Acacia Koa A. Gray **Koa**

Leguminosae Legume family

Craig D. Whitesell

From the time of the early Hawaiians, koa ***(Acacia koa)*** has been prized for its exceptionally fine wood and is currently considered the most valuable of the common native timber species in Hawaii *(29,60)*. Koa frequently has curly grain and striking coloration and has excellent working properties *(11,37,75)*. It grows in nearly pure stands or in admixtures with ohia ***(Metrosideros polymorpha)***. Other tree species are sparse in these forests. A large evergreen hardwood tree endemic to the State, koa belongs to the thornless, phyllodinous group of the ***Acacia*** subgenus Heterophyllum.

Koa forests were more extensive in the past than they are today. Land clearing, poor cutting practices, and destruction by animals, insects *(49)*, and fire *(26,36,67,96)* have all taken a toll. The volume of koa sawtimber totaled about 187 million board feet in 1970. At that time the commercial koa forest land in the State totaled about 7500 ha (18,600 acres), and commercial ohia-koa forests about 17 500 ha (43,200 acres). The estimated growing-stock volume of commercial koa exceeded 0.7 million m^3 (25 million ft^3) in 1978 *(50)*.

Koa is an important component of montane Hawaiian rain forests. It is a nitrogen-fixing species. In dense, pole-size stands, nitrogen-rich koa foliage can account for 50 to 75 percent of the leaf-litter biomass produced annually (68). On the floor of cool mesic forests, koa phyllodes decompose rapidly; mean residence time has been estimated at 0.6 year *(68)*. The abundance and distribution of the akiapolaau, akepa, and Hawaiian creeper, three of the endangered forest birds on the island of Hawaii, are strongly associated with koa in forest communities (66). Mature koa is needed for bird habitat: endangered birds do not use young, pure stands of koa, but do use the old, mixed-species stands adjacent to young stands (65).

Habitat

Native Range

The range of koa (fig. 1) extends from longitude 154" to 160" W.; its latitude ranges from 19" to 22" N. It is found on all six of the major islands of the Hawaiian chain: Kauai, Oahu, Molokai, Maui, Lanai, and Hawaii.

The author is Principal Research Silviculturist, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

Climate

Hawaii is tropical in latitude, with mild and equable temperatures at low elevations (table 1). Day length is nearly uniform year-round, varying by 2 hours. The northeasterly trade winds dominate; however, "Kona" storms from the south or west during winter, and occasional tropical storms throughout the year, bring high winds and heavy rains to the islands. Hawaii's mountains, especially massive Mauna Loa and Mauna Kea on Hawaii, and Haleakala on Maui, have a strong influence on the weather and provide climates ranging from the tropic to the subarctic *(7)*.

Table l-Mean temperature at five stations on the east flank of Mauna Kea, island of Hawaii[1]

Station	Elevation	Mean temperature	
		January	August
	m	*°C*	*°C*
Olaa (6)	85	21	24
Waiakea Forest	550	18	21
Waiakea Forest	915	17	19
Waiakea Forest	1220	13	16
Kulani Camp (6)	1580	4	14
	ft	*°F*	*°F*
Olaa	280	70	75
Waiakea Forest	1,800	64	69
Waiakea Forest	3,000	62	67
Waiakea Forest	4,000	55	61
Kulani Camp	5,190	39	58

[1]Data on file at the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Honolulu, HI.

Rainfall varies greatly within short distances. Monthly amounts recorded over a period of years at weather stations in the koa belts show a phenomenal range. A Forest Service station at 1200 m (4,000 ft) elevation recorded a mean annual rainfall of 4300 mm (170 in) for a 14-year period, with extremes of 3450 to 5500 mm (136 to 216 in). During the driest month, only 19 mm (0.74 in) was recorded; the wettest month was 1380 mm (54.4 in).

Koa grows best in the high rainfall areas, those receiving 1900 to 5100 mm (75 to 200 in) annually. It also grows in areas that receive much less than this amount, but growth is slower and tree form is generally poorer. Cloud cover and fog commonly shroud the middle forest zone (600 to 1800 m or

