Wood Density and Growth of Some Conifers Introduced to Hawaii

Roger G. Skolmen

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The Author

Roger G. Skolmen's first Forest Service assignment, in 1959, was as a member of the Experiment Station's soil-vegetation survey in Berkeley and Arcata, California. In early 1961, he joined the station's research staff in Honolulu, Hawaii, where he has been investtigating the uses, properties, and processing of forest products. A native of San Francisco, he holds bachelor's and master's degrees in forestry from the University of California, Berkeley.

Each year Hawaii imports 70 to 100 million board feet of lumber. Of this amount, about 92 percent is softwood.[1] Obviously, locally produced softwood construction lumber would find a ready market if it could compete with imports in quality and price.

Since conifers are not native to Hawaii, the need for a local supply of coniferous timber species was recognized as early as the late 1880's (Territory of Hawaii 1903). During the past 80 years many potentially suitable conifers have been introduced and. planted experimentally. Most trial plantings have failed, but a few species have grown well in certain locations and some are now being planted fairly extensively. Stands and stand remnants from the original plantings may be found on all the islands, but most commonly on Hawaii and Maui.

With the growing interest in the quality of wood being produced in Hawaii, the B. P. Bishop Estate in 1952 arranged for tests of Hawaii-grown redwood *(Sequoia sempervirens)* at the U.S. Forest Products Laboratory in Madison, Wisconsin. Redwood from Hawaii was found to be very similar to second-growth redwood from California (Youngs 1960). In 1958 the Forest Products Laboratory tested wood from a slash pine *(Pinus elliottii)* grown near Olinda, Maui.[2] The wood proved to be suited for millwork and pattern stock, but not for construction—the main use of softwood in Hawaii. It resembled sugar pine *(P. lambertiana)* or eastern white pine *(P. strobus)*, rather than normal slash pine, both in appearance and in strength properties. Its specific gravity was 0.35—an excellent indicator of low strength properties. Mainland slash pine has a specific gravity of 0.56; sugar pine, 0.35; and eastern white pine, 0.34.

The exploratory tests of slash pine indicated that growth conditions in Hawaii might produce unusual variations in wood quality. It was necessary to determine the extent of these variations as a guide to forestation programs.

This paper reports on a study of the specific gravity and growth characteristics of 14 coniferous species under several site conditions in Hawaii.

Effects of Environment

Many aspects of the environment in Hawaii are quite different from those of the temperate regions from which most conifers were introduced. The State has a semitropical climate. It is warm throughout the year at low elevations and cool throughout the year at higher elevations. Forests range in elevation from sea level to about 8,000 feet. Seasonal and diurnal temperature fluctuations are small. Daylength (sunlight) varies only about 2 hours from winter to summer. Strong winds are common in many locations throughout the year. Rainfall is extremely variable. Some areas receive 400 inches annually, others less than 20. Some areas are almost constantly shrouded in mist so that sunlight seldom reaches the forest. Soils usually exhibit phosphate deficiency. Potash is also often unavailable owing to a high exchangeable magnesium content. Highly exchangeable manganese may interfere with iron uptake by plants.

Under these variable conditions, many species planted have developed unusual forms. Some are greatly deformed (fig. 1), some have oddly shaped crowns and branching habit, but may still be considered potential timber trees (fig. 2), and others have normal form and grow as well as or better than in their native habitat (fig. 3).

[1] Lucas, E. Evaluation of market data as a guide for forest development in Hawaii. 1963. (Unpublished master's thesis on file at Dept. Agr. Econ. Univ. Hawaii, Honolulu.)

[2] Bohr, A. W. A few strength tests on *Pinus elliottii* from Hawaii. 1958. (Unpublished report on file at Forest Prod. Lab., U.S. Forest Serv., Madison, Wis.)

Because environment affects tree growth, it probably also affects wood quality. Wood within the live crown portion of stems has a lower specific gravity than wood near the base of high-crowned trees (Larson 1962). Thus, the wood of open-grown trees, with live crowns extending to the ground, will have a lower specific gravity at breast height than the wood of short-crowned trees in dense stands. Crown size and vigor also affect specific gravity; thus, dominant trees generally produce less dense wood than somewhat suppressed trees.

Intraspecific variation within the wide ranging species brought to Hawaii is an important factor. For example, lowland variants planted at higher elevations will have a longer growing season than trees native to the higher elevation, and thus will produce weaker wood (Larson 1962). In Hawaii, records of seed source for the older plantings, many of which were of species with very broad ranges, are not available.

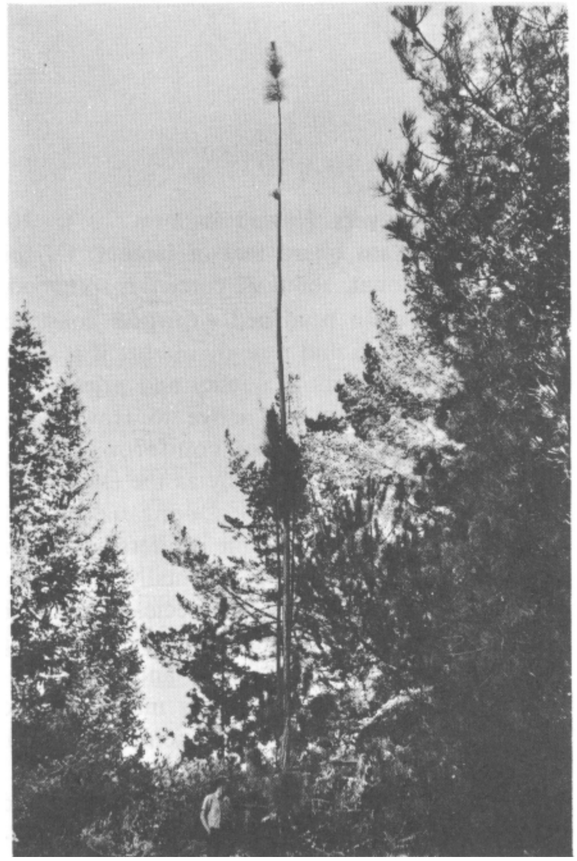


Figure 1.—Longleaf pine at Keanakolu, island of Hawaii. Forty-two feet of clear stem in 28 years. Heredity or environment?

Specific Gravity and Wood Density

Why Measure Specific Gravity?

Specific gravity provides a simple and useful index to several qualities of wood. It is closely related to the mechanical strength of wood—so closely in fact that several strength properties can be estimated from specific gravity alone, at least for well known and thoroughly tested species (U.S. Forest Products Laboratory 1941). Specific gravity also provides some indication of how well wood will perform when painted or glued. Use of specific gravity to compare wood strength between species can only be general.

Wood density has long been the primary criteria in grading southern pine and Douglas-fir *(Pseudotsuga menziesii)* structural lumber. Density is even more important in determination of pulp yields. For every 2-pound increase in wood density, about 1 pound more of Kraft pulp per cubic foot of wood is produced (Mitchell and Wheeler 1959).

To convert specific gravity measurements into density (lbs./cu. ft.), multiply by 62.4 (weight in pounds of a cubic foot of water). The density figure derived from specific gravity measurements made by using the green volume and oven-dry weight is the dry weight of the wood.

