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Technical Report 174

Rare plant stabilization projects at Hawai`i Volcanoes National Park, 1998-2008

July 2011

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PCSU is a cooperative program between the University of Hawai`i and U.S. National Park Service, Cooperative Ecological Studies Unit.

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Recommended Citation:
Belfield, T., T. Tunison, J. Chase, and S. McDaniel. 2011. Rare Plant stabilization projects at Hawai`i Volcanoes National Park, 1998-2008. Technical Report No. 174. Pacific Cooperative Studies Unit, University of Hawai`i, Honolulu, Hawai`i. 121 pp.

Key words:
Endangered plant species, species of concern, rare plant species, stabilization, recovery, restoration, coastal strand

Place key words:
Hawai`i, Hawai`i Volcanoes National Park

Editor: Clifford W. Morden, PCSU Deputy Director (e-mail: cmorden@hawaii.edu)

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ACKNOWLEDGMENTS

The authors express our thanks for the dedication and botanical/GPS skills of Resource Management volunteers Carol and Mark Johnson who joined us in re-monitoring 19 of the 31 planting sites in 2010. This final monitored gave us a more realistic assessment of long-term survival and the effectiveness of the stabilization program. Carol also provided photographs for Figs. 3-8 and 13. We also want to thank Allison Janson, an intern for Resource Management, who monitored all the rain forest plantings in 2009, and Corie Yanger, a Resource Management Biotech, who monitored the Ka`aha-Kaluē plantings at the coast. The founders for a number of the species came from state forest reserves and natural area reserves. We are grateful to the Hawai`i Division of Forestry and Wildlife, particularly Lyman Perry and Lisa Hadway for granting permits, access, and sharing knowledge of founder locations. Other founders came from Pōhakuloa Training Area and we appreciate the support of their rare plant restoration staff in sharing propagules. We want to also thank Patty Moriyasu and her staff at the Volcano Rare Plant Facility in sharing her expertise in propagation and donating propagated material for outplanting. We are grateful to Tanya Rubenstein and the Three Mountain Alliance and Rob Robichaux and the Hawaiian Silversword Foundation in coordinating and assisting with outplanting. We are deeply indebted to Linda Pratt, a Botanist with the US. Geological Survey, Biological Resources Discipline. Linda freely shared data and information from her draft rare plant limiting factors studies. She also shared her taxonomic expertise, time for monitoring in the field, and above all her passion and knowledge about rare plants. Linda's rare plant surveys at Hawai`i Volcanoes National Park in the 1990s and plantings of *Hibiscadelphus giffardianus* as part of a study on rat impacts were the catalysts for the rare plant stabilization program.

SUMMARY

Approximately 15% of the native vascular plant flora of Hawai`i Volcanoes National Park (HAVO) is listed by the US Fish and Wildlife Service (USFWS) as endangered, threatened, candidate endangered, or species of concern. Another 15% is considered to be rare in HAVO by park botanists. Restoration actions including alien ungulate and invasive plant control are underway in many areas of the park, and common native vegetation is noticeably recovering in some areas. However, rare plant surveys in the 1990's indicated that little recovery of rare plant species populations was occurring in spite of partial recovery of park ecosystems. This is understandable in that rare plant research in the park indicates that rare plants in recovering ecosystems are limited by rodents, slugs, loss of pollinators, small population size, and other factors not affected by landscape-level restoration.

From 1998-2008, HAVO implemented a program of 10 projects to stabilize populations of 42 of the 62 species in HAVO listed by the USFWS, 12 species not listed but rare throughout the park, and seven species rare in one of the seven ecosystems targeted for rare plant species stabilization. An additional 26 uncommon and common species were outplanted in conjunction with rare plant stabilization, largely for the purpose of restoring plant communities or plant community diversity. Stabilization through augmentation and reintroduction involves establishing enough individuals and small populations to maintain species until recovery efforts could be formulated and implemented. Stabilization was carried out by greenhouse propagation and outplanting with the goal of meeting the Hawai`i/Pacific Plant Restoration Coordinating Committee (HPPRCC) standards of three populations of 25 reproductive individuals per population for long-lived perennials or 50 individuals per population of short-lived perennials. Seed additions were used in three sites. Plantings were placed in 31 locations across seven ecosystems of the park including coastal strand, lowland dry-mesic forest, mid-elevation woodland, montane rain forest, montane mesic forest, upper montane, and subalpine. Plantings were monitored for growth, vigor, and the presence of flowers or fruits, typically one of more times for 1-4 years; all plantings except those in the montane mesic forest were monitored in 2009 or 2010, after 6-12 years.

