4

HAMAKUA
FOREST RESOURCE REPORT

Prepared by

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HAMAKUA FOREST RESOURCE REPORT

CONTENTS

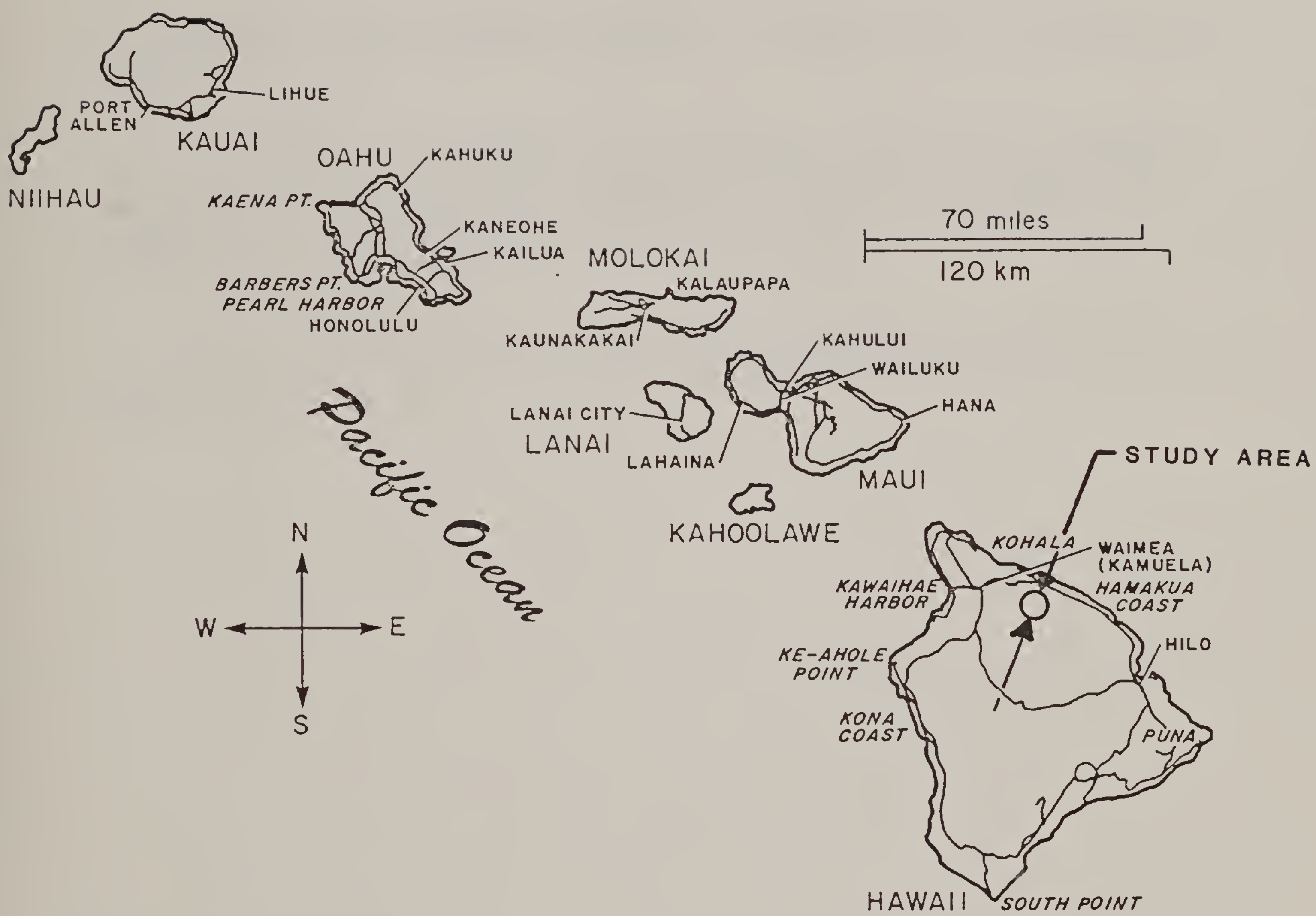
APPENDIX

LOCATION MAP

Hamakua Area Agricultural Water Study

Hamakua, Hawaii

Figure 1



LOCATION MAP

State of Hawaii

Figure 2

ABSTRACT

The Forestry Resource Report for the Hamakua Area Agricultural Water Study (HAAWS) Project provides data and information about the study area.

Forestry input is limited to data related to forest plantation establishment, an alternative land use, as identified in the HAAWS Plan of Work.

As a member of the Field Advisory Committee (FAC), the USDA Forest Service served as the gatherer and compiler of data from many sources including the Hawaii Division of Forestry and Wildlife (DOFAW), the Department of Land and Natural Resources (DLNR), and other agencies and individuals within the State.

This report provides problem and concern statements, available resource data and analysis, identifies benefit/costs, and potentials for forest plantation use.

HAMAKUA FOREST RESOURCE REPORT

I. INTRODUCTION

The USDA Forest Service participates in conducting cooperative river basin studies under Section 6 of Public Law 83-566. The Forest Service's Forest Resource input to the Hamakua Area Agricultural Water Study (HAAWS) is conducted under this Law.

The USDA-FS used existing data and inventory information in preparing this report and include highlights from significant documents by other individuals, groups, and agencies.

This report describes the current and projected forest and land resources in the Hamakua study area to meet needs identified by the sponsors as outlined in the Hamakua Area Agricultural Water Study Plan of Work.

Objectives of Study

The objectives of this report are to:

1. Describe the forest resources and related resources,

2. project forest resource use,

3. assess the potential for forest, plantation establishment on grassland vegetative types, and

4. evaluate the potential for and the effects of plantation establishment in the Hamakua Area Agricultural Water Study.

II. FOREST RESOURCES

State

Hawaii is an isolated archipelago, more than 2,000 miles from the U.S. mainland. It is geologically, ecologically, and culturally a separate entity. Because the State consists of islands, the lines of interdependence which tie each to the others, and the State as a whole to other parts of the globe, especially the Pacific, are readily apparent. Dependence on tourist income and heavy imports of food and energy are basic to Hawaii's reliance on others and the islands' need to increase toward self-sufficiency.

Hawaii's forest land area is 1.4 million acres. Of this, about 950,000 acres are considered commercial forest land. (See Glossary for definitions.) About 5% of the commercial forest land is in plantations, the rest being native forest.

Island of Hawaii

The island of Hawaii produces slightly more than 60% of Hawaii's commercial forest land. At present, only 26% is commercial forest land. Most commercial forest is a mixture of native ohia and koa trees. Planted eucalyptus occupy about 2% of the commercial forest lands; representing 23% of the total sawtimber volume.

Care must be exercised in forest development for commercial use. Hawaii's biologically unique native forest is extremely sensitive to disruption. For example, ohia, the dominant native species in the forests of Hawaii, has been subject to an unexplained decline.