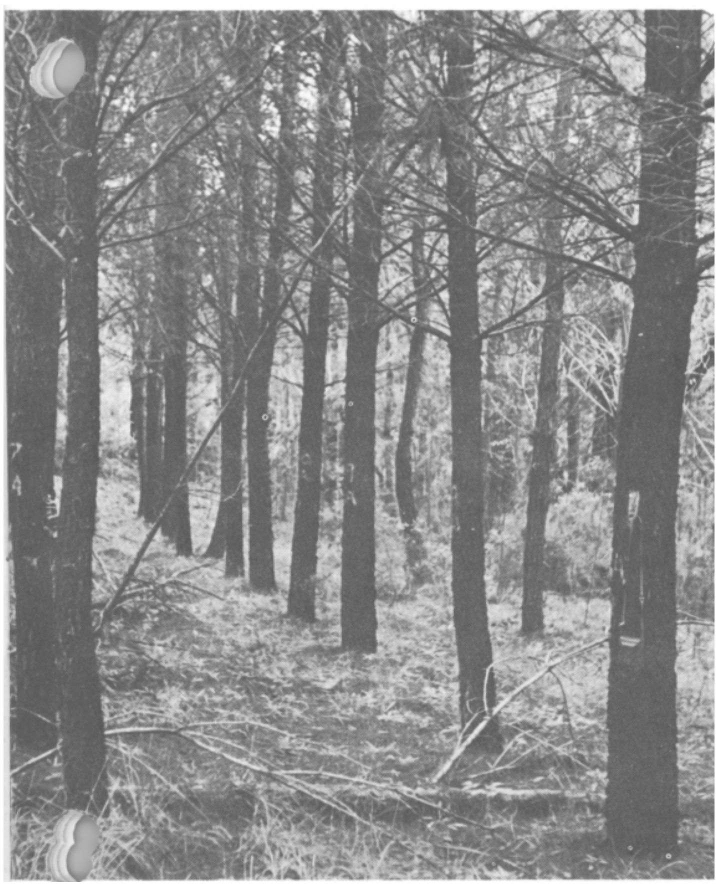
Increment Core Measurement

Measurement of specific gravity by use of increment cores is a system developed in recent years that is now being more and more widely used. Several workers have correlated measurements from cores with those made by conventional methods and found the accuracy of the method to be within acceptable limits when many trees were sampled.[3] The Forest Survey in Mississippi used

[3] Fielding and Brown 1960; Markwardt and Paul 1946; Spurr and Hsiung 1954; Tackle 1962; Wahlgren and Fassnacht 1959.

Figure 2.—Monterey pine at Keanakolu, island of Hawaii. The oddly misshapen crowns are typical of the species in Hawaii.

Figure 3.—Shortleaf pine at Olinda, Maui. At 14 years these trees are far outstripping their mainland counterparts—both in height and in diameter growth.



the method and gathered valuable data on four pine species growing there (Mitchell and Wheeler 1959). Several studies of wood density in southern pines have been made using core measurements (Larson 1957; Zobel and McElwee 1958; Zobel and Rhodes 1955). Cores have been used in Australia for studies of Monterey pine density (Fielding and Brown 1960). They are being used in the western wood density survey to determine density variation in all the more important conifers of the Western United States. A survey of Monterey pine by increment cores is also underway in New Zealand (New Zealand Forest Service 1962).

Specific gravity based on one increment core taken at breast height is not necessarily a true measure of the average specific gravity of the whole stem. The relationship between specific gravity of an increment core at breast height and of the tree has been worked out only for the southern pines (Wahlgren and Fassnacht 1959) and lodgepole pine (Tackle 1962) to date. For other species, core specific gravity merely indicates trends in tree specific gravity. But it is satisfactory for comparing trees of the same species and about the same age. Core specific gravity is closely correlated with tree age so that age must always be considered in comparing trees or stands (Wheeler and Mitchell 1962).

The Study

Procedures

Specific gravity measurements were made by using increment core samples taken at breast height. Only, trees 10 years old and older were bored because wood of very young trees is known to be of atypically low specific gravity. To avoid compression wood, we made borings on the uphill side of trees on slopes or on the side opposite the direction of lean on leaning trees. Cores were trimmed in the field to include a length from cambium to pith. Immediately after cores were extracted, measurements of core length, growth ring width, and amount of summerwood were made in the field.

Standard (0.16—0.18-inch diameter) increment borers calibrated to 0.001 inch were used. This calibration was used as the diameter measurement of the cores in obtaining volume measurements. Length of the cores was measured immediately after extraction to 0.01 inch. In the laboratory, the cores were oven-dried to constant weight and weighed to 0.001 gram. We used individual desiccator bottles to avoid picking up moisture during cooling and weighing. The desiccator bottles were weighed before and after weighing each core.

The distance from the start of springwood of the fifth ring from the pith to the end of summerwood of the tenth ring, and similar distances for rings 15-20, 25-30, and so forth were measured to 0.01 inch. These distances were divided by five to arrive at rings-per-inch. Thus, for trees less than about 20 years old, rings-per-inch measurements were averages of only five rings. In most species these rings were not necessarily annual rings because the total number of rings often exceeded the known age of the trees. With all sampled Jeffrey pine and cluster pine, however, the rings were apparently truly annual.

Percent summerwood was calculated from measurements of summerwood contained within each 5-ring segment to .01 inch. Summerwood boundaries were determined with a 10 X lens, but the cores had not been stained so that measurements were not highly accurate. When we saw compressioriwood in the fresh cores, we recorded it.

Because few trees were available, we attempted to bore a sample of only 10 trees of a species at each location. In manv instances we found fewer than 10 trees owing either to the small number originally planted or, more often, to poor survival. In some cases only one or two trees were bored at a location. This procedure was followed to obtain an indication of wood quality for the species at a particular site, although we recognized that the results would in all likelihood be statistically inadequate.

At each location visited, we noted all coniferous species present. Only species that had produced a form generally acceptable for sawtimber were bored. Site factors, including elevation, precipitation, slope, and aspect, and soil texture, depth, and pH, were recorded for each location. Data recorded for each sample tree included diameter at breast height, total height, height of clear stem (if unpruned), age, spacing, general tree form, crown class, and vigor.

Species and Locations

The age limitation that the trees must be at least 10 years old excluded many recent plantations from consideration. Most *Pinus* spp. Plantings in the State known to contain several surviving trees over 10 years old were visited. These plantings are mostly in arboretums containing a few trees of each species, usually in single isolated rows. Often the pines were planted in mixture with other conifers or hardwoods. Five representative stands of the more widely planted Norfolk-Island-pine *(Araucaria excelsa)* were chosen for sampling. Douglas-fir was sampled at two locations where trees of reasonably acceptable form were found.

