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NATIVE PLANT RESTORATION ON

Hawaii

Tara Luna |

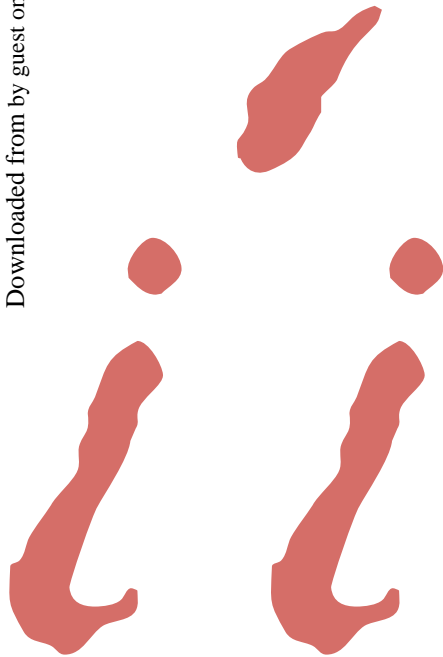
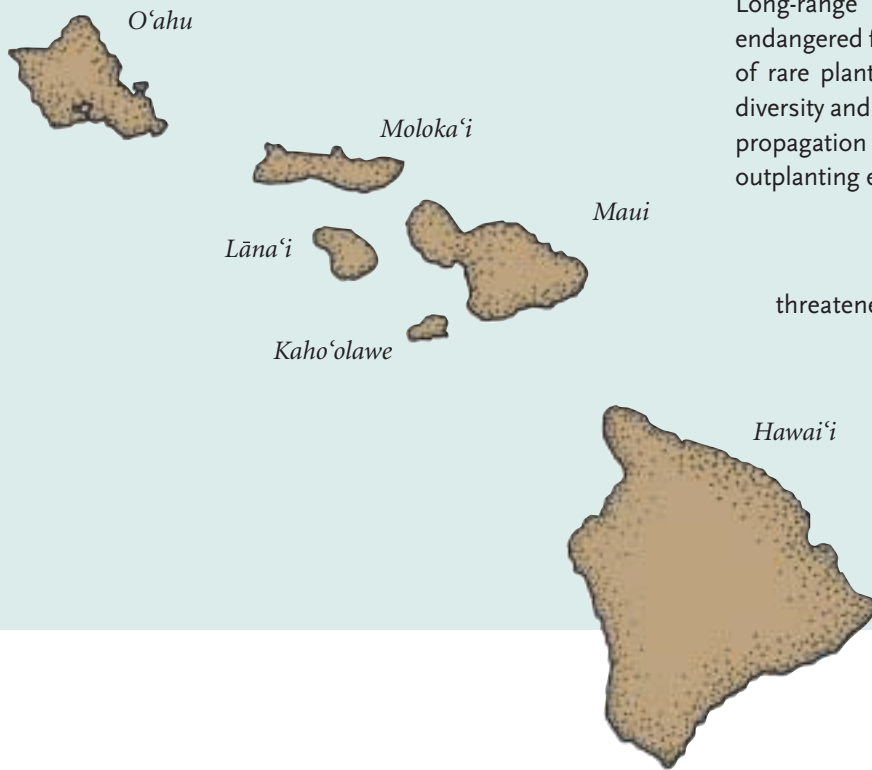
Restoration projects and nurseries from 7 Hawaiian islands are working jointly to propagate and reestablish rare and endangered plant species and to rehabilitate island habitats. Long-range goals of these projects may benefit rare and endangered fauna. Conservation of habitat and augmentation of rare plant populations are crucial for preserving genetic diversity and recovery. Such efforts have resulted in successful propagation of many at-risk species. The propagation and outplanting efforts of these unique species are described.

KEY WORDS

threatened and endangered species, species of concern, propagation, nurseries, outplanting

NOMENCLATURE

(plant and animal names) ITIS (2002);
(Hawaiian names) UHB (2002)



One of the richest and most threatened environments on earth are the Hawaiian Islands. The uniqueness of the flora and fauna and the islands themselves lies in the geologically recent formation of land, where by immeasurably small chance events, species arrived via wind, water, or the wings of birds to the most isolated land mass in the world. Species arrived at the rate of one every 10 000 y. Hawai'i is known as the evolutionary capital of the world; species diversified through adaptive radiation, an evolutionary process where an ancestral species colonizes and disperses, thus proceeding to evolve into many specialized and unique species that differ greatly from one another (Figure 1). Hawai'i has one of the highest levels of endemism in the world and the highest levels of threatened taxa and extinctions. Of all native taxa, 89% are endemic and over half of these are at risk. Ninety-two plant species are extinct, and the state has the unfortunate distinction of having the highest number of threatened, endangered, and species of concern in the US.