Stabilization of rare plants in the coastal strand was carried out in the context of a community restoration project involving the planting of common and uncommon species at six coastal strand sites. The average survivorship of the 21 species outplanted was the lowest (4%) of all target ecosystems, partly because of the near failure of *Portulaca villosa* and *Ischaemum byrone* plantings, which accounted for nearly one-half of the outplantings in the coastal strand, and because of low survivorship of other rare and uncommon species. The average survivorship of plantings of common species such as *Scaevola taccada, Ipomoea pes-caprae*, *Osteomeles anthyllidifolia*, and *Sida fallax* was 30%, indicating potential for the restoration of matrix species and the coastal strand community. In two forest kīpuka of the lowland dry-mesic forest, 12 listed and rare species were planted with an average survivorship of 18%. Three common species were also planted and alien plant control was initiated to help restore the lowland dry-forest and create habitat for rare plants.

The survivorship of *Pleomele hawaiiensis* (85%) over both sites was high, and the survivorship of *Reynoldsia sandwicensis* (47%), *Senna gaudichaudii* (23%), *Erythrina sandwicensis* (23%), and *Nototrichium sandwicense* (24%) was moderately high in one of the two sites. Sixteen rare species were planted in the mid-elevation woodlands, mostly in the context of a project to develop seed orchards to create propagules for further rare plant restoration and rehabilitation of burned areas. The 14 species planted had a mean survivorship of 14%, an average dragged down by very low survivorship of the intensively planted *Portulaca sclerocarpa* and low survivorship of other rare species such as *Nototrichium sandwicense* and *Rhus sandwicensis.* Three species had relatively high survivorship: *Bidens hawaiensis* (38%), *Myrsine lanaiensis* (33%), and *Neraudia ovata* (43%). Eleven listed and rare species were planted in montane rain forest with an average survivorship of 21% after 6-7 years. Average survivorship is expected to drop over time because of the anticipated decline of planted *Clermontia peleana* which accounts for over half of the surviving plantings. There was moderately high survivorship of *Phyllostegia floribunda*, *Stenogyne macrantha*, and *S. scrophularioides*. Twenty-two species, including 10 listed and six species rare on a park-wide basis were planted in the montane mesic forest with an average survivorship higher than that of all other planting sites, 46%. Survivorship of plantings of over 330 *Hibiscadelphus giffardianus* in three populations was 73%. Future survivorship may decrease because this environment was monitored for a shorter time-frame than other environments. Average survivorship in the intergrading upper montane and subalpine communities was 17%, with low survivorship in five of the six target rare species, but relatively high survivorship for the intensively planted *Plantago hawaiensis*. For each planting environment, reasons are offered for survivorship patterns and management considerations are discussed for improving the survivorship of future plantings of current and for including additional species.

Stabilization, as defined by HPPRCC guidelines, was achieved by the high survivorship of plantings of *Hibiscadelphus giffardianus* in three populations and partly by *Bidens hawaiensis*, *Clermontia hawaiiensis*, and *Plantago hawaiensis*, surviving in sufficient numbers, but only in two sites. There was relatively high survivorship of 12 other species with moderate to high numbers of plantings in at least one site. Additional stabilization efforts are recommended for species with some survivorship success, those very rare and in danger of extirpation, and other listed or rare species not addressed by the current stabilization projects. Management considerations are offered for increasing survivorship in species with low survival rates including propagation, site selections, and management of limiting factors determined from USGS studies. Survivorship tended to be high for almost all species one to two years following planting, but declined in many species between two and six years. This pattern of mortality over time also suggests the need for longer-term monitoring and an additional monitoring in the montane mesic forest where high survivorship may be partly a function of the shorter-time frame for final monitoring there. Suggestions are offered for documenting site selection, standardizing the identification of plantings, and developing effective and efficient monitoring protocols. These actions would facilitate adaptive management that could increase survivorship of future plantings.