The species included in the survey were:

Common name	*Scientific name*
Douglas-fir	*Pseudotsuga menziesii*
Norfolk-Island-pine	*Araucaria excelsa*
Pine, cluster	*Pinus pinaster*
Pine, eastern white	*P. strobus*
Pine, jelecote	*P. patula*
Pine, Jeffrey	*P. jeffreyi*
Pine, loblolly	*P. taeda*
Pine, longleaf	*P. palustris*
Pine, Luzon	*P. insularis*
Pine, Masson	*P. massoniana*
Pine, Monterey	*P. radiata*
Pine, shortleaf	*P. echinata*
Pine, slash	*P. elliottii*
Pine, Yunnan	*P. yunnanensis*

Statistical Analysis[4]

An analysis of variance between different locations was made of the relationships between specific gravity, percent summerwood, and rings-per-inch for each species that had been sampled at two or more locations with five or more observations at each location. Scheffe's test was used to compare the location means because it allowed compensation for unequal sample size.

In a second analysis, by multiple weighted regression, the relationship between the dependent variables of specific gravity, percent summerwood, and rings-per-inch were compared with the independent variables of age, elevation, and annual rainfall. This analysis was made only for Monterey pine, jelecote pine, and Norfolk-Island-pine.

A third analysis, also by weighted regression, was made of the correlation between specific gravity, percent summerwood, and rings-per-inch for the six species: Norfolk-Island-pine, slash pine, jelecote pine, cluster pine, Monterey pine, and loblolly pine. No significant correlation was found for any species except cluster pine. Lack of significant correlation may just reflect the small number of locations sampled, although the correlations were generally of the level found in similar studies. Or, it may be that the sample of rings-per-inch and percent summerwood taken for each core did not truly represent all rings in the core.

Wood Quality and Tree Growth

All specific gravity values reported in this study were based on green volume and oven-dry weight.

Table 1 (appendix) lists information on environment for each location together with average values obtained for each species. Standard deviations for rings-per-inch and percent summerwood were usually very large. The faith that should be placed in the figures on specific gravity, rings-per-inch, and percent of summerwood should be governed by the number of trees sampled to obtain the data. Figures that are averages of numerous trees are more likely to be valid estimates than those that are based on only 20 or 30 cores—or in some cases only one or two cores—because of the large possibility of error induced by the increment core sampling method used. Thus, the Statewide averages are better estimates than the averages for one location.

Norfolk-Island-Pine

(Araucaria excelsa)

Locations: 5 **Trees:** 50

Hawaii core specific gravity (25-50 years)—

Average: 0.434

Range: 0.371–0.537

Wood Quality

Norfolk-Island-pine wood has not been used to any large extent anywhere in the world. Several other species of the genus *Araucaria* are more widely used, notably parana-pine *(A. angustifolia),* Klink araucaria *(A. klinkii),* hoop-pine *(A. cunninghamii),* and bunya-bunya *(A. bidwillii).*

The core specific gravity of Hawaii-grown Norfolk-Island-pine is close to that of hoop-pine (0.437) (Kingston and Risdon 1961). Assuming the core specific gravity is not greatly different from tree specific gravity, this species is not as dense as parana-pine (0.53) (Kukachka 1962), though denser than Klink araucaria (0.38) and bunya-bunya (0.38) (Kingston and Risdon 1961). Norfolk-Island-pine is probably suited to structural use, but physical and mechanical property tests will be required to establish this. Moreover, compression wood, observed in several rings of almost every sample core, may cause seasoning difficulties and problems in use.

Growth

The species grows well in areas below 2,000 feet and having 50 or more inches of rainfall. The Hawaii Forestry Division reports that the trees require tending for 1 to 3 years after planting before they are safely above competing vegetation. Norfolk-Island-pine is subject to epicormic sprouting if the stems are opened to light. Survival as indicated by the plantations examined seemed excellent.

[4] I am indebted to Mrs. R. R. Taylor, geneticist on the staff of the Pacific Southwest Forest and Range Experiment Station, for developing the analytical systems used and for interpreting the machine-processed data.

Figure 4.—Norfolk-Island-pine. An unmanaged 27-year-old plantation at Kukuihaele, Hawaii.

Self-pruning in stands spaced even as widely as 12 by 12 feet is more rapid than with any of the introduced true pines. At 10- by 10-foot spacing and 27 years of age, the length of clear stem of the Kukuihaele stand averaged 10 feet, and height to the first live branch 51 feet. At 12- by 12-foot spacing and 50 years, the Haiku stand had self-pruned to an average of 14 feet and averaged 32 feet to the first live branch.

Slash Pine (*Pinus elliotii*)

Locations: 4 **Trees:** 23

Hawaii core specific gravity (20-29 years, 2 locations)—

Average: 0.423

Range: 0.388–0.522

Native habitat core specific gravity (20-30 years):

0.51 (Mitchell and Wheeler 1959)

Wood Quality

Core specific gravity at the two locations where the species grew in acceptable form was low for the age of the trees. Analysis of variance indicated no significant difference in specific gravity between the two stands.

The strength of the wood can be estimated from available literature (U.S. Forest Products Laboratory 1941; fig. 1). Since green slash pine has a modulus of rupture of 8,900 pounds per square inch at a specific gravity of 0.56, it would be expected to be about 6,200 spin at 0.42. The Hawaii-grown wood is so different from mainland-grown wood that its suitability for structural use should be determined by mechanical property tests at an early date.

Trees at Kalialinui and Keanakolu were too poor in form for sawtimber. The two Keanakolu trees also had wood of extremely low density for this species. The sampled trees at Puu Ohu, a very windy area, had all developed compression wood on their leeward sides.

Figure 5.—Slash pine. Thirty-year-old trees at Olinda, Maui. Jelecote pine is in the background.

Growth

Height growth of dominants at Olinda equaled or excelled growth of the best slash pine sites on the mainland (Barnes 1955; U.S. Department of Agriculture 1929). At Puu Ohu, dominants had grown at a rate equal to better mainland sites. Diameter growth at both locations was quite good.

At Puu Ohu, slash pine exhibited fewer forked tops than loblolly pine, but must still be considered highly susceptible to wind deformation. Self-pruning of the Olinda stand averaged 5.4 feet high. Though good for this age, this was poor when related to diameter, for the trees were mostly already of merchantable size.

Survival of slash pine has varied. It was very good at Puu Ohu and fair at Olinda. These stands were probably never tended. Elsewhere in the State, slash pine has usually failed when grown above 4,000 feet elevation. At lower elevations, such as on Molokai and near the Volcano Road on Hawaii, young slash pine has shown excellent survival in untended stands.

