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Species Adaptability Trials For Man-made Forests In Hawaii

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In Hawaii very few of the native tree species are of value for timber production. Over the past 100 years, introduced species from the Pacific Basin proved more useful for reforestation. Introduced species were usually easier to propagate in the nurseries, and many performed better than the native species when outplanted. Before 1960 the major emphasis was on establishment of protection forests. These forests replaced native stands decimated for fuelwood, and served to protect denuded watersheds and to cover erosion scars. Interest in the establishment of new forests for timber production developed about 1960. Species adaptability trials were begun, with the aim of identifying economically valuable timber trees adapted to local growing conditions, and at the same time eliminating useless candidate species as quickly as possible. These trials were made on a wide range of sites.

Tree seeds were obtained from cooperators in 38 countries in the tropics, subtropics, and warm temperate zone. Seeds from 144 provenances, representing 90 species, were sown in beds or containers; the seedlings were later outplanted as bare-root or potted stock.

A total of 16 planting sites were established on the islands of Hawaii, Maui, Molokai, Oahu and Kauai during the 1960's. On these sites elevation ranged from near sea level to 6360 feet (1940 m); rainfall ranged from less than 20 inches to more than 200 inches (500 to 5000 mm); and soils ranged from thin mucks overlying lava rock to deep, highly leached latosols.

The experimental plantings were laid out in a randomized block design, usually with five replications and 6-tree row plots for each species. When a shortage of seedlings occurred, two or more species were sometimes included in a row plot. Survival, growth measurements, vigor, and stem quality of the trees were recorded at the end of the first, third, and fifth years after outplanting.

Ten conifers and thirty-two hardwood species were rated as having promise for timber production, craftwood, amenity plantings, or for protection forests. Fourteen of these species are native to Australia; and ten are eucalypts. On some of our test sites, several species grew well, at other sites few or none of the species proved well adapted. The performance of most of the high quality hardwood species tested was disappointing.

The eucalypts outperformed other species, especially on the low quality sites. *Eucalyptus camaldulensis* lived up to its worldwide reputation as the eucalypt capable of growing well on a wide range of moisture regimes and soils. Two Southern Hemisphere conifers initially promising are *Araucaria angustifolia* from Brazil and *Callitris endlicheri* from Australia. *Pinus kesiya* and *P. engelmannii* were among the six true pines considered promising. *Swietenia mahagoni, S. macrophylla* and *Cedrela odorata* showed sufficient promise to justify further investigations. This was also true for *Cordia subcordata* and *Thespesia populnea,* two species useful as craftwood and introduced by the early Polynesians.

Many of the promising species exceeded our minimum performance standard, which is a combination of 60 percent survival, height growth of 3 feet (1 m) per year, and 70 percent good vigor. These criteria were lowered for species planted on low rainfall sites (under 40 inches or 1000 mm per year). Very few trees died from disease or insect attack. Most failures and unsatisfactory performances relate to harsh site conditions, such as low soil fertility, droughts, desiccating winds, and weed competition.

The species rated promising for timber production will be tested more intensively in pilot-scale plantings. Several of the eucalypts deserve special attention for use in short-rotation "energy plantations"—that is, as a substitute for fuel oil in generating electricity. This is presently feasible on the islands of Hawaii and Maui. Growth of these species suggests that under intensive management, fuelwood production on short rotations would become more profitable as oil prices rise.

Man's activities have adversely altered growing conditions for native forest trees on many thousands of acres in Hawaii. These lands can again become productive if they are reforested. But reforestation success on a particular site depends to a large extent on the choice of tree species. Foresters have long been faced with this problem; in 1665 John Evelyn stated it in his classic work, *Silva:* "First it will be requisite to agree upon the species: as to what trees are likely to be of greatest use, and the fittest to be cultivated and then to consider how planting may be best effected."

Species adaptability trials, which basically are short-term elimination trials, serve to identify tree species deserving further attention for planting on these modified habitats.

Although native Hawaiian trees collectively serve as valuable protection forests, only a few species have proven satisfactory for either reforestation programs or urban beautification. Hawaiian species have not shown superior adaptive characteristics on sites radically altered by erosion, fire, cultivation, or other destructive agents. On such areas trees from other countries often prove to be more useful for the establishment and development of man-made forests. These forests will help to meet the increasing demand for forest products and at the same time will provide other benefits such as recreational areas.

Only coordinated, long-term studies can determine the suitability of exotic species to Hawaii's conditions. The initial step is to screen many species in adaptability trials. Those which show promise are then tested in larger scale pilot planting trials. This paper presents the results of adaptability trials established by the U.S. Forest Service in cooperation with the Hawaii Division of Forestry. The performance of 90 hardwood and coniferous species from 38 countries in the tropical, subtropical, and warm temperate zones of the world was appraised.

Our primary objective on most sites was to evaluate the performance of timber trees, especially fast growing species recognized in the world market for their high quality. Considerable research emphasis was therefore directed toward screening high-quality hardwoods—for example, members of the mahogany family (*Meliaceae*). Species adapted to adverse sites, such as dry and eroding lands, were also sought for use in the establishment of protection forests. Later, for selected sites, the scope of the study was broadened to assess the value of species for craftwood, amenity plantings, and Christmas tree production.

These field trials have identified 10 coniferous species and 32 hardwood species that merit more intensive trials for timber production or other uses. This paper reports results of the trials according to site, identifying the species as promising, unsatisfactory, or failures, and tabulating the significant characteristics of the species performance on the individual site. A general index gives seed source and performance rating for each species planted; for promising species, site characteristics (island, elevation, rainfall) and recommended uses are tabulated. A table of relevant soil classification equivalents is also provided.

TREE INTRODUCTIONS IN HAWAII

Hawaii is a unique place for growing trees. A chain of eight major volcanic islands, it is situated in the North Pacific Ocean, just south of the Tropic of Cancer (*fig. 1*). The islands lie between 18°54′ and 22°14′ north latitude and between 154°48′ and 160°15′ west longitude. They are separated from the United States mainland by 2400 miles (3860 km).

There are two seasons. Summer is the season of northeast trade winds. Winter is a period when the trades are occasionally interrupted by southerly and westerly winds, bringing increased cloudiness, humidity, and storms. These storms bring Hawaii its heavi-

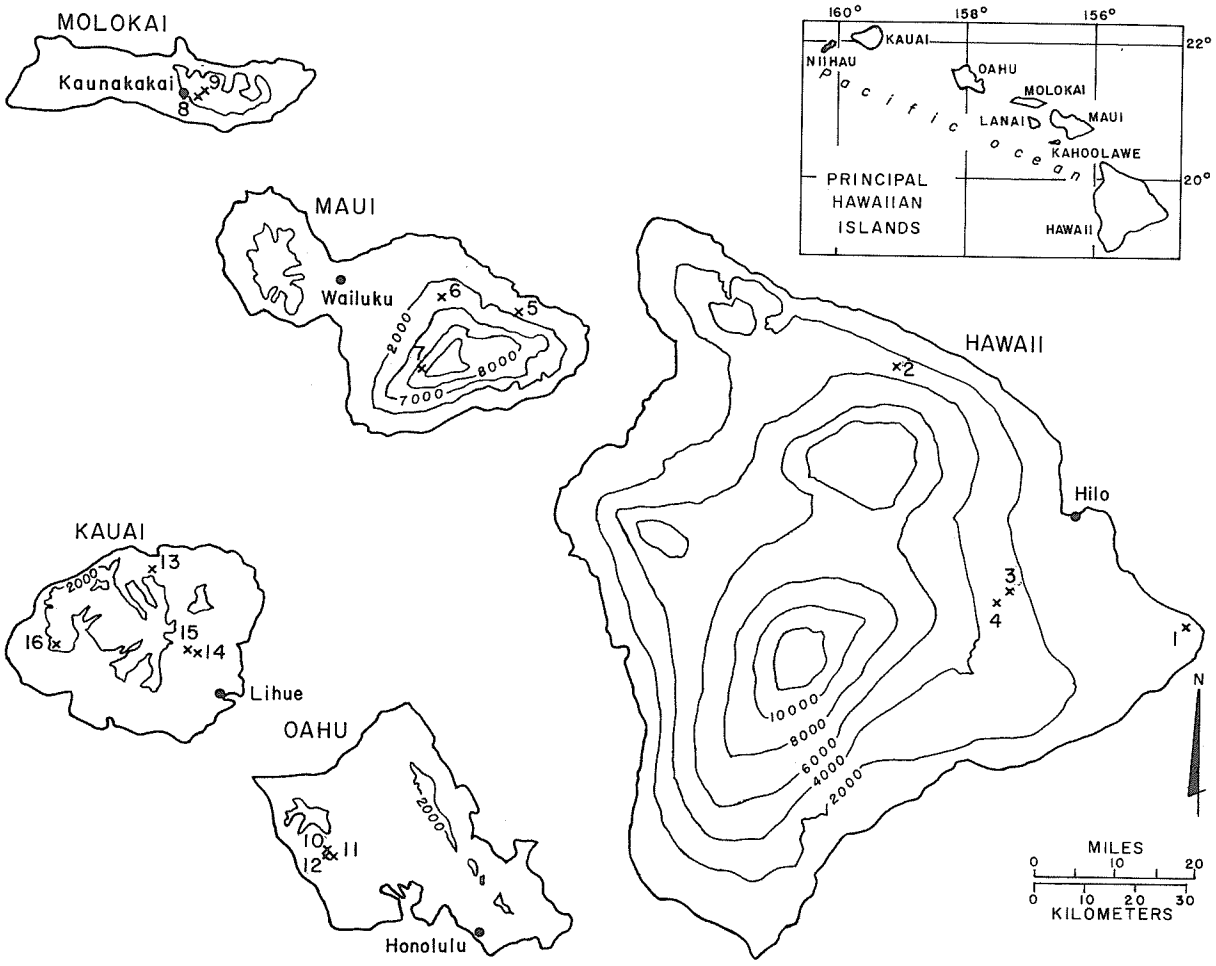

Figure 1—Species adaptability trials were made on the numbered sites shown here, on five of the Hawaiian islands. These trials serve to identify tree species deserving further attention for planting.

est rains, and are usually the only source of rainfall for the dry, leeward areas. Severe, extended droughts may occur in these areas when the winter storms fail to materialize (Price 1973).

Hawaii's mountains influence all aspects of its climate. The northeast trade winds bring rain to the windward areas most of the year. On the higher mountains annual rainfall may range from 100 to over 450 inches (2540 to 11,400 mm). Generally, above 3000 feet (914 m) on the windward slopes, the average annual rainfall begins to decrease rapidly—slopes above 7000 feet (2134 m) receive less than 30 inches (760 mm). Temperatures decrease as elevation increases, by about 3° F per 1000 feet (1° per 100 m). Near sea level, average temperatures range from about 75° F (24° C) in March to 80° F (27° C) in September. In most areas the daily range exceeds the seasonal range by about 3° F (1.7° C) (Price 1973). Cloud cover, which is almost a daily occurrence over some areas at mid-elevations, greatly influences temperature, radiation, and humidity, and therefore plant growth.

The purposeful introduction of trees into Hawaii began with the arrival of the first Polynesians over 1200 years ago. They brought the kukui or candlenut-tree (*Aleurites moluccana* [L.] Willd.), now Hawaii's state tree, milo (*Thespesia populnea* [L.] Soland.), kou (*Cordia subcordata* Lam.), and many others. Like the first Polynesians, later immigrants to Hawaii brought trees that were important to them.

Many of these introductions, which now total in the hundreds (Nelson 1965; St. John 1973), have become so familiar that they seem almost a part of the natural flora. Many of the ornamental trees brought here are also appreciated elsewhere in the tropics for landscaping, shade, food production, and other uses.