INTRODUCTION

The native vascular plant flora of Hawai`i Volcanoes National Park (HAVO) has a high proportion of endangered, threatened, and rare plant species. Of the more than 400 species in the park's flora (Higashino *et al*. 1988; Benitez *et al.* 2008), 23 species are listed by the US Fish and Wildlife Service as endangered and one is listed as threatened. In addition, six species in HAVO are candidate endangered species and 33 are species of concern (Pratt *et al.*, 2011). Finally, over 60 additional species, not listed by the US Fish and Wildlife Service, were characterized as rare in park plant checklists (Higashino *et al*., 1988; Benitez *et al.,* 2008).

The high proportion of endangered, threatened, and rare plant species in the Hawaiian flora and in HAVO is due to the direct impacts of humans, especially their introductions. Hawaiians occupied the lowlands of all the major Hawaiian Islands and greatly modified the coastal landscapes of the park with agriculture and deliberate burning (Allen, 1979). Introduced on various European exploring expeditions, cattle, feral goats, and pigs became major modifiers of all environments in the nineteenth century (Stone, 1985). Later, game animals such as axis deer and mouflon sheep were introduced. The browsing, grazing, trampling, and rooting activities of these introduced ungulates are probably directly responsible for the decline of many Hawaiian plant species (Cuddihy and Stone, 1990). Hawaiian vegetation did not evolve with large mammalian herbivores and lack defenses against browsing and grazing.

Invasive alien plant species have also greatly modified many plant communities, and undoubtedly are responsible for the rarity of some plant species (Smith, 1985; Cuddihy and Stone, 1990). Many alien plant species form monospecific stands, directly eliminating native plants by competition. Others modify nutrient and soil-moisture regimes, and a number of introduced, fire-promoting grasses have increased fire size, frequency, and intensity. Wildfires, carried by fire-promoting alien grasses, have caused the decline of many native dry lowland species (Smith and Tunison, 1986).

Introduced rodents and arthropods may also be responsible for the decline of native plant species. Introduced rats and mice are voracious seed predators and also girdle the bark of some native plant species (Pratt *et al*., 2010*;* VanDeMark *et al.,* 2010). Introduced insects and yellow jacket wasps may be responsible for the loss of native avian and insect pollinators (Wilson *et al.,* 2009). Slugs are implicated as limiting factors of some native plants, particularly in rain forest environments (VanDeMark *et al.*, 2010).

Recognizing early on the value of the threatened flora of HAVO, park managers developed an intermittently active program of propagation and planting from the 1920s through the 1970s (Morris, 1967; Zimmer, unpublished report). Responding to criticism in the 1970s from university and agency scientists about species selection, planting strategies, record keeping, and a misplaced emphasis on single-species management, park resource managers suspended the rare plant propagation and planting program in

1981 until the late1990s. During this period, the focus was on landscape-level ecosystem restoration strategies stressing feral ungulate removal and control of key alien plant species. Rare plant activities during this period emphasized mapping and monitoring of rare plants to determine their distribution, status, and response to alien ungulate and invasive plant control measures. Studies of rare plant distribution and status were undertaken in the 1990s in lowland dry-mesic forest (Abbott and Pratt, 1996), wet forest (Pratt and Abbott, 1997; Belfield, 1998), montane mesic forest (Pratt and Abbott, unpublished data; Belfield and Pratt, unpublished data), and upper montane and subalpine (Belfield and Pratt, 2002). Other studies emphasized the recovery of plant communities following invasive species management (Tunison *et al*., 1994; Tunison *et al*., 1995; Loh and Tunison, 1999; and Pratt *et al*., 1999). In general, ecosystem recovery monitoring indicated that feral ungulate and alien plant control programs stimulated the recovery of native vegetation in many ecosystems of the park, particularly the response of common plant species in upland environments. However, rare plant monitoring studies generally indicated declining populations of rare plants and the extirpation of species from the park (Abbott and Pratt, 1996; Pratt and Abbott, 1997; Belfield and Pratt, 2002). Rare plant demographic inventories revealed that one threatened species, *Silene hawaiiensis* (Hawaiian catchfly), appeared to be relatively stable and that another rare species, *Geranium cuneatum* (nohoanu), appeared to be recovering following the removal of alien ungulates (L. Pratt, pers.comm.).