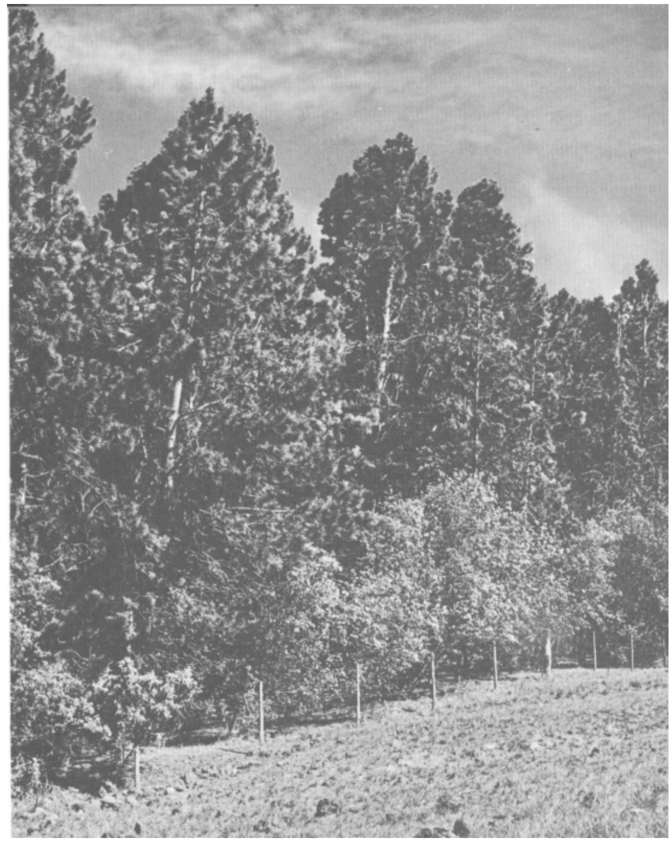


Figure 6.—Jeffrey pine. A 51-year-old plantation at Puu Laau, Hawaii, fenced against feral sheep.

Jeffrey Pine (Pinus jeffreyi)

Locations: 3 **Trees:** 30
Hawaii core specific gravity (51 years)—
Average: 0.472
Range: 0.417—0.542
Native habitat tree specific gravity (all ages):
0.37 (Markwardt and Wilson 1935)

Wood Quality

Wood density was high for this species at all three locations. On the basis of its core specific gravity, the wood should be better suited for structural use than that of mainland-grown Jeffrey pine.

The Hosmer Grove stand lies in an area of much higher rainfall than the other two stands, yet the analysis of variance indicated no significant difference in core specific gravity.

Growth

In comparison with Jeffrey and ponderosa pines in their native habitat, the sampled trees had from average to poor height growth (Dunning and Retneke 1933; Meyer 1938). As would be expected, average height growth was best in the most closely spaced stand, although the open-grown Hosmer Grove trees did almost as well as the closely spaced Puu Laau trees. This may have been a reflection of the better site afforded by the lower elevation and higher rainfall at Hosmer Grove.

Form was good except for excessive taper. The species resisted wind deformation very well. Self-pruning was very poor at 51 years, even at close spacing. Survival seemed satisfactory, though it was not known whether the original seedlings survived or were replaced one or more times after failure.

Jelecote Pine (Pinus patula)

Locations: 6 **Trees:** 52
Hawaii core specific gravity (12 years)
Average: 0.357
Range: 0.311—0.403
Hawaii core specific gravity (18-30 years)
Average: 0.438
Range: 0.314—0.540
South Africa tree specific gravity (8 years):
0.380; (30 years): 0.496 (Scott 1953)
New Zealand tree specific gravity (37 years):
0.370 (Entrican et al. 1957)

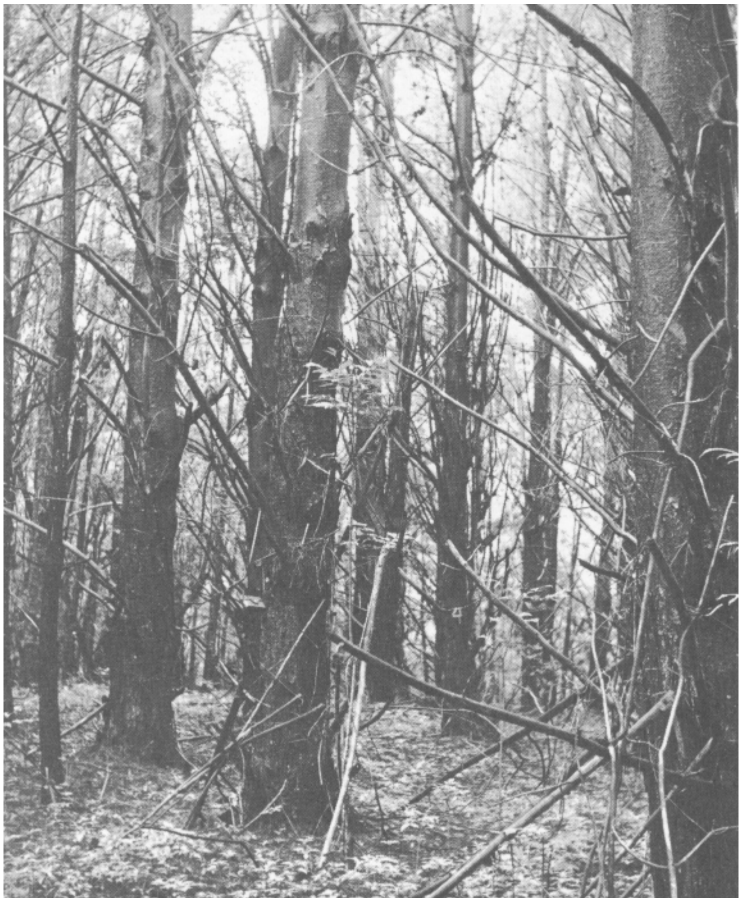


Figure 7.—Jelecote pine. A 30-year-old unmanaged plantation at Olinda, Maui. The steep branch angle is typical of the species in Hawaii.

Wood Quality

Wood density of this species in Hawaii is somewhat lower than that grown in South Africa, but higher than that grown in New Zealand.

Probably because of their young age, trees at Keanakolu differed significantly in mean specific gravity from those at all the other locations.

An analysis of specific gravity, rings-per-inch, and percent summerwood on age, elevation, and rainfall showed significant (5 percent) correlation of age both with specific gravity and with rings-per-inch.

Growth

Height growth of 95-foot dominant trees 28 and 29 years old in the closely spaced stands at Makawao and Poli poll excelled that of trees from New Zealand where a 40-year-old stand achieved 104 feet (Fielding and Brown 1960). The species in Hawaii is extremely susceptible to wind deformation; height growth was good only in areas well sheltered from the wind. Forked and multiple tops were common in all stands, particularly so in windy areas.

Branching habit is very poor. Branches are very steeply angled. Their tips keep up with the tree leader so they are not shaded out even in denser stands. Form is usually very poor because these large, live, steeply angled branches are included in the stem close to the ground.

Survival of this species was quite good in all areas, whether of high or low rainfall, high or low elevations, and tended or untended stands.

Cluster Pine (Pinus pinaster)

Locations: 4 **Trees:** 38

Hawaii core specific gravity (12 years)—
Average: 0.401
Range: 0.370–0.443

Hawaii core specific gravity (24–32 years)—
Average: 0.489
Range: 0.401–0.549

South Africa tree specific gravity (age not given):
0.576 (Scott 1953)

Australia tree specific gravity (age not given):
0.490 (Kingston and Risdon 1961)

Wood Quality

Core specific gravity of the older trees indicated that the wood being produced should be acceptable for structural and other uses. Significant differences in specific gravity are probably related to the age of the trees. Well defined growth rings were produced at all locations. Compression wood may be a problem as the species often produces crooked stems in Hawaii.

