REFORESTATION RESEARCH IN HAKALAU FOREST NATIONAL WILDLIFE REFUGE

C. EUGENE CONRAD, U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, 1151 Punchbowl Street, Room 323, Honolulu, HI 96813

PAUL G. SCOWCROFT, U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, 1151 Punchbowl Street, Room 323, Honolulu, HI 96813

RICHARD C. WASS, U.S. Fish and Wildlife Service, Hakalau Forest National Wildlife Refuge, 154 Waianuenue Avenue, Room 219, Hilo, HI 96720

DONOVAN S. GOO, U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, 1643 Kilauea Avenue, Hilo, HI 96720

1988 TRANSACTIONS OF THE WESTERN SECTION OF THE WILDLIFE SOCIETY 24:80-86

Abstract: Mountain land on Mauna Kea on the island of Hawaii is being acquired by the U.S. Fish and Wildlife Service to provide a refuge for Hawaiian birds. The area of the refuge between 1,800 and 2,000 m was previously used as mountain pasture and the forest cover was mostly altered to grassland. Below 1,800 m the forest canopy is open forest to woodland down to about 1,700 m. Fenced exclosures were established in woodland at 1,700 m and in open grassland at 2,000 m elevation to evaluate natural revegetation and planted seedlings without disturbance by cattle. First-year survival of the resulting regeneration was good. Condition of the planted koa (*Acacia koa*) seedlings and rooted 'ohi'a (*Metrosideros polymorpha*) cuttings in the exclosure at 2,000 m elevation was only fair. Scarifying by disking in the exclosure at 1,700 m elevation was followed by good establishment of vigorous koa seedlings.

The Hakalau Forest National Wildlife Refuge on Hawaii is being established on the eastern slope of Mauna Kea for the long term conservation of endangered forest birds (Fig. 1). The refuge, owned and managed by the U. S. Fish and Wildlife Service, is planned to be 12,500 ha. Several endangered forest birds and category-one candidate plant species for listing as endangered or threatened may be in the Hakalau NWR habitats.

All of the Refuge was once forested and even now most of it is forest. However, the subalpine zone between 1,700-2,000 m was either converted by former owners to grassland or has declined to scattered trees (5-25 percent tree crown cover), or woodland (25-60 percent tree crown cover) (Scott et al. 1986). The entire forest area has been subjected to varying degrees of cattle and pig impact.

Regenerating native Hawaiian forest on the non-forested area is a priority refuge management objective. Desirable reforestation would provide habitat for native forest birds (Scott et al. 1986). Our research should provide the prescriptions needed for establishing several of the key native species in the overstory and understory.

The principal goal of our research is to determine how to regenerate a forest dominated by native Hawaiian forest species in the upper 600 ha of the Hakalau Refuge. The goal should be achieved by planting where forest regeneration is not likely by other methods. Objectives established to reach the goal are: (1) determine if an existing seed bank in the soil is adequate to meet reforestation requirements, (2) develop procedures for growing planting stock of native forest species, (3) determine the efficacy of alternate types of seedbed preparation for stimulating natural regeneration of native forest species in Hakalau, and (4) test procedures for planting and for care of regenerated stands of selected native forest species.

STUDY AREA

The study area is on the east slope of Mauna Kea in the 600-ha subalpine zone of Hakalau Forest National Wildlife Refuge. Rainfall, estimated from isohyet maps, is between 2,000 and 3,000 mm distributed more or less uniformly throughout the year. The soil is ash and cinder mostly over aa lava.

Native Habitats

Prior to conversion to grassland, the upper one-third to one-half of the study area probably was park-like woodland or forest. The upper edge of the study area was probably on the margin between mamane (*Sophora chrysophylla*) and Hawaiian koa (*Acacia koa*) woodlands or forests. Below the mamane woodland, the upper part of Hakalau graded into koa forest with increasingly more 'ohi'a (*Metrosideros polymorpha*) in the overstory. Below 1,700 m elevation, forest was continuous.