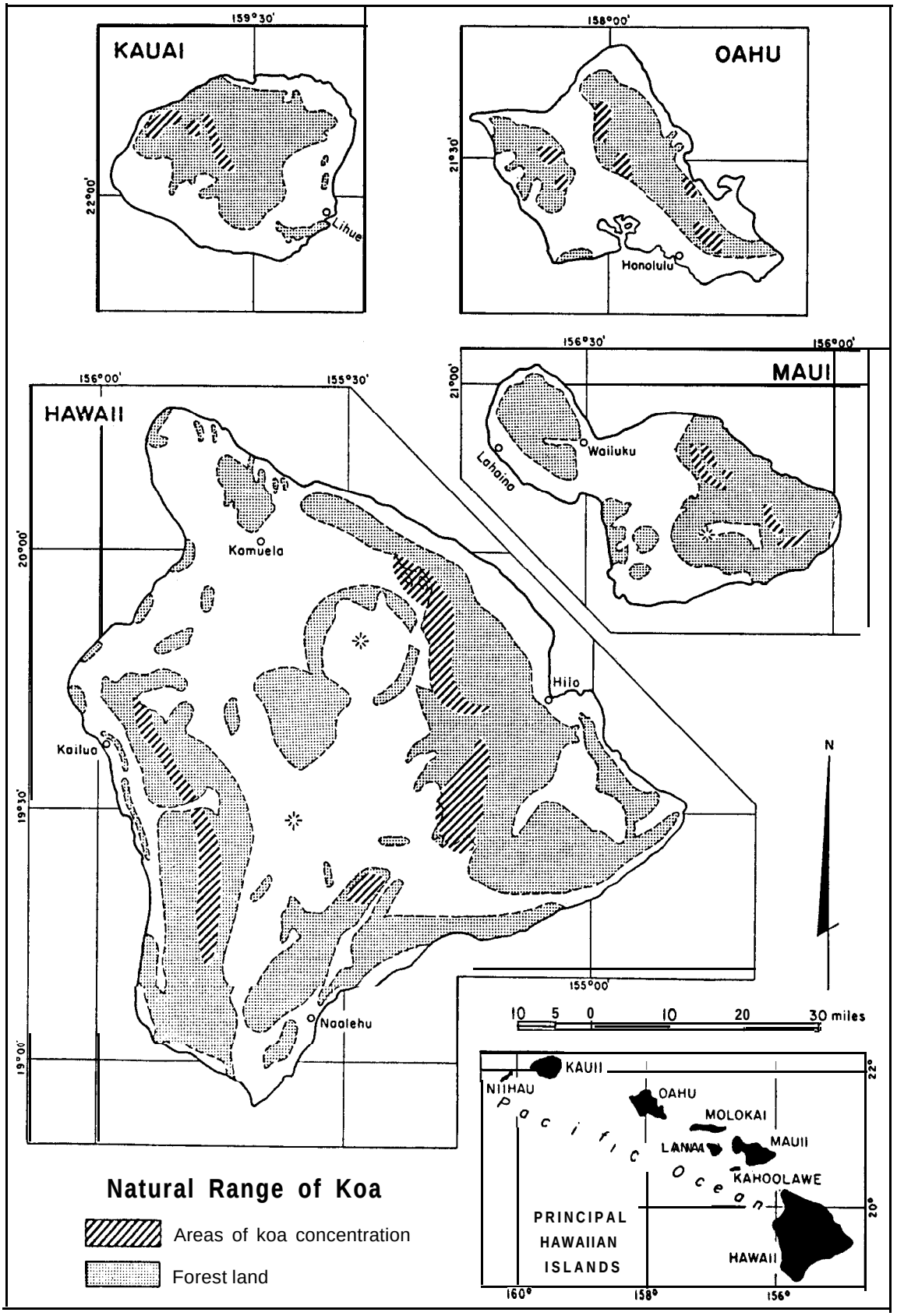

Figure *1-The native range of koa.*

2,000 to 6,000 ft) where commercial koa stands are concentrated. Frost is not uncommon during winter months above 1200 m (4,000 ft) elevation. Temperature ranges within the koa belt are small, as may be seen from data for Mauna Kea, island of Hawaii (table 1).

Soils and Topography

Koa is found on volcanic soils of all geologic ages and degrees of development, from the young ash and "aa" lava rock soils on the island of Hawaii to the oldest soils on Oahu and Kauai. The tree grows best on moderately well drained and well drained, medium to very strongly acid soils. These recent soils are higher in plant nutrients, having been subjected to less leaching and erosion than have the soils on the older islands.

Most koa forests grow on two of the great groups in the soil order Inceptisol: Hydrandepts and Dystrandepts. Hydrandepts are found in areas of high rainfall. They are high in amorphous materials and have high cation exchange capacities, but extremely low base saturations due to the high rainfall. Although deficient in available phosphorus, sodium, potassium, calcium, and silica, they have a high content of organic matter and hydrous oxides of iron and aluminum, manganese, and titanium. Infiltration rates are rapid and erosion is slight to moderate, depending upon the degree of slope. Dystrandepts are formed under lower rainfall than the Hydrandepts. They have slightly greater base saturations than the Hydrandepts.

The next most abundant soil great group on which koa grows is the well drained Tropofolists (organic soils of the order Histosols). Other minor soils include Haplohumults and Kandihumults of the order Ultisols and Hapludox and Acrudox of the order Oxisols.