Growth

Height growth of this species was less than several other pines in Hawaii (Monterey, jelecote, slash, loblolly), but compares favorably with the superior Leiria (Portuguese) race growing in South Africa. The Leiria had a mean height on 14 plots at 43 years of 71 feet (Scott 1962).

Tree form is acceptable for sawtimber, though slightly crooked stems are common—even in closely spaced stands. Knot swellings are large at the branch whorls and may produce distorted grain for many years after pruning. The species does not self-prune rapidly in Hawaii.

Survival has been quite variable—very good at Olinda and Keanakolu; quite poor in the other two sample locations. The tree was extensively planted at wide spacing at Kalialinui and failed badly probably because of high winds. Survival at Makawao of hundreds of trees outplanted was almost nil. The variable survival probably is not related to soil differences because this species is noted for its ability to withstand poor soils (Scott 1962).

Monterey Pine (Pinus radiata)

Locations: 13 **Trees:** 105

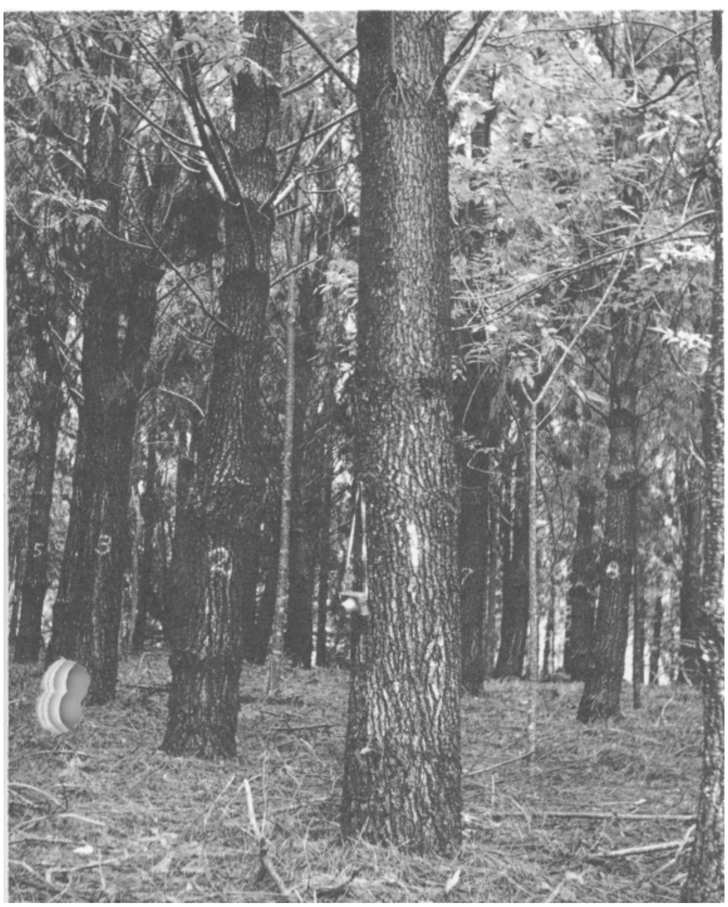
Tree origin:	Specify gravity of trees at— 10-20 years	20-30 years	30-40 years
Hawaii (core)	0.434	0.462	0.503
Australia	.404	—	[1].485
New Zealand	—	[1].400	—
South Africa (age not given)	—	[2].544	—
Native habitat (43-77 years)	—	[3].460	—

[1] Kingston and Risdon 1961.
[2] Scott 1953.
[3] Cockrell 1959.

Wood Quality

Density of Monterey pine was higher over a wider range of site conditions than that of any other species surveyed. In all locations listed except the high elevation Puu Kihe, the samples indicated that the species was producing wood of a density suited to structural purposes. Though the 12-year-old stand at Keanakolu had low density wood, a 28-year-old stand at the same location had wood with a core specific gravity equal to the tree specific gravity of wood produced by mainland trees. Compression wood may be a problem as trees are often crooked or lean. Tree form and branching habit have more effect on wood quality with this species than wood specific gravity.

Figure 8.—Cluster pine. A 32-year-old plantation at Olina, Maui. Pruned in 1945, many trees still show knot bumps.



A regression analysis of age, elevation, and rainfall on specific gravity, rings-per-inch, and percent summerwood and on each other showed that specific gravity, percent summerwood, and rainfall were significantly correlated with elevation. Rings-per-inch and rainfall were highly significantly correlated. All correlations other than rainfall with elevation were negative.

The negative correlation of specific gravity with elevation bears out recent findings in New Zealand where an increment core survey of Monterey pine is underway. Indications there are that highest density wood is found at low elevations and low latitudes regardless of rainfall or soil type—presumably indicating that temperature has a major influence on specific gravity (New Zealand Forest Service 1962, p. 62)—and that wood from phosphate deficient sites is much denser than from nearby normal sites. This relationship might be applicable in Hawaii, where phosphate is often low, and may help explain the high specific gravity found for many of the very fast grown trees.

From these correlations, these conclusions can be drawn: wood grown at lower elevations will have higher density and a higher percent summerwood than that grown higher. Diameter growth (rings-per-inch) will increase (fewer rings-per-inch) as rainfall, increases, but there will not necessarily be any connection between faster growth, percent summerwood, and specific gravity, although rainfall increases as elevation increases.

Growth

Height growth at Kalialinui, in a wind sheltered gulch, was superior to the best sites in the Canterbury Plains, New Zealand (Gorman 1933). Trees at Kapaakea (upper), Olinda, Keanakolu (12 years old), Lalakea, Honuaula, and Poll poli (lower) all also had outstanding height growth. A 34-year-old tree at Poli poli (lower) stood 147 feet tall, with a 36.3-inch d.b.h.; another, 142 feet,

Figure 9.—Monterey pine at Poli Poli, Maui. At 34 years, the seven trees at this site average 37 inches d.b.h. and 142 feet in height.

with 45.6-inch d.b.h. A 23-year-old tree at Honuaula (lower) was 141 feet, with 28.7-inch d.b.h.

Though its growth rate is excellent, the species leaves much to be desired as to form and branching habit (fig. 2). Even in closed stands branches are steeply angled and light-seeking, and live for many years. Multiple tops are usual, though two 16-foot logs are usually produced before the tree forks. Stems sprout after pruning even in low rainfall areas.

Most plantings are small remnants of original plantings of hundreds of trees. This is especially true in those plantations that were not tended for the first few years. Survival with this species is thus highly questionable. At Poli poli, for example, the seven remaining trees are the only survivors of several early plantings that totaled 563 trees.