Hawaii's forests and watershed areas are vital to agricultural use since the State's freshwater supply is dependent on rainfall percolating into the freshwater aquifers. Hawaii's multiple use forests are also valued for timber, recreational areas, erosion control, wildlife habitats, and visual resources. One potential use of forest lands is as a biomass energy resource.

Hamakua Study Area

The Hamakua study area is located along a 25-mile long section of the northeastern coast of the island of Hawaii, from Laupahoehoe to Waipio Valley. Elevational range within the study area is from sea level to about 8,000 feet, on the slopes of Mauna Kea. Forestry resources are greatly influenced by the annual rainfall variations across the study area. The average annual rainfall ranges from 20 inches to more than 100 inches.

Forestry related resources within the study area are composed of six vegetative types including ohia-koa, commercial forest land plantations, noncommercial forest land (tree and shrub types), grassland, and herbacious and improved pasture. There is a total of 4,100 acres (rounded to nearest 100 acres) of plantations within the study area of which 1,200 acres (rounded to nearest 100 acres) have been cutover (harvested) during the period 1975-1979. These plantations and future plantings occur in areas above the sugarcane lands (at about the 2,000-foot elevation) to about the 5,500 feet elevation, and have an annual average rainfall of 35 inches or greater.

III. FOREST RESOURCES USE-CURRENT AND PROJECTED

The Hamakua study area's forest resources can be expanded to meet market demand for pulpwood and fuelwood needs in the future.

Table 1--Existing and projected forest plantation acreage

Item[1]	1980 basis[2] (acres)	Projected 1990 Total acres
Commercial Forest land		
Existing plantations--		
sawlogs	4,100	2,000[3]
Cutover	1,200[4]	2,100[5]
Potential pulpwood/fuelwood area	-	10,000[6]

Source: Forest Inventory Data, Hawaii, 1970.

[1]See Glossary.

[2]1970 data has been adjusted to 1980 condition.

[3]Acreage reduced to reflect change from sawlog to fuel chip production objective.

[4]Period 1974-1980.

[5]Period 1980-1990

[6]Chapter IV.

Situation

Statewide, Hawaii has a heavy dependence on imported petroleum. Biomass, one of the State's many indigenous natural energy resources is an important source of energy.

The biomass resource includes terrestrial and aquatic plant life and agricultural wastes. These renewable resources have received and transformed solar energy into stored chemical energy, which can be converted into usable energy products. Biomass can be collected and burned directly or converted into liquid or gaseous fuels, chemicals, or energy-intensive products.

The biomass resource is widely dispersed, has high bulk, and is relatively site specific. These factors limit its use to particular regions and, because of transportation costs, restrict the scale of economically sensible processing facilities to sizes much smaller than those of fossil fuel-fired generating plants. Widespread use of biomass may eventually compete for scarce resources such as high quality arable lands and water. Intensive use of biomass for energy may have impacts on the environment and the ecosystem, although as related to intensive agricultural cropping, the impacts are insignificant.

Biomass resources are available from existing forest areas. Biomass could supply enough indigenous biofuel to replace imported fuel oil used at sugarmills in the HAAWS.

Biomass resources could have an even more significant effect on the energy demands by individual islands. The State's demand figures are heavily influenced by uneven population distribution. Most of Hawaii's industry, 80% of its population, and about 90% of the statewide

energy consumption takes place on the island of Oahu. In the Stanford University-University of Hawaii Biomass Energy Study Team Report (1977), it was estimated that "a 23 megawatt power plant, fueled with chips from a eucalyptus plantation, would provide about 2% of the total State's 1975 electricity demand." The proposed power plant would fill one-third of the Big Island's 1985 electrical requirements. The Hawaiian Electric Light Company, Ltd. (HELCO) would be expected to utilize existing boiler capacity before constructing new facilities.

The benefits of using biomass in Hawaii go beyond returns on investment. Biomass is an indigenous fuel source with the potential to reduce Hawaii's reliance on petroleum imports. Direct effects of developing biomass plantations as an energy source include stimulating industry, diversifying the State's economy, providing new jobs, and encouraging research and development. Environmental benefits may also result since fuelwood is low in sulfur, and power plants burning this fuel would emit fewer sulfur oxides than a petroleum-fired plant. Particles associated with combustion of wood can be controlled more easily than particles for fossil fuel plants.

Biomass is very flexible and can be used to produce a variety of fuels. Fuels produced, which range from pyrolytic gases to methane, alcohol and gasoline, depend on market demands, economic conditions, amount of capital required, and potential markets. Since direct burning of the biomass is possible, by-products and alternate uses for the biomass product play an important role in economics. Eucalyptus "hogged" material or chips can either be burned in a power plant or sold for paper pulp. The BioEnergy Development Corporation, a C. Brewer Co., is utilizing a U.S. Department of Energy (DOE) grant to develop forest biomass technology. Research and development programs could bring biomass energy rapidly from a planning and research concept to a reality. Energy development of biomass is one way to move toward this goal. Biomass offers the potential for a significant energy supply in the near future. It remains State, County, and Federal governments, private industry, and private citizens' responsibility to actively develop energy plantations in the Hamakua Study area.

Further additions to the State's fuel supply could occur after an initial period of research and development, and when the world price of petroleum increases to the point that other projects not currently economically competitive, could become feasible. The world average price of crude oil is approaching $36 per barrel.

Plantation Feasibility

Biomass plantation establishment in the Hamakua area is very feasible. The major issue of physical feasibility for a plantation is land availability and acquisition. The problem is one of land availability or quantity, not quality. A biomass plantation can utilize marginal agricultural lands; i.e., pasture or higher elevation cane lands. Although sufficient acreage exists, ownership and owners' management objectives are varied, and present use complicates development

of biomass plantations. Species suitable for energy plantation such as eucalyptus, are available, and biomass plantation operation appears to be environmentally acceptable. The technology for harvesting large size logs and chipping or hogging material of all sizes is known. An energy plantation would not face insurmountable technical problems. In fact, there are no serious problems except possible protection from wind and fire losses.

Economic feasibility depends strongly on current markets and reliable sources. Competing markets exist for paper pulp and fuel. Currently, the production of wood chips for paper pulp provides a higher rate of return than use for fuel. Considerations such as diversifying the State's energy base and reducing its dependence on imported petroleum fuel oil present strong arguments to support establishment of biomass plantations as an alternative energy source. Use for pulp or fuel could have a significant effect on the State's economy, both in terms of imports and exports.