Figure 1. The 'i'iwi (*Vestiaria coccinea* Forster [Fringillidae]) has a specialized beak for feeding in unique Hawaiian flowers like this 'ōhi'a lehua (*Metrosideros polymorpha* Gaud. [Myrtaceae]).

Photo by Jack Jeffrey Photography

Photo by Alan McCray Photos



Photo by William Garnett

Figure 2. *Cyanea superba* (Cham.) Gray (Campanulaceae) growing on O'ahu.

O'AHU

Hawai'i has 150 distinct ecosystems, which makes it a unique global bioregion. Ecosystems include tropical dry forest, subalpine grasslands, montane bogs, alpine communities, coastal dunes, and cliffs. For many of Hawai'i's rarest flora and fauna, loss of habitat is a primary cause for their decline. Of the 150 recognized natural communities, 85 are considered critically endangered. While the loss of a single species is of serious concern, the loss of entire natural communities represents a massive crisis (HNHP 2002).

Racing against time to save, restore, and preserve Hawaiian habitats and rare endemic species has resulted in one of the most collaborative interagency/organization efforts in the world. Propagation techniques and problems are worked on jointly, and restoration strategies are developed according to each island's unique climate and site conditions. The threats that each species potentially face following outplanting also must be addressed. Restoration of habitats and rare plant propagation require an understanding of the reproductive biology and ecology of each species. In many cases, special pollination efforts prior to seed collection are needed due to lack of native pollinators and extreme rarity. In addition, over 15% of Hawai'i's native flowering plants are dioecious, the highest level of diocity in the world. This requires identifying male and female individuals, and in many cases, manual transfer of pollen between isolated individuals. Yet, for many of these species, overwhelming logistics have been overcome, and propagation and outplanting survival have been successful. In other cases, the only hope is the development of micropropagation techniques. Each nursery, by working together and enlisting extensive volunteer support, has been successful both with single species recovery and large-scale restoration projects.

On the island of O'ahu, 66 listed endangered plants are found, including 3 critically endangered plant taxa: haha (sharktail cyanea, *Cyanea pinnatifida* (Cham.) F. Wimmer [Campanulaceae]), cliff face catchfly (*Silene perlmanii* W.L. Wagner, Herbst & Sohmer [Caryophyllaceae]), and 'aiakeakua (Hawai'i horse-nettle, *Solanum sandwicense* Hook. & Arn. [Solanaceae]). These plants have become extinct in the wild during the last 7 y. The Department of Fish and Wildlife's (DOFAW) O'ahu Rare Plant Recovery Program was started in 1995 and all 3 species are currently under propagation, planting, and long-term storage phases of recovery (Garnett 2002).

Rare plant recovery and restoration on O'ahu is a collaborative effort by DOFAW, the US Army, The Nature Conservancy, the Lyon Arboretum at the University of Hawai'i, and volunteers. All partners assist in seed collection, propagation, outplanting, monitoring, and maintenance of restoration sites.

The O'ahu Rare Plant Recovery Program targets propagule collection from wild individuals of threatened and endangered O'ahu species that are without genetic representation in current ex situ populations. In the past 2 y, cuttings and seeds were collected from 44 rare species. The facility consists of a fog-house and 4 shadehouses that vary in shade cover from 99% shade to full sun. Plants are moved from the fog house to the shadehouses in a series of hardening phases that is so critical to outplanting survival.

The Lyon Arboretum tissue culture lab produces plants that come to the Pahole Rare Plant Facility in flasks. The fog house at Pahole creates ideal conditions for the transition from the flask to nursery. Nursery-produced seeds of ko'olua 'ula (*Abutilon*

menziesii Seem. [Malvaceae]), diamond head schiedea (*Schiedea adamantis* St John [Caryophyllaceae]), 'oha (*Delissea subcordata* Gaud. [Campanulaceae]), *Cyanea pinnatifida*, and *Solanum sandwicense* have been sent to Lyon Arboretum for long-term seed storage trials. The arboretum is cooperating with federal and state agencies and with other organizations to ensure that rare plants, several of which have been saved from extinction, are outplanted in native habitats on O'ahu and other islands.

Rare species are outplanted into protected areas located on state, federal, and private lands. To date, approximately 1000 plants of 28 species have been planted in 11 maintained sites (Figure 2). Some of the older plants of other species are being maintained in the nursery to produce seeds and to wait for favorable weather conditions and sites to assure survival in the field. In addition to the threatened and endangered species, 20 species of common native plants are grown to replace weeds and create native canopy on planting sites.