Rare plant population and demographic monitoring lead in the late 1990s to a strategy of stabilizing rare plant species, as an interim measure. Stabilizing populations, maintaining at least minimal numbers of individuals and a minimal number of populations, would reduce the risk of loss of rare species from chance demographic or environmental events. Stabilization was to be achieved through propagation and outplanting. A stabilization strategy applied especially to those rare species most at risk with very small or declining populations and those without signs of regeneration (NPS, 1999). It also applied, through reintroduction, to species that have been extirpated from the park in recent years.

Stabilization would allow time for continued habitat recovery to take place and to complete more detailed studies on demography and limiting factors needed for well-informed recovery programs. Understanding limiting factors might lead to developing tools to address them. Limiting factors studies began in 2006 on 13 rare plant species across a broad range of park environments in which alien ungulates have been removed and alien plant control has been initiated. The results of these studies are in the process of being drafted or published (L. Pratt, pers. comm; Pratt *et al*., 2010; VanDeMark *et al*., 2010). Preliminary results indicate, in general, which life stage was most vulnerable, and that other factors, such as rodents, slugs, alien insects, Kalij pheasants, small population size and a paucity of compatible mates, often limited rare plant species. Multiple limiting factors may operate simultaneously. These types of limiting factors are not addressed by landscape-level ecosystem restoration measures including alien ungulate and invasive plant management.

The central purpose of this report is to document efforts and results of rare species plantings carried out from 1998-2008 to stabilize rare plant populations at

Hawai`i Volcanoes National Park. The results will be used to evaluate the effectiveness of the rare plant stabilization program and offer management considerations for further stabilization, recovery, and rare plant research. The results of community restoration efforts in the coastal strand and lowland dry-mesic forest will be characterized and evaluated, along with recommendations for continued restoration work in these communities, particularly as it affects rare species stabilization and recovery. Format of this report will include a general Methods section to be followed by separate sections for each of the seven park ecosystems, each to include a description of the Study Area and Methods, Results, and Discussion.

METHODS

Beginning in 1998, funding was secured to initiate eight rare plant stabilization projects for many of the park's listed and rare plants. The projects involved collecting propagules from the wild, propagating plants in the Resource Management nursery facility, planting the nursery grown seedlings or cuttings in suitable habitat within the current or former range, and monitoring the survival, growth, and vigor of plantings. Except for plantings of *Argyroxiphium kauense* in Kahuku, plantings for rare plant stabilization and community restoration in the coastal strand and lowland dry-mesic forest targeted species and sites found in the Kīlauea and Mauna Loa Strip sections of park. Kahuku was acquired in 2003 after funding was secured for many of the rare plant projects; plant inventories at Kahuku were not completed until 2006 (Benitez *et al*., 2008).

The reintroduction and augmentation of *Argyroxiphium kauense*, the endangered Ka`ū silversword, was an important early focus of the stabilization program. This was carried out through a partnership with the Hawaiian Silversword Foundation and the Volcano Rare Plant Facility. Two funded projects supported exclosure fencing, propagation, outplanting, and monitoring of over 11,000 seedlings in the subalpine of Kīpuka Kulalio and Kīpuka Mauna'iu on the Mauna Loa Strip (Robichaux, 2008). Two other funded projects supported the same stabilization and recovery activities for over 9,000 seedlings in three exclosures in mesic transitional upper montane forest and subalpine in the Kahuku addition (Robichaux, 2009). The results of *A. kauense* stabilization efforts will be reported separately.