Considering growth and yield, ease of production, and economics, a biomass plantation based on short-rotation management of forest hardwood species such as eucalyptus has promise. Tree crops seem most desirable as a biomass source. A biomass plantation located on marginal lands poses fewer problems than if the land was used for food or agricultural production. Extensive, rather than intensive agricultural techniques ensure minimal damage to soil and watershed. Longer rotations than agricultural crops provide protection against an occasional poor year and allow a long-term supply of conversion fuel. Establishment of biomass plantation on marginal grasslands will require that suitable soils be found and that adequate erosion control measures would be installed. One of the benefits of biomass production versus grazing is its built-in soil stabilization. During recent harvesting, mauka of Paauilo, large stands of bluegum eucalyptus were clearcut on some of the most erosive soils on the Big Island. No significant erosion problem has resulted. The stands have now regenerated and the soil is again protected. Based on these considerations, Eucalyptus plantation establishment will be analyzed in Chapter IV.

Hamakua Study Area Assumptions

1. Forest plantations would be planned to produce short-rotation (5 to 7 years) eucalyptus stands.

2. Short-rotation eucalyptus would be grown on non-forested grazing land or marginal agricultural lands.

3. Protection of the native forest ecosystem would be an important consideration.

4. Replacement of native forest species with exotic species such as eucalyptus will not be considered.

5. Potential forest plantation areas need to be examined to estimate the productive potential, current ownership, soil type and properties, terrain, and access.

6. A forest plantation could be located within the HAAWS area.

7. Marginal agricultural grazing lands or other areas used for forest plantations would not need to be in one contiguous parcel.

8. About one-fifth of the total eucalyptus would be planted during each of the first 5 years operation.

9. Forest plantations would be harvested and chipped or hogged after 5 to 7 years' growth.

Land Use Change and Soil Considerations

Some of the lands within the study area have a low agricultural productivity rating. To avoid depletion of marginal agricultural soils, crops must be utilized which will return nutrients to the soil. Annuals or short-rotation crops require more nutrients than slower-growing plants. The slash material, leaves, twigs, and crown can be lopped and scattered during the harvesting operation and left as mulch. This material contains large quantities of nitrogen and minerals. Organic matter incorporated into the soil in this fashion will reduce the need for fertilization of future crops.

Species Suitability for Forest Plantations

Exotic forest species for biomass production

The genus *Eucalyptus* (family Myrtaceae) is native to Australia, where 500 to 600 species and varieties comprise 75% of the total flora. In dense coastal rain forests, eucalyptus trees grow tall and straight to heights of more than 200 feet; dwarf, shrubby forms appear at timberline and in the dry outback. Other forest species also have been introduced into the State of Hawaii. Information is provided in the appendix about the other significant species.

Eucalyptus saligna Sm., Saligna (Sydney Bluegum)

Whether trees currently called saligna in Hawaii are hybrids between *E. saligna* and *E. grandis* or even *E. grandis* itself (Rosegum or Flooded Gum) appears to make little difference. All types grow very rapidly on favorable sites. Annual increments average 1 inch dbh and 10 feet growth in height. *Eucalyptus saligna* grow well in Hawaii. For example, at 45 years of age, one tree measured 49 inches dbh and 235 feet tall.

Since 1960, *E. saligna* has been used for watershed protection and timber production. The island of Hawaii had 14 million fbm of sawtimber along the Hamakua Coast located above sugarcane fields, until it was logged recently.

The same difficulties associated with growth stress and seasoning found in *E. robusta* and to a lesser degree in *E. globulus* make special milling techniques necessary for saligna. *Eucalyptus saligna* is a much

taller, better formed tree than _E. robusta_ and on the same site will provide greater yield. The wood is similar in appearance to _E. robusta_, but is paler in color and finer-textured. In other countries (South Africa and Brazil), saligna represents an important timber species. Saligna chips provide fiber for paper, particle board, hardboard, and rayon.

Eucalyptus is not native to Hawaii. Extensive areas of planted eucalyptus would represent a growth form and habitat that has not co-evolved with native flora and fauna or with Hawaiian physiography and climate. On the other hand, forest plantations would comprise a relatively small fraction of the island's total area and amount to only less than 50% of the areas currently planted in eucalyptus.

Forest Plantations of _Eucalyptus_

Advantages:

1. Rapid growth and good yields are attainable on non-agricultural land with little or no cultivation.

2. Yields can be greatly increased by applying minimal cultivation.

3. Extensive plantings are present in Hawaii, indicating adaptability to soil and climate conditions.

4. No significant problems concerning insect or fungal pests have arisen in the 70 years eucalyptus has been planted in Hawaii.

5. Cut stumps coppice repeatedly with height growth from several feet tall at 6 months after harvest, to 20-30 feet tall after 2 years, as observed at Paauilo Mauka, Hawaii, on Capitol Chip Company harvest areas. However, yields on these stands are only about 3 tons/acre/year, after 6 years.

6. Harvest technology for large-sized material exists in Hawaii.

7. Chips produced could be marketed for either pulp or energy.

8. Mechanized planting technology is feasible under specific limitations.

Disadvantages:

1. Forest plantation yield is not as high as intensively cultivated field crop such as sugarcane, hence more acreage would be needed.

2. Land devoted to closely-spaced tree crops would be more difficult to reconvert to an alternative land use than lands in non-woody crops.

IV. FOREST PLANTATION ESTABLISHMENT POTENTIAL

Market Overview

Changing conditions in world petroleum and pulpwood markets may have a significant effect on future land and water use patterns in the Hamakua study area. Rising world petroleum prices provide increased incentives for developing alternative energy sources. In less than a decade, petroleum product prices have increased more than tenfold. At the same time, increasing demands for pulpwood products, combined with supply uncertainties in other parts of the world, are increasing world market prices for wood chips. The pulpwood market is the fastest growing segment of the overall timber products market.

Fast-growing forest plantations could be established in the Hamakua area to serve the growing markets for petroleum substitutes and pulpwood. These markets are currently being served to a limited extent by current forestry operations on the Big Island. The sawmill industry in Hilo currently sells 5,000 to 10,000 tons of residue produced each year, to fuel steam-electric generators operated by the sugar industry. This residue is produced as a byproduct from the manufacture of koa lumber. As boiler fuel, wood substitutes fuel oil at a rate of approximately 1 ton of green wood (50% moisture content) per barrel of oil. The pulpwood industry in Kawaihae has manufactured as much as 100,000 green tons of wood chips per year for sale to the Japanese paper industry. Chips are manufactured from both eucalyptus and ohia. During 1980, the source of ohia for chip production was from outside the study area and from lands being converted for urban development. Ohia makes up only a small percentage (less than 1.0%) of the wood chip market.

Residue from the chipping process has also been sold for seasonal sugarmill startup and could be sold as petroleum substitute for the generation of steam-electric power. Residue from Kawaihae chipping facility, now inoperable, had the added advantage of being located in a low rainfall area. This residue material is much drier than green fuels. Pulpwood and fuelwood operations are based on the harvest of exotic species plantation established for other purposes and minor amounts of native forest species. As markets for petroleum substitutes and pulpwood continue to grow, economic incentives for expanding forest plantation acreage in the Hamakua area will increase. The extent of forest plantation expansion will depend upon production and opportunity costs, market conditions, and landowner acceptance. Opportunity costs are the costs of alternative land uses foregone as a result of forest plantation establishment.