One century ago, Clarke (1875), remarking on the decadence of Hawaiian forests, suggested certain exotic and native species for renewing the beauty of the islands. The introduction of trees for reforestation began around 1870, during the reign of King Kalakaua (Lubker 1886; Walker 1887). By this time many of the native forests had been decimated by timber and firewood cutting, fires, and clearing for farming and ranching. Insects, disease, feral animals, and aggressive introduced plants contributed to the decline of the native forests. Initially, native species were tried for reforestation. Most of these plantings failed, however, probably because the environment under which these species once flourished had deteriorated. Needed were trees that were easier to propagate and could survive and grow under harsh conditions. Attention turned to exotic species, principally *Eucalyptus* and *Casuarina* species from Australia.

From about 1903 to 1960, the Hawaii Division of Forestry screened hundreds of tree species for their adaptability to local conditions (Bryan 1947; Crosby and Hosaka 1955; Hosmer 1912; Kraebel 1922; and Margolin 1911). The value of these trees, selected principally for watershed protection, was continuously reappraised, and some species became more favored than others. Unfortunately, planting records were not always kept, or have been lost.

In about 1960, the State began to emphasize reforestation activities aimed at increasing timber yields on the forest reserves (Hawaii 1962). Many of the earlier tree plantings had shown that timber trees could be successfully grown in Hawaii, and that growth rates on good sites far exceeded those obtained in temperate zone areas (Carlson and Bryan 1959; Pickford 1962; Pickford and LeBarron 1960). By 1973 only 38 thousand (4 percent) of Hawaii's 938 thousand acres of commercial forests were planted, yet these forests contain about 40 percent of the sawtimber growing on these lands (Nelson 1973). The field trials described in this paper were established for the purpose of identifying useful timber species adapted to the many diverse sites throughout the State.

METHODS

Species Selection and Planting Practices

Species were selected by

- Screening the literature to identify the species most likely to succeed.
- Evaluating species performance in older local trials.
- Seeking suggestions from tropical foresters.

Tree seeds were obtained from 38 countries in the tropical, subtropical, and warm temperate zones. A total of 144 provenances, representing 90 species, were obtained and outplanted. These are listed, with the sites in Hawaii where they were planted, in the appendix (*table 17*). Information on location, elevation, rainfall, and stand and site conditions of the seed source was usually partially or wholly lacking. Our alternative was to rely on available literature, which provided useful information for many but not all species. Countries in the British Commonwealth were the most informative sources of literature on species introductions.

Seeds were sown in flats, cans, plastic bags, and nursery beds at forest nurseries throughout the State. Seedlings were treated with fertilizers, fungicides, and insecticides as required. Both bare-root and potted stock were outplanted. In the field, site preparation consisted of removing all competing vegetation. Spacing was 5 feet (1.5 m) within rows, 8 feet (2.4 m) between rows, and 10 feet (3.0 m) between blocks. Brush and grasses were controlled by periodic chopping, and occasionally weedicides were applied.

Planting Site Selection and Experimental Design

Sixteen sites, representing extremely diverse site conditions throughout the State, were selected for these species adaptability trials. Most of these areas were within or adjacent to areas that had been planted with trees in previous years. In general, we chose sites typical of large areas in need of productive

forest cover. Many of these areas were known to present difficult establishment problems, and none resemble the romantic vision of a lush tropical island. Elevations range from 100 feet to 6360 feet (30 to 1939 m); annual rainfall varies from about 20 inches to over 200 inches (500 to 5080 mm); and soils vary from old, deep, and highly leached to lava rock overlaid by shallow muck.

The soils, identified by series names, and placed in the U.S. Soil Taxonomy, are listed in the appendix (*table 18*). This system is also correlated with the older U.S. Classification System of 1938, the FAO/UNESCO Legend, and the French Soil Classification (Beinroth and others 1974). This provides a way to compare soils of Hawaii with those of other tropical regions.

The experimental design consisted of five replicated blocks, each with 10 or more randomized row plots. Each plot usually consisted of six trees from one seed lot, for a total of 30 seedlings tested. Occasionally, as few as five seedlings per seed lot were represented (1 tree per lot). Ten or more species were planted at each experimental area.

Different provenances of a species were often grown in different nurseries at different times, and planted in the field under varying conditions. Similarly, seedlings from the same seed lot were often raised at different nurseries and planted at different sites. For these reasons each planting of a given provenance at a given site is considered a separate test. No statistical comparisons were made between species or provenances.

Observations, Measurements, and Performance Assessment

Observations and measurements were usually recorded at the conclusion of the first, third, and fifth years. The trees were examined for survival, total height, vigor, and stem form. Tree vigor was rated as either good or poor, based upon crown development and general condition.

Survival, height growth, and vigor were considered in judging the performance of a species on a specific site. Species were rated as "promising," "unsatisfactory," or "failures." Performance standards to distinguish a species as promising were usually based upon a composite rating of survival, annual height growth, and vigor. Minimum performance for a species to be rated promising, on areas receiving over 40 inches (1000 mm) of rainfall, was survival of 60 percent, average annual height growth of 3 feet (1 m), and good vigor of 70 percent of the trees. On dry sites (rainfall under 40 inches), an annual growth of 2 feet (0.6 m) was considered acceptable. However, our criteria allowed a species to be rated promising although not meeting the above standards for one or two factors, if it excelled for another. Stem quality assessments were used only to judge the sawtimber potential of a species.

A species was rated "unsatisfactory" if survival was low and growth rate and/or vigor were low. A species was judged a "failure" if survival was very low, growth was slow, and a high percentage of the trees showed low vigor.

SITE CONDITIONS AND SPECIES PERFORMANCE

Hawaii Island

SITE 1

The planting site is in the Nanawale Forest Reserve, about 0.7 mile (1.1 km) northwest of Cape Kumukahi. Latitude is 19° 32′ north and longitude is 154° 51′ west. Elevation is 100 feet (30 m); aspect is east, with slopes of from 1 to 15 percent. The average annual rainfall is about 100 inches (2500 mm), with an average of 5 inches (125 mm) or more, usually occurring each month. Dry periods of a month or longer may occur at any time during the year.

The soil is Malama extremely stony muck, a thin organic soil overlying fragmented aa lava. This soil is well drained; permeability is rapid, and runoff is very slow. The soil is strongly acid (pH 5.3). Tree roots may extend to a depth of 24 inches (60 cm) or more into cracks in the lava (USDA 1972). During site preparation the stony muck became mixed with cinders laid down in the 1960 eruption.

Objective—Trials on this site were established to identify tree species useful for timber production. However, recently, adjacent holdings in private ownership have been rezoned urban. Now species are being appraised for their amenity values as well as their timber potential.

Results and Recommendations—Seventeen species were tested, of which nine were rated as promising for both timber and ornamental purposes, after 5 years (*table 1*). Most of the promising species had over 83 percent survival and an average annual growth rate of more than 4 feet (1.2 m). The most outstanding species was *Albizia falcataria,* which had 100 per-

Table 1—*Performance of species and provenances planted at Site 1, Nanawale Forest Reserve, Hawaii Island, evaluated after 5 years*

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent	*Feet*			*Percent*
PROMISING						
Albizia falcataria (Hawaii) 203	18	[1] 100	30	11 to 41	14.3	94
Araucaria columnaris (Hawaii) 239	18	83	14	4 to 24	2.8	100
Eucalyptus citriodora[2] (Hawaii) 246	41	[2] 38	43	24 to 56	6.7	88
Flindersia brayleyana (Australia) 200	18	83	23	9 to 32	4.6	100
(Hawaii) 219	18	61	18	1 to 26	3.6	90
Hibiscus elatus (Puerto Rico) 104	18	94	16	6 to 49	3.2	88
Pithecellobium saman (Hawaii) 237	18	[2] 94	21	1 to 30	4.2	88
Pterocarpus echinatus (Philippine I.) 5	18	100	22	7 to 35	4.4	61
Swietenia mahagoni (Hawaii) 221	18	94	18	6 to 29	3.6	41
(Hawaii) 258	44	[2] 95	27	5 to 40	4.2	62
Tectona grandis (Malaya) 164	9	100	23	19 to 30	4.6	100
UNSATISFACTORY						
Chlorophora excelsa (Nigeria) 67	18	94	12	6 to 27	2.4	41
Serialbizzia acle (Philippine I.) 102	9	78	8	3 to 12	1.6	14
Sindora supa (Philippine I.) 43	18	56	7	3 to 11	1.4	40
Terminalia superba (Ghana) 179	18	33	13	3 to 20	2.6	33

FAILURES: *Entandrophragma utile* 186; *Mansonia altissima* 254; *Pahudia rhomboidea* 44; *Pericopsis elata* 255.

[1] Age 2.1 years.
[2] Age 6.4 years, seed sown in prepared spots.

cent survival and averaged 30 feet (9.1 m) in height at age 2.1 years. These trees were removed because they were overtopping adjacent species. *Flindersia brayleyana* was represented by two provenances—one from Australia and the other from Hawaii. Both sources proved satisfactory. *Swietenia mahagoni* trees which developed from seeds sown in prepared seed spots outgrew planted stock. Only 38 percent of the *Eucalyptus citriodora* trees planted survived. The high mortality was caused by an unidentified watermold (*Pithium* sp.) which appeared during an extended wet period. No trees of this species died after the third year.

The priority now is to establish these nine promising species in pilot scale plantings, where they can be further evaluated as they develop under closed stand conditions.

SITE 2

The planting site is in the Kalopa Section, Hamakua Forest Reserve, located approximately 4 miles (6 km) southwest of Honokaa town. Latitude is 20° 02′ north and longitude is 155° 26′ west. The elevation is 2100 feet (640 m); aspect is northeast, with slopes of from 6 to 20 percent. Annual rainfall has averaged about 110 inches (2800 mm) during the last 10 years.[1] Rainfall is usually well distributed throughout the year, but extended droughts occur every few years.

The soil is Honokaa silty clay loam, formed in volcanic ash. It is well drained; permeability is rapid, and runoff is slow. This soil is friable when moist, but sticky and plastic when wet, and it dehydrates irreversibly into fine gravel-size aggregates. Roots can penetrate to depths of 5 feet (1.5 m) or more (USDA 1973). This soil is strongly acid to medium acid (pH 5.3 to 5.7). Low soil fertility limits growth of some tree species on this site.

Objective—Trials were made to identify tree species useful for timber production and for amenity plantings.

Results and Recommendations—Thirty-seven species were tested, with five represented by two or

[1] Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Honolulu, Hawaii.

more provenances (*table 2*). Eight species were rated as promising for timber production, and should be included in pilot scale plantings. These include the two provenances of *Araucaria angustifolia; A. columnaris; Cedrela odorata; Chukrasia tabularis; Eucalyptus deglupta; Flindersia brayleyana; and Hibiscus elatus.* The Hawaiian provenance of *Flindersia brayleyana* grew over twice as fast as the Australian provenance. *Grevillea robusta,* known to be well adapted to the site (Pickford and LeBarron 1960; Nelson and Honda 1966) grew well, but was very limby. This species is deserving of intensive silvicultural research to improve its form.

Fraxinus uhdei and *Liquidambar formosana,* the latter represented by two provenances, grew vigorously, but form was poor. Further plantings for timber production are not recommended for either species until progeny of trees of superior form are tested.