Koa grows at elevations ranging from 90 m (300 ft) on Oahu (45) to 2100 m (7,000 ft) on Hawaii *(37),* on flatlands and slopes. Koa has been listed as a component of the forests occupying gulch and ravine walls sloping 40 to 80" (49). The flora of Hawaii have been divided into groups occupying different zones of elevation (29):

The lowland zone, at or near sea level; open country, with isolated trees or clumps of trees. Koa rarely grows here.

The lower forest zone, upper limit 300 to 600 m (1,000 to 2,000 ft); tropical in character, woods rather open. Koa grows in scattered stands, in admixture with ohia.

The middle forest zone, upper limit 1500 to 1800 m (5,000 to 6,000 ft); within the region of clouds, where vegetation develops the greatest luxuriance. Here koa reaches its greatest development in size and number (fig. 2).

The upper forest zone, upper limit as high as 2400 to 2700 m (8,000 to 9,000 ft). Koa reaches into this zone, but seldom above 2100 m (7,000 ft).

Associated Forest Cover

Botanists and foresters have listed more than 80 trees, shrubs, vines, herbs, ferns, club mosses, grasses, and sedges associated with koa. Trees associated with koa *(20,33,48)* include:

'ahakea (*Bobea* spp.)
'ala'a *(Pouteria sandwicensis)*
kalia *(Elaeocarpus bifidus)*
kauila *(Alphitonia ponderosa)*
kawa'u *(Ilex anomala)*
kolea *(Myrsine lessertiana)*
kopiko *(Psychotria* spp.)
loulu palm *(Pritchardia* spp.)
mamani *(Sophora chrysophylla)*
naio *(Myoporum sandwicense)*
'ohe'ohe *(Tetraplasandra hawaiiensis)*
'ohi'a *(Metrosideros polymorpha)*
'olapa *(Cheirodendron trigynum)*
olomea *(Perrottetia sandwicensis)*
olopua *(Osmanthus sandwicensis)*
pi10 *(Coprosma* spp.)
sandalwood *(Santalum* spp.)

Life History

Koa is a phyllodial species that undergoes a change from true leaves (consisting of 12 to 15 paired, bipinnate leaflets) to sickle-shaped phyllodes (dilated petioles). In most cases where light is sufficient, the change occurs while plants are smaller than saplings, i.e. < 2 m (6 ft) tall. Investigations suggest that true leaves promote more rapid early growth when moisture is adequate, whereas, during periods of drought, phyllodes are better adapted (27). Phyllodes persist under moisture stress, transpiring about 20 percent as much as true leaves, and their stomata close four times faster after dark (97). Old trees usually bear only laurel green phyllodes, but sometimes true leaves appear on the trunk or lower branches, or after wounding.

Reproduction and Early Growth

Flowering and Fruiting-The flowers of koa are borne over the outer part of the crown. Seedlings have been observed in flower and fruit *(3,80)* at 2 and 3 years of age. One of the pollinating insects found

on koa flowers is the honeybee *(Apis mellifera)*. The extent to which other insects, birds, and wind affect pollination is not well documented. Koa initiates flower development nearly year-round at the high elevation on Mauna Loa, reaching a peak during the wet season in late winter (46). On adjacent Mauna Kea, koa flowers appear from December through February, with few flowers at any other time. At lower elevations, on all of the islands, flowering usually occurs from late winter to early summer (July). Weather conditions, especially severe droughts, influence the timing and extent of flowering at any time of the year.

The inflorescence of koa is an axillary raceme of pale yellow heads averaging 8.5 mm (0.3 in) in diameter *(29)*, one to three on a common peduncle, and composed of many hermaphroditic (bisexual) flowers. Each flower has an indefinite number of free stamens and a single elongated style. The heads are highly dichogamous, with anthers dehiscing 3 to 8 days before the stigmas are fully exserted *(8)*.

Figure *2-A superior koa tree chosen for seed collection, island of Hawaii.*

The fruit is a legume, slow to dehisce, about 15 cm (6 in) long and 2.5 to 4 cm (1 to 1.5 in) wide. The pods contain about 12 seeds that vary from dark brown to black. They mature at different times throughout the year, depending on location and weather conditions.

Seed Production and Dissemination-No records of the frequency of exceptionally good or poor seed years are available, but seed years do vary.

Koa seed pods dehisce while on the tree or fall to the ground unopened, where they either dehisce or disintegrate. "The horny seed often remains on the tree for a year after it ripens, and when lying on the ground is known to have retained for a period for 25 years its ability to germinate" *(37)*. Koa seeds are seldom dispersed far beyond the crown, but, occasionally, wind may carry unopened pods some distance. Seeds from koa growing in gulches may be carried downstream to lower elevations, especially during torrential rains.