Production Costs and Returns

Production costs (including opportunity costs) are estimated here for forest plantation expansion on grasslands currently used for grazing. Of the six major vegetation types in the Hamakua area, grassland is

considered to be the best suited for conversion to forest plantation use. The major reasons for this assumption are outlined below:

1. Ohia-koa forests offer little opportunity for conversion. Conversion within forest reserves would be contrary to State policy for preservation of native flora and fauna. Conversion of private lands outside forest reserves would entail high costs for land clearing and site preparation (even if following timber harvests) and could encounter stiff public opposition to the loss of native flora and fauna.

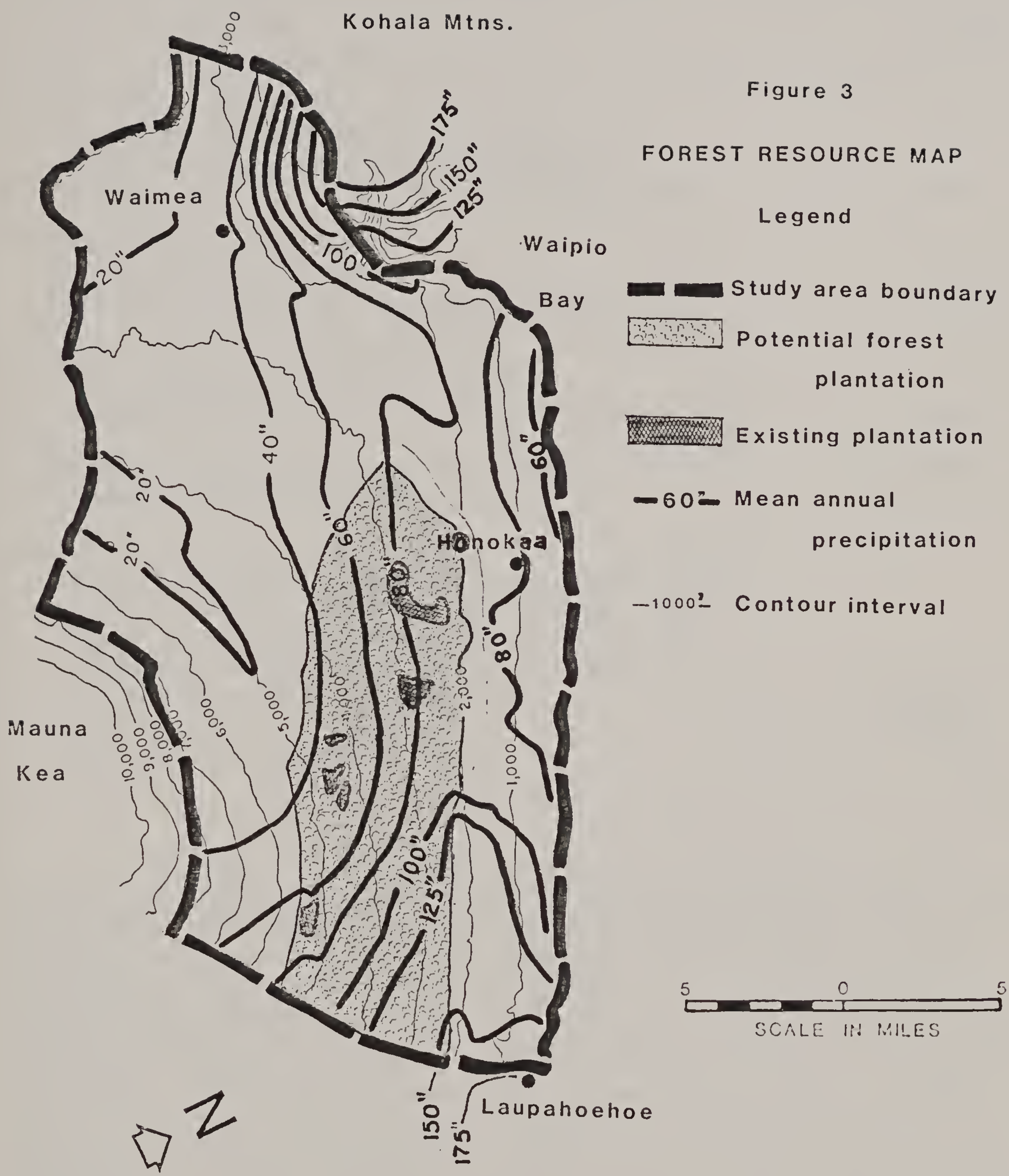
2. Noncommercial forest types cover few acres in the Hamakua area. Conversion would entail high costs for land clearing and site preparation.

3. There is little economic incentive for converting land currently used for sugarcane production to forest plantation. Sugarcane bagasse itself is a petroleum substitute. On a per acre basis, average sugarcane biomass yields are roughly double average forest plantation yields. In the sugarcane belt (roughly below 2,000 feet elevation in the Hamakua area), economic returns from sugarcane production are higher than returns expected from forest plantations.

4. Grassland between 2,000 and 5,500 feet in elevation east of Kahaupu Gulch has the greatest potential for forest plantation establishment. This area is above the sugarcane belt, below the elevation where forest yields begin to decline rapidly, in the area with annual rainfall above 35 inches, and outside the Hawaiian Homes Commission area near Waimea that is being developed as an agricultural park.

The Forest Resource Map (figure 3) which follows, indicates the existing and potential plantation areas based on the above assumptions 1 to 4.

There has been little operational experience with establishment and management of fast-growing forest plantations for pulpwood and fuelwood use in Hawaii. For this reason, production cost estimates in Table 1 are only rough estimates. Forest management costs are assumed to increase at an average annual rate of 7 percent. Interest on borrowed capital (or minimum acceptable return on equity capital) is assumed to be 15 percent. Forest plantation yields over a 7-year rotation period are assumed to average 20 green tons per acre per year. Under these assumptions, stumpage costs of plantations established in 1980 for harvest in 1987 would total $9 to $10 per green ton (table 2). Harvesting and marketing costs would total $80 per green ton. Total delivered costs, at the dock or power plant, would total $90 per green ton.