Survival of outplanted individuals is the first measure of success. By utilizing well-grown plants in deep tree Stuewe® pots (262 and 656 ml [1 and 2 gal]) and selecting proper planting sites and time of year, survival rates in excess of 90% have been achieved for all but 1 species of rare O'ahu plants. Some factors associated with mortality are prolonged drought, low vigor, allopathic leaf litter, and stochastic events. In the past year, 12 rare species flowered or fruited on the restoration sites. With the exception of 2 species, all produced fruits with viable seeds, verified by germination trials. Three of these species made it to the recruitment stage of recovery on site.

Site preparations include removal of nonnative plants and replacement with appropriate common native species. After outplanting, the plants are monitored regularly to ensure that sufficient water (2.5 cm [1 in] per wk minimum) is provided for the initial 3 to 5 wk. Bait stations are maintained to control rodents in the immediate planting area.

The O'ahu Rare Plant Recovery Program was the first in the state to build catchments and watering systems for outplantings and to use the deep tree Stuewe® pots and power augers to dramatically increase survival. Recently, individual ice-drip watering systems have been used to support new plantings and increase survival in remote areas where catchment is not practical (Garnett 2003). Cages are being used to protect young plants from desiccation and predation. Many volunteers such as youth groups, conservation organizations, partner agencies, and other organizations contribute significantly to the program. Students from the University of Hawai'i's botany and horticulture programs work at the Pahole Rare Plant Nursery Facility.

Future plans include additional plantings at all existing sites and implementation of new plantings at Koolaus, offshore

islands, and lower Ka'ala National Army Reserve. The rare plant recovery program develops and shares proven techniques for outplanting, maintenance, transport, and propagation of rare plants with other agencies on O'ahu and other islands.

MAUI

Over 20 species listed as endangered are found on the island of Maui in a variety of habitats, including forests, bogs, shrublands, and volcanic cliffs. Lands that support these species are owned by private individuals, state, city, county, and federal agencies. Much of the federal land is found within Haleakalā National Park (NP).

Haleakalā NP protects more imperiled species than any other national park: 6 endangered bird species, 14 endangered plant species, and many rare invertebrates and plant species of concern. The park has 5 nurseries varying in locations that range from near sea level to montane elevations. The objective

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for species recovery included the construction of small nurseries near proposed outplanting sites. These nurseries exclude foreign biota during propagation and optimize acclimatization of nursery stock for outplanting. Many rare and endangered species are targeted for propagation, such as nohoanu (*Geranium multiflorum* Gray [Geraniaceae]), a unique species that is adapted for bird pollination. Overall dispersal from parent plants in the wild is a problem for some species such as kalealaha beggarticks (*Bidens micrantha* ssp. *kalealaha* Nagata & Ganders [Asteraceae]) within Haleakalā Crater. Haleakalā NP grows this species to augment ex situ populations.

Other management practices have improved natural regeneration of some of Maui's endemic species, such as the 'ahinahina (Haleakalā silversword, *Argyroxiphium sandwicense* DC. ssp. *macrocephalum* (Gray) Mérat [Asteraceae]). Plants were decimated in earlier years due to feral animals and vandalism. Today, the species is still found throughout the crater, and natural regeneration has been dramatic. However, invasion of nonnative ants to the upper elevations of the park may negatively impact the species' natural pollinators (Anderson 2002). Recovery of the Haleakalā silversword is one of the most dramatic single-species conservation success stories known.



Another restoration project is a multiagency collaboration targeting unique dryland forest of southeastern Maui in the Auwahi and Kama'ole districts. Auwahi is one of the richest botanical areas in Hawai'i and is the location of many endangered plant species with very small and isolated populations. The project involves large numbers of volunteers from the Maui community. Art Medeiros of the US Geological Survey is spearheading the project whose initial efforts were focused on an especially rich 4-ha (10-ac) tract near Pu'u-ouli (Medeiros 2003). A game-proof enclosure was constructed and invasive plant species were removed. To date, 8000 dryland forest tree species have been planted and overall survival is at approximately 80%. The Pu'u-ouli outplanting is creating appropriate microhabitat conditions for the recovery and restoration of several endangered and rare plant species. Another phase of the project in the Kamaole district is the Pu'u-o-kali Forest Reserve, a 94 ha (236 ac) diverse wili wili (*Erythrina sandwicensis* O. Deg [Fabaceae]) forest on lava flows located on the southwestern flank of Haleakalā Volcano (Figure 3).

The 'Ulupalakua endangered species greenhouse currently propagates rare and endangered species including: māhoe (*Alectryon macrococcus* var. *auwahiensis* G. Linney [Sapindaceae]), alani (*Melicope knudsenii* (Hbd.) T.G. Hartley & B.C. Stone [Rutaceae]), and a'e (Hawai'i pricklyash, *Zanthoxylum hawaiiense* Hbd. [Rutaceae]), as well as the rare tree, 'aiea (*Nothocestrum latifolium* Gray [Solanaceae]), which is the native host plant for the endangered Blackburn's hawkmoth (*Manduca blackburni* Butlern [Sphingidae]). To date, 239 'aiea seedlings have been outplanted and more are currently being propagated. Each species presented its own challenges for seed collection and propagation (Medeiros 2002).