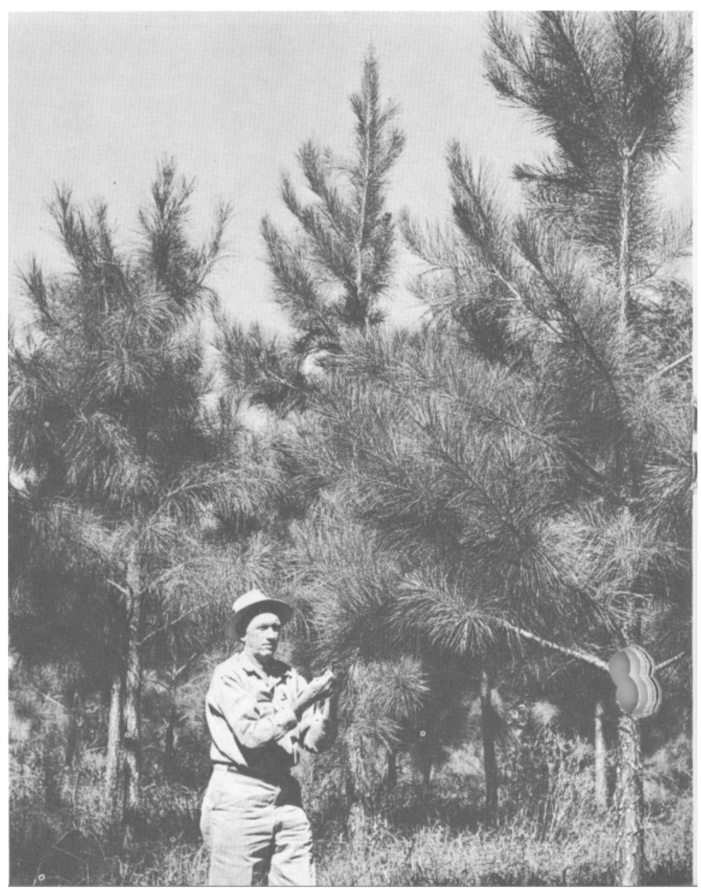
Loblolly Pine (Pinus taeda)

Locations: 4 **Trees:** 38

Hawaii core specific gravity (19–25 years)—
Average: 0.419
Range: 0.333–0.524

Native habitat core specific gravity (19–25 years):
0.48 (Mitchell and Wheeler 1959)

Figure 10.—A 4-year-old mixed planting of loblolly and slash pines on Molokai. The island contains many acres of these young, vigorous stands.



Wood Quality

Only the trees at Aina Hou have produced wood that nearly matches the density of loblolly pine in its native habitat. The specific gravity of trees at Aina Hou was not significantly different from trees at Honuaula and Lalakea. Therefore the wood from sampled trees of this species at the four locations all may be less dense than wood from trees grown in their native habitat and perhaps may not be suitable for structural purposes. This suitability should be determined by mechanical property testing at an early date. Compression wood formation was pronounced at Puu Ohu and will probably be a problem with all trees from windier sites.

Growth

Height growth of dominants and co-dominants at Aina Hou and Lalakea indicated sites equal to the better sites in the Southeastern States (Allen 1960; Czarnowski and Burns 1960). It was slightly lower at Puu Ohu, probably due to wind, and was somewhat below the mainland average at Honuaula (upper). In the windiest area, Puu Ohu, almost every tree was badly forked at 12 to 20 feet, indicating susceptibility of the species to high wind. At Lalakea the trees had been pruned. At the three other locations, the height of limb-free stem averaged 3 feet, with no apparent difference due to spacing difference.

Survival of this species was good except at Honuaula, which is much higher than the other three locations. Loblolly pine has been tried at several areas of 5-6,000 feet elevation in Hawaii and Maui, but has failed almost completely except at Honuaula.

Other Species

Several species were not available in enough numbers or locations to provide more than an indication of trends. Limited data were obtained for seven species (table 9).

Of the seven species, shortleaf pine is the most promising; both wood density and growth were quite good for this species. Though growth was very good for longleaf pine at Olinda, core specific gravity was low. Masson pine also showed excellent growth, but had wood of somewhat low density, steeply angled branches, and rather crooked stems. Although wood density of Douglas-fir was in the range for Douglas-fir from the Rocky Mountains, its height growth in Hawaii was comparable only to the poorest mainland sites.

Other species have had varying success. Luzon pine has been planted extensively in Hawaii and has generally shown very poor survival. Eastern white pine does well and reproduces naturally at Hosmer Grove, but the wood from two trees resembled that from the species in its native habitat. This wood is not particularly well suited for structural use. Yunnan pine may be solely an ornamental; its form and branching habit make it unsuited for sawtimber at the one location where it was observed.

Summary and Conclusions

The results, though based on a limited sample, suggested that Norfolk-Island-pine, cluster pine, and Monterey pine were producing at good growth rates wood that should be suitable for structural use. Although slash pine and loblolly pine were growing well, the few trees available for sampling indicated that they were not producing at the sites occupied wood of a density suited for structural use. Jelecote pine had such poor form in most areas and was producing such low density wood that it is probably unsuited to timber production.

On the basis of this study, shortleaf pine, longleaf pine, Masson pine, and Douglas-fir showed some promise and deserve further trial in Hawaii. Not sampled sufficiently were Luzon pine, eastern white pine, and Yunnan pine. The poor survival of the Philippine pine, the normally rather low density of white pine, and the form of the Chinese pine in Hawaii suggested that there are more suitable species for future trials.

Species requiring tests of mechanical properties to determine how well their wood is suited for structural use are Norfolk-Island-pine, slash pine, cluster pine, Monterey pine, and loblolly pine.

Based on observations in the study, a number of suggestions for management can be given. Early mechanical pruning is essential with all true pine species in order to produce clear wood at the commonly used plantation spacings on the short rotations indicated by the rapid growth rate. But the economic feasibility of this requirement is, of course, questionable. Early high pruning may also reduce too rapid growth where it is limiting to wood density. Closer spacing of planted trees may improve self-pruning.

Protective measures would help plantation establishment. All true pines, except possibly Jeffrey pine, should be shielded from strong winds by natural barriers, close spacing, or planting windbreaks of more vigorous species, such as saligna eucalyptus *(Eucalyptus saligna),* when plantations are established. Planting in areas with a large feral pig population should be avoided. These animals, when in large numbers, were observed to have girdled and killed longleaf pine and to have damaged Monterey pine and loblolly pine.

The success of softwood plantations in Hawaii as a means of watershed protection is quite evident, but their success as a source of timber will remain uncertain for many years to come. Not enough information is available from previous experimental plantings to provide sound guideposts. As a first step in future research, stands should be established from seed selected from trees of superior wood density.

Several important questions directly bearing on the feasibility of softwood production in Hawaii need to be answered. Site selection can be critical because even though most species surveyed were doing well at one or two locations, the same species were doing very poorly at others. Also, most land best suited to conifers is even better suited to one or more quality hardwood species. Not to be ignored is the matter of marketing conifer products.

The basic questions remain: Can Hawaii produce a significant volume of coniferous timber that will compete successfully with the higher grades of softwood lumber from the mainland? Can Hawaii's sawmills produce softwood lumber that will be competitive in price with lumber produced by the large volume mills of the mainland?

I hope this report will contribute some guides to help in making the difficult policy decision of how much money and effort should be put into planting conifers now for future timber production in Hawaii.