Six other funded projects focused on stabilization of 60 rare plant species across 30 locations in seven park ecosystems on the Mauna Loa Strip and Kīlauea sections of HAVO: 1998, Restore Nāulu Forest (PMIS 8333); 1999, Restore Biodiversity, Mauna Loa (PMIS 48820); 2000, Restore Biodiversity to Park Mesic Forest (PMIS 48860); 2000, Stabilize Endangered and Rare Plant Species in Hawaiian Parks (PMIS 56700); 2002, Restore Coastal Strand Community at Kahue to Enhance Camping Experience Wildlife and Viewing (PMIS 84652); 2002, Reintroduce Extirpated Endangered Plant Species to Hawai`i Volcanoes National Park (PMIS 91421); and 2003, Restore Native Plant Biodiversity in Degraded, Dry 'Ōhi`a Woodland (PMIS 102156). The results of these projects are described in this technical report.

Some of these funded projects also included plantings of uncommon and common species for the restoration of communities, including restoration of species diversity. Stabilization of rare and also uncommon plant species in the coastal strand environment was conducted in the context of a community restoration project across six sites involving the planting of a number of common or matrix species. Stabilization of rare plants was carried out in the lowland dry-mesic forest community in conjunction with plantings of some common native species for restoration purposes and initial control of invasive plant species. Stabilization in the montane mesic forest also included plantings of species common in other ecological zones of the park, but rare in mesic forest or common in one of the three target planting sites, but rare or absent in the other planting sites. The purpose of these plantings was to increase evenness-diversity in montane mesic forest. The results of the planting of common and uncommon park species in the coastal strand, lowland dry-mesic forest, and montane mesic forest ecosystems are included in this report because of their relevance to potential future restoration efforts involving these species and because of the linkage of community restoration efforts to rare plant stabilization.

Stabilization efforts were carried out, to the degree feasible, to meet minimum standards prescribed by the Hawai`i/Pacific Plant Restoration Coordination Committee (HPPRCC) for interim stabilization and recovery (USFWS, 1994). HPPRCC was established by the US Fish and Wildlife Service and includes the Center for Plant Conservation, US Geological Survey—Biological Research Discipline, University of Hawai`i, other state and federal agencies, as well as many botanical gardens. HPPRCC standards have been widely adopted in Hawai`i with its large number of critically endangered species and need for a triage approach in recovery. For interim stabilization, the HPPRCC standards prescribe a minimum of three populations, of 25 reproductive individuals each; for long-lived perennials, three populations of 50 individuals each for short-lived perennials; and five populations of 100 reproductive individuals each for annuals (USFWS, 1994).

Augmenting existing populations enhances the long term viability of a rare species by increasing population size. Furthermore, establishing or reintroducing additional populations enhances long-term viability of these species. A single population may be more vulnerable to stochastic environmental variability, e.g., lava flows in the case of HAVO. Stabilization efforts with *Hibiscadelphus giffardianus*, an endangered species represented by nine individuals prior to recent outplanting efforts, provides an ideal example. Over 330 seedlings were planted at the site of the existing population, Kīpuka Puaulu, and in two other montane mesic forest sites, Kīpuka Kī, and a third kīpuka along the boundary with Keauhou Ranch.

In the absence of a detailed understanding of the breeding systems and genetics of the species to be stabilized, a conservative genetics management guided the stabilization projects based on detailed, formal park protocols (NPS, 1996). As many founders as possible were utilized to increase genetic diversity. Founders were to be derived preferentially from park populations and then, if necessary, from nearby populations in similar ecological settings to utilize locally adapted genotypes. As an example, plantings of *Ischaemum byrone* (Hilo Ischaemum) were derived from approximately 20 individuals at Kamoamoa in the park, collected just prior to being covered by lava. Additional seed was collected of *Ischaemum byrone* a few miles outside the park boundary to increase the number of founders. In some cases, only small numbers of founders could be located or propagules were available only from a subset of potential founders. For example, there were only two *Antidesma pulvinatum* (hame) trees left in the park when the stabilization project started. They were at the proposed augmentation site so their propagules would have provided, theoretically, locally adapted genetic material. However, the absence of fruiting material in the park necessitated getting propagules from five founders in the nearest known site, also in dry-mesic forest, at Manukā in South Kona.