A'e is an extremely rare species with only 3 individuals on Maui in the Auwahi district. The genus is known to be dioecious, and only rarely do monoecious individuals occur. The trees in Maui are isolated from each other and not within the range of natural pollinators. One of the Auwahi individuals is of the rare monoecious type. Developing fruits were protected prior to seed collection. Resulting plants will be planted in close proximity to each other within the enclosure. When these trees begin to flower and fruit in 5 to 10 y, the distance should be compatible with short-flight pollinators, and viable seeds will hopefully result. Seed propagation of this species has been easy and may succeed in rescuing the nearly extinct Maui genotype.

There is a single wild individual of alani in the Auwahi district. This endemic species, known only from Maui and Kaua'i, is now limited to this 1 wild individual and another in cultivation. Although it produces fruit, the seeds have not reached full maturity due to insect predation. Micropropagation techniques at the Lyon Arboretum on O'ahu and Volcano Native

Figure 3. Wili wili (*Erythrina sandwicensis*) growing on lava flows on the southwestern flank of Haleakalā Volcano.

Plant Propagation Facility have been successful at germinating recalcitrant seeds collected from this wild individual.

The māhoe consists of 2 varieties, one of which is restricted to Maui and the Auwahi district (var. *auwahiensis*). Until last year, this Auwahi genotype was known from 11 individuals in the wild. In 2000, 4 seedlings were outplanted increasing the wild population by 36%.

As part of the restoration of the Pu‘u-o-kali lava flows, the Maui Nui Botanical Garden currently propagates the endemic Hawaiian State flower, or ma‘o hau hele (*Hibiscus brackenridgei* Gray [Malvaceae]), perhaps the rarest hibiscus in the world. On Haleakalā, the ma‘o hau hele only occurs at Pu‘u-o-kali.

During the past 2 y, volunteer response to restoration projects at Auwahi has achieved goals in a shorter time frame than expected (Figure 4). Recently, a special program was organized with Hawaiian youth. Such programs reconnect relationships with Hawaiians and the unique forests. Large-scale restoration projects on Maui would not be possible without the extensive community volunteer support. Small pilot projects continue to dispel the idea that Hawaiian dryland forests are lost ecosystems. Additional projects are planned on Maui.

LĀNA‘I

In western Lāna‘i, several patches of rare old growth Hawaiian dryland forest have remained intact. The area has been protected since 1918, when ranch manager George Munroe recognized their significance. For 30 y, he removed feral pigs, planted windbreaks, and erected fences in the area. Today, this forest region, protected as part of Kanepu‘u Preserve and managed by The Nature Conservancy, represents one of the last remaining examples of a forest type that once covered the dry lowlands of the main Hawaiian islands. The preserve consists of 7 disjunct management units covering a total of 239 ha (590 ac) (TNCKP 2002).

The preserve contains large remnants of olopuā/lama (Hawai‘i olive, *Nestegis sandwicensis* Gray) O.& I. Deg. & L. Johnson [Oleaceae]/ native ebony (*Diospyros sandwicensis* (A. DC.) Fosberg) [Ebenaceae]) dry land forest and is home to 49 rare plant species, including 3 species that are federally endangered: ‘iliahi (Lāna‘i sandalwood, *Santalum freycinetianum* var. *lanaiense* Rock) [Santalaceae]), nā‘ū (Hawai‘i gardenia, *Gardenia brighamii* Mann [Rubiaceae]), and Hawai‘i lady’s nightcap (*Bonamia menziesii* Gray [Convolvulaceae]).

Plant propagation at TNC’s nursery began in 1996, which was an excellent seed collection year for many species (Figure 5). Propagation procedures for some species were developed through collaborative efforts with the National Pacific Tropical Botanical Garden and the Lyon Arboretum at the University of Hawai‘i. The Arboretum developed micropropagation procedures for the Hawai‘i gardenia. Since then, TNC’s nursery has successfully propagated it from seeds (Valley 2002).

The facility consists of a shadehouse and has developed successful propagation techniques for many other species. Some species such as the Lāna‘i sandalwood were initially produced from cuttings because seeds exhibited complex dormancy that would take a few weeks to 2 y to satisfy. This species is also hemiparasitic on the roots of other trees, at least initially, so companion planting was necessary for establishment and growth.