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Appendix

Table 1. Stand descriptions and specific gravity data of Hawaii conifers

Island	Location	Eleva-tion	Annual precip-itation	Spacing	Trees sampled	Age	D.b.h.	Height	Rings-per-inch	Standard deviation	Summer-wood	Standard deviation	Core specific gravity	Standard deviation
		Feet	*Inches*	*Feet*	*Number*	*Years*	*Inches*	*Feet*			*Percent*			
		ARAUCARIA EXCELSA (NORFOLK-ISLAND-PINE)												
Hawaii	Kukuihaele	1,800	77	10 x 10	10	27	15.5	106	--	--	--	--	.417	.012
Maui	Mahinahina	2,040	95	12 x 12	10	25	13.3	54	4.3	1.37	37.0	20.28	.445	.028
Maui	Haiku	1,000	50	10 x 14	10	50	21.1	121	5.4	.60	30.1	12.07	.438	.042
Oahu	St. Louis Hts.	1,060	60	12 x 12	10	27	14.0	60	3.1	.65	17.8	8.34	.462	.017
Oahu	Nuuanu	760	95	10 x 10	10	27	13.1	61	3.6	.61	24.95	16.05	.410	.026
		PINUS ECHINATA (SHORTLEAF PINE)												
Maui	Olinda	3,620	50	8 x 8	10	13	8.7	47	5.2	1.40	27.7	9.40	.466	.031
		PINUS ELLIOTTII (SLASH PINE)												
Hawaii	Keanakolu	5,500	110	(1)	2	28	13.8	37	3.7	--	22.8	--	.340	--
Hawaii	Puu Ohu	3,280	40	8 x 8	10	20	12.5	52	5.0	1.23	35.0	8.57	.419	.028
Maui	Olinda	3,620	50	8 x 8	10	29	14.7	84	5.5	1.62	26.0	10.13	.426	.040
Maui	Kalialinui	6,730	104	(1)	1	15	5.6	23	3.5	--	11.3	--	.429	--
		PINUS INSULARIS (PHILIPPINE PINE)												
Hawaii	Keanakolu	5,500	110	(1)	1	21	6.5	32	--	--	--	--	.364	--
Oahu	Round Top Drive	1,400	120	(1)	2	40	32.7	70	--	--	--	--	.539	.109
		PINUS JEFFREYI (JEFFREY PINE)												
Hawaii	Puu Laau	7,500	20	7 x 7	10	51	11.4	48	9.1	2.24	23.1	8.47	.464	.049
Hawaii	Puu Ulaula	9,000	18	12 x 12	10	51	16.1	38	5.5	1.40	22.6	8.35	.469	.032
Maui	Hosmer Grove	6,730	104	(1)	10	52	14.6	47	7.5	2.47	25.6	.6.99	.484	.040
		PINUS MASSONIANA (MASSON PINE)												
Maui	Olinda	3,620	50	8 x 8	10	13	10.0	62	3.9	.97	15.2	4.11	.429	.031
		PINUS PALUSTRIS (LONGLEAF PINE)												
Hawaii	Keanakolu	5,500	110	(1)	3	28	8.6	47	8.5	1.87	13.6	1.06	.421	.035
Maui	Olinda	3,620	50	(1)	6	13	10.2	54	3.4	.85	27.5	5.81	.425	.025

Table 1. Stand desccriptions and specific gracity data of Hawaii conifers, continued

Island	Location	Elevation	Annual precipitation	Spacing	Trees sampled	Age	D.b.h.	Height	Rings-Per-inch	Standard deviation	Summer-wood	Standard deviation	Core specific gravity	Standard deviation
		Feet	*Inches*	*Feet*	*Number*	*Years*	*Inches*	*Feet*			*Percent*			
		PINUS PATULA (JELECOTE PINE)												
Hawaii	Puu Ohu	3,280	40	10 x 10	2	20	12.9	27	3.3	0.40	39.2	9.10	.395	.012
Hawaii	Keanakolu	5,500	110	10 x 12	10	12	8.5	35	2.4	1.36	17.6	3.92	.357	.030
Maui	Poli poli (lower)	5,280	42	6 x 8	10	28	13.9	85	8.2	2.48	23.9	7.31	.419	.031
Maui	Olinda Road	2,630	75	7 x 7	10	18	11.7	53	4.1	1.61	23.6	10.24	.423	.052
Maui	Olinda	3,620	50	8 x 8	10	30	13.8	77	6.5	1.77	30.9	8.50	.437	.044
Maui	Makawao	2,200	100	6 x 8	10	29	13.6	89	5.0	2.37	26.8	6.86	.472	.051
		PINUS PINASTER (CLUSTER PINE)												
Hawaii	Keanakolu	5,500	110	10 x 12	10	12	7.4	36	2.3	.56	30.1	14.49	.397	.017
Hawaii	Honuaula (upper)	6,250	50	10 x 20	8	12	6.7	26	2.4	.29	19.5	4.36	.404	.021
Maui	Poli poli (upper)	6,200	42	(1)	10	24	14.8	56	3.8	1.50	10.3	3.12	.464	.041
Maui	Olinda	3,620	50	8 x 10	10	32	13.6	70	6.5	1.42	28.3	8.80	.514	.034
		PINUS RADIATA (MONTEREY PINE)												
Hawaii	Keanakolu	5,500	110	(1)	10	28	22.9	75	2.6	.95	16.3	5.80	.466	.028
Hawaii	Keanakolu	5,500	110	10 x 12	10	12	7.1	42	2.1	.39	13.4	8.40	.340	.024
Hawaii	Honuaula (lower)	5,200	60	10 x 20	10	23	19.7	100	3.5	1.79	23.9	8.99	.458	.029
Hawaii	Puu Kihe	7,800	45	(1)	5	16 & 30	12.7	40	3.5	.92	10.0	4.90	.377	.107
Hawaii	Lalakea	2,750	70	(1)	2	25	19.4	90	2.1	.40	18.2	2.29	.480	.013
Hawaii	Nina hou	2,900	84	10 x 12	1	19	9.5	44	2.8	--	15.5	--	.500	--
Maui	Kailua gulch	2,320	40	8 x 12	10	35	23.4	102	4.2	1.26	25.2	6.76	.552	.053
Maui	Poli poli (lower)	5,280	42	15 x 20	7	34	37.2	142	2.6	.64	13.9	5.49	.459	.015
Maui	Olinda	3,620	50	12 x 12	10	12	9.5	48	2.7	1.37	16.0	7.00	.442	.042
Maui	Kalialinui	6,730	104	12 x 12	10	14	13.2	70	2.2	.69	16.0	7.10	.425	.029
Molokai	Kapaakea (upper)	2,450	45	9 x 9	10	13	8.1	55	4.1	1.35	26.9	7.20	.478	.031
Molokai	Waikolu	3,550	67	10 x 10	10	14	12.4	49	2.3	1.07	32.7	19.81	.462	.029
Molokai	Kapaakea (lower)	1,950	35	10 x 10	10	13	7.3	32	4.2	.99	17.6	6.36	.454	.022
		PINUS STROBUS (EASTERN WHITE PINE)												
Maui	Hosmer Grove	6,730	104	6 x 6	2	52	13.7	70	5.6	3.35	12.6	6.52	.370	.019
		PINUS TAEDA (LOBLOLLY PINE)												
Hawaii	Aina hou	2,900	84	10 x 12	10	19	11.9	52	2.8	.54	23.9	11.75	.460	.036
Hawaii	Honuaula (upper)	6,250	50	10 x 20	10	19	9.6	40	3.0	.75	22.3	5.55	.415	.040
Hawaii	Lalakea	2,750	70	(1)	8	25	21.3	68	2.3	1.05	34.5	10.37	.404	.055
Hawii	Puu Ohu	3,280	40	10 x 10	10	20	11.6	41	3.1	.63	32.8	7.28	.394	.018
		PINUS YUNNANENSIS (YUNNAN PINE)												
Hawaii	Keanakolu	5,500	110	(1)	2	28	10.8	48	4.1	.10	9.9	1.10	.388	.007
		PSEUDOTSUGA MENZIESII (DOUGLAS-FIR)												
Hawaii	Puu Kihe	7,800	45	10 x 20	4	25	14.0	38	2.8	.10	20.6	5.85	.419	.018
	Kaluakauka	5,950	105	10 x 12	10	27	13.2	54	5.2	2.89	41.7	16.34	.398	.020