prepared by: USDA-Forest Service

Table 2--Forest plantation production and opportunity costs per acre

Activity		Dollars
First year costs (1980)		
Plantation establishment site preparation, nursery stock, planting, maintenance		400
Compound interest on investment--7 years @15%		660
Second year costs (1981)		
Plantation maintenance		50
Compound interest on investment--6 years @15%		70
Pasture rental foregone (1980-1987)		
$15 per acre per year for 7 years and compound interest on investment--7 years @15%		170
Subtotal, stumpage costs per acre (1987)	=	1,350
stumpage cost = $9-10 per green ton		
Harvest year costs (1987)		
Cost of logging, trucking, chipping, storage, and delivery to power plant or dock--$50 per green ton in 1980 escalated @7% per year for 7 years to $80 per green ton in 1987. At 140 green tons harvested per acre, total cost		$11,200
Total cost per acre (1987)	=	12,550
Total cost per green ton (1987)	=	90

The magnitude of the potential returns from investments in forest plantations depends upon how rapidly pulpwood and petroleum market prices increase in relation to production costs. Although prices in both of these markets are expected to increase faster than the rate of general inflation, there is considerable uncertainty about the magnitude of future price increases. For this analysis, it is assumed that pulpwood market prices would increase at a total compound annual rate of 9 percent annually (7 percent for general inflation plus 2 percent for "real" price increases). Under these assumptions, current market prices of roughly $60 per green ton ($120 per dry ton equivalent) would increase to $110 per green ton by 1987. Real price increases of 2 percent annually are comparable to those experienced in timber product markets over the last 50 years. A 7 percent rate of general inflation is higher than rates experienced over the long term in the past, but less than rates experienced in recent years.

Two petroleum market price projections are made under two different assumptions. The first assumes that prices will increase at a total compound annual rate of 12 percent annually (7 percent for general inflation plus 5 percent for "real" price increases). With this

projection, residual fuel oil would increase from $30 per barrel in 1980 to about $65 per barrel by 1987. Assuming that fuelwood continues to sell at $5 per green ton less than its fuel oil equivalent (to cover the incremental costs associated with using wood rather than oil), under this projection, fuelwood prices would increase to $60 per green ton under this projection. The second projection assumes that fuel oil prices will increase at a total compound annual rate of 20 percent annually. This is higher than most published projections, but lower than rates that have occurred over the past decade. Under this projection, fuelwood prices would increase to about $100 per green ton by 1987.

Table 3 shows comparison of costs, revenues, and net returns that might be achieved under these assumptions. Net returns vary between a positive $20 per ton and a negative $30 per ton, depending upon the price estimates used. Given the great uncertainty about production costs and future market prices, forest plantation enterprises in the Hamakua area must be considered speculative investments--at least for the near term. Pulpwood production appears to be somewhat less speculative than fuelwood production since a positive net return on investment is less dependent upon continued rapid price increases relative to costs in the future. Although pulpwood market prices are somewhat volatile, price volatility is also an inherent characteristic in livestock markets--the market served by the competing alternative land use.

Table 3--Forest plantation enterprise costs, revenues, and net return estimates

Item	Annual price increase percentage Pulpwood 9%	 Fuelwood 11%	 Fuelwood 20%
		1987 dollars	
Cost per green ton	90	90	90
Cost per acre	12,550	12,550	12,550
Revenue per green ton	110	60	100
Revenue per acre	15,400	8,400	14,000
Net return per green ton	20	-30	10
Net return per acre	1,850	-4,150	1,450

Potential Plantation Acreage

The acreage that might be converted from grassland to forest plantation is dependent upon the potential market and large landowners' acceptance, expected costs, and returns. The export market for pulpwood is much larger than the local market for fuelwood in Hawaii County.

The pulpwood operation at Kawaihae has sold as much as 100,000 green tons per year. Sustained production at this level would require a forest plantation base of 5,000 acres. Japanese imports of wood fiber are

increasing by more than 5 percent annually. If Hawaii were to maintain its relative Japanese market share, forest plantation acreage would have to be increased to more than 8,000 acres by 1990 and to about 13,000 acres by the turn of the century. With increasing instability in many less developed countries and tightening supplies on the U.S. mainland and Canada, Hawaii could potentially increase its share of the chip export market. Hawaii's pulp chip shipments amount to less than 1 percent of chip exports from the western U.S. mainland.

On the island of Hawaii, 5,000 to 10,000 tons of fuelwood are currently burned by the sugar industry each year. This fuelwood is burned along with fuel oil and bagasse to produce power for running sugar mill operations and for sale to HELCO. Between 3,000 to 4,000 acres of forest plantation would be needed to provide an additional 60,000 to 80,000 green tons of fuelwood per year to displace fuel oil burned at the sugar mills. If new power plants, capable of burning fuelwood for electricity or synthetic fuels plants for making liquid fuels from wood, were to be constructed, the potential fuelwood market could be expanded. However, due to the long lead times required, this type of market expansion seems unlikely for a decade or more.

Based on these estimates, pulpwood and fuelwood markets are of sufficient size to absorb the up to 12,000 acres of forest plantation output in the next decade. Assuming that no more than 2,000 acres of existing forest plantation would be available for pulpwood or fuelwood use, there appears to be a potential market for the output from 10,000 acres of new forest plantation. How many acres of forest plantation may actually be established on existing grasslands in the future is dependent on landowner interest and capabilities. Due to the relatively high risk and high capital investment required, plantation establishment by landowners with larger land holdings and incomes is more likely than by the smaller landowners. These larger landowners have greater access to capital and are more likely to be able to minimize market risks either through use in their own facilities or by negotiating marketing contracts directly with paper companies and/or other power plant operators.

APPENDIX

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APPENDIX

Forest Plantation Establishment Cost Summary

Costs per acre for field establishment

Research findings related to costs per acre for establishing containerized Eucalyptus saligna seedlings are given on the following pages. Field establishment costs include growing seedlings in the nursery, transporting them to the field, preparing the sites, planting the seedlings, and maintaining them until they have overtopped the weed species. The analysis includes assumptions on: number of planted acres per year, the number of seedlings per acre to be planted, minimum acceptable stocking levels of 80 percent, seedling production costs, site preparation costs, planting rates, survival and stem dieback rates, and seedling maintenance costs. Land costs or opportunity costs are not included in this cost summary.

Containerized seedlings

Forest plantation establishment costs using containerized seedlings are about $295 per acre. Bare-root seedling establishment costs based on an equivalent stocking to containerized seedlings, are about $387 per acre. Containerized seedlings are more expensive to grow and transport, but these higher costs are more than offset by the lower costs to plant, replant, and maintain than for bare-root seedlings. Using containerized seedlings results in a substantial savings in establishment costs.

Costs Per Acre for Establishing Seedlings

Assumptions

1. Plant 3,000 acres annually.

2. Average spacing of 8 by 8 feet or 680 trees per acre.

3. Minimum acceptable survival rate of 80 percent.[1]

4. Annual seedling requirement (no replanting necessary) is 2 million seedlings. If replanting is necessary to meet a stock minimum of 80%, an additional 0.5 million seedlings are needed.