Situated in the rain shadow of Maui, climate at the preserve and the nursery is very dry, averaging only 54 cm (20 in) of precipitation per year. During the last 4 y, the island had an average of only 25 cm (10 in) of precipitation. During the drought, drip irrigation was installed at outplanting sites. Most seedlings average 15 to 30 cm (6 to 12 in) growth in height per year when outplanted and the drip irrigation systems facilitated substantial growth during this period. Some species, such as the more common koa (*Acacia koa* Gray [Fabaceae]), can produce up to 0.9 m to 1.8 m (3 to 5 ft) of growth per year.

Outplanting seedlings proved difficult in some situations. Introduced rats (*Rattus rattus* L. [Muridae]) are a problem,



Photo by AC Medeiros

Figure 4. Volunteer groups, like this one on Maui, are essential to the success of restoration activities throughout the Hawaiian Islands.



Photo by Brian Valley

Figure 5. The Nature Conservancy’s nursery in Kanepu‘u Preserve on Lāna‘i.

Photo by Brian Valley



Figure 6. Hawaiian gardenia (*Gardenia brighamii*).

especially with Lānaʻi sandalwood. During the past few drought years, however, rats have disappeared from the lower elevations on the preserve, and natural seedling recruitment of this species has increased.

Ants are a problem for some species, especially those in the Sapotaceae family, including ʻālaʻa (*Pouteria sandwicensis* (Gray) Baehni & O. Deg.) and keahi (*Nesoluma polynesicum* (Hbd.) Bail.). Outplanting success is very limited as control measures for ants are not feasible. However, the highly imperiled species, Hawaiʻi lady's nightcap, Hawaiʻi gardenia, Lānaʻi sandalwood, and the common koa have at least 85% outplanting survival rates.

Twenty-eight individual plants of Hawaiʻi gardenia are left in the wild, and 10 of these individuals were found on Lānaʻi (Figure 6). To date, 200 seedlings have been outplanted in the preserve. A private landowner with the most extensive acreage on the island has also outplanted gardenia seedlings in cooperative efforts. Today, over 2000 containerized plants of rare, endangered, and some of the more common species have been outplanted in the preserve.

The Nature Conservancy works with the community group Hui Mālama Pono o Lānaʻi and other local residents and volunteers to protect and restore the area. In 1991, the Dole Food Company granted TNC a permanent conservation easement to continue the restoration of the forest and ensure its protection. The long-term goal is to restore a self-perpetuating ecosystem that requires little human assistance for its survival. Propagation and restoration techniques developed at Kanepuʻu are contributing to the overall efforts throughout the state.

HAWAIʻI

The island of Hawaiʻi is the largest, highest, and youngest of the islands and was formed by at least 6 volcanic mountains. Plants grow in a wide variety of habitats, elevations, and precipitation regimes. Twelve of the state's 26 listed endangered species are found only on the Big Island.

Hakalau Forest National Wildlife Refuge

Hakalau Forest National Wildlife Refuge consists of the 13200-ha (32620-ac) Hakalau Forest and 2120-ha (5300-ac) Kona Forest units on the Big Island. The Hakalau district of the refuge was established in 1985 to conserve endangered forest birds and is one of the finest remaining montane rainforests in Hawaiʻi. Eight endangered bird species, an endangered bat, and 29 plant species of concern (including 9 threatened and endangered [T&E] species) exist in the refuge. The critically endangered species ʻōhā wai (*Clermontia pyrularia* Hbd. [Campanulaceae]) is found only within the refuge.

The USFWS is in the process of creating a corridor of native vegetation that native forest birds can use in their migrations up and down the slopes of Mauna Kea. Numerous volunteers help plant native trees, shrubs, and ferns in abandoned pasture and forest clearings. At least 250800 trees have been planted since 1987. The earlier plantings of koa are now providing forage, cover, and nesting sites to many native forest birds. The highly endangered honeycreeper, ʻakiapolaʻau (*Hemignathus munroi* Pratt. [Drepanidinae]) was seen foraging in the koa plantings last year (Figure 7).



Photo by Jack Jeffrey Photography

Figure 7. The highly endangered honeycreeper, 'akiapola'au (*Hemignathus munroi*), is benefitting from 15 y of tree planting efforts in Hakalau Forest National Wildlife Refuge.

A greenhouse was built in 1995 and Baron Horiuchi, the refuge's horticulturist, was hired to develop propagation and outplanting techniques for other native species. Fourteen additional native species have been propagated including 6 T&E species and 3 species of concern. The greenhouse produces over 24000 plants per year for outplanting into the refuge. The greenhouse is located on the east slope of Mauna Kea at 1920-m (6400-ft) elevation. The refuge relies heavily on volunteers from conservation groups, schools, service clubs, and other organizations to help with propagation, outplanting, and removal of nonnative plants and animals.