Koa seeds, like those of other acacias, are among the most durable of tree seeds and need not be kept in sealed containers. They will germinate after many years of storage if kept in a cool, dry place. The seeds have hard coats that retard germination unless they are first mechanically scarified, briefly treated with sulfuric acid, or soaked in hot water. The water treatment is the most practical. The seeds are placed in nearly boiling water, after the heat source is removed, and allowed to soak for 24 hours. Seeds that fail to swell the first time may again be subjected to this pregermination treatment, often with success (99). In seven samples, the number of clean seeds ranged from a low of 5,300/kg to a high of 16,300/kg (2,400 to 7,400/lb).

Seedling Development-The mode of germination is epigeal *(99)*. Light is not a requirement for germination (83). Under favorable conditions-bare mineral soil, adequate moisture, and exposure to sunlight-koa seedlings will grow readily. Soil aeration and soil temperature may influence germination *(83)*.

Until recent years, the standard nursery practice was to sow koa seeds in wooden flats, then transplant the seedlings to tin cans *(35)*. Now, plastic bags or tubes are used. Tube-grown seedlings are easier to plant.

Properly pretreated koa seeds should be covered with 6 to 12 mm (0.25 to 0.5 in) of soil; they begin to germinate within a week. Seedlings in bags or

tubes can be grown to plantable size of 20 cm (8 in) high in 10 to 14 weeks.

Direct seeding of koa on prepared seed spots has been moderately successful *(9,13)*. In two trials comparing broadcast sowing with direct sowing into prepared spots, stocking was four times higher on the direct seeded spots on Maui, whereas no difference in the percentage of stocked spots or of height growth was evident on the island of Hawaii.

Koa has been recommended for watershed planting on well drained areas *(34,37,39)* and is described as "the one native tree which can be easily handled in nursery and planting operations...suitable for the larger portion of areas in need of reforestation and particularly for the drier ridges and slopes" (35).

Other investigators, less enthusiastic about planting koa, did not recommend it *(13,17)*, commenting as follows: "Results on older soil formations have been uniformly disappointing. Frequently, the trees die out after 15 to 20 years" *(17)*. Plantations established on Maui during the late 1930's developed scattered, large trees of exceptionally poor form. Relatively few koa seedlings were planted after World War II. However, in the past 10 years, private land owners on the island of Hawaii, influenced by the short supply, began planting koa *(104)*.

Seedlings usually appear soon after land is cleared for pasture or roads, or after fires. As many as 354,700 koa seedlings per hectare (143,537/acre) were counted in the vicinity of old koa trees in burned-over areas *(41)*. Seeds escaping the flames may be induced to germinate by the heat.

Koa seedlings grow rapidly. One month after a burn, koa seedlings were at least 2.5 cm (1 in) tall; after 3 months they ranged from 10 to 28 cm (4 to 11 in) tall, averaging about 13 cm (5 in) *(41)*. On a cleared area at 500 m (1,700 ft) elevation, l-year-old seedlings ranged from 0.6 to 4 m (2 to 13 ft) tall and averaged 2 m (6 ft). On favorable sites, seedlings attain 9 m (30 ft) in 5 years (37). Eight months after a fire on Kauai, koa regeneration was most common near fire-killed parent trees, and maximum height growth was 4.6 m (15 ft) *(103)*. The abundance, distribution, growth, and mortality of koa on burned-over areas on Oahu were monitored over a 2.5-year period (73). During this time, seedling density declined dramatically. The root-crown fungus *Calonectria crotalariae* caused more than half of this mortality. On these sites the seedlings grew about 2.3 cm (1 in) per month. Koa did poorly when planted on abandoned sugarcane land on the windward coast of the island of Hawaii. Survival at age 6 years was 78 percent, but trees averaged only 3 m (10 ft) tall, and only 62 percent were judged vigorous. Tree form varied from good to poor, with 77 percent cull *(101)*.

The abundance and distribution of natural regeneration after logging were studied on a 200-ha (500-acre) tract heavily infested with pigs and vines on the island of Hawaii *(70)*. Seedling density of koa was about three times as great in disturbed as in undisturbed areas. Most koa seedlings found on the ground disturbed by logging were well established, but none of those growing on undisturbed ground were large enough to have much chance of surviving the menacing pigs and cattle. Koa seedlings in disturbed areas tend to be clustered around seed trees *(70)*. In 1922, Krabel stated: "Where cattle have been excluded for a number of years, koa groves are developing with surprising speed on exposed and barren ridges" (43).