Costs and rates for containerized seedlings:

1. Seedling production costs[2]	$75/m
2. Seedling transport costs	$4/m
3. Site preparation costs	$200/acre
4. Planting rate[3]	700/man-day
5. Stem dieback rates	5 percent

6. Stem dieback recovery rates
   Fifty percent of seedlings require 3 months to attain their original height.

7. Seedling maintenance
   4.5 man-days per acre for trees planted 8 by 8 feet when initial growth is slow (Division of Forestry estimate).

8. Average wage of field labor $5/hour

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[1]Minimum stocking figure obtained from State Forester.

[2]Based on Division of Forestry data, research data, and mainland bare-root and containerized nursery data.

[3]Figures derived from public and private planting operations of containerized seedlings.

Source: "Why Hawaii is changing to the dibbling-tube system of forestation" by Gerald A. Walters (to be published).

Forest Planting and Site Preparation Costs

Item	Cost per acre[1]
	1980 Dollars
Nursery production	
Initial	51.00
Seedling transport	
Initial	2.72
Field establishment	
Site preparation (initial)	200.00
Planting (initial)	38.86
Maintenance	2.69
Total cost per acre	295.27

[1]Planting of 680 seedlings per acre.

Other Forest Species with Potential for Forest Production

Native forest species

Koa (Acacia koa Gray) and ohia (Metrosideros collina [Forst.] Gray subsp. polymorpha [Gaud.] Rock.) make up 60% of Hawaii's commercial forest. Koa forest, a commercial species grows primarily on Hawaii, above 4,000-foot elevations. Timber volume is estimated at 120 million bd/ft. Commercial uses of koa include furniture and cabinet making, carved bowls and turnery, veneer, flooring, and musical instruments.

A member of the Leguminoseae subfamily mimosoideae family (or legume family), koa grows rapidly, but reproduces rarely because the abundant reproduction is destroyed by insects or animals before it develops an extensive root system. Efforts are underway to improve the survival rate of koa seedlings and to eventually reforest grazing areas and decadent stands.

Ohia, in the family Myrtaceae (as is the genus Eucalyptus) grows slowly and is currently severely threatened by a decline syndrome of unknown cause. All potentially commercial and operable stands of ohia, the most abundant tree in the State, occur on the island of Hawaii.

As the main forest species on Hawaii, these trees have evolved over long periods of time as members of complex ecosystems. Destruction of natural species associations, whatever their apparent condition and replacement with an exotic forest adds instability to a system that has not evolved naturally.

Forest plantations establishment pose less of a hazard to native flora and fauna if planted on land already cleared of native forest or infested with pest species. Eucalypts have now been in Hawaii 110 years and have spread significantly from where they were first planted. They have not significantly reproduced in or taken over native forests even where they have been planted inside native forest areas. Where planted on degraded lands just makai of the native forest as along the Hamakua coast, they have served positively as a buffer against weed invasion into the native forest.

Biomass from Native Forest Species--Koa and Ohia

Advantages:

Large areas of forest already exist, offering rapid start-up of a fixed lumber-chip operation; areas of older or diseased stands might also be cut on a salvage or thinning basis.

These species are native to Hawaii.

Both are valued for specialized wood products.

Disadvantages:

Neither species has coppicing ability, hence frequent replanting would be required.

Production and establishment of vigorous ohia seedlings have proved difficult.

Yields are extremely slow, averaging only 5-6 M bd ft/acre of sawtimber and correspondingly low tonnage of biomass. Therefore, woods operations have a low net return (a large work input for a low yield of product).

Both species are susceptible to insect and disease pests.

Introduced "Exotic" Species

Eucalyptus globulus Labill., Bluegum (Tasmanian bluegum)

Bluegum has been planted in Hawaii since about 1880, mainly on the island of Hawaii (56 million fbm) and Maui (100 million fbm). Although it is easily established and adapted to many sites with its best growth occurring above 2,500 feet, it is not considered a good sawtimber species. Its wood is heavy and very hard with a large shrinkage in drying. Bluegum wood is dense (55 lb/cu.ft. at 12% moisture) and light-colored, well suited for pulp and fiber products. Its bark is thin, smooth and regularly shed in strips from above, resulting in a thinly clad, blue-grey mottled trunk. Unlike many trees, the bark of bluegum can be pulped, which allows the entire tree trunk to be chipped for pulp without de-barking. Bluegum may grow faster than saligna at sites above 5,000 feet, while at the same time producing a denser wood; i.e., more biomass.

Eucalyptus robusta Sm., Robusta (Swamp Mahogany)

Prior to 1960, *E. robusta* was the most extensively planted species in Hawaii's reforestation programs. The islands of Hawaii and Maui contain 150 million fbm of trees 11-inch dbh or greater. Growth stress produces end-splitting upon bucking of robusta logs and causes boards to spring during milling. Construction techniques must account for the wood's shrinking and swelling during changes in humidity.

Robusta trees have a thick, soft, deeply furrowed bark covering a single, straight stem. Because of the large proportion of bark and the dark color of the wood, robusta is not suitable for whole tree chipping to supply pulp and fiber markets. The tree is very tolerant of poor sites and may be suitable for the poorest of the marginal lands available, as long as they are below 3,000 feet elevation.

Leucaena leucocephala, Koa haole or Giant Ipil-ipil or Tangan tangan

A member of the Leguminosae family (Fabaceae) and closely related to the native koa, koa haole grows extensively in Hawaii at low elevations. In the tropics, *Leucaena* serves as a major source of high-protein cattle feed and as a fuel. A new variety, "Hawaiian Giant," capable of rapid growth, has been introduced and bred by the University of Hawaii.

Although *Leucaena* is capable of tree-size growth at very rapid rates, land available and suited for forest plantations in the Hamakua area on the Big Island usually lies above 2,000 feet elevation. Koa haole will grow well only in neutral to slightly acid soils and seems best suited to a low elevation coastal, field-crop style plantation. Frequent "forage-type harvests" of closely-spaced rows could provide a continuous supply of biomass for conversion. Research is needed to determine proper spacing.

Another possible use would be to combine *Leucaena* and other green chop forage to provide a high protein cattle feed. However, *Leucaena* is not a good species for the Hamakua area because the soil ph is too acidic.

Advantages:

Extreme vigor--at a 4-ft spacing grows to 55 ft in height in 6 years.

High yields, although all yield data is based on very small test areas and is subject to a high probability of error, due to multiplier effect.

Few known pests

Disadvantages:

Slow growing above 2,000 ft elevation

On an entire plant basis, koa haole is very high in nitrogen which could cause problems in energy conversion.

May be difficult to eradicate when desired.

Production Costs--Log, haul, chip, and storage

The following are costs related to chip export from Eureka, California:

Item		Cost/green ton
Logging[1]		$17
Log haul[2]		10
Log handling and storage[3]		6
Chipping[4] and delivery--Chip haul[5]		14
Chip storage and loading		8
Total cost	=	$55
Cost per dry ton equivalent[6]	=	$110

Selling price on 5/1/80 was $130/dry ton.[7]

[1]Log truck cost @ $32-34/hour, with operator. Log trucks make 3 loads/day. Stumpage was free and slash disposal not required, as operation was to remove material not otherwise used.