Table 2—*Performance of species and provenances planted at Site 2, Hamakua Forest Reserve, Hawaii Island*

Species, seed source, and Hawaii seed lot number	Trees planted	Age	Survival	Height			Good vigor
				Average	Range	Annual growth	
		Years	*Percent*	*Feet*			*Percent*
PROMISING							
Araucaria angustifolia (Argentina) 300	10	4.4	80	10	8 to 12	2.3	100
(Brazil) 364	6	5.9	83	21	19 to 23	3.6	100
Araucaria columnaris (Hawaii) 398	10	5.3	90	12	8 to 16	2.3	100
Cedrela odorata (Mexico) 144	30	5.9	100	17	2 to 32	2.9	66
Chukrasia tabularis (India) 331	30	5.9	100	21	10 to 32	3.6	70
Eucalyptus deglupta (Australia) 227	30	5.0	97	27	5 to 45	5.4	89
Flindersia brayleyana (Hawaii) 219	30	5.0	100	11	2 to 23	2.2	90
Grevillea robusta (Hawaii) 225	30	5.0	97	16	7 to 27	3.2	89
Hibiscus elatus (Puerto Rico) 104	30	5.0	87	11	4 to 24	2.2	84
Liquidambar formosana (Taiwan) 324	30	5.3	100	17	13 to 21	3.2	100
(Hong Kong) 325	30	5.9	100	19	13 to 25	3.2	100
Tabebuia heterophylla (Puerto Rico) 271	30	5.3	80	12	5 to 17	2.3	91
UNSATISFACTORY							
Agathis australis (New Zealand) 213	30	5.3	73	4	3 to 6	0.8	81
Cardwellia sublimis (Australia) 401	30	5.9	53	12	2 to 24	2.0	81
Castanospermum australe (Australia) 285	30	5.3	77	7	1 to 17	1.3	100
Cedrela odorata (Mexico) 143	30	5.0	90	7	2 to 16	1.4	62
(Trinidad, W.I.) 208	30	5.3	70	11	1 to 25	2.1	95
Cordia alliodora (Costa Rica) 177	30	5.3	93	7	1 to 17	1.3	60
(Venezuela) 393	30	5.9	100	13	4 to 25	2.2	53
(Fiji) 395	30	5.9	100	9	1 to 24	1.5	33
(Costa Rica) 264	30	5.3	100	5	1 to 13	0.9	50
Flindersia brayleyana (Australia) 200	30	4.7	90	6	1 to 18	1.3	74
Fraxinus uhdei (California) 15	30	5.0	100	22	9 to 32	4.4	90
Juglans australis (Bolivia) 400	5	5.9	100	11	4 to 16	1.7	40
Juglans boliviana (Costa Rica) 338	30	5.3	63	7	1 to 21	1.3	73
Maesopsis eminii (Kenya) 293	9	5.3	89	8	1 to 21	1.5	67
Phoebe porosa (Brazil) 412	15	5.9	100	9	4 to 13	1.5	26
Pterocarpus echinatus (Philippine I.) 5	30	4.4	100	8	3 to 15	1.8	40
Swietenia macrophylla (British Honduras) 336	30	5.9	77	5	2 to 9	0.8	21
Tectona grandis (Australia) 164	10	5.3	100	3	1 to 7	0.6	30
Terminalia ivorensis (Nigeria) 204	30	5.9	100	6	1 to 14	1.0	3

FAILURES

Amburana sp. 89
Berrya cordifolia 314
Brosimum sp. 383
Chlorophora excelsa 67
Gyrocarpus americanus 328
Mansonia altissima 254
Pahudia rhomboidea 44
Pericopsis elata 255
Roseodendron donnell-smithii 272
Sindora supa 43
Taxodium distichum 161
Terminalia ivorensis 180
Terminalia superba 179
Tieghemelia heckelii 181

The five species recommended for amenity plantings include *Liquidambar formosana* (colorful foliage during the summer months), the two *Araucaria* species (symmetrical shape), *Hibiscus elatus* (red flowers), *Eucalyptus deglupta* (multicolored bark), and *Tabebuia heterophylla* (showy pink flowers).

SITE 3

The planting site is in the Waiakea Forest Reserve, approximately 8.4 miles (13 km) southwest of Hilo, on the northeast flank of Mauna Loa. Latitude is 19° 37′ north and longitude is 155° 10′ west. The elevation is 2050 feet (625 m); aspect is east, with a general slope of 5 percent. Annual rainfall during the last 10 years averaged about 220 inches (5600 mm). September is usually the driest month, averaging about 11 inches (280 mm), and April is usually the wettest month, averaging about 32 inches (800 mm).[1]

The soil is Kiloa extremely stony muck. It is usually well drained; permeability is rapid, and runoff is very slow. The layer consists of organic material from 1 to 8 inches (2 to 30 cm) thick, underlain by fragmented aa lava. Kiloa muck has high shrinkage (over 50 percent) upon drying. Roots can penetrate through cracks in the lava to depths of 2 feet (0.7 m) or more (USDA 1973). The soil is strongly acid (pH 5.1) and fertility is low.

Objective—Trials were made to identify tree species useful for timber production.

Results and Recommendations—Three of the 14 species tested appeared promising after 5 years (*table 3*). *Acacia melanoxylon* was the most outstanding in terms of height growth—4 feet (1.3 m) per year. The Taiwan provenance of *Liquidambar formosana* averaged 3.6 feet (1.1 m) height growth per year, while the Hong Kong source averaged only 1.3 feet (0.4 m). Stem form was also poor for this species on this site. *Araucaria angustifolia,* although growing at an average annual rate of only 2 feet (0.6 m), appears adapted to this site. These three species are recommended for pilot scale planting trials. *Cedrela tonduzii,* rated very promising at age 3 years, has proven unsatisfactory because of terminal dieback and low vigor.

SITE 4

The planting site is in the Waiakea Forest Reserve, about 13 miles (21 km) southwest of Hilo. Latitude is 19° 35′ north and longitude is 155° 12′ west. The elevation is 2860 feet (870 m); aspect is east, with a general slope of 5 percent. The mean annual rainfall over the last 10 years was about 210 inches (5330 mm). September is usually the driest month, averaging about 10 inches (250 mm) and April is usually the wettest month, averaging about 30 inches (760 mm).[1]

Table 3—*Performance of species and provenance planted at Site 3, Waiakea Forest Reserve, Hawaii Island, evaluated after 5.3 years*

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent		*Feet*		*Percent*
PROMISING						
Acacia melanoxylon (Uruguay) 365	30	93	22	8 to 32	4.2	78
Araucaria angustifolia (Brazil) 370	5	100	10	3 to 23	1.9	80
Liquidambar formosana (Taiwan) 279	30	100	19	12 to 28	3.6	86
UNSATISFACTORY						
Cardwellia sublimis (Australia) 401	30	70	12	3 to 29	2.3	52
Castanospermum australe (Australia) 285	15	73	4	1 to 9	0.8	0
Cedrela odorata (Trinidad, W.I.) 208	15	53	5	1 to 12	0.9	12
Cedrela tonduzii (Costa Rica) 408	30	100	10	1 to 19	1.9	60
Chukrasia tabularis (India) 331	30	77	4	1 to 19	0.8	4
Cordia alliodora (Costa Rica) 348	30	47	5	1 to 28	0.9	14
Dalbergia sissoo (India) 407	15	87	3	1 to 12	0.6	0
Liquidambar formosana (Hong Kong) 325	30	300	7	1 to 21	1.3	46
Phoebe porosa (Brazil) 412	30	83	3	1 to 10	0.6	8
Tabebuia heterophylla (Puerto Rico) 271	30	97	10	2 to 16	1.9	34

FAILURES: *Melia dubia* 286; *Pterocarpus santalinus* 332.

The soil is Kiloa extremely stony muck. It is usually well drained; permeability is rapid, and runoff is very slow. The surface layer consists of organic material from 1 to 8 inches (2 to 30 cm) thick, underlain by fragmented aa lava. Kiloa muck has high shrinkage (over 50 percent) upon drying. Roots can penetrate through cracks in the lava to depths of 2 feet (0.7 m) or more (USDA 1973). The soil is strongly acid (pH 5.0), and fertility is low.

Objective–Trials were made to identify tree species useful for timber production.

Results and Recommendations–Fourteen species were tested (*table 4*); *Flindersia brayleyana* was represented by two provenances. After 5.5 years only the Hawaii provenances of *Flindersia brayleyana* and *Eucalyptus robusta* were rated as promising. Both species have proven to be adapted to this rocky, rainforest area and have been included in general reforestation projects.

Although *Eucalyptus saligna* and *Hibiscus elatus* were not rated promising, they have grown well in reforestation plantings on similar sites. Large variations in soil depth and drainage over short distances resulted in great differences in growth and vigor among individuals of a species. For example, tree heights of *Hibiscus elatus* ranged from 1 to 31 feet (0.3 to 9.4 m) after 5.5 years. Mean annual growth of the 28 surviving trees was 1.8 feet (0.6 m), which we rated unsatisfactory. However, the 17 trees with good vigor averaged 14 feet (4.3 m) tall, an annual height increment of 2.5 feet (0.8 m).

Maui Island

SITE 5

The planting site is in the Koolau Forest Reserve, on the windward coast of East Maui, about 1 mile (1.6 km) south of the village of Keanae. Latitude is 20° 51′ north and longitude is 156° 09′ west. The elevation is 420 feet (128 m); aspect is north, with a slope of from 5 percent or less. Mean annual rainfall is about 175 inches (4450 mm), usually well distributed throughout the year. The monthly totals may vary greatly from year to year, however.

The soil is Kailua silty clay, developed from volcanic ash. It is moderately well drained to well drained, permeability is moderately rapid, and runoff is slow. This soil is hard and friable when dry, and sticky and plastic when wet. The soil is very strongly acid (pH 4.7 to 4.9) in both the surface layer and subsoil. It is very low in available phosphorus, potassium, and calcium. These nutrient deficiencies adversely influence growth of most tree species.

Objective–Trials were made to identify tree species useful for timber production.

Results and Recommendations–None of the 13 species planted on this site proved promising after the

Table 4–*Performance of species and provenances planted at Site 4, Waiakea Forest Reserve, Hawaii Island, evaluated after 5.5 years*

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent	*Feet*			*Percent*
PROMISING						
Eucalyptus robusta (Hawaii) 290	30	97	16	1 to 35	2.9	52
Flindersia brayleyana (Hawaii) 219	30	100	11	1 to 28	2.1	63
UNSATISFACTORY						
Eucalyptus saligna (Hawaii) 240	30	53	7	1 to 34	1.3	19
Flindersia brayleyana (Australia) 200	30	100	6	1 to 23	1.1	46
Hibiscus elatus (Puerto Rico) 104	30	93	10	1 to 31	1.8	60
Terminalia ivorensis (Ghana) 180	10	50	10	4 to 21	1.8	60

FAILURES

Chlorophora excelsa 67
Entandrophragma utile 186
Gmelina arborea 215
Mansonia altissima 254
Pericopsis elata 255
Pterocarpus echinatus 5
Pterocarpus indicus 4
Sindora supa 43
Terminalia superba 179

6.6-year trial period (*table 5*). Seedling establishment proved difficult on this soil, and growth of most species was poor and erratic. For example, the average height of the seven vigorous *Pterocarpus echinatus* saplings was 23 feet (7 m). The 16 other surviving trees of this species averaged only 7 feet tall. Only one *Pinus kesiya* tree survived. It was straight, vigorous, and 28 feet (8.5 m) tall at age 6.6 years.

Further research should include a pilot-scale planting of *Pterocarpus echinatus* on a related well-drained soil in the area. Soil nutrient deficiencies, especially of phosphorus, should be corrected at the time of planting. Future introduction trials on this soil should emphasize eucalyptus and coniferous species, which have proven to be adapted on related soils.

