hawai'i*. Ku Pa'a Publishing and Press Pacifica, Honolulu, HI.
- McDonald, M. A. and P. R. Weissich. 2003. *Nā Lei Makamae. The Treasured Lei*. University of Hawai'i Press, Honolulu, HI.
- Moomaw, J. C., M. T. Nakamura, and G. D. Sherman. 1959. Aluminum in some Hawaiian soils. *Pac. Sci.* 13: 335-341.

**Literature cited**

- Mueller-Dombois, D. 1983. Canopy dieback and successional processes in Pacific forests. *Pac. Sci.* 37: 317-325.
- Mueller-Dombois, D. 1985. 'Ōhi'a dieback in Hawai'i: 1984 synthesis and evaluation. *Pac. Sci.* 39: 150-170.
- Mueller-Dombois, D. 1987. Forest dynamics in Hawai'i. *Trends Evol. Ecol.* 2: 216-220.
- Mueller-Dombois, D. 1994. Vegetation dynamics and evolution of *Metrosideros polymorpha* in Hawai'i. *Phytocoenologia* 24: 609-614.
- Mueller-Dombois, D. and F. R. Fosberg. 1998. *Vegetation of the Tropical Pacific Islands*. Springer-Verlag, New York, NY.
- Mueller-Dombois, D. J. D. Jacobi, R. G. Cooray, and N. Balakrishnan. 1980. *Ohia Rainforest Study: Ecological Investigations of the 'Ōhi'a Dieback Problem in Hawai'i*. Misc. Pub. 183. CTAHR, University of Hawai'i, Honolulu, HI.
- Neal, M. C. 1965. In *Gardens of Hawai'i*. Bish. Mus. Spec. Pub. 50. Bishop Museum Press, Honolulu, HI.
- NTBG. 1993. *Metrosideros polymorpha*. Native Hawaiian Plant Information Sheets. Hawai'i Plant Conservation Center, National Tropical Botanical Garden, Lawai, HI.
- Papp, R. P., J. T. Kleijunas, R. S. Smith, Jr., and R. F. Scharpf. 1979. Associations of *Plagithmysus bilineatus* (Coleoptera: Cerambycidae) and *Phytophthora cinnamomi* with decline of 'ōhi'a forests in the Island of Hawai'i. *Forest Ser.* 25:187-196.
- Porter, J. R. 1973. The growth and phenology of *Metrosideros* in Hawai'i. USIBP Island Ecosystems IRP Technical Report 27. Honolulu, HI.
- Pukui, M. K. 1972. Aspects of the word lei, pp. 103-115 in: A. L. Kaeppler and H. A. Nimmo (eds.), *Directions in Pacific Traditional Literature, Essays in honor of Katherine Luomala*. Bish. Mus. Spec. Pub. 62. Bishop Museum Press, Honolulu, HI.
- Raich, J. W., A. E. Russell, and P. M. Vitousek. 1997. Primary productivity and ecosystem development along an elevational gradient on Mauna Loa, Hawai'i. *Ecology* 78: 707-721.
- Rauch, F. D. and D. Hensley. 1997. 'Ōhi'a lehua. *Ornamentals and Flowers Series No. 11*. CTAHR, University of Hawai'i, Honolulu. Online: <http://www.ctahr.hawaii.edu/oc/freepubs/pdf/OF-11.pdf>.
- Rauch, F. D., K. Niino, and J. McEwen. 1997. Vegetative Propagation of Yellow 'Ōhi'a Lehua. Hort. Res. Note HRN-3. CTAHR, University of Hawai'i, Honolulu, HI. Online: <http://www.ctahr.hawaii.edu/oc/freepubs/pdf/HRN-3.pdf>.
- Rock, J. F. 1974. *The Indigenous Trees of the Hawaiian Islands*. Charles E. Tuttle, Co., Inc., Rutland, VT, U. S. A. and Tokyo, Japan. (Reprinted, originally published privately in 1913).
- Scowcroft, P. G., F. C. Meinzer, G. Goldstein, P. J. Melcher, and J. Jeffrey. 2000. Moderating night radiative cooling reduces frost damage to *Metrosideros polymorpha* seedlings used for reforestation in Hawai'i. *Restor. Ecol.* 8: 1161-169.
- Skolmen, R. G., 1974. *Some Woods of Hawai'i: Properties and Uses of 16 Commercial Species*. Tech. Rep. PSW 8/1974. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.
- Smith, C. W. and J. T. Tunison. 1992. Fire and alien plants in Hawai'i: Research and management implications for native ecosystems, pp. 394-408 in: C. P. Stone, C. W. Smith, and J. T. Tunison (eds.), *Alien Plant Invasions in Native Ecosystems of Hawai'i*. University of Hawai'i, Cooperative National Park Resources studies Unit, Honolulu, HI.
- Staples, G. W. and D. R. Herbst. 2005. *A Tropical Garden Flora. Plants Cultivated in the Hawaiian Islands and Other Tropical Places*. Bishop Museum Press, Honolulu, HI.
- St. John, H. 1979. *Metrosideros polymorpha* (Myrtaceae) and its variations. *Hawaiian Plant Studies* 88. *Phytologia* 42: 215-218.
- Stemmerman, L. 1983. *Ecological Varieties of 'Ōhi'a Varieties (Metrosideros polymorpha Myrtaceae), the Dominants in Successional Communities of Hawaiian Rainforest*. Ph.D. Dissertation. University of Hawai'i, Honolulu.
- Stemmerman, L. and T. Ihsle. 1993. Replacement of *Metrosideros polymorpha*, 'ōhi'a, in Hawaiian dry forest succession. *Biotrop.* 25: 36-45.
- Tanabe, M. J. and B. Frazier. 1984. The influence of auxin on the airlayering of 'ōhi'a lehua in: F. D. Rauch, W. W. McCall, and K. W. Leonhardt (eds.), *Second Fertilizer and Ornamentals Short Course*. CTAHR, University of Hawai'i, Honolulu, HI.
- UH CTAHR. 2012. *Hawaiian Native Plant Propagation Database. Metrosideros polymorpha*. Online: <http://www2.hawaii.edu/~eherring/hawnprop/met-poly.htm>. Accessed July 1, 2012.
- Vitousek, P. M. and H. Farrington. 1997. Nutrient limitation and soil development: experimental tests of a biogeochemical theory. *Biochem.* 37: 63-75.
- Weissich, P. R. 1995. Hawaiian native plants in the landscape. *Comb. Proc. Int. Plant. Prop. Soc.* 44: 332-335.