[2]Cost is equivalent to 25-27 ton of logs delivered to mill. Log truck @ 25 tons/load = 3.5 MBF/load.

[3]Cost includes interest at chip facility.

[4]Size of material such that chipping could be done without splitting.

[5]Capacity of chip van = 11.5 dry units/load or 11.5 BDUs.

[6]One (1) dry ton or unit = two (2) green tons. (±10%).

[7]Market variable.

Source: 1980. Personal communication, USFS discussion with operator-exporter. Eureka, California.

FOREST SERVICE PROGRAMS FOR STATE AND AND PRIVATE LANDS IN HAWAII

The Forest Service, U.S. Department of Agriculture, administers a number of programs designed to strengthen State forestry agencies and to protect and improve forest, range, and related resources in nonfederal ownership, to improve the utilization of wood by loggers and processors, and to provide urban forestry assistance. These programs are implemented by providing technical, financial, and related assistance to the Hawaii Division of Forestry and Wildlife. The Division in turn provides assistance to nonfederal landowners, loggers and processors, and urban areas.

These programs are authorized by Public Law 95-313, the Cooperative Forestry Assistance Act of 1978. Major program areas are listed below:

Multiple resources and forest management (Sec. 3.)
Forestry incentives program (Sec. 4.)

Forest insect and disease control (Sec. 5.)
Urban forestry assistance (Sec. 6.)
Rural fire prevention and control (Sec. 7.
Management assistance, State forest resource planning assistance, and technology implementation (Sec. 8. and 10.)

The Forest Service also administers the forestry aspects of Watershed Protection and Flood Prevention Projects, River Basin Surveys, Resource Conservation and Development Areas, the Rural Clean Water Program, Forestry Incentives Program, and the Agricultural Conservation Program in cooperation with other U.S. Department of Agriculture agencies.

LIST OF UNITS AND ABBREVIATIONS

The following abbreviations are used throughout this report:

bbl	barrel
BDT	bone-dry ton
BDU	bone-dry unit
Btu	British thermal unit
^oC	degrees Celsius
cm	centimeter
cu	cubic
dbh	diameter-at-breast-height
^oF	degrees Fahrenheit
fbm	foot board measure; board feet
ft	foot
gal	gallon
gm	gram
ha	hectare
hr	hour
in	inch
km	kilometer
kw	kilowatt
kwh	kilowatt-hour
lb	pound
l	liter
m	meter
mi	mile
min	minute
ml	milliliter
mm	millimeter
mpg	miles per gallon
mph	miles per hour
mw	megawatt
oz	ounce
sec	second
sq	square
yd	yard
yr	year

GLOSSARY

Annual: Plants with a life cycle of one growing season. Living or lasting for only 1 year or season.

Big Island: The island of Hawaii, used in this report to eliminate confusion between references to the island and the State.

Coppice: Sprout or regrow from a cut stump or root.

d.b.h.: diameter at breast height, diameter of a tree 4.5 feet above ground level.

Dibbling tubes: Tapered tubes in which seedlings are growing in nursery operations.

Hawaiian Homes Land: Homesteads set aside for native Hawaiians by Federal act in 1921. Homestead lands, leased for 99 years at $1 per year, cover approximately 200,000 acres and are occupied by 2,200 families in Hawaii.

HECO: Hawaiian Electric Company, Inc., the state's main electric utility, located on Oahu.

HELCO: Hawaii Electric Light Company, Ltd., the HECO subsidiary which serves the island of Hawaii.

Marginal agricultural land: Land characterized by limited productivity for crop growing.

Makai: Hawaiian directional word meaning "toward the ocean."

Mauka: Hawaiian directional word meaning "toward the mountains."

Pali: Hawaiian word for cliff.

Perennial: Plants which lives for more than 2 years--an indefinite number of years. Herbaceous plants that produce flowers and seed from the same root structure year after year.

Styroblocks: Used in nursery operations, the trays which hold the dibbling tubes.

Glossary

DEFINITIONS OF TERMS

Land Classes

Land areas are those reported by the Bureau of the Census as land, including dry land, marshes, streams less than ⅛ mile wide, and water bodies less than 40 acres.

Forest reserves are lands set aside through statute or executive order for various conservation purposes. The reserves include privately owned lands as well as state-owned lands.

FOREST LAND

Land at least 16.7 percent stocked by forest trees of any size, or formerly having such tree cover and not currently developed for other use; and land supporting shrubs, the crowns covering more than 50 percent of the ground. The minimum area recognized as forest land is 1 acre.

Commercial Forest Land

Forest land which is producing, or can produce usable crops of industrial wood and is not withdrawn from timber utilization by statute or administrative regulation.

Noncommercial Forest Land

Forest Land not yielding crops of industrial wood.

Productive Reserved Forest Land—Land capable of producing timber crops, but reserved from commercial timber use through administrative regulation or statute, such as national parks.

Unproductive Forest Land—Forest land incapable of yielding usable crops of industrial wood because of adverse site conditions. Includes forest lands which although unproductive for timber, may be productive for range, water, recreation, or wildlife.

NONFOREST LAND

Land that has never supported forests, or was formerly forested and is currently developed for nonforest uses. Includes cultivated areas, pastures, and urban areas.

Ownership Classes

PUBLIC OWNERSHIP GROUP

Hawaiian Homes Lands

State-owned lands administered by the Hawaiian Homes Commission.

Other State Lands

State-owned lands, with the exception of Hawaiian Homes Lands.

Miscellaneous Federal Lands

All federally-owned lands, with the exception of national parks and monuments.

PRIVATE OWNERSHIP GROUP

Corporate Lands

Lands owned by private corporations, companies, or other business groups.

Individual Lands

Lands under individual private ownership.

Forest Types

COMMERCIAL FOREST TYPES

Forests of commercial tree species on commercial forest land or productive reserved land, which are sawtimber stands or are likely to develop into such stands. Commercial tree species occupy at least 10 percent of the growing space occupied by trees.

Commercial Native and Naturalized Forest Types

Forests of native and introduced commercial tree species established through natural processes.

'Ohi'a—Forests in which 'ohi'a trees are predominant and make up 25 percent or more of the stand, and in which koa or other trees make up less than 25 percent of the stand.

Koa—Forests in which koa trees are predominant and make up 25 percent or more of the stand, and in which 'ohi'a or other trees make up less than 25 percent of the stand.

'Ohi'a koa—Forests in which koa and 'ohi'a trees are predominant and each make up 25 percent or more of the stand.

Monkey-pod—Forests in which monkey-pod trees are predominant and make up 25 percent or more of the stand.