The stimulating effect of soil scarification on seedling emergence is helpful in regenerating koa on degraded forest land where seed reserves still exist in the soil. Disking in the sparsely wooded pastures of the Hakalau Forest National Wildlife Refuge resulted in koa reproduction. Even in open areas far removed from live or skeletal remains of koa, a few seedlings emerged *(15)*.

In the natural rain forest, koa seedlings can emerge from mineral soil and organic seedbeds, such as decaying logs and treefern trunks. Seedling growth is generally slower on old logs than on mineral soil, possibly due to low nutrient availability. However, seedlings tend to survive better on organic seedbeds because these sites are elevated and out of reach of feral pigs. In the Kilauea Forest, more than 60 percent of the mature koa initially emerged from logs or other large organic seedbeds *(16)*. Nevertheless, rarely do koa seedlings survive in the dense rain forest unless openings have been created, as by windthrow. Gap-phase replacement seems to be the primary mechanism by which koa is maintained in natural rain forest communities (53). Serious disturbances, such as fire or hurricane-induced windthrow, typically stimulate large-scale koa reproduction.

Vegetative Reproduction-An intensive study of koa reproduction was made in 1943 (5) in an area of the Volcanoes National Park on the island of Hawaii, where annual rainfall is about 1000 mm (40 in). Koa stands appeared to regenerate almost entirely by means of root suckers on this once heavily grazed site. The researchers reported that "many vigorous suckers arise from the buried and exposed roots of a single tree. In three cases, suckers were seen 15, 27, and 29 m (50, 90, and 95 ft) away from the base of isolated koa trees. Suckers developed into healthy trees 8 to 16 cm (3 to 6 in) in diameter breast height in 5 to 6 years and were estimated to be 4 m (12 ft) tall." Koa colonies (root sprouts originating from the

mother tree) in the park expanded at the rate of 0.5 to 2.5 m (1.5 to 8 ft) per year *(51)*. In 1973, a study to determine the influence of feral goats on growth of these root suckers found that the suckers became more numerous and vigorous once the goats were excluded (84). Suckering, however, did not occur where the soil was covered with tall dense grass (83).

Koa can be propagated by rooting of cuttings under mist and shade when the material is in the immature, true-leaf stage of growth. Air layers of root suckers gave 16 percent rooting success, but rooting of root sucker cuttings under mist was highly variable, generally with a 20 percent success rate (76). Koa can be also propagated by callus cultures derived from shoot tips, but the method is slow and labor-intensive and not presently adaptable to large scale propagation (79). However, one clone, comprised of hundreds of ramets, has been produced by tissue culture of seedling shoot-tip callus *(81)*. These tissue-cultured trees have been successfully outplanted in progeny tests (82).

Koa root sprouts are common in rain forests as well as in savanna stands. Efforts to induce suckering of roots of selected plus trees, in situ, on both wet and dry areas failed, however. Attempts to simulate the actions of pigs and cattle with treatments including knife wounding, "chewing" with pliers, pounding, and exposure had no effect. Koa root suckers in rain forests are much more common on roots in deep shade or hidden under dense grass than in roots exposed to direct sunlight (76). Stump sprouts have rarely been observed but do occur.

Sapling and Pole Stages to Maturity

Growth and Yield-Age of koa trees cannot be determined. Growth rings were not correlated with "annual rings" *(102)*. Old relic forests still in existence were probably present at the time Captain James Cook discovered the Hawaiian Islands in 1778. The largest koa tree on record had a d.b.h. of 363 cm (143 in), total height of 43 m (140 ft), and a crown spread of 45 m (148 ft) (56).

Stocking and growth data for natural regeneration on heavily disturbed sites and one plantation on the island of Hawaii are available (table 2).

The form of koa varies greatly. Most mature trees have large, open, scraggly crowns with limby, fluted boles. In the rain forests, on deep, rich soil, an occasional koa tree may surpass 34 m (110 ft) in height, but few possess clean, straight boles. On drier sites, the form of koa is even poorer, and trees are often stunted and misshapen. Precise yield figures from koa stands are not available.

Missing from the koa and ohia-koa forests in many areas are the koa-size classes that normally form the recently mature, vigorous stands. In 1913, the condition of large tracts of koa forest was graphically described by Rock *(62)*:

"Above Kealakekua, South Kona, of the once beautiful koa forest, 90 percent of the trees are now dead, and the remaining 10 percent in a dying condition. Their huge trunks and limbs cover the ground so thickly that it is difficult to ride through the forest, if such it can be called.... It is sad, however, to see these gigantic trees succumb to the ravages of cattle and insects."