Propagation of plants was conducted at the HAVO nursery facility located at the Research/Resource Management center in the park; a few species were propagated at the University of Hawai`i Volcano Rare Plant Facility in Volcano Village. Seed additions were used on a one-time basis in a three sites in the coastal strand and mid-elevation woodland. Park rare plant protocols (NPS, 1996) required rigorous sanitation, quarantine and inspection prior to outplanting. Greenhouse/nursery facilities were kept free of pest species; nursery plants were rigorously monitored and sanitized before planting to avoid contamination of target locations. A report on propagation and greenhouse nurturing techniques for species in the rare plant stabilization projects will be published separately.

Plantings or seed additions for a total of 86 species were carried out, all in the Kīlauea and Mauna Loa Strip areas of the park. These included 15 of the park's 23 endangered or threatened species, five of the six candidate endangered species, and 21 of the 33 species of concern. It also included plantings of 12 species rare in HAVO and seven species rare in one of the seven target ecosystems. The rest of the species propagated and planted were common, uncommon, or introduced native species, planted for community restoration or diversity purposes.

The target species were placed in 31 different sites or locations across seven broad ecosystems of the park including the coastal strand, lowland dry-mesic forest, mid-elevation woodland and scrub, montane rain forest, montane mesic forest, and upper montane, and lower subalpine (Figure 1 and 2). All of these sites reported here are in the Kīlauea and Mauna Loa Strip areas of the Hawai`i Volcanoes National Park. Multiple species were typically placed at each planting site to make planting, watering, and monitoring efforts more efficient. In the case of lowland dry-mesic forest and montane mesic forest, there was limited suitable, recovering habitat for plantings, resulting in considerable consolidation of plantings.

Planting locations or sites were determined largely on current or historical geographic and ecological ranges of the target plants, both inside and outside the park. It was recognized that historical ranges of rare species may have been broader than current ranges and that collection records for park species may not be completely representative. For reintroductions to the park, consideration was also given to matching the habitat of the park planting site with the site of the founders outside the park. For example, *Neraudia ovata*, a target species in the stabilization project, is known only from a very small, historical population on the boundary of the park with Kapapala Ranch. *Neraudia ovata* was planted near the historical collection site, in kīpuka on older lava with some ash soil because of the potential for higher soil moisture, and 10 km to the east at a similar elevation in mid-elevation woodland, the described habitat on park collections. It was also planted three kilometers to the north in an ecotone between montane season forest on deep ash soil and *Metrosideros polymorpha* (`ōhi`a) woodland on a much younger `ā`ā flow. The last site is distinctly more mesic than the known, highly restricted range, but more similar to current habitat in other areas within the range of *Neraudia ovata* on Hawai`i Island.

Planting was typically carried out during longer rainy periods. In the dry or the dry-mesic habitats of the coastal strand, lowland dry-mesic forest, mid-elevation woodland, and upper montane/subalpine, microsites with deeper soil were selected. These were often in gaps or on the edge of stands of native shrubs. Stands of dense alien vegetation were typically avoided.

In the nursery, plants were hardened off to water and fertilizer before planting. The plantings were watered thoroughly after planting, but watering was tapered off over time and discontinued altogether as early as one month but maintained for several months in drier environments. Plants were not fertilized after outplanting. Plantings in drier environments were often mulched with leaf litter or rocks.

Plantings were monitored, typically within one year and up to three or more years. Height or length of plants was measured. In addition, the presence of flowering or fruiting was noted, and the vigor of plantings was determined subjectively in one of five categories (vigorous growth, healthy, fair, poor, or dead) or more broadly as good, fair, or poor. In almost all cases, an identifying metal tag was attached or associated with the planting so that growth, survival, and phenology could be tracked per individual planting. Final monitoring was also conducted in 2009 or in 2010 for most planting locations. The length of time at final monitoring varied from 4-12 years.

For the final monitoring in 2009 or 2010, shape files were generated of planting locations. Using GPS, the areas were systematically searched for survivors starting 50-100 m outside the most outlying coordinates. In most cases, where feasible, the longest dimension of the plant, height or length, vigor, and phenology were determined. Metal tags could not be found in many cases, particularly in the coastal strand environment, thus tracking of individuals plantings was not systematic in 2009 and 2010. Metal identification tags and flagging were removed from dead plantings.