Commercial Forest Plantations

Forests of planted commercial tree species with at least 10 percent of the growing space occupied by

planted tree species, regardless of the predominance of native and naturalized species.

Eucalpyts—Forest plantations predominantly of commercial *Eucalyptus* species.

Other hardwoods—Forest plantations predominantly of commercial broad-leaved (dicotyledonous) species other than eucalypts.

Conifers—Forest plantations predominantly of commercial softwood species. These are evergreens, usually having needles or scale-like leaves.

NONCOMMERCIAL FOREST TYPES

Forests of noncommercial tree species on commercial forest land, or of any species on noncommercial forest land. These are forests that will not develop sawtimber.

Noncommercial native and Naturalized Forest types

Forests of native and introduced noncommercial species established through natural processes.

Tree Types—Forests in which trees occupy 10 or more percent of the area: *Kukui type*—Forests in which kukui trees are the predominant species; *Kiawe type*—Forests in which kiawe trees are the predominant species; *'Ohi'a-koa type*—Forests in which 'ohi'a or koa trees, singly or in combination, are the predominant tree species, on sites where these species will not likely develop into sawtimber trees; and *Other noncommercial tree types*—Tree types not defined elsewhere.

Shrub Type—Woody vegetation is the predominant cover, with trees occupying less than 10 percent of the area. Includes koa-haole *(Leucaena glauca)*, guava *(Psidium* spp.), lantana *(Lantana camara)*, pukiawe *(Styphelia tameiameiae)*, and mamane *(Sophora chrysophylla)*.

Noncommercial Forest Plantations

Forests of planted noncommercial tree species, or of planted commercial tree species on noncommercial forest land, with at least 10 percent of the growing space occupied by planted tree species, regardless of the predominance of native and naturalized species.

Tree Classes

GROWING STOCK

Live trees of commercial species that are now or may be expected to become suitable for use as industrial wood.

Sawtimber Trees

Live trees of commercial species at least 11.0 inches diameter breast height (d.b.h.). Conifers must contain at least one 12-foot saw log, and hardwoods one 8-foot saw log.

Poletimber Trees

Live trees of commercial species between 5.0 and 10.9 inches d.b.h., having the soundness and form necessary to develop into sawtimber trees.

Seedling and Sapling Trees

Live trees of commercial species less than 5.0 inches d.b.h., and having the potential to become poletimber trees.

SOUND CULL TREES

Live trees 1 inch d.b.h. or larger which do not qualify as growing stock because of species, poor form, or excessive limbs.

ROTTEN CULL TREES

Live trees 1 inch d.b.h. or larger, which are not growing stock or sound cull because of excessive rot.

SALVABLE DEAD TREES

Standing or down dead trees, of commercial species, 11.0 inches or more d.b.h., containing 50 percent or more of sound volume and at least one merchantable 8-foot log.

Stand-size Classes

SAWTIMBER STANDS

Stands at least 10 percent stocked with growing stock, with one-half or more of the stocking in sawtimber and poletimber trees, and with sawtimber stocking at least equal to poletimber.

POLETIMBER STANDS

Stands failing to qualify as sawtimber but at least 10 percent stocked with growing stock trees, at least half poletimber.

SAPLING AND SEEDLING STANDS

Stands not qualifying as sawtimber or poletimber, but at least 10 percent stocked with seedlings and saplings.

Timber Volume

The International ¼-inch kerf log rule is the standard board-foot log rule adopted nationally by the Forest Service for the presentation of Forest Survey timber volume statistics.

SAWTIMBER VOLUME

The net volume of the saw log portion of sawtimber trees, in board feet, International ¼-inch rule.

SAW LOG PORTION

The bole of sawtimber trees between the stump and the saw log top, 9 inches diameter outside bark (d.o.b.). Logs must meet minimum specifications of approved log grades to qualify as saw logs.

UPPER STEM PORTION

The bole of sawtimber trees above the saw log top to a 4-inch top d.o.b., or to the point where the central stem breaks into limbs.

CRAFTWOOD BOLTS

Those 4-foot sections of the upper stem or limbs of koa and monkey-pod trees, exclusive of the saw log portion, having diameters of 9 inches or greater inside bark at the small end, and meeting minimum defect specifications.

GROWING STOCK VOLUME

Volume in cubic feet of sound wood in the bole of sawtimber and poletimber trees from the stump to a minimum top d.o.b. of 4.0 inches, or to the point where the main stem breaks into limbs.

ALL TIMBER VOLUME

Volume in cubic feet of sound wood in the bole of growing stock, cull, and salvable dead trees 5.0 inches d.b.h. or larger, from the stump to a minimum top d.o.b. of 4.0 inches.

TREEFERN

Gross volume in cubic feet of fern trunks from ground level to a point 3 feet below the base of live fronds.

Tree Species

Commercial tree and treefern species—Tree species suitable for industrial wood products.

Hardwoods

Scientific name	*Common name*
Acacia koa	Koa
Metrosideros collina (Polymorpha)	'Ohi'a
Pithecellobium saman	Monkey-pod
Eucalyptus spp.	Eucalypts

Other hardwoods—Includes *Albizia* spp., *Fraxinus* spp., *Grevillea* spp., *Flindersia* spp., and others.

Conifers—Includes *Pinus* spp., *Araucaria* spp., *Cryptomeria* spp., *Agathis* spp., and others.

Treefern

Scientific name	*Common name*
Cibotium splendens	Hapu'u-pulu
Cibotium menziesii	Hapu'u-'i'i

Noncommercial tree species—Tree species not suitable for industrial wood products.

Scientific name	*Common name*
Aleurites moluccana	Kukui
Prosopis pallida	Kiawe

Other Useful Terms

Diameter breast height(d.b.h.)—Tree diameter in inches, outside bark, measured at 4½ feet above the ground for normal trees, and 18 inches above the stilt or swell for abnormal trees.

Diameter of treefern—Trunk diameter, in inches, measured 1 foot above the ground or just above any excessive basal swell.

Industrial wood—Commercial roundwood products, such as saw logs, veneer logs, and pulpwood; fuelwood, fence posts, and treefern are excluded.

Log grades—A classification of logs based on external characteristics as indicators of quality or value. Grade 1 is the highest quality, grade 2 intermediate, and grade 3 lowest quality of standard hardwood factory logs (USDA Forest Serv. 1965). Grade 4 logs are suitable for ties and timbers.

Mortality—The growing stock or sawtimber wood volume lost because of tree death; often given as average annual mortality.

Net annual growth—The annual change in the volume of growing stock or sawtimber.

Stand basal area—The combined cross-sectional area of trees 5 inches d.b.h. or larger in a stand, usually expressed in square feet per acre.

Stocking classes—A classification of forest stands according to the extent that growing space is occupied by trees, expressed in square feet of basal area per acre.