Forest survey data from 1959-61 (98) indicated the condition of much of the sawtimber-size koa (trees more than 27.7 cm [10.9 in] in d.b.h.). Of 103 trees classified according to merchantability on the basis of form and defect, 36 percent were merchantable, 15 percent sound cull (with such defects as crook, excessive limbs, or poor form), and 49 percent rotten cull (excessive rot). Of the 103 trees, the average d.b.h. was 89 cm (35 in); of 31 trees, the average height was 22 m (72 ft), and the average crown diameter was 18 m (58 ft). Log grades were determined for logs in 103 koa trees. Less than two-fifths of all butt logs (first 4.9 m [16 ftl) met the specifications for either factory lumber logs or tie and timber logs. More than three-fifths were cull. Only 35 percent of the 103 trees sampled had an upper log of 2.4 m (8 ft) or more, and more than half of these logs were graded cull (98). Remeasurements in 1969-70 of the plots inventoried 10 years earlier (54) permit esti-

Table S-Characteristics of koa growing in three natural stands and a plantation in Hawaii[1]

Location	Annual rainfall	Age	Stand stocking	Dominants D.b.h.	Dominants Height
	mm	*yr*	*stems/ha*	*cm*	*m*
Natural stands					
1	3810	8	3460	12.7	6.0
2	5080	17	790	23.1	17.4
3	2540	15	2720	18.5	13.1
Plantation	3810	27	395	31.0	14.4
	in	*yr*	*stems/acre*	*in*	*ft*
Natural stands					
1	150	8	1,400	5.0	19.6
2	200	17	320	9.1	57.0
3	100	15	1,100	7.3	43.0
Plantation	150	27	160	12.2	47.3

[1]Ching, Wayne F. 1981. Growth of koa at selected sites on the island of Hawaii. Unpublished report. Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife, Honolulu, HI. 10 p.

mates of annual growth and mortality of koa on the island of Hawaii. Net annual growth was found to be a negative 4.52 million board feet of sawtimber and a negative 15 660 m^3 (553,000 ft^3) of growing stock (50). One study offers guidelines for estimating the volume of unsound wood associated with log surface defects common in koa (12).

Rooting Habit-Little is known of the root development of koa. The tree grows on the deep Hawaiian soils, but also reaches impressive size on the shallow "aa" lava flows. "The root system of the mature koa is shallow and extensive, spreading out radially from the base for distances as great as 30 m (100 ft) or more" (5). "The tree has a shallow rooted system, a flat plane of roots spreading out in all directions just beneath the surface of the ground. For this reason the larger top-heavy trees are easily overturned by severe windstorms...." (37). Large koa trees were toppled during a severe earthquake on the island of Hawaii in 1973. In describing the root systems of lava-flow plants, a researcher classified koa as one of the comparatively deep-rooted woody species (48).

Reaction to Competition-Koa is classed as intolerant of shade both in the dry forest (28) and in the rain forest, and at all ages (26). Under favorable light, moisture, and soil conditions, koa competes aggressively with other vegetation.

Koa has been classified in various ways by different investigators. One referred to koa as a pioneer species on the grassy slopes of dry forest sites *(28)*, but another considered it a climax species ***(21).*** Koa has been considered the ultimate forest type, following the ohia forest on the ancient "aa" lava flows (37). "At maturity a grove (of koa) casts a shade in which its own seedlings have difficulty in growing, and unless they fill a vacancy in the parental ranks, they must seek the outer limits of the stand" (64). Another investigator believed that koa "reproduction need not be especially frequent to maintain the forest (type)" *(45)*.

Koa failed when underplanted in a dense native ohia rain forest at 870 m (2,850 ft), showing poor survival (44 percent), vigor, and form (70 percent cull), but three introduced nonleguminous species from Australia performed well (100).

The effect of thinning and/or fertilizing a 12-year-old, stagnated koa stand were studied on the island of Maui. In this precommercial thinning, the number of stems was reduced 50 percent. Basal area growth rates for a 3-year period indicated that thinning increased growth significantly. Fertilizer yielded limited response; and the investigator thought that the fertilizer should be applied before crown closure *(72)*.

Damaging Agents--Hawaiian forestry literature is full of references to the disastrous effects of cattle, pigs, sheep, and goats on koa and other native species *(1,4,5,17,26,35,38,40,77)*. Records of the Hawaii Division of Forestry and Wildlife show that more than 250,000 pigs, goats, and sheep were destroyed from 1921-46 in the forests of the island of Hawaii *(10)* during an eradication program. Such efforts did much to reduce the amount of browsing by these animals on koa forests. Feral cattle are particularly fond of koa root sprouts, seedlings, pods, and leaves. They straddle and trample large saplings to devour the foliage and bark. Feral goats have nearly disrupted the replacement cycle of koa on the Hawaii Volcanoes National Park (84). In recent years, park rangers have taken steps to radically reduce the size of the goat herds within the park. A study was conducted on the recovery of vegetation on koa parklands on Maui following the exclusion of goats. After 7 years, young koa regeneration was present both within and outside the enclosure, but the koa got large only if the goats were excluded (69). Koa will recover on these parklands if goats are eliminated. A large number of feral pigs inhabit the koa rain forests, and their rooting destroys many koa seedlings. It is thought that if the pig population is permitted to increase, the koa rain forest ecosystem will deteriorate ***(16).***