[1]Open.

Table 2. Characteristics and stand means of Norfolk-Island-pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp. gr.	Comparison of means[1]
	Feet	*Inches*	*Feet*	*Years*		
St. Louis Heights	12 x 12	14.0	60	27	0.462	
Mahinahina	12 x 12	13.3	54	25	.445	
Haiku	10 x 14	21.1	121	50	.438	
Kukuihaele	10 x 10	15.5	106	27	.417	
Nuuanu	10 x 10	13.1	61	27	.410	

[1]Brackets group specific gravity means not significantly different at 5 percent level.

Table 3. Characteristics and stand means of slash pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp. gr.	Comparison of means[1]
	Feet	*Inches*	*Feet*	*Years*		
Kalialinui	(2)	5.6	23	15	0.429	1 tree Only[3]
Olinda	8 x 8	14.7	84	29	.426	
Puu Chu	8 x 8	12.5	52	20	.419	
Keanakolu	(2)	13.8	37	28	.340	2 trees Only[3]

[1]Brackets group specific gravity means that are not significantly different at 5 percent level.

[2]Open.

[3]Not tested owing to sample size, included here only to show range.

Table 4. Characteristic and stand means of Jeffrey pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp. gr.	Comparison of means[1]
	Feet	*Inches*	*Feet*	*Years*		
Hosmer Grove	(2)	14.6	47	52	0.484	
Puu Ulaula	12 x 12	16.1	38	51	.469	
Puu Laau	7 x 7	11.4	48	51	.464	

[1]Brackets group specific gravity means not significantly different at 5 percent level.

[2]Open.

Table 5. Characteristics and stand means of Jelecote pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp. gr.	Comparison of mean[1]
	Feet	*Inches*	*Feet*	*Years*		
Makawao	6 x 8	13.6	89	29	0.472	
Olinda	8 x 8	13.8	77	30	.437	
Olinda Road	7 x 7	11.7	53	18	.423	
Poli poli (lower)	6 x 8	13.9	85	28	.419	
Puu Ohu	10 x 10	12.9	27	205	[2].395	
Keanakolu	10 x 12	8.5	35	12	.357	

[1]Brackets group specific gravity means not significantly different at 5 percent level

[2]Not included in the analysis owing to the small sample size. Shown here only to show place in range.

Table 6. Characteristics and stand means of cluster pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp. gr.	Comparison of means [1]
	Feet	*Inches*	*Feet*	*Years*		
Olinda	8 x 10	13.6	70	32	0.514	
Poli poli (upper)	(2)	14.8	56	24	.464	
Honuaula (upper)	10 x 20	6.7	26	12	.404	
Keanakolu	10 x 12	7.4	36	12	.397	

[1] Brackets group specific gravity means not significantly different at the 5 percent level.

[2] Open.

Table 7. Characteristics and stand means of Monterey pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp. gr.	Comparison of means [1]
	Feet	*Inches*	*Feet*	*Years*		
Kailua Gulch	8 x 12	23.4	102	35	0.552	
Aina hou	10 x 12	9.5	44	19	[2] .500	
Lalakea	(3)	19.4	90	25	[2] .480	
Kapaakea (upper)	9 x 9	8.1	55	13	.478	
Keanakolu	(3)	22.9	75	28	.466	
Waikolu	10 x 10	12.4	49	14	.462	
Poli poli (lower)	15 x 20	37.2	142	34	.459	
Honuaula (lower)	10 x 20	19.7	100	23	.458	
Kapaakea (lower)	10 x 10	7.3	32	13	.454	
Olinda	12 x 12	9.5	48	12	.442	
Kalialinui	12 x 12	13.2	70	14	.425	
Puu Kihe	(3)	12.7	40	16, 30	.377	
Keanakolu	10 x 12	7.1	42	12	.340	

[1] Brackets group specific gravity means not significantly different at 5 percent level.

[2] Not included in the analysis owing to of sample size. Shown here only to indicate place in range.

[3] Open.

Table 8. Characteristics and stand means of loblolly pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp.gr.	Comparison of means[1]
	Feet	*Inches*	*Feet*	*Years*		
Aina Hou	10 x 12	11.9	52	19	0.460	
Honuaula (upper)	10 x 20	9.6	40	19	.415	
Lalakea	(2)	21.3	68	25	.404	
Puu Ohu	10 x 10	11.6	41	20	.394	

[1]Brackets group specific gravity means not significantly different at 5 percent level.

[2]Open.

Table 9. Stand means of other species sampled

Species	Location	Trees	Age	Av. height dominants	Av. d.b.h.	Av. core sp.gr
		Number	*Years*	*Feet*	*Inches*	
Douglas-fir	Puu Kihe	4	25	38	14.0	0.419
	Kaluakauka	1	27	54	13.2	.398
Pine, eastern white	Hosmer Grove	2	52	70	13.7	.370
Pine, longleaf	Olinda	6	13	54	10.2	.425
	Keanakolu	3	28	47	8.6	.421
Pine, Luzon	Keanakolu	1	21	32	6.5	.364
	Round Top Drive	2	40	70	32.7	.539
Pine, Masson	Olinda	10	13	62	10.0	.429
Pine, shortleaf	Olinda	10	13	47	8.7	.466
Pine, Yunnan	Keanakolu	2	28	48	10.8	.388

GPO 968-581

Skolmen, Roger G.

1963. **Wood density and growth of some conifers introduced to Hawaii.** Berkeley, Calif., Pacific SW. Forest & Range Expt. Sta. 20 pp., illus. (U.S. Forest Serv. Res Paper PSW-12)

The specific gravity of the wood of 14 conifers grown in Hawaii was measured by means of increment cores. Most species were growing in environments quite different from their native habitats. The specific gravity and growth characteristics under several site conditions were compared. Described in some detail are Norfolk-island-pine, slash pine, Jeffrey pine, jelecote pine, cluster pine, Monterey pine, and loblolly pine. More limited information is given for shortleaf pine, Luzon pine, Masson pine, longleaf pine, eastern white pine, Yunnan pine, and Douglas-fir.

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