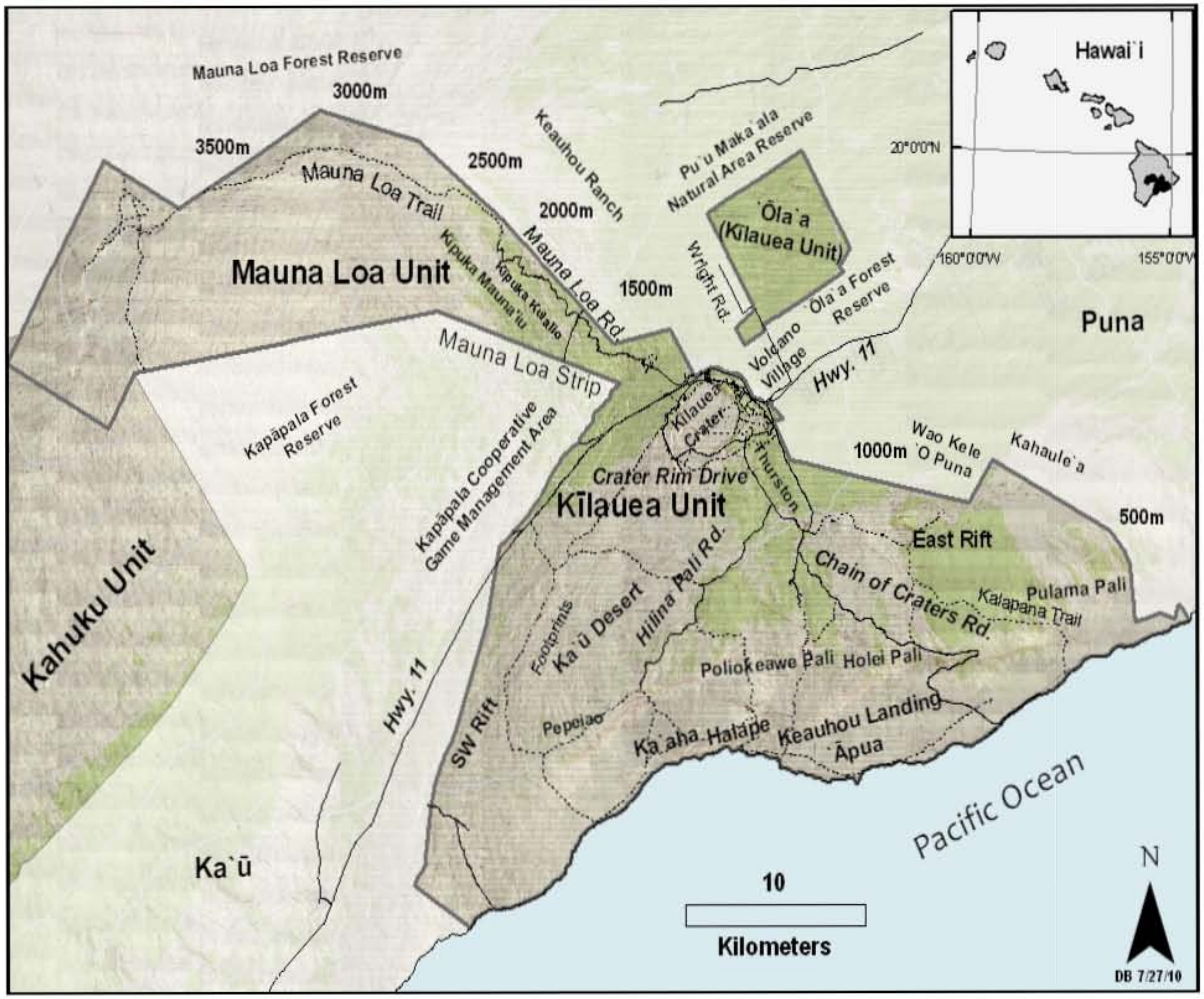

Figure 1. General locations within Hawai'i Volcanoes National Park and surrounding communities.