Koa attracts other kinds of animals. Black-tailed deer, introduced from Oregon to the island of Kauai in 1961, eat koa seedlings, but have little impact on the native vegetation. Less than 10 percent of the koa was browsed (94). The tree rat and the Hawaiian rat damage koa saplings by stripping off bark. One thousand koa saplings (2 to 5 years old) along an elevation transect from 770 to 1330 m (2,520 to 4,370 ft) in the Laupahoehoe area of the Hilo Forest Reserve were examined ***(71).*** Thirty percent of the trees had been wounded by rats, with wounds occurring as high as 10 m (33 ft). Bark along the main trunk and on lateral branches was subject to stripping. Terminal and lateral shoot dieback were observed where complete girdling occurred. In a study of mortality of koa saplings severely wounded by rats, damage was reported most severe in the vicinity of brush piles where nests were likely to be located.

In 1925, more than 40 species of native insects were considered enemies of koa *(92)*, and by 1983 the number of phytophagous insects associated with koa reached 101 (87). Insect damage to koa is well documented *(18,22,58,59,91)*. One authority believes

"there are more endemic insect species attached to this koa complex *(Acacia koa* and related koa members) than to any other genus in the Hawaiian islands" (93).

One of the most destructive insects of koa is the koa moth *(Scotorythra paludicola),* a lepidopterus defoliator found on the islands of Hawaii, Maui *(105),* Oahu, and Kauai (87). Severe outbreaks occur periodically. When these insects appear in large numbers, they may completely defoliate koa stands. Following an outbreak on Maui in which 1841 ha (4,550 acres) were completely defoliated, growth was reduced 71 percent, and about one-third of the trees died within 20 months (88).

The introduced koa haole seed weevil *(Araecerus levipennis)* is the most prevalent insect that infests koa seeds, the next most common being *Stator limbatus* (85). The koa seedworm *(Cryptophlebia illepida)* destroys seeds and is a problem to control when seeds are collected for reforestation purposes. Eighty percent of the damage from this Tortricid occurs above 1037 m (3,400 ft) *(85).* Three other Tortricid species destroy koa pods or seeds *(85,91).* These seed moths may destroy 90 percent or more of any given seed crop in the pods (93). Stein (86) reviewed the biology and host range of koa seed insects, their parasites, and hyperparasites.

At high elevations, koa terminals are sometimes heavily attacked by the Fuller rose beetle *(Pantomorus cervinus),* but the attacks appear to be highly seasonal and of no serious consequence. The acacia psyllid *(Psylla uncatoides),* first found in Hawaii in 1966, feeds and breeds in the new growth of koa. This psyllid also has become a serious pest of the closely related koaia *(Acacia koaia)* (47). The black twig borer *(Xylosandrus compactus)* is associated with injury and mortality.

Information on diseases of koa has increased in recent years. Seedlings may be attacked by *Calonectria theae,* which causes a shoot blight (55) and *C. crotalariae,* which causes a crown rot (57). This pathogen also caused a collar rot that severely affected koa seedlings regenerating a burned-over area (2). A wilt disease, *Fusarium oxysporum,* was observed among koa seedlings (24). This fungus may contribute to the premature decline or death of old koa trees growing within the Hawaii Volcanoes National Park. Indications are that this fungus is seedborne, but seed disinfection did not reduce disease incidence (24). Koa was moderately tolerant to *Phytophthora cinnamomi* in greenhouse tests (42).

Dieback is common in the crowns of old trees, and it was observed in more than half the sawtimber-size koa measured during the 1959-61 forest survey. The root-rot fungus *Armillaria mellea* is associated with this dieback *(44,61).* Stands possibly weakened by old age, extended droughts, and grazing have succumbed to attacks by this fungus. Other diseases of koa are those caused by the sooty molds, such as *Meliola koae,* that cover the leaves and restrict growth.

Four rust fungi, *Uromyces koae, U. digitatus, Endoraceium acaciae,* and *E. hawaiiense,* occur on koa *(25,32).* Both species in the genus *Uromyces,* obligate parasites, cause witches' brooms and leaf blisters that deform branches and phyllodes. When infections are heavy, they can deform and debilitate both young and old trees *(23,30,31).*

The Hawaiian mistletoe *(Korthalsella complanata)* has been observed in many koa stands, and it can deform young koa. Heart rot, caused principally by *Laetiporus sulphureus* and *Pleurotus ostreatus,* is common in most mature and overmature koa (6). More than half the large koa measured in the 1959-61 forest survey were unmerchantable because of excessive rot (98).