Most of the upper part of the study area has been converted to grassland. Mamane has been extirpated from the study area but dead trunks are still found within 1 km of the boundary. Scattered individuals or open stands of koa and 'ohi'a are found throughout the area. The lower one-third of the area is mostly woodland grading into forest just below the study area. Kolea (*Myrsine lessertiana*) and at least eight other trees are found as understory species. Only a few tree fern (*Cibotium* sp.) plants remain, but *Dryopteris* spp. ferns are commonly associated with the forests and woodlands around the study area.

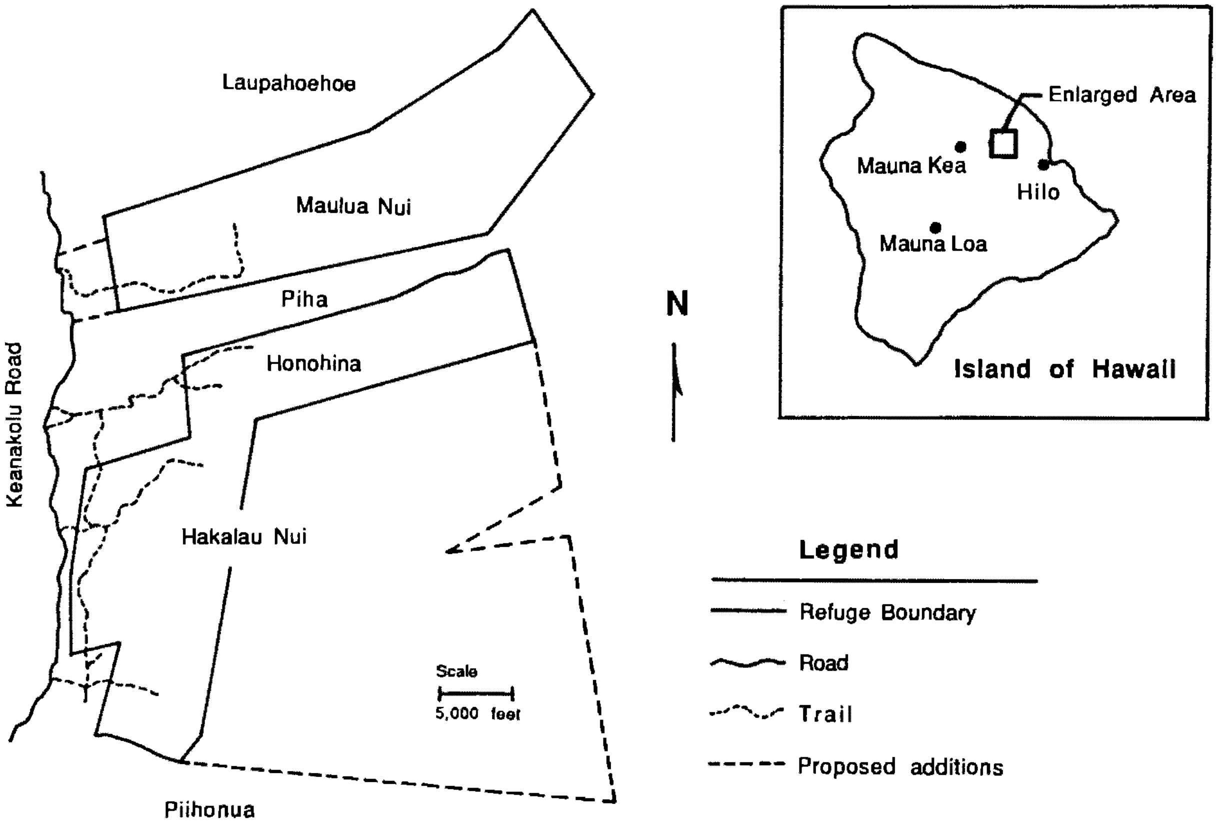

Fig. 1. Hakalau Forest National Wildlife Refuge.

Introduced Plant Problems

Competition from introduced plant species is a serious problem. Dense stands of introduced grasses, especially kikuyu (*Pennisetum clandestinum*), are found in much of the study area. Clumps of gorse (*Ulex europaeus*), an introduced shrub that forms impenetrable brushfields, appear to be growing larger in area. Following removal of cattle, the threat of invasion by banana poka (*Passiflora mollissima*), an introduced vine, from the adjacent infested forest is also serious. The problem of grass competition is a general one and must be dealt with throughout the study. Gorse and banana poka have potential to become widespread in the upper part of Hakalau Refuge.

Animal Problems

Cattle and feral pigs have been common in the study area. These as well as various rodents are the only animals in upper Hakalau that are potential or present threats to reforestation. Pigs and cattle can devastate reforestation projects. Cattle graze or browse many of the native plants, especially koa seedlings and saplings. They strip the bark from young koa when the foliage is beyond their reach. Pigs cause considerable seedling loss by rooting activity and by eating the growing tips of the seedlings.

SPECIES SELECTION AND PROPAGATION

The second objective in the research was to develop procedures for growing planting stock of native forest species. The decision to emphasize work on developing procedures to establish the most common species was made soon after beginning the research. We were confident that progress would be most rapid with these species. In the area between 1,500 and 1,800 m elevation, nine trees and three ferns are good candidates for research to find methods for establishing them in appropriate sites in upper Hakalau (Table 1).

The best candidates of this group are koa, 'ohi'a, and mamane. Methods for producing planting stock of these species is already well known (Walters and Horiuchi 1979, Scowcroft 1981, Skolmen amd Fujii 1980). These three species are overstory trees and are important succession species (Mueller-Dombois et al. 1981). They were probably the principal overstory species found in upper Hakalau prior to extensive modification of the area for grazing by cattle, sheep, and goats.

Koa is an early succession species (Mueller-

Table 1. Candidate native forest species for propagating and planting in upper Hakalau Forest National Wildlife Refuge.

Latin name	Common Name	Forest Position
Araliaceae, *Cheirodendron trigynum*	Olapa	understory tree
Aquifoliaceae, *Ilex anomala*	Kawa'u	understory shrub/tree
Leguminosae, *Acacia koa*	Koa	overstory tree
Leguminosae, *Sophora chrysophylla*	Mamane	overstory tree
Myrsinaceae, *Myrsine lessertiana*	Kolea	understory tree
Myrtaceae, *Metrosideros polymorpha*	'Ohi'a	overstory tree
Rubiaceae, *Psychotria hawaiiensis*	Kopiko	understory shrub/tree
Rubiaceae, *Gouldia* sp.	Manono	understory tree
Rubiaceae, *Coprosma* sp.	Pilo	understory tree
Aspidiaceae, *Athyrium sandwichianum*	Ho'i'o	understory fern
Blechnaceae, *Sadleria cyatheoides*	Ama'u	understory fern
Dicksoniaceae, *Cibotium glaucum*	Hapu'u pulu	understory tree fern

Dombois et al. 1981). During secondary succession which follows major disturbance, koa is commonly established in monospecific juvenile stands and eventually replaced by mixed species. This secondary succession process is long-term and information about time scale is not known (Scowcroft and Nelson 1976, Skolmen and Fujii 1980, Mueller-Dombois et al. 1981). One koa stand in an unrelated project is about 28 years old and the overstory is still pure koa. A stand about 35 years old at another site has lost most of the koa regeneration.

As much as possible, seeds and vegetative cuttings to use for producing planting stock were collected from nearby trees in the study area. However, due to absence of live mamane, seeds and cuttings for propagation have been collected from trees in the adjacent grassland. The criteria for selecting source trees were that they be vigorous and near the exclosure. Tree form was not considered important.

Seedling propagation of species such as koa and 'ohi'a can be done by sowing into media-filled dibble tubes or onto greenhouse flats (Walters and Horiuchi 1979). Koa seedlings should reach 30 to 36 cm planting size in 3 to 4 months, while 'ohi'a seedlings are likely to require more than a year before they are 15 to 25 cm planting size. We have found that 'ohi'a cuttings of new growth can be rooted with good success. With proper treatment, 60-70 percent of the 'ohi'a cuttings will produce plantable stock within six months.

Germinating most of the other native plant seeds is slow and percentageof survival is low. Seed scarification seems to be a common requirement which is, perhaps, an indication that seeds of many species passed through bird guts. However, several species will root from cuttings. It is likely that continuing to work on improving success at generating plantable rooted cuttings of understory trees will result in most rapid reforestation success.

Little is known about the environmental requirements for germinating seeds of these species. However, as an aid to understanding long term forest regeneration requirements, some future work should be concerned with studies to improve germination success. Seeds of forest species often germinate on fallen trees and tree ferns rather than on the forest floor. It is possible that germination of several forest species will be significantly improved by taking advantage of situations that mimic normal forest conditions.

FIRST YEAR PROGRESS

The first unit of the Hakalau Forest National Wildlife Refuge was acquired in 1985 and we began forest regeneration experiments in early 1986. Two fenced exclosures were established to protect these experiments from disturbance by cattle and feral pigs. One exclosure was established in open grassland at Magnetic Hill (2,000 m elevation) and the other in open woodland at 1,700 m elevation.

Magnetic Hill Exclosure

A 2.6 ha grassland plot located near Magnetic Hill in the southwest corner of Hakalau was fenced to exclude cattle. Feral pigs do not presently use this Magnetic Hill unit of the study area but, if necessary, the fence can be improved to exclude pigs. The exclosure includes a variety of topographic and edaphic conditions as a result of including a seasonal stream channel and two hills. The hill slopes in the exclosure are steep with only a small flat area on the top of each. Small areas of nearly level ground occur at the base of the hills. Annual rainfall is estimated from map isohyets to be 2,030 mm per year. Elevation is about 2,000 m and temperatures below freezing can occur at least from November through April. In May 1987, experiments to achieve objective (4) of the research were started in the Magnetic Hill exclosure.

Methods.—Treatments replicated three times were established to determine if koa seedlings, rooted 'ohi'a cuttings, and mamane seedlings or rooted cuttings could be successfully established in the exclosure. If the seedlings and cuttings become established, effects on growth of spacing and competition between species will be measured. The design calls for testing koa in pure stands and interplanted with 'ohi'a. Mamane will be grown in pure stands and in combination with koa.

Koa was planted in all plots except those set aside for pure mamane. Plantings were done at 2 m and 2.5 m spacing in a 7x7-tree matrix of each species. In 1987, some plots planted with koa from the two spacing treatments were interplanted with a 7x7-tree matrix of rooted 'ohi'a cuttings. Each interplanted tree was approximately equal distance from planted koa seedlings. Thus each of the two species were in a 2 or 2.5 m spacing but the spacing between species was 1 or 1.25 m and comparison of species with and without competition is not valid.

Sufficient plots of koa were planted in 1987 to provide for interplanting 'ohi'a and mamane rooted cuttings or seedlings in 1988 or 1989. The treatments of pure mamane and mamane interplanted with koa were not started in 1987 because the required number of seedlings or rooted cuttings could not be produced.

Site preparation prior to planting was minimum. Initial intent was to spray the location of each seedling with an application of glyphosate herbicide and wait until the herbage died back then plant the stock in a dibbled hole. Unfortunately, we could not use herbicide because of nearly continuous inclement weather. Instead, the vegetation was scalped from a circular area about 0.3 m across at each planting spot. The plantlets were then planted in the center. Since planting, weed control has not been necessary because competition has not become a serious threat to seedling survival.

Treatment effects were evaluated by measuring growth, seedling condition, and counting survival. Plant vigor or condition was rated according to a simple scale: good, average, and poor. The vigor class was subjectively assigned on the basis of color, fullness of foliage, amount of new growth, and appearance of the growing tip. In determining the "poor" category, major consideration was given lack of normal green leaf color and absence or scarcity of leaves.

Results.—The January 1988 observations indicated that growth of both koa and 'ohi'a after eight months was slow in the Magnetic Hill exclosure compared with the woodland exclosure, which is at a lower elevation. The maximum difference in average height among treatments was only 10 cm. Because the difference among treatments was not statistically significant, the data were combined for this report. Growth of koa seedlings since planting averaged only about 10 cm. Their average height was 48 cm ($\pm$0.8 cm SE). Only three 'ohi'a treatments had been planted by January 1988. Their average height was about 20 cm ($\pm$ 4.3 cm SE). None of the treatment differences were significant. Growth averaged only 5 to 7.6 cm.

Overall, vigor was rated average for the koa and below average for the 'ohi'a. 'Ohi'a leaves tended to be lighter green and fewer than normal suggesting the effects of stress, especially where the plants were most exposed. The plants that looked best were those under some cover of surrounding herbaceous plants. Plots containing the poorest survival of 'ohi'a were those in the most exposed habitats and probably the poorest soil. Frost damage could be a major cause for relatively poor vigor of the 'ohi'a.

Survival of the planted stock was surprisingly high. As of January 1988, average koa seedling survival per plot was 97 percent. The lowest average survival for a three plot treatment was 95 percent. 'Ohi'a survival was less than koa. Over all plots 'ohi'a survival was 88 percent, but one plot had only 43 percent survival while koa survival was 100 percent on the same plot. Exposure of the 'ohi'a to temperature extremes seemed particularly severe on this plot due to lack of associated weeds. Soil quality may also have been poor on this plot.

The Woodland Exclosure

A 16 ha woodland plot at 1,700 m elevation about 2.4 km east of the refuge headquarters cabin was fenced in 1987 to exclude cattle. This woodland exclosure had previously been impacted by cattle and by pigs. The fence will be improved to exclude pigs. Rainfall is higher in this area than at the Magnetic Hill exclosure. The topography within the exclosure is rolling with no major stream channels. The soil is similar to the rest of the study area. In July 1987, experiments in the woodland exclosure to achieve objectives (1) and (3) of the research project were started.

Methods.—Within the woodland exclosure, studies were begun to determine the efficacy of soil scarification for producing adequate koa forest regeneration from the residual soil seed bank. If koa seeds are widely distributed over the landscape, it is reasonable that selected areas could be treated with this technique to cause seed germination, thus initiating forest regeneration. Previous work has shown that the use of bulldozers during logging to smash down shrubs and small trees is an effective method for getting dense koa regeneration (Skolmen and Fujii 1980). The operation clears the soil surface, allows sunlight to penetrate and warm the soil, and probably also effects the seed coat of the soil-stored seeds.

We abandoned the idea of using a bulldozer because the resulting disturbance was not acceptable. An effort to avoid major disruption of existing woody vegetation and avoid leaving large piles of soil and debris resulted in excessive wear and tear on the equipment. An alternative was to use a disk plow. The equipment must be heavy to withstand being dragged over rough, rocky ground, and sometimes in tight circles to get between trees and tree snags. In order to achieve adequate scarification, the disk needs to be set so it cuts 12 to 15 cm into the soil and turns sod over if possible. Several passes results in more uniform scarification and seed germination.

Five live individuals, five clusters of live koa trees, five dead and down koa trees, and five open spots were selected at random for scarifying by disking. The open spots selected were at least 30 m from a live or dead koa and were marked to be about 10 m across after disking (Fig. 2). These 20 plots were scarified by disking but one of the plots set for a cluster of live trees was unacceptable. The tractor operator was asked to get as near as possible to trees, shrubs, and logs within each plot. Consequently the plot polygons as shown in Fig. 2 vary in size and shape. The representations of the plots are not drawn to scale. We have measured only one area in detail (Fig. 2) but the polygons shown for plots in open areas were laid out so they would be about 78 m² where there were no mature koa trees within 30 m. 'Ohi'a trees as near as 10 m from the center of the open area polygons were the closest trees. More detailed field measurements are needed if the polygons (Fig. 2) that contain different types of seed trees are to be separated in order to estimate the source of the seedlings.

The seedlings established as of January 1988 were counted and flagged as a baseline to study the establishment and distribution of seedlings resulting from scarifying. Seedlings measurements included seedling height, basal diameter, condition, and survival. Competition from other species was assessed by estimating the cover of the surrounding vegetation. The competing vegetation is primarily grass.

Results.—The number of koa seedlings in the disked polygons was variable, but all of the polygons associated with live trees contained at least 29 seedlings. The range of 0 to 17 seedlings in the polygons that did not contain a tree suggests that at least some seeds are spread away from the existing mature trees. Seedling counts associated with dead trees ranged from 1 to 660 seedlings. The dead tree at the left side of Fig. 2 where only one seedling was found appeared to have been dead and down for many years. The other dead trees appeared to have died more recently. Even the number of seedlings associated with live trees varies considerably.

In October 1987, detailed measurements were made in one polygon for use as base line data for future evaluation of growth and survival (Fig. 3). The diamond in the center marks the base of one dead, down seed tree.

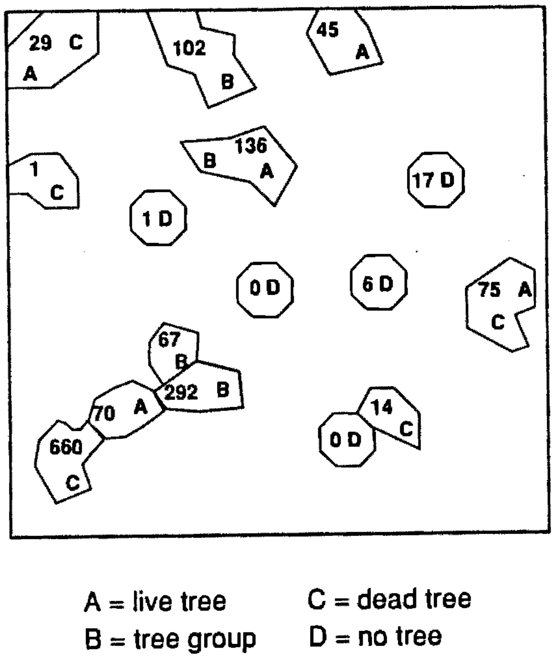

Fig. 2. Number of seedlings established seven months after disking in the Hakalau woodland exclosure.

The large open area on the right side of the base is the area covered by the downed tree. The continuous line connecting the outer and inner perimeter of dots marks the boundary of the scarified area. The circle has a radius of about 20 m from the base at the center of the tree. Each dot represents the location of one seedling found during field measurement in October 1987. By January 1988, 85 additional seedlings had emerged in areas where competing grass had not obscured the soil surface. Only five of the October seedlings had disappeared. The distribution of seedlings within the area beginning about 5 m from the base of the tree to about 35 m from the tree will be estimated. Based on preliminary examination, these data indicate that seedlings were distributed more or less uniformly around the tree studied in October.

Overall seedling condition was good in October and January. Seedling color is darker green and seedlings appear to have more foliage than at Magnetic Hill. In January seedling height was much more variable than at Magnetic Hill because some seedlings were just emerging and others had been established for several weeks or months. The tallest were greater than 40 cm tall. Grass competition increased with time since scarifying and by January only small areas of bare soil surface were still present. New seedling emergence occurred only in areas where the soil surface was visible through the grass. Seedlings that were established prior to grass recovery appeared to grow normally even though they were in dense grass. There was no discernible difference in the

LITERATURE CITED

MUELLER-DOMBOIS, D., K.W. BRIDGES, and H.L. CARSON, eds. 1981. Island ecosystems, biological organizations in selected Hawaiian communities. US/IBP Synthesis Series 15, Hutchinson Ross Publishing Co., Stroudsburg, PA. 583pp.

SCOTT, J.M., S. MOUNTAINSPRING, F.L. RAMSEY, and C.B. KEPLER. 1986. Forest bird communities of the Hawaiian Islands: their dynamics, ecology, and conservation. Studies in Avian Biology Biology No. 9., Cooper Ornith. Society. 431pp.

SCOWCROFT, P.G. 1981. Regeneration of mamane: effects of seedcoat treatment and sowing depth. Forest Science 27:771-779.

________, and R.E. NELSON. 1976. Disturbance during logging stimulates regeneration of koa. U.S. Forest Service, Pacific Soutwest Forest and Range Experiment Station, Research Note PSW-306: Berkeley, CA. 7pp.

SKOLMEN, R.G. and D.F. FUJII. 1980. Growth and development of a pure stand of *Acacia koa* at Keauhou-Kilauea. Pages 301-310 *in* C.W. Smith, ed. Proceedings Third Conference in Natural Sciences, Hawaii Volcanoes National Park, University of of Hawaii, Honolulu.

WALTERS, G.A. and H. HORIUCHI. 1979. Containerized seedlings: key to forestation in Hawaii. Pages 87-92 *in* Proceedings Intermountain Nurseryman's Association, Meeting Collection 13-16.