SITE 6

The planting site is in the Makawao Forest Reserve, located about 3.4 miles (5.5 km) southwest of the town of Makawao. Latitude is 20° 50′ north and longitude is 156° 16′ west. Elevation is 3200 feet (975 m); aspect is northwest, with a slope of 10 percent. Average annual rainfall is about 90 inches (2285 mm), well distributed throughout the year. It is usually wettest around March and driest around September, but almost any month can be either the wettest or the driest.

The soil is Olinda silty clay loam, developed in volcanic ash. This soil is well drained; permeability is moderately rapid, and runoff is slow to medium. Soil depth to slightly weathered basic igneous rock ranges from 36 to more than 60 inches (90 to over 150 cm). The soil is friable when dry, and sticky and plastic when wet. It is strongly acid (pH 5.1 to 5.4).

Strong, desiccating winds and low soil fertility adversely influence seedling survival and growth on this narrow, flat ridge.

Objective—Trials were made to identify fast-growing timber species.

Table 5—*Performance of species planted at Site 5, Koolau Forest Reserve, Maui Island, evaluated after 6.6 years*

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent	*Feet*			*Percent*
PROMISING						
None						
UNSATISFACTORY						
Chukrasia tabularis (India) 331	30	[1] 30	3	1 to 4	0.5	11
Hibiscus elatus (Puerto Rico) 104	30	63	10	1 to 25	1.5	31
Liquidambar formosana (Taiwan) 279	30	97	9	1 to 17	1.8	24
Mansonia altissima (Ghana) 254	30	63	4	1 to 9	0.6	5
Pinus kesiya (Viet Nam) 163	30	3	28	–	4.2	100
Pterocarpus echinatus (Philippine I.) 5	30	77	11	1 to 29	1.7	30
Tectona grandis (New Britain) 406	30	73	6	1 to 15	0.9	0

FAILURES

Chlorophora excelsa 67
Cordia alliodora 264
Entandrophragma utile 186
Gyrocarpus americanus 328
Juglans boliviana 338
Swietenia macrophylla 336

[1] Age 6.1 years.

Results and Recommendations—Twenty-nine species were tested (*table 6*). Three of these species—*Eucalyptus saligna, Araucaria angustifolia,* and *Tabebuia heterophylla*—were represented by two provenances each. After 4.5 years, nine species, including both provenances of *Eucalyptus saligna,* were rated promising. This trial included eight species of eucalyptus, six of which proved adapted to the site. Three coniferous species were rated promising. *Callitris endlicheri* and *Pinus elliottii* grew equally well. Although survival of *Pinus occidentalis* was less than desirable, the vigor expressed by several individuals indicates that this species is adapted to this site. These nine species are recommended for pilot scale plantings.

SITE 7

The planting site is in the Kula Forest Reserve, about 0.8 mile (1.3 km) northeast of Poli-poli Spring State Park. Latitude is 20° 42′ north, and longitude is 156° 19′ west. The site is on the leeward slope of Mt. Haleakala, a dormant volcano. The elevation is 6360 feet (1940 m); aspect is west, with slopes of from 5 to 38 percent. Mean annual rainfall is about 40 inches (1000 m), but the yearly total varies greatly from year to year. The rainy season is from October to March, when storms usually bring heavy rains. The rest of the year may be very dry. The mean annual temperature is 53° F (12° C). Frosts occur occasionally during the winter. Cloud cover or fog is almost a daily occurrence and influences plant growth. Strong winds commonly cause windthrow where the soil is shallow.

The soil is Laumaia loam, shallow phase, developed from volcanic ash and cinders. It is well drained, permeability is moderately rapid, and runoff is slow. Soil depth is 14 inches (36 cm) to cinders and sand. Some cementation is present and hinders root penetration. This soil is very low in phosphorus, but moderately high in calcium. It is medium acid to slightly acid (pH 5.9 to 6.5).

Table 6—*Performance of species and provenances planted at Site 6, Makawao Forest Reserve, Maui Island, evaluated after 4.5 years*

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent	*Feet*			*Percent*
PROMISING						
Callitris endlicheri (Australia) 330	15	100	12	8 to 17	2.7	100
Eucalyptus botryoides (Uruguay) 366	30	63	19	5 to 31	4.2	94
Eucalyptus microcorys (Brazil) 318	15	53	16	5 to 26	3.6	100
Eucalyptus punctata (Uruguay) 368	30	93	15	4 to 30	3.3	89
Eucalyptus saligna (Hawaii) 345	30	33	25	11 to 35	5.6	90
(Uruguay) 369	30	97	24	6 to 37	5.3	100
Eucalyptus sideroxylon (Uruguay) 372	15	93	19	3 to 26	4.2	92
Eucalyptus tereticornis (Uruguay) 373	30	87	14	3 to 26	3.1	76
Pinus occidentalis (Dominican Rep.) 326	30	50	11	3 to 20	2.4	100
UNSATISFACTORY						
Dalbergia sissoo (India) 403	15	100	5	3 to 7	1.1	80
Eucalyptus camaldulensis (Australia) 444	30	83	11	4 to 24	2.4	76
Eucalyptus deglupta (New Guinea) 350	30	83	6	2 to 13	1.3	24
Liquidambar formosana (Taiwan) 279	29	100	5	3 to 8	1.1	100
Pinus brutia (Turkey) 436	12	100	7	5 to 12	1.6	100

FAILURES:

Apeiba membrancea 382
Araucaria angustifolia 349, 431
Cardwellia sublimis 401
Castanospermum australe 285
Cedrela tonduzii 408
Chukrasia tabularis 331
Manikara hexandra 289
Melia dubia 286
Phoebe porosa 412
Pterocarpus echinatus 5
Pterocarpus santalinus 332
Swietenia macrophylla X mahagoni 445
Tabebuia heterophylla 211, 271
Tectona grandis 386
Terminalia ivorensis 180

Strong winds, long dry periods, and shallow soil are the major factors adversely influencing tree growth.

Objective–Trials were made to identify species suitable for the development of multiple use forests; timber products, recreation, and watershed management.

Results and Recommendations–Nine species were tested, and four were rated as promising after 5.6 years (*table 7*). Three species made satisfactory growth and showed good vigor on this poor site–*Pinus durangensis, P. elliottii,* and two provenances of *P. kesiya.* Stem quality of these species was poor. Some individuals were overtopped by faster growing trees, others were damaged by strong winds. *Pinus engelmannii* proved to be a hardy species, and although growth was slow–1 foot (0.3 m) per year–the trees show good stem form. Planted on the deeper, modal Laumaia soil, these four species could prove useful. They are recommended for inclusion in pilot-scale planting trials.

At age 3 years, all of the *Pinus caribaea* were rated as vigorous and height growth was satisfactory. At age 5.6 years, however, two-thirds of the survivors were sickly.

Table 7–*Performance of species and provenances planted at Site 7, Kula Forest Reserve, Maui Island, evaluated after 5.6 years*

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent	*Feet*			*Percent*
PROMISING						
Pinus durangensis (Mexico) 23	30	57	14	3 to 24	2.5	82
Pinus elliottii (Georgia) 52	30	83	14	5 to 19	2.5	68
Pinus engelmannii (Mexico) 25	30	77	6	2 to 11	1.1	91
Pinus kesiya (Viet Nam) 163	30	60	13	6 to 19	2.3	83
(Thailand) 188	30	63	11	5 to 17	2.0	84
UNSATISFACTORY						
Pinus caribaea (Bahama I.) 184	30	60	13	9 to 17	2.3	33
Pinus oocarpa (Mexico) 32	30	37	4	1 to 8	0.7	36

FAILURES: *Eucalyptus saligna* 414; *Tetraclinis articulata* 168; *Tristania conferta* 346.

Molokai Island

SITE 8

The planting site is in the Molokai Forest Reserve, 5.7 miles (9.1 km) northeast of the coastal town of Kaunakakai. Latitude is 21° 9′ north and longitude is 156° 58′ west. The elevation is 2350 feet (716 m); aspect is southwest, with slopes of from 5 to 20 percent. Average annual rainfall is about 40 inches (1000 mm), mostly occurring during the period from October through February.

The soil is Olelo silty clay, formed in material derived from basic igneous rock. It is well drained, permeability is moderately rapid, and runoff is slow. Olelo soil is hard and friable when dry, and very sticky and plastic when wet. It is very strongly acid (pH 4.5 to 5.0).

Strong winds, dry periods, low soil fertility, and competing shrubs are factors limiting tree growth on this site.

Objective–Trials were made to identify tree species useful for erosion control, timber production, and recreational forests.

Results and Recommendations–By the end of the third year none of the 13 species planted proved

adapted to the site (*table 8*). Adjacent plantings of *Pinus taeda, P. elliottii,* and *Eucalyptus saligna* planted by the Hawaii Division of Forestry have grown well. Additional adaptability trials have been established in this area.

Table 8–*Species planted at Site 8 Molokai Forest Reserve, Molokai Island, evaluated after 3 years*

FAILURES

Cedrela odorata 208
Cedrela tonduzii 408
Chlorophora excelsa 217
Chukrasia tabularis 331
Dalbergia sissoo 407
Liquidambar formosana 279
Melia dubia 286
Pinus occidentalis 326
Tabebuia heterophylla 271
Taxodium distichum 182
Tectona grandis 406
Tetraclinis articulata 168
Tristania conferta 346

SITE 9

The planting site is in the Molokai Forest Reserve, 6.7 miles (10.8 km) northeast of the coastal town of Kaunakakai. Latitude is 21° 8′ north and longitude is 156° 56′ west. The elevation is 3250 feet (990 m); aspect is northwest, with slopes of from 4 to 8 percent. Annual rainfall varies greatly from year to year, averaging about 60 inches (1525 mm). There is generally a dry period between June and October.

The soil is Kahanui gravelly silty clay, developed in material weathered from basic igneous rock. It has a discontinuous ironstone sheet at a depth of 12 to 24 inches (30 to 60 cm), which is impermeable to roots. This soil is moderately well drained; permeability is moderately rapid above the ironstone sheet, and runoff is slow to medium. The soil is very strongly acid throughout the profile (pH 4.5 to 5.0), and is deficient in all essential soil nutrients. Trees on this soil develop flat root systems and are subject to windthrow.

Objective–Trials were made to identify tree species useful for timber production.

Results and Recommendations–Thirteen species were tested; four of these proved promising on this poor site after 5.8 years (*table 9*). Some of the taller trees were windthrown. *Eucalyptus robusta* was included in this planting trial because it was not anticipated that more useful species would grow well, and *E. robusta* is known locally for its ability to grow on wet, poorly drained soils. The annual height growth of both this species and *E. botryoides* was about 6 feet (1.8 m). The most outstanding individual was an *E. botryoides* tree that grew 59 feet (18 m) tall in 6 years.

Acacia melanoxylon and *Liquidambar formosana* grew 3.6 and 2.1 feet (1.1 and 0.6 m) in height, annually. These two species, together with the two eucalypts, are recommended for pilot-scale plantings. All should exhibit better form and resist windthrow when grown under closed stand conditions. Site preparation should include deep plowing to break through the ironstone sheet that hinders normal root development.