Hawai'i Volcanoes National Park

Native species were grown at Hawai'i Volcanoes National Park from the 1920s until the mid 1970s. The nursery became operational again in 1996 and has 2 rare plant nurseries and a tree nursery. The research center rare plant greenhouse is located at 1140-m (3800-ft) elevation and consists of 7 small greenhouses, a hoop-house, and outdoor nursery benches that are used for hardening plants prior to outplanting. The second rare plant nursery is located at a lower elevation. A separate nursery is used for the production of 25 common tree species that are being grown for fire rehabilitation and other restoration projects in the park.

The intensive rare plant management program at the park focuses on the rapid increase of population sizes of rare species to minimize local extinction. Over 60 species (including 11 T&E species) are currently being propagated at the nurseries (Tunison 2002). Cuttings and seeds were taken from as many founder

plants within the park as possible, and in some cases, special permits were obtained for collections in adjacent forest reserves. This year, the nursery achieved high germination rates for several rare species including the 'ahakea (*Bobea timonioides* Hook. f.) Hbd. [Rubiaceae]). One of the few native Hawaiian orchids, 'awapuhiakanalao (*Liparis hawaiiensis* Mann. [Orchidaceae]), is targeted for micropropagation (Hosokawa 2002).

Prior to outplanting, all plants are sanitized and tagged. From earlier plantings, optimal planting times and microsites have been identified for some species. Most of the rare species have been monitored at least once to assess vigor, survivorship, and regeneration, and an intensive monitoring program for all outplantings is being developed. A database is being developed to track species from founder plants to successful propagation techniques and survivorship.

Volcano Rare Plant Facility

Volcano Rare Plant Facility is operated by the University of Hawai'i. During the past 10 y, horticulturist Patty Moriyasu and her staff have successfully grown more than 130 species of rare plants from throughout the islands. Of these, 70 are part of the genetic safety net program. Many are tissue cultured at the Lyon Arboretum and sent to Volcano Rare Plant Facility for acclimatization and continued growth.

Kūlani Correctional Facility Greenhouse

The Kūlani Correctional Facility Greenhouse is located at 1589-m (5300-ft) elevation on the slopes of Mauna Loa Vol-

(continues on page 32)

(continued from page 29)

cano near Volcanoes National Park. In cooperation with the National Park Service and Hawai'i Community College, an environmental horticulture program was developed for inmates to prepare for workforce training. Inmates can look forward to employment upon release. Kūlani staff and inmates built a native plant greenhouse at the correctional facility and are currently growing many common native species (Figure 8). Inmates propagate and outplant species and are developing landscaping, educational displays, and interpretive trails at the facility. They are also involved with outplanting on other cooperative partnership lands, fencing construction, nonnative plant removal, and mapping and monitoring projects. Over 3000 Mauna Loa silverswords (*Argyroxiphium kauense* (Rock & Neal) O. & I. [Asteraceae]) have been planted through this program within the Kūlani highlands.

Future plans for the greenhouse include native plant propagation research and expanding the numbers of species produced for large-scale restoration projects. Staff and inmates will grow up to 30000 native plants this year.

MOLOKA'I

Kalaupapa National Historical Park (NHP) plans to restore several community types: loulou (*Pritchardia hillebrandii* Kuntze Becc. [Arecaceae]) coastal forest, coastal strand, coastal sea cliffs, and lowland dry to mesic forest in Kauhako Crater. Dominant native trees in Kauhako Crater are wili wili, 'ohe makai (*Reynoldsia sandwicensis* Gray [Araliaceae]), and hala pepe (*Pleomele auwahiensis* St. John [Liliaceae]). In addition,

the park is currently involved in a rare plant stabilization project, which includes fencing and removal of feral ungulates, seed collection, propagation, outplanting, and augmentation.

Kalaupapa NHP restoration and recovery plans include 4 T&E species and 4 species of concern (Table 1). Seven of the 8 species are represented by less than 25 individuals in Kalaupapa NHP (Hughes 2002). Priority for propagation and restoration include those species most at risk for local extinction. Stabilization through augmentation is needed for species with small populations, particularly those without signs of regeneration.

A conservative genetics management strategy will guide outplanting in the absence of a detailed understanding of breeding systems and genetics. Seeds are collected from as many extant founders within the park as possible. Many of these species persisted only in inaccessible locations to feral goats and other ungulates. Special pollination efforts prior to seed collection were needed due to lack of native pollinators, extreme rarity, or dioecism of some of the species. Pua 'ala were hand pollinated from precipitous cliff faces by botanists from the National Tropical Botanical Garden. Only 5% of the flowers produce pollen and very few fruits are produced per inflorescence (Wood 2002). Mā'oli'oli (*Schiedea globosa* Mann [Caryophyllaceae]) is subdioecious; individuals are male, female, or hermaphroditic (Sakai and Weller 1991). Special efforts were needed to identify flowers of each individual so that pollen could be collected and transferred to females or hermaphrodites at the appropriate stage of stigma receptivity.