Pole-size and small, sawtimber-size koa have thin bark and are easily damaged by fires.

Weeds are serious problems in certain areas. The banana poka *(Passiflora mollissima)* smothers both koa reproduction and mature trees by laying a curtain of vines over them. The German-ivy *(Senecio mikanioides)* is also difficult to control.

Special Uses

The most important use of koa timber by the Hawaiians was to build canoes. The largest of the giant war canoes extended 21 m (70 ft). Canoe hulls were made of single, giant koa logs. Koa was also used for surfboards, some 5.5 m (18 ft) or longer, for paddles, and for framing grasshouses. The bark provided dye to tapa, a light cloth made from the bark of wauke *(Broussonetia papyrifera) (11,19).*

Koa wood is now used primarily for furniture, cabinet work, and face veneers. It is widely used in woodcraft. Cabinet makers recognize a dozen or more types of koa wood, including curly or "fiddle back" koa, red koa, and yellow koa *(11).* One local use is for making ukuleles. At one time koa was sold on the world market as Hawaiian mahogany (62).

Large logs have a narrow, creamy-white band of sapwood. The heartwood may vary through many rich shades of red, golden brown, or brown. The heartwood seasons well without serious degrade from warping, checking, or splitting (74).

Although it has been stated that foresters in Hawaii have paid little attention to koa *(83),* more than 1.3 million koa seedlings were planted by the Hawaii Division of Forestry and Wildlife between 1915 and 1946 (78) for watershed protection. Koa,

however, did not perform as well as many introduced species on these deteriorated sites.

Genetics

Morphological differences in koa have been observed on several islands. In 1920, Rock *(63)*, named two varieties: *Acacia koa* var. *Zanaiensis* (Hillebrand's *A. koa-B* var.> and *A. koa* var. *hawaiiensis,* after the islands on which they were found. Ecotypic variation can be found from island to island. Studies of such variation are complicated by past plantings of mixed seed lots collected throughout the islands; such mixed plantings could now be hybridizing.

Collections of the koa group, all commonly referred to as koa, were studied, and in 1979 this classification was presented by St. John *(90)*:

Acacia koa var. *koa,* grows on the six larger islands.

Acacia koa var. *waianaeensis* grows only on Oahu, and most commonly in the Waianae Mountains.

Acacia koa var. *latifolia; syn. A. koa* var. *hawaiiensis* Rock, grows on the island of Hawaii in the rain forest, and at higher elevations on the more open ranch and park land. Altitudinal races of koa probably exist (52).

Two other native species related to koa are recognized. On western Kauai, one of the oldest Hawaiian Islands, a form of acacia is found that differs from koa in sepals, petals, inflorescence *(63)*, and seed shape (37). This species, also called koa, is *Acacia kauaiensis.* A second species closely related to koa is koaia *(A. koaia),* a narrowly distributed, small, shrubby tree occupying dry, leeward sites below 1050 m (3,500 ft) on Molokai, Maui, and Hawaii *(89)*. *Acacia koaia* differs from koa in the shape of the pods and phyllodes (63). The native and introduced species of *Acacia* found on Lanai have been described *(20)*.

Other *Acacia* species related to koa are found outside of Hawaii. *Mascarene acacia (A. heterophylla)* is endemic to Reunion island and Mauritius island, both about 725 km (450 mi) east of Madagascar, in the Indian Ocean. It is so similar to koa that the trees were initially identified as the same species. The two were identified by another botanist as separate species, however, entirely on the basis of distance and isolation. In 1969, significant differences were found in fruit and seed size, corolla structure, and morphology of the first two leaves of the two species (95).

Tasmanian blackwood *(Acacia melanoxylon),* native to Australia but planted in many countries, resembles koa. It has straighter and shorter phyllodes, a narrower curved pod, a more pointed crown *(63)*, but similar wood. Another closely related species, *A. simplicifolia,* grows in Samoa, New Hebrides, New Caledonia, and Fiji *(20,59,60)*.

In 1948, one investigator determined that koa is a tetraploid with 2n = 52 and stated that all other phyllodinous acacias studied have the diploid chromosome complement (3). He reasoned "that polyploidy in *Acacia koa* occurred after the initiation of phylloidy. This is supported by its distribution as an endemic island extension of the Australian flora." In 1978, koa was observed to have a gametic number of 26, verifying that it is tetraploid *(14)*. Another investigator (95) reported on the work of Lescanne, who observed that the closely related *A. heterophylla* was also a tetraploid, with 2n = 52.

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