Table 9–*Performance of species planted at Site 9, Molokai Forest Reserve, Molokai Island, evaluated after 5.8 years*

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent	*Feet*			*Percent*
PROMISING						
Acacia melanoxylon (California) 1	10	70	21	11 to 31	3.6	71
Eucalyptus botryoides (Uruguay) 366	30	67	35	10 to 59	6.0	80
Eucalyptus robusta (Brazil) 322	15	73	34	23 to 45	5.9	81
Liquidambar formosana (Taiwan) 279	30	97	12	5 to 16	2.1	96
UNSATISFACTORY						
Chamaecyparis thyoides (Virginia) 172	15	20	9	7 to 10	1.6	33
Tristania conferta (Hawaii) 346	30	40	10	1 to 17	1.7	66

FAILURES:

Chlorophora excelsa 354
Chukrasia tabularis 331
Cordia alliodora 264
Melia dubia 286
Pinus occidentalis 326
Tectona grandis 406
Terminalia ivorensis 180

Oahu Island

SITE 10

This planting site is on the Lualualei Naval Magazine, on the dry leeward coast 4 miles (6 km) east of Waianae. Latitude is 21° 27′ north and longitude is 158° 07′ west. The elevation is 250 feet (76 m); aspect is west, and the topography is nearly level. The annual rainfall is about 20 inches (500 mm), mostly occurring between November and April. There are often prolonged dry periods during the summer months.

The soil is Lualualei clay, developed in alluvium and colluvium. It is well drained, and permeability and runoff are slow. When wet, this montmorillonitic soil is very sticky and very plastic. During dry periods it becomes very hard and cracks develop, often to depths of 3 feet (1 m) and widths of from 1 to 4 inches (2 to 10 cm) (McCall 1973). Plant roots may be broken by soil shrinkage. Some roots, however, penetrate to a depth of 5 feet (1.5 m) or more. Lualualei clay is medium acid to neutral (pH 6.0 to 6.6).

Strong winds, long dry periods, the shrink-swell properties of the soil, and vigorous plant competition strongly influence survival and growth of planted trees on this site.

Objective—Trials were made to identify tree species useful for the development of protection forests, for amenity plantings, and to provide shade and shelter for livestock.

Results and Recommendations—Twenty-four species were tested, but only two were rated as promising after 5 years (*table 10*). Only *Eucalyptus camaldulensis* and *Phytolacca dioica* surpassed a desirable annual growth rate of 2 feet (0.6 m) on this dry site. *Eucalyptus camaldulensis* proved outstanding, averaging nearly 4 feet (1.2 m) of height growth per year. *Phytolacca dioica* had high initial mortality (87 percent) but the two surviving trees were vigorous and grew at an annual rate of 2.4 feet in height. This species is also suitable for providing shelter and shade for livestock.

These two promising species are recommended for pilot scale planting trials, where their growth and development under closed stand conditions can be determined. Future introduction trials on this site should again include five species that had fairly good survival and vigor, although growth was slow: *Callitris endlicheri, Cordia subcordata, Gyrocarpus americanus, Melia azedarach,* and *Tetraclinis articulata.* Two eucalypts, *Eucalyptus punctata* and *E. tereticornis,* suffered high initial mortality, and should also be tested again.

Table 10—*Performance of species and provenances planted at Site 10, Lualualei, Oahu Island, evaluated after 5.0 years*

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent		*Feet*		*Percent*
PROMISING						
Eucalyptus camaldulensis (Uruguay) 245	30	57	19	7 to 30	3.9	94
Phytolacca dioica (Argentina) 259	15	13	12	9 to 15	2.4	100
UNSATISFACTORY						
Berrya cordifolia (Ceylon) 314	30	17	3	2 to 4	0.6	100
Callitris endlicheri (Australia) 330	28	11	6	5 to 8	1.2	100
Cordia subcordata (Hawaii) 449	15	47	6	4 to 9	1.2	71
Gyrocarpus americanus (Kenya) 328	30	63	5	3 to 8	1.1	89
Melia azedarach (Cyprus) 261	15	60	6	4 to 9	1.2	88
Tectona grandis (Australia) 406	30	33	7	1 to 11	1.4	80
Tetraclinis articulata (Tunisia) 168	30	7	5	4 to 5	1.0	100
Thespesia populnea (Hawaii) 448	15	13	6	3 to 8	1.2	50

FAILURES:

Chlorophora excelsa 354
Cordia alliodora 177, 264
Cupressus sempervirens 169
Dalbergia sissoo 407
Eucalyptus camaldulensis 367
Eucalyptus macrorrhyncha 443
Eucalyptus punctata 368
Eucalyptus tereticornis 373
Liquidambar formosana 325
Pinus brutia 438
Roseodendron donnell-smithii 272
Swietenia macrophylla 336
Tabebuia heterophylla 271
Tristania conferta 346

SITE 11

This planting site is at the Lualualei Naval Magazine, 5 miles (8 km) east of Waianae. Latitude is 21° 27′ north, and longitude is 158° 07′ west. The elevation is 580 feet (177 m); aspect is west, with a slope of 12 percent. The mean annual rainfall is about 28 inches (700 mm), mostly occurring between November and April. There are prolonged dry periods during the summer months.

The soil is Lualualei clay, stoney phase, developed in alluvium and colluvium (USDA 1972). This soil is well drained; permeability and runoff are slow. This montmorillonitic soil is very sticky and very plastic when wet. During dry periods the soil becomes very hard, and cracks develop, often to depths of 3 feet (1 m) and from 1 to 4 inches (2 to 10 cm) in width (McCall 1973). Plant roots may be broken by this soil shrinkage. Some roots, however, penetrate to depths of 5 feet (1.5 m) or more. Lualualei clay, stony phase, is medium acid to neutral (pH 5.8 to 7.0). It differs from the soil at Site 10 in that there are many stones and boulders on the surface and throughout the profile.

Strong winds, extended dry periods, the shrink-swell properties of the soil, and vigorous plant competition strongly influence survival and growth. Also, on occasion, small trees are damaged by giant African snails (*Acnatina fulica* Bowditch).

Objective–Trials were made to identify tree species useful for the development of protection forests, and to evaluate their potential for timber, amenity plantings, and Christmas trees.

Results and Recommendations–Nineteen species were tested, 11 of which were judged promising after 5.6 years (*table 11*). *Eucalyptus camaldulensis* and *Phytolacca dioica* were the most promising species in height growth, averaging 27 feet (8 m) and 23 feet (7 m) respectively. *Eucalyptus camaldulensis* appears useful for protection forest development and for timber, fuelwood, and wood fiber production. *Phytolacca dioica* appears ideal for livestock shelter and shade, and for amenity plantings.

Cordia alliodora, Swietenia macrophylla, Tectona grandis, and *Tetraclinis articulata* are among the species that performed satisfactorily. *Tectona grandis* is included in this group despite its relatively slow growth (for this species); its success is contingent

Table 11–*Performance of species planted at Site 11, Lualualei, Oahu Island, evaluated after 5.6 years*

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent	*Feet*			*Percent*
PROMISING						
Araucaria columnaris (Hawaii) 453	30	30	5	1 to 9	0.9	77
Callitris endlicheri (Australia) 330	30	20	12	4 to 16	2.1	83
Cordia alliodora (Costa Rica) 264	30	77	11	5 to 21	2.0	82
Cordia subcordata (Hawaii) 449	15	100	7	2 to 12	1.2	66
Eucalyptus camaldulensis (Uruguay) 367	15	73	26	15 to 38	4.6	90
Phytolacca dioica (Argentina) 259	15	87	23	18 to 29	4.1	100
Roseodendron donnell-smithii (Puerto Rico) 272	5	60	8	2 to 11	1.4	100
Swietenia macrophylla (British Honduras) 336	5	60	15	13 to 19	2.7	100
Tectona grandis (Australia) 406	30	100	11	3 to 19	2.0	93
Tetraclinis articulata (Tunisia) 168	24	71	8	4 to 13	1.4	82
Thespesia populnea (Hawaii) 448	15	93	11	6 to 14	2.0	100
UNSATISFACTORY						
Berrya cordifolia (Ceylon) 314	15	60	8	5 to 14	1.4	66
Cedrela odorata (Trinidad W.I.) 208	15	73	13	8 to 18	2.3	90
Chlorophora excelsa (Uganda) 354	30	83	9	3 to 16	1.6	84
Dalbergia sissoo (India) 407	15	67	11	4 to 22	2.0	60
Tabebuia heterophylla (Puerto Rico) 271	15	20	6	4 to 8	1.1	33
Tristania conferta (Hawaii) 346	30	50	18	8 to 23	3.2	100

FAILURES: *Liquidambar formosana* 325; *Pinus brutia* 438.

upon continuous weedings until it overtops the brush.

Thespesia populnea and *Cordia subcordata,* small trees valued for craftwood, grew well enough to merit further plantings; *Callitris endlicheri,* which also produces valuable wood (Streets 1962), had high initial mortality but survivors have satisfactory growth, vigor, and stem form. Two of the three surviving *Roseodendron donnel–smithii* trees were vigorous and averaged 11 feet (3.4 m) tall. This species–gold tree–is one of the most beautiful of the large ornamental trees planted in the tropics. *Araucaria columnaris,* valued as a handsome ornamental and for Christmas trees, is promising even though it grew slowly. Its color and general attractiveness could be improved with fertilizer applications.

Tristania conferta and *Dalbergia sissoo* looked very promising initially, but are now rated as unsatisfactory. Mortality in *Tristania conferta* was caused by severe droughts and subsequent attacks by wood borers. The growth rate of *Dalbergia sissoo* has decreased greatly during the last 2.5 years. *Cedrela odorata* and *Chlorophora excelsa* now suffer from terminal dieback, and their value on this site is questioned. *Berrya cordifolia* suffered repeated attacks by the Chinese rose beetle (*Adoretus sinicus* Burmeister).

The 11 species rated as promising after a 5.6-year trial period are recommended for pilot scale plantings on this site.

SITE 12

The planting site is on the Lualualei Naval Magazine, about 5 miles (8 km) east of Waianae. Latitude is 21° 27′ north and longitude is 158° 07′ west. The elevation is 580 feet (177 m); aspect is west with a slope of 12 percent. The mean annual rainfall is about 28 inches (700 mm), mostly occurring between November and April. There are long dry periods during the summer months.

The soil is Ewa silty clay, developed in alluvium derived from basic igneous rock. It is well drained, permeability is moderate, and runoff is slow. This soil is sticky and plastic when wet, but becomes very hard upon drying. Ewa silty clay is medium acid to slightly acid (pH 5.8 to 6.5).

Strong winds during the winter months, extended dry periods, and vigorous plant competition are the major limiting factors for tree growth on this site.

Objective–Trials were made to identify tree species useful for the development of protection forests, and to evaluate their potential for timber and amenity plantings.

Results and Recommendations–Six of the 12 species tested were rated as promising after 6.6 years (*table 12*). *Acacia implexa,* the most promising species averaged 23 feet (7 m) in height. *Acacia melanoxylon,* a tree closely related to *A. implexa* (Streets 1962), failed on this low-elevation dry site. Two conifers, *Callitris endlicheri* and *Tetraclinis articulata,* appear well adapted, growing about 2 feet (0.6 m) in height annually. *Melia azedarach* had high survival and good vigor, but averaged only 1.4 feet (0.5 m) in height growth per year. *Tectona grandis* grew well enough to be utilized in protection forest plantings. *Cordia alliodora, Pithecellobium saman,* and *Pterocarpus echinatus* suffered from terminal dieback, and at present do not appear promising.

Table 12–*Performance of species planted at Site 12, Lualualei, Oahu Island, evaluated after 6.6 years*

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent	*Feet*			*Percent*
PROMISING						
Acacia implexa (Australia) 69	9	78	23	20 to 26	3.5	100
Callitris endlicheri (Australia) 330	18	56	12	5 to 19	1.8	100
Chlorophora excelsa (Uganda) 217	18	72	11	6 to 16	1.7	92
Melia azedarach (Cyprus) 261	18	89	9	5 to 14	1.4	81
Tectona grandis (Australia) 406	18	78	12	2 to 22	1.8	64
Tetraclinis articulata (Tunisia) 168	18	100	13	2 to 16	2.0	94
UNSATISFACTORY						
Cordia alliodora (Costa Rica) 348	18	33	11	4 to 11	1.7	66
Pithecellobium saman (Hawaii) 411	15	80	11	1 to 15	1.7	67
Pterocarpus echinatus (Philippine I.) 5	18	94	10	4 to 16	1.5	76

FAILURES: *Acacia melanoxylon* 98; *Hibiscus elatus* 104; *Tristania conferta* 410.

All six of the species rated as promising are recommended for pilot-scale plantings on this site.

Kauai Island

SITE 13

Two planting sites were on Hawaii Homes Authority lands, about 1 mile (1.6 km) south of the town of Hanalei. Latitude is 22° 11′ north, and longitude is 159° 30′ west. The trials are on upland flats and terraces at elevations between 100 and 200 feet (30 and 60 m). Aspect varies from north to east, with slopes of from 1 to 14 percent. The mean annual rainfall is 100 inches (2540 mm) distributed uniformly throughout the year.

The soil is Hanamaulu silty clay, developed in alluvium washed from upland areas. It is found on stream terraces, and is moderately well drained, permeability is moderately rapid, and runoff is slow. Hanamaulu silty clay is very strongly acid (pH 4.5 to 5.0), with very low soil fertility. Soil nutrient deficiencies are related to the high soil acidity and aluminum toxicity, characteristics of this soil.

Objective—Trials were made to identify tree species suitable for timber production and erosion control.

Results and Recommendations—None of the 31 species planted met our criteria of a promising species (*table 13*). A few individuals of three species—*Acacia melanoxylon, Eucalyptus grandis,* and *Flindersia brayleyana*—exceeded 20 feet (6 m) at age 5.0 years. On the average, growth of all species was disappointing, vigor was poor, and mortality was high. Follow-up pilot scale plantings of *Acacia melanoxylon* and *Flindersia brayleyana* on the same area failed. Correction of the soil nutrient deficiencies appears to be necessary on this site to obtain satisfactory survival and initial growth. Studies on the effects of soil amendments and fertilizers on the growth of selected species, primarily other eucalypts, are recommended for this site.

Table 13—*Performance of species planted at Site 13, near Hanalei, Kauai Island, evaluated after 5 years*

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent		*Feet*		*Percent*
PROMISING						
None						
UNSATISFACTORY						
Acacia melanoxylon (Hawaii) 379	5	40	23	19 to 26	4.6	100
Araucaria columnaris (Hawaii) 239	25	96	2	1 to 4	0.4	45
Cassia siamea (Hawaii) 303	30	17	3	1 to 5	0.6	40
Eucalyptus citriodora (Hawaii) 359	30	23	2	1 to 5	0.4	14
Eucalyptus deglupta (Hawaii) 378	30	23	6	1 to 16	1.2	42
Eucalyptus grandis (Hawaii) 357	30	77	6	2 to 26	1.2	21
Flindersia brayleyana (Australia) 275	25	60	5	1 to 20	1.0	46
Fraxinus uhdei (Hawaii) 361	30	67	3	0 to 10	0.6	35
Gmelina arborea (Ceylon) 196	25	60	3	1 to 6	0.6	46
Hibiscus elatus (Puerto Rico) 104	30	70	2	1 to 6	0.4	0
Khaya nyasica (Hawaii) 358	5	60	3	2 to 4	0.6	33
Liquidambar formosana (Taiwan) 324	10	80	2	1 to 4	0.4	37
Pterocarpus echinatus (Philippine I.) 5	30	80	3	1 to 9	0.6	4
Sindora supa (Philippine I.) 43	5	40	1	1 to 1	0.2	50
Swietenia macrophylla (Hawaii) 238	9	22	3	1 to 4	0.6	50
Terminalia ivorensis (Nigeria) 204	30	53	2	1 to 4	0.4	31

FAILURES:

Agathis australis 213
Amburana sp. 89
Castanospermum australe 185
Cedrela odorata 208
Chlorophora excelsa 67
Cordia alliodora 177
Dacrydium cupressinum 270
Eucalyptus pilularis 360
Mansonia altissima 254
Pericopsis elata 255
Pithecellobium saman 237
Roseodendron donnell-smithii 301
Serialbizzia acle 102
Terminalia superba 80
Toona ciliata v. *australis* 362

SITE 14

The planting site is on the Lihue-Koloa Forest Reserve, 8 miles (13 km) west of the coastal town of Kapaa. Latitude is 22° 03′ north, and longitude is 159° 27′ west. The elevation is 720 feet (220 mm); aspect is northeast, with slopes of from 0 to 5 percent. Annual rainfall averages about 100 inches (2540 mm), but varies greatly from year to year.

The soil is Hanamaulu silty clay, developed in alluvium washed from upland areas. It is found on stream terraces, and is moderately well drained, permeability is moderately rapid, and runoff is slow. Hanamaulu silty clay is very strongly acid (pH 4.5 to 5.0) and very infertile. It is not as well drained and not as deep as the Hanamaulu soil on Site 13.

Objective–Trials were made to identify tree species suitable for timber production.

Results and Recommendations–Twelve species were tested, but only three showed promise for timber production after 5 years (*table 14*). *Eucalyptus camaldulensis* had a mean annual growth of 10 feet (3 m). *E. deglupta* averaged 5 feet (1.5 m) of height growth annually even though several trees were overtopped by their neighbors. *Liquidambar formosana* exhibited satisfactory growth and high vigor but the provenance tested had poor stem form–that is, multiple stems and forks–limiting its value as a timber tree.

Acacia melanoxylon made satisfactory height growth, but at age 5 years, the trees appeared sickly and were dying. *Cardwellia sublimis* grew well–nearly 4 feet (1.2 m) per year–but had very poor form. *Tectona grandis* had high survival, but stem form was poor.

Eucaluptus camaldulensis and *E. deglupta* should be further tested in pilot scale plantings on this site. *Liquidambar formosana* should also be included, if seed from superior mother trees on Taiwan can be obtained.

SITE 15

The planting site is on the Lihue-Koloa Forest Reserve, about 7.2 miles (11.6 km) west of Kapaa. Latitude is 22° 04′ north and longitude is 159° 26′ west. The elevation is 780 feet (238 m); aspect is east, with slopes of from 2 to 5 percent. Annual rainfall averaged 116 inches (2950 mm) between 1919 and 1966. Extremes recorded during this period ranged from 59 inches (1500 mm) to 151 inches (3835 mm).

The soil is Halii gravelly silty clay, developed in material weathered from basic igneous rock and mixed with volcanic ash. It is well drained, permeability is moderately rapid, and runoff is slow. The shallow surface horizon contains ironstone gravel and a coarse sand. This soil is extremely acid to very strongly acid (pH below 4.5 to 4.6).

The principal factors which adversely affect seedling survival and subsequent growth on this site are low soil fertility and severe weed competition.

Objective–Trials were made to identify tree species suitable for timber production.

Table 14–*Performance of species planted at Site 14, Lihue-Koloa Forest Reserve, Kauai Island, evaluated after 5 years*

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent		*Feet*		*Percent*
PROMISING						
Eucalyptus camaldulensis (Uruguay) 367	30	90	51	28 to 73	10.0	92
Eucalyptus deglupta (New Britain) 428	30	77	26	4 to 43	5.1	47
Liquidambar formosana (Taiwan) 279	30	90	19	13 to 28	3.7	100
UNSATISFACTORY						
Acacia melanoxylon (Uruguay) 365	30	47	21	8 to 37	2.7	14
Araucaria angustifolia (Brazil) 431	30	53	3	1 to 9	0.6	43
Cardwellia sublimis (Australia) 401	15	20	20	18 to 21	3.9	100
Cedrela odorata (Trinidad, W.I.) 208	30	33	9	2 to 28	1.8	20
Chukrasia tabularis (India) 331	30	83	5	1 to 14	1.0	16
Tectona grandis (Costa Rica) 418	30	97	12	1 to 22	2.4	65

FAILURES: *Cordia alliodora* 393; *Pithecellobium saman* 527; *Roseodendron donnell-smithii* 301.

Results and Recommendations—Only three of the 18 species tested indicated promise for timber production (*table 15*). *Eucalyptus deglupta* averaged about 15 feet (4.6 m) in height, an annual increment of 2.6 feet (0.8 m). Heights of 6-year-old *Hibiscus elatus* varied greatly,ranging from 3 to 34 feet (1 to 10 m). The smaller, less vigorous trees suffered from terminal dieback. Stem form of this species was unsatisfactory but should improve if grown under closed stand conditions. This is also true for *Liquidambar formosana.*

Only *Eucalyptus deglupta* is recommended for a pilot scale planting trial on Halii soil when the soil pH is 4.7 or lower. Where the soil pH is higher than 4.7, *Hibiscus elatus* and *Liquidambar formosana* are also recommended. Seeds of these two species should be collected from mother trees of superior form.

SITE 16

The planting site is in the Puu Ka Pele Forest Reserve, on a dry leeward ridge about 16 miles (26 km) northwest of Waimea town. Latitude is 22° 05′ north and longitude is 159° 42′ west. The elevation is 2350 feet (716 m); aspect is west, with a slope of 5 percent. Mean annual rainfall is about 38 inches (965 mm). Long dry periods occur almost every summer.

The soil is Mahana silt loam, developed in volcanic ash. It is well drained, permeability is moderately rapid, and runoff is slow. This soil is highly weathered and extremely erodible. The silty materials in this soil consist largely of iron or titanium minerals, concentrated near the surface. Mahana silt loam ranges in soil acidity from very strongly acid to strongly acid (pH 4.9 to 5.2).

Limiting factors for seedling establishment and growth include the long dry periods, low soil fertility, and shallow soils.

Objectives—Trials were made to identify tree species suitable for erosion control, watershed protection, and recreation forests. Timber production is a secondary consideration on this forest reserve.

Table 15—*Performance of species and provenances planted at Site 15, Lihue-Koloa Forest Reserve, Kauai Island*

Species, seed source, and Hawaii seed lot number	Trees planted	Age	Survival	Height			Good vigor
				Average	Range	Annual growth	
		Years	*Percent*	*Feet*			*Percent*
PROMISING							
Eucalyptus deglupta (Hawaii) 302	30	5.7	97	15	7 to 24	2.6	68
Hibiscus elatus (Puerto Rico) 104	30	5.8	100	17	3 to 34	2.9	83
Liquidambar formosana (Taiwan) 279	30	4.8	97	10	4 to 17	2.1	72
UNSATISFACTORY							
Agathis australis (New Zealand) 269	30	4.8	57	2	1 to 4	0.4	11
Araucaria angustifolia (Brazil) 431	33	4.8	88	3	1 to 9	0.6	82
Cassia siamea (Hawaii) 303	30	5.8	97	10	2 to 28	1.7	58
Chukrasia tabularis (India) 331	30	4.8	50	2	1 to 4	0.4	46
Cordia alliodora (Costa Rica) 177	30	4.8	37	2	1 to 6	0.4	9
Pterocarpus echinatus Philippine I.) 5	30	5.8	97	7	1 to 16	1.2	55

FAILURES:

Castanospermum australe 285
Chlorophora excelsa 67
Entandrophragma utile 186
Flindersia brayleyana 200
Mansonia altissima 254
Melia dubia 286
Pericopsis elata 255
Roseodendron donnell-smithii 301
Swietenia mahagoni 221

Results and Recommendations—Fourteen species were appraised over a 7-year period (*table 16*). Two eucalypts and four conifers grew well, and were rated as promising. *Eucalyptus camaldulensis* grew nearly 6 feet (1.8 m) annually. This species would be a good substitute for the commonly planted *E. saligna* and *E. grandis* at lower elevations on these ridges, where the rainfall is lower. *Eucalyptus punctata* averaged 5 feet (1.5 m) in height growth annually, but generally its vigor and stem form varied greatly. The shade-tolerant *Callitris endicheri,* which grew relatively slowly but exhibited good survival and form, appears suitable for underplanting in eucalyptus plantations. *Pinus kesiya* (Viet Nam provenance), *P. caribaea* var. *bahamensis* and its close relative *P. occidentalis* all grew nearly 5 feet (1.4 m) per year. For several years, one-third of the *P. caribaea* trees exhibited the stem characteristic called "foxtailing"—that is, no lateral branch development. *Eucalyptus tereticornis* had very poor form.

Eucalyptus camaldulensis and *Pinus caribaea* var. *bahamensis* were outstanding species on this site. Pilot-scale planting trials should include these species as well as *P. kesiya* and *Callitris endlicheri. P. occidentalis* should again be tested in species introduction trials, as the few survivors grew rapidly.

Table 16—*Performance of species and provenances planted at Site No. 16, Puu Ka Pele Forest Reserve, Kauai Island*

Species, seed source, and Hawaii seed lot number	Trees planted	Age	Survival	Height			Good vigor
				Average	Range	Annual growth	
		Years	*Percent*	*Feet*			*Percent*
PROMISING							
Callitris endlicheri (Australia) 439	30	4.8	97	10	3 to 14	2.1	96
Eucalyptus camaldulensis (Uruguay) 367	30	4.8	97	28	2 to 42	5.8	89
Eucalyptus punctata (Uruguay) 368	30	4.8	90	24	7 to 39	5.0	62
Pinus caribaea v. *bahamensis* (Bahama I.) 184	30	6.8	83	31	17 to 41	4.6	96
Pinus kesiya (Viet Nam) 163	30	6.0	53	29	21 to 36	4.8	100
Pinus occidentalis (Dominican Rep.) 327	28	6.0	7	29	29 to 29	4.8	100
UNSATISFACTORY							
Eucalyptus tereticornis (Uruguay) 373	30	4.8	83	19	3 to 43	4.0	40
Pinus brutia (Turkey) 436	24	4.8	92	5	3 to 7	1.0	95
Pinus durangensis (Mexico) 111	20	5.8	90	5	2 to 8	0.9	100
Pinus rudis (Mexico) 130	30	5.8	57	3	0 to 7	0.5	82

FAILURES:

Cupressus sempervirens 170
Pinus canariensis 174
Pinus hartwegii 114
Pinus insularis 40
Pinus kesiya 188
Pinus occidentalis 326
Pinus pinaster 339

CONCLUSIONS—A LOOK INTO THE FUTURE

As summarized in the appendix (*table 19*), ten conifers and 32 hardwood species may have use for timber production, craftwood, roadside beautification, protection forests, or brush control. At some of the trial sites, several species grew well; at other sites few or none of the species proved well adapted. The performance of most of the high-quality hardwood species tested was disappointing at most sites. Those high-quality wood species rated unsatisfactory because their survival and growth were somewhat erratic should again be included in subsequent adaptability trials. For these species, intensive silvicultural management practices appear to be both necessary and justified. These practices would emphasize fertilizer treatments and weed control.

We attribute many failures and low vigor to adverse site conditions—for example, low soil fertility, droughts, desiccating winds, and weed competition. Most mortality occurred during the first few months following outplanting. Most species from the humid torrid zones, especially tropical African species, were not at home in Hawaii's cool rain forests.

The next phase in our experimental program for species selection is the establishment of pilot scale

planting trials. In these trials most of the species judged "promising" for timber in our adaptability trials will be grown under closed stand conditions and will be critically evaluated. Concurrent research is needed, including fertilizer trials to assure rapid initial growth, provenance trials to identify the best seed sources for Hawaii's conditions, and propagation of plus trees selected from older forest plantations.

Very recently there has been a great increased demand in the world market for wood fiber. At the same time, the energy crisis has forced a reappraisal of the place of wood for fuel. In today's market fuelwood may be an economically feasible substitute for oil in the production of electricity in Hawaii. Many species which may be adapted to Hawaii's low-quality sites can be used for fiber and fuel. Hawaii's forest lands are capable of growing such products at exceptionally high rates. Many of the eucalypts and true pines, rated promising in this report or proven so in earlier plantings, could help meet this increased demand on the world's forests.

Callitris spp. and other conifers have performed well on arid sites in Hawaii. These deserve greater local recognition for reforesting currently unproductive wildlands.

Close cooperation by research agencies in other countries contributed markedly to the progress of the investigations described here. Continuance of this cooperation, by mutual exchange of information and plant material, will permit increased research productivity along the lines described briefly above.

Although these adaptability trials were designed primarily to screen the initial performance of selected species, further observations and reevaluations are recommended at age 10 years. Losses or damage from disease or from destructive insects, or a radical change in growth, would give cause to revise the performance rating of a species.

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APPENDIX

Table 17--Species index for Hawaii adaptability trials, identifying seed sources, locations where planted by study site number, and performance rating (P, Promising; U, Unsatisfactory; F, Failure)

Species	Hawaii seed lot number	Seed source	Study site number and rating
Acacia implexa Benth.	69	Australia	12-P
A. melanoxylon R. Br.	1	California	9-P
	98	Italy	12-F
	365	Uruguay	3-P, 14-U
	379	Hawaii	13-U
Agathis australis (D. Don in Lamb.) Salisb.	213	New Zealand	2-U, 13-F
	269	New Zealand	15-U
Albizia falcataria (L.) Fosberg	203	Hawaii	1-P
Amburana sp.	89	Peru	2-F, 13-F
Apeiba membrancea Spruce	382	Peru	6-F
Araucaria angustifolia (Bert.) Kuntze	300	Argentina	2-P
	349	Argentina	6-F
	364	Brazil	2-P
	370	Brazil	3-P
	431	Brazil	6-F, 14-U, 15-U
A. columnaris (Forst. f.) Hook	239	Hawaii	1-P, 13-U
	398	Hawaii	2-P
	453	Hawaii	11-P
Berrya cordifolia (Willd.) Burret	314	Ceylon	2-F, 10-U, 11-U
Brosimum sp.	383	Peru	2-F
Callitris endlicheri (Parl.) F.M. Bail.	330	Australia	6-P, 10-U, 11-P, 12-P
	439	Australia	16-P
Cardwellia sublimis F.v.M.	401	Australia	2-U, 3-U, 6-F, 14-U
Cassia siamea Lam.	303	Hawaii	13-U, 15-U
Castanospermum australe A. Cunn.	285	Australia	2-U, 3-U, 6-F, 13-F, 15-F
Cedrela odorata L.	143	Mexico	2-U
	144	Mexico	2-P
	208	Trinidad, W. I.	2-U, 3-U, 8-F, 11-U
C. tonduzii C. DC.	408	Costa Rica	3-U, 6-F, 8-F
Chamaecyparis thyoides (L.) B.S.P.	172	Virginia	9-U

Species	Hawaii seed lot number	Seed source	Study site number and rating
Chlorophora excelsa Benth. & Hook. f.	67	Nigeria	1-U, 2-F, 4-F, 5-F, 13-F, 15-F
	217	Uganda	8-F, 12-P
	354	Uganda	9-F, 10-F, 11-U
Chukrasia tabularis A. Juss.	331	India	2-P, 3-U, 5-U, 6-F, 8-F, 9-F, 14-U, 15-U
Cordia alliodora (Ruiz & Pav.) Oken	177	Cost Rica	2-U, 10-F, 13-F, 15-U
	264	Cost Rica	2-U, 5-F, 9-F, 10-F, 11-P
	348	Costa Rica	3-U, 12-U
	393	Venezuela	2-U, 14-F
	395	Fiji	2-U
C. subcordata Lam.	449	Hawaii	10-U, 11-P
Cupressus sempervirens L.	169	Tunisia	10-F
	170	Tunisia	16-F
Dacrydium cupressinum Soland.	270	New Zealand	13-F
Dalbergia sissoo Roxb.	403	India	6-U
	407	India	3-U, 8-F, 10-F, 11-U
Entandrophragma utile Sprague	186	Ghana	1-F, 4-F, 5-F, 15-F
Eucalyptus botryoides Sm.	366	Uruguay	6-P, 9-P
E. camaldulensis Dehnh.	245	Hawaii	10-P
	367	Uruguay	10-F, 11-P, 14-P, 16-P
	444	Australia	6-U
E. citriodora Hook.	246	Hawaii	1-P
	359	Hawaii	13-U
E. deglupta Blume	227	Australia	2-P
	302	Hawaii	15-P
	350	New Guinea	6-U
	378	Hawaii	13-U
	428	New Britain	14-P
E. grandis (Hill) Maiden	357	Hawaii	13-U
E. macrorrhyncha F.v.M.	443	Australia	10-F
E. microcorys F.v.M.	318	Brazil	6-P
E. pilularis Sm.	360	Hawaii	13-F
E. punctata DC.	368	Uruguay	6-P, 10-F, 16-P
E. robusta Sm.	290	Hawaii	4-P
	322	Brazil	9-P
E. saligna Sm.	240	Hawaii	4-U

Species	Hawaii seed lot number	Seed source	Study site number and rating
	345	Hawaii	6-P
	369	Uruguay	6-P
	414	Hawaii	7-F
E. sideroxylon A. Cunn. ex. Benth.	372	Uruguay	6-P
E. tereticornis Sm.	373	Uruguay	6-P, 10-F, 16-U
Flindersia brayleyana F.v.M.	200	Australia	1-P, 2-U, 4-U, 15-F
	219	Hawaii	1-P, 2-P, 4-P
	375	Australia	13-U
Fraxinus uhdei (Wenzig) Lingelsh.	15	California	2-U
	361	Hawaii	13-U
Gmelina arborea L.	196	Ceylon	13-U
	215	India	4-F
Grevillea robusta A. Cunn.	225	Hawaii	2-P
Gyrocarpus americanus Jacq.	328	Kenya	2-F, 5-F, 10-U
Hibiscus elatus Sw.	104	Puerto Rico	1-P, 2-P, 4-U, 5-U, 12-F, 13-U, 15-P
Juglans australis Griseb.	400	Bolivia	2-U
J. boliviana (C. DC.) Dode	338	Cost Rica	2-U, 5-F
Khaya nyasica Stapf ex Baker f.	358	Hawaii	13-U
Liquidambar formosana Hance	279	Taiwan	3-P, 5-U, 6-U, 8-F, 9-P, 14-P, 15-P
	324	Taiwan	2-P, 13-U
	325	Hong Kong	2-P, 3-U, 10-F, 11-F
Maesopsis eminii Engl.	293	Kenya	2-U
Manilkara hexandra (Roxb.) Dubard	289	Ceylon	6-F
Mansonia altissima A. Chev.	254	Ghana	1-F, 2-F, 4-F, 5-U, 13-F, 15-F
Melia azedarach L.	261	Cyprus	10-U, 12-P
M. dubia Cav.	286	Australia	3-F, 6-F, 8-F, 9-F, 15-F
Pahudia rhomboidea (Blanco) Prain	44	Philippine Islands	1-F, 2-F
Pericopsis elata (Harms) Van Meeuwen	255	Ghana	1-F, 2-F, 4-F, 13-F, 15-F
Phoebe porosa (Nees & Mart.) Mez	412	Brazil	2-U, 3-U, 6-F
Phytolacca dioica L.	259	Argentina	10-P, 11-P

Species	Hawaii seed lot number	Seed source	Study site number and rating
Pinus brutia Ten.	436	Turkey	6-U, 16-U
	438	Afghanistan	10-F, 11-F
P. canariensis C. Sm.	174	Morocco	16-F
P. caribaea Morelet v. bahamensis Barrett & Golfari	184	Bahama Islands	7-U, 16-P
P. durangensis Martinez	23	Mexico	7-P
	111	Mexico	16-U
P. elliottii Engelm.	52	Georgia	6-P, 7-P
P. engelmannii Carr.	25	Mexico	7-P
P. hartwegii Lindl.	114	Mexico	16-F
P. kesiya Royle ex Gord.	40	Burma	16-F
	163	Viet Nam	5-U, 7-P, 16-P
	188	Thailand	7-P, 16-F
P. occidentalis Sw.	326	Dominican Republic	6-P, 8-F, 9-F, 16-F
	327	Dominican Republic	16-P
P. oocarpa Schiede	32	Mexico	7-U
P. pinaster Ait.	339	Hawaii	16-F
P. rudis Endl.	130	Mexico	16-U
Pithecellobium saman (Jacq.) Benth.	237	Hawaii	1-P, 13-F
	411	Hawaii	12-U
	527	Hawaii	14-F
Pterocarpus echinatus Pers.	5	Philippine Islands	1-P, 2-U, 4-F, 5-U, 6-F, 12-U, 13-U, 15-U
P. indicus Willd.	4	Philippine Islands	4-F
P. santalinus L.f.	332	India	3-F, 6-F
Roseodendron donnell-smithii (Rose) Miranda	272	Puerto Rico	2-F, 10-F, 11-P
	301	Hawaii	13-F, 14-F, 15-F
Serialbizzia acle (Blanco) Kosterm.	102	Philippine Islands	1-U, 13-F
Sindora supa Merr.	43	Philippine Islands	1-U, 2-F, 4-F, 13-U
Swietenia macrophylla King	238	Hawaii	13-U
	336	Belize	2-U, 5-F, 10-F, 11-P
S. macrophylla x mahagoni	445	Virgin Islands	6-F
S. mahagoni (L.) Jacq.	221	Hawaii	1-P, 15-F
	258	Hawaii	1-P

Species	Hawaii seed lot number	Seed source	Study site number and rating
Tabebuia heterophylla (DC.) Britton	211	Trinidad W. I.	6-F
	271	Puerto Rico	2-P, 3-U, 6-F, 8-F, 10-F, 11-U
Taxodium distichum (L.) Rich.	161	Mississippi	2-F
	182	Florida	8-F
Tectona grandis L. f.	164	Malaya	1-P, 2-U
	386	Peru	6-F
	406	New Britain	5-U, 8-F, 9-F, 10-U, 11-P, 12-P
	418	Costa Rica	14-U
Terminalia ivorensis A. Chev.	180	Ghana	2-F, 4-U, 6-F, 9-F
	204	Nigeria	2-U, 13-U
T. superba Engl. & Diels	80	Nigeria	13-F
	179	Ghana	1-U, 2-F, 4-F
Tetraclinis articulata (Vahl) Mast.	168	Tunisia	7-F, 8-F, 10-U, 11-P, 12-P
Thespesia populnea (L.) Soland. ex Corr.	448	Hawaii	10-U, 11-P
Tieghemella heckelii Pierre ex Cheval.	181	Nigeria	2-F
Toona ciliata Roem. var. australis (F.v.M.) C. DC.	362	Hawaii	13-F
Tristania conferta R. Br.	346	Hawaii	7-F, 8-F, 9-U, 10-F, 11-U
	410	Hawaii	12-F

Table 18--Classification of the planting site soil series in four systems[1/]

Island	Site number	Soil series	U. S. Soil Taxonomy subgroup and family[2/]	U. S. Systems of 1938 Great Soil Group[3/]	FAO/UNESCO legend[4/]	French soil classification subgroup[5/]
Hawaii	1	Malama	Typic Tropofolists dysic, isohyperthermic	Lithosols	Dystric Histosols	II/212
Hawaii	2	Honokaa	Typic Hydrandepts thixotropic, isothermic	Hydrol Humic Latosols	Ochric Andosols	IV/221
Hawaii	3,4	Kiloa	Typic Tropofolists dysic, isothermic	Lithosols	Dystric Histosols	II/212
Maui	5	Kailua	Typic Hydrandepts thixotropic, isothermic	Humic Latosols	Ochric Andosols	IV/221
Maui	6	Olinda	Entic Dystrandepts medial, isomesic	Latosolic Brown Forest Soils	Humic Andosols	IV/221
Maui	7	Laumaia	Typic Dystrandepts medial, isomesic	Latosolic Brown Forest Soils	Humic Andosols	IV/222
Molokai	8	Olelo	Humoxic Tropohumults clayey, oxidic, isothermic	Humic Ferruginous Latosols	Humic Acrisols	X/231
Molokai	9	Kahanui	Petroferric Acrohumox clayey, ferritic, isothermic	Humic Ferruginous Latosols	Humic Ferralsols	X/313
Oahu	10,11	Lualualei	Typic Chromusterts very fine, montmorillonitic, isohyperthermic	Dark Magnesium Clays	Chromic Vertisols	III/111
Oahu	12	Ewa	Torroxic Haplustolls fine, kaolinitic, isohyperthermic	Low Humic Latosols	Haplic Phaeozems	VI/412
Kauai	13,14	Hanamaulu	Tropeptic Umbriorthox clayey, oxidic, isohyperthermic	Humic Latosols	Humic Ferralsols	X/241
Kauai	15	Halii	Typic Gibbsihumox clayey, ferritic, isothermic	Humic Latosols	Humic Ferralsols	X/322
Kauai	16	Mahana	Typic Acrohumox clayey, oxidic, isothermic	Humic Ferruginous Latosols	Humic Ferralsols	X/321

1/ Adapted from Beinroth, Ikawa, and Uehara (1974). This table should be read from left to right only. It should not be used for general correlations of the different units of the four systems.
2/ McCall 1973.
3/ Cline 1955.
4/ FAO 1970.
5/ Commission de Pédologie et de Cartographie des Sols (1967).

Table 19--Tree species identified as promising in species adaptability trials in Hawaii, 1964-74, for timber (T), protection forests (P), amenity plantings (A), Christmas trees (C), craftwood (Cw) or shade and shelter (S)

Species	Hawaii seed lot number	Study site number	Island	Elevation	Annual rainfall	Uses
				Feet	Inches	
Acacia implexa	69	12	Oahu	580	25-30	A,P,T
A. melanoxylon	1	9	Molokai	3250	50-60	T
	365	3	Hawaii	2060	200	T
Albizia falcataria	203	1	Hawaii	100	100	A,T
Araucaria angustifolia	300	2	Hawaii	2100	110	T,A
	364	2	Hawaii	2100	110	T,A
	370	3	Hawaii	2060	200	T
A. columnaris	239	1	Hawaii	100	100	T,A,C,
	453	11	Oahu	580	25-30	A,C
	398	2	Hawaii	2100	110	T,C
Callitris endlicheri	330	11	Oahu	580	25-30	A,P,T
	330	12	Oahu	580	25-30	A,P,T
	330	6	Maui	3200	90	T
	439	16	Kauai	2350	35-40	P
Cedrela odorata	144	2	Hawaii	2100	100	T
Chlorophora excelsa	217	12	Oahu	580	25-30	A,P,T
Chukrasia tabularis	331	2	Hawaii	2100	110	T
Cordia alliodora	264	11	Oahu	580	25-30	P,T
C. subcordata	449	11	Oahu	580	25-30	Cw
Eucalyptus botryoides	366	9	Molokai	3250	50-60	T
	366	6	Maui	3200	90	T
E. camaldulensis	245	10	Oahu	250	15-20	A,P,S
	367	11	Oahu	580	25-30	A,P,T
	367	14	Kauai	720	100	T
	367	16	Kauai	2350	35-40	P,T
E. citriodora	246	1	Hawaii	100	100	A,T
E. deglupta	227	2	Hawaii	2100	110	T
	302	15	Kauai	780	116	T
	428	14	Kauai	720	100	T
E. microcorys	318	6	Maui	3200	90	T
E. *punctata*	368	6	Maui	3200	90	T
	368	16	Kauai	2350	35-40	P,T
E. robusta	290	4	Hawaii	2860	200	T
	322	9	Molokai	3250	50-60	T
E. saligna	345	6	Maui	3200	90	T
	369	6	Maui	3200	90	T
E. sideroxylon	372	6	Maui	3200	90	T
E. tereticornis	373	6	Maui	3200	90	T
Flindersia brayleyana	200	1	Hawaii	100	100	A,T
	219	1	Hawaii	100	100	A,T
	219	2	Hawaii	2100	110	T
	219	4	Hawaii	2860	200	T
Grevillea robusta	225	2	Hawaii	2100	110	A,P,T
Hibiscus elatus	104	1	Hawaii	100	100	A,T
	104	15	Hawaii	780	116	T
	104	2	Hawaii	2100	110	A,T
Liquidambar formosana	279	14	Kauai	720	100	T
	279	15	Kauai	780	116	T
	279	9	Molokai	3250	50-60	T
	279	3	Hawaii	2060	200	T
	324	2	Hawaii	2100	110	A
	325	2	Hawaii	2100	110	A
Melia azedarach	261	12	Oahu	580	25-30	A,P
Phytolacca dioica	259	10	Oahu	250	15-20	P,S
	259	11	Oahu	580	25-30	A,P,S
Pinus caribaea v. bahamensis	184	16	Kauai	2350	35-40	P,T
P. durangensis	23	7	Maui	6360	40	P,T
P. elliottii	52	6	Maui	3200	90	T
	52	7	Maui	6360	40	P,T
P. engelmanii	25	7	Maui	6360	40	P,T
P. kesiya	163	7	Maui	6360	40	P,T
	163	16	Kauai	2350	35-40	P,T
	188	7	Maui	6360	40	P,T
P. occidentalis	326	6	Maui	3200	90	T
	327	16	Kauai	2350	35-40	P,T
Pithecellobium saman	237	1	Hawaii	100	100	A,T
Pterocarpus echinatus	5	1	Hawaii	100	100	A,T
Roseodendron donnell-smithii	272	11	Oahu	580	25-30	A
Swietenia macrophylla	336	11	Oahu	580	25-30	P,T
S. mahagoni	221	1	Hawaii	100	100	A,T
	258	1	Hawaii	100	100	A,T
Tabebuia heterophylla	271	2	Hawaii	2100	110	A
Tectona grandis	164	1	Hawaii	100	100	A,T
	406	11	Oahu	580	25-30	P
	406	12	Oahu	580	25-30	P
Tetraclinis articulata	168	11	Oahu	580	25-30	A,P,T
	168	12	Oahu	580	25-30	A,P,T
Thespesia populnea	448	11	Oahu	580	25-30	Cw

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Whitesell, Craig D., and Gerald A. Walters

1976. **Species adaptability trials for man-made forests in Hawaii.** USDA Forest Serv. Res. Paper PSW-118, 30 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

The performance of 90 species, mostly from the tropics and subtropics, was appraised in field trials for 5 years. Planting sites ranged from near sea level to 6360 feet (1940 m) elevation; rainfall from less than 20 inches to more than 200 inches (500 to 5000 mm); and soils from thin mucks overlaying lava rock to deep, highly leached latosols. Thirty-two hardwoods and 10 conifers were rated as promising for either timber production, watershed production, erosion control, or amenity plantings. Fourteen are native to Australia, and are eucalypts. Few of the high quality timber species tested proved well adapted, with low soil fertility the primary limiting factor. Very few trees died from disease or insect attack.

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