Kalaupapa NHP nursery is in the initial phases of seed collection and propagation of rare species. Additional propagation techniques will be developed by nursery manager William Gar-



Photo by James Ferrell

Figure 8. The greenhouse at Kūlani Correctional Facility was built by inmates and is used to produce native plants for restoration and to train inmates to enter the workforce.

nett and other partners. At least 36 common native species also will be grown. The new nursery consists of a greenhouse, propagation house, shadehouse, and soil sterilization equipment.

A database is being developed that will track outplantings back to mother plants or founders and describes growth, vigor, reproduction, and survival of each individual and that will include propagation and population trends in outplanted material.

KAUAI

The island of Kaua'i is the northernmost and oldest of the Hawaiian Islands. Because of its age and isolation, Kaua'i has the greatest species diversity in Hawai'i and is where additional endemics have been recently discovered and described. Thirty-seven taxa are endangered and threatened and many more are rare without former protection. Many of the species occur on lands owned and managed by the state. Reforestation projects on Kaua'i are contributing to the long-term restoration efforts.

National Tropical Botanical Garden

The National Tropical Botanical Garden (NTBG) on Kaua'i is a major propagation center, having successfully propagated over 400 native species and serving as a major resource for germplasm of rare species. The garden serves the conservation community by developing propagation protocols and conducting botanical inventories and by contributing significantly

to the development of conservation and restoration plans throughout Hawai'i.

The garden has developed and maintains a genetic safety-net germplasm collection for 130 of the most highly imperiled Hawaiian species. Duplicates reside in the National Seed Storage Laboratory at Fort Collins, Colorado. Additional duplicates are deposited at the Lyon Arboretum where tissue material is also sent for micropropagation.

In addition to the living collections gardens, the propagation facility is an open-air nursery that uses a mist system and shade structures that have gradient shade cloth coverings ranging from nearly full shade to full sun. A new nursery has been designed and funded and will include composting facilities, additional shadehouses, additional seed bank facilities, a new micropropagation laboratory, and a display area for conservation interpretation.

The outstanding rare and endangered Hawaiian plant propagation program is due to commitment and dedication of garden staff. Bob Nishek, nursery manager, propagates and maintains many highly imperiled species and continues to develop innovative propagation methods for other species brought to the garden. Kerin Rosenberger was NTBG's native plant propagator for over 10 y and developed protocols for 400+ native species—over 200 of which were at-risk species and had never been grown in cultivation. She has summarized her findings in a forthcoming book. Nishek and Rosenberger's work is instrumental in maintaining healthy ex situ rare collections. Steve Perlman, Ken Wood, and Tim Flynn are field

TABLE 1

Status of rare, threatened, and endangered plants at Kalaupapa National Historical Park.

Species	Family	Hawaiian name	Common name	Current status individuals and populations
<i>Bidens molokaiensis</i> (Hbd.) Sherff.	Asteraceae	ko'oko'olau	Moloka'i beggarticks	<15 and 1
<i>Brighamia rockii</i> St. John	Campanulaceae	pua 'ala	Moloka'i ohaha	<15 and 2
<i>Canavalia molokaiensis</i> O. & I. Deg. & Sauer	Fabaceae	'āwikiwiki	Moloka'i jackbean	5 and 1
<i>Peucedanum sandwicense</i>	Apiaceae	makou	Makau	<15 and 1
<i>Portulaca villosa</i> Cham.	Portulacaceae	'ihi	Hairy purslane	<10 and 1
<i>Phyllostegia mannii</i> Sherff	Lamiaceae	ulihī	Mann's phyllostegia	<5 and 1
<i>Reynoldsia sandwicensis</i> Gray	Araliaceae	'ohe makai	Ohe	<40 and 1
<i>Schiedea globosa</i> Mann	Caryophyllaceae	mā'oli'oli	Schiedea	< 20 and 1

Photo by R. Yokoyama



Figure 9. 'Ōlulu (*Brighamia insignis*) blooming in its cliff face habitat. Its natural pollinators thought to be extinct, this rare plant must be pollinated by hand.

botanists who have helped to develop conservation protocols, plans, and to identify areas of greatest endemism and highly imperiled areas throughout the state. They have made many new discoveries of species, rediscoveries of species thought to be extinct, and discovery of a new genus.

'Ōlulu (*Brighamia insignis* Gray [Campanulaceae]), an endangered Kaua'i endemic, is representative of the mission of the garden (Figure 9). Its native pollinator is believed to be extinct. Plants have been pollinated in the wild by NTBG botanists, and seeds were collected and propagated ex situ at NTBG. Many seeds were shared with other botanical gardens. The species is rapidly declining in the wild, and other gardens with specimens were contacted to help with restoration of the species. The gardens are sending leaf material to the Chicago Botanical Garden for molecular fingerprinting to identify individuals. Seed or micropropagated plants from these other genotypes will be grown and outplanted (Chapin 2002). Ex situ botanical garden collections and the sharing of plants and germplasm can ultimately lead to the restoration of critically imperiled species. NTBG are also involved in restoration projects on Kaua'i. As a result, a Kaua'i endemic palm (*Pritchardia limahuliensis* St. John. [Arecaceae]) has been successfully collected in the wild, propagated at NTBG, and outplanted back into a NTBG preserve. The garden has conducted botanical inventories and provided plant materials for other restoration projects on Kaua'i owned by the state and private landowners (Chapin 2002).

The success of NTBG involves many other individuals and organizations including USFWS and state agencies that have pro-

vided funding for fencing enclosures, transport costs, necessary collection permits, and land access. NTBG works closely with the US Army, The Nature Conservancy, and private land owners.

Hawai'i Reforestation Company

Most of the lowlands of Kaua'i have been converted to agriculture. Hawai'i Reforestation Company produces and outplants forest tree seedlings for nonindustrial private landowners on lowland Kaua'i. Upland Kaua'i koa was genetically compromised many years ago when off-island seed sources were introduced (and exotic species) to reforest entire watersheds. In the past, this nursery has supplied landowners a small volume (several thousand seedlings per year) of koa from sources on the Big Island and smaller offerings of other native trees, shrubs, and groundcovers from seeds donated by government agencies (Edson 2002).

In 2002, for the first time, it became possible for private nurseries to purchase commercial permits from the Department of Forestry and Wildlife for limited seed collection from designated forest reserves, resulting in the availability of Kaua'i native tree seed for reforestation projects. A 0.8 ha (2 ac) koa improvement trial, containing over 1000 seedlings from 29 provenances across the state, was implemented in cooperation with the Hawai'i Agricultural Research Corporation and Agro Resources Inc. The new koa improvement trial, and others like it, will eventually create an increased supply of koa seeds suitable for low-elevation plantings on Kaua'i. Seed collection from state lands will boost seedling production for native forest restoration projects that are already planned.

KAHO'OLAWE

Perhaps the most massive and difficult restoration project is the rehabilitation of the island of Kaho'olawe. For 200 y, goats, fires, bombing practice, and road building removed the island's vegetation, which led to massive erosion. There are many complicated logistics in restoring the island. Each planting hole must be checked and cleared of unexploded ordnance, which poses danger and creates liability problems for the state. Feral mammals and exotic vegetation must be removed, and soil erosion must be controlled. Paul Higashino is the restoration ecologist heading the project.

Through charcoal and pollen analysis, researchers are identifying species formerly found on the island and charting their likely distribution. Kaho'olawe probably was once covered in vegetation similar to the northeast and Kanepu'u areas of Lāna'i. Higashino is studying traditional indigenous land management practices for guidance for the island's recovery. Short-term research projects are aimed at developing water sources, controlling erosion, building and conditioning soil, preventing fires, selection and propagation of plants, and ultimately rein-



Photos by Ken Wood

Figure 10. Discovered in 1992, *Kanaloa kahoalawensis* survived possible extinction by growing on an ungulate-inaccessible sea stack along the coast of Kaho'olawe.



roducing native invertebrates and birds. Those studies will help create a restoration plan that could determine the course of the island's ecological recovery over the next 50 to 100 y. The first priority is to stop erosion of certain areas. The restoration of Kaho'olawe is a monumental undertaking and will serve to guide other large-scale restoration projects in the state.

Significant change in the island's vegetation cover has been seen since goats have been removed and brush fires have been reduced. In the midst of the initial inventory of the island's vegetation, a new genus was discovered by NTBG botanists. Kanoaloa (*Kanaloa kahoalawensis* D.H. Lorence & K.R. Wood [Fabaceae]) was found in 1992, soon after the state of Hawai'i assumed ownership of the island from the military. Only a few plants were found growing on sea stacks off the coast of the island (Figure 10). Although fossil pollen analysis has revealed that this species was once common on several islands, today, only 1 plant still exists in the wild. Two plants propagated from seeds are maintained at NTBG but they have produced 99.9% staminate flowers. The

Lyon Arboretum is trying tissue culture techniques to resuscitate the nearly extinct species.

SUMMARY

Dedicated professionals, agencies, communities, and volunteers are working against time and difficult logistics to preserve and restore the habitats of some of the world's irreplaceable biological treasures.

Continuing inventories are leading to discoveries of new species within a fragmented Hawai'i. Instrumental in restoration is the identification and development of critical habitat sites, recovery plans, and the sharing of successful propagation and outplanting techniques. The tremendous commitment and cooperative efforts, combined with the education, involvement, and support of the Hawaiian community, serve as a valuable model for restoration efforts elsewhere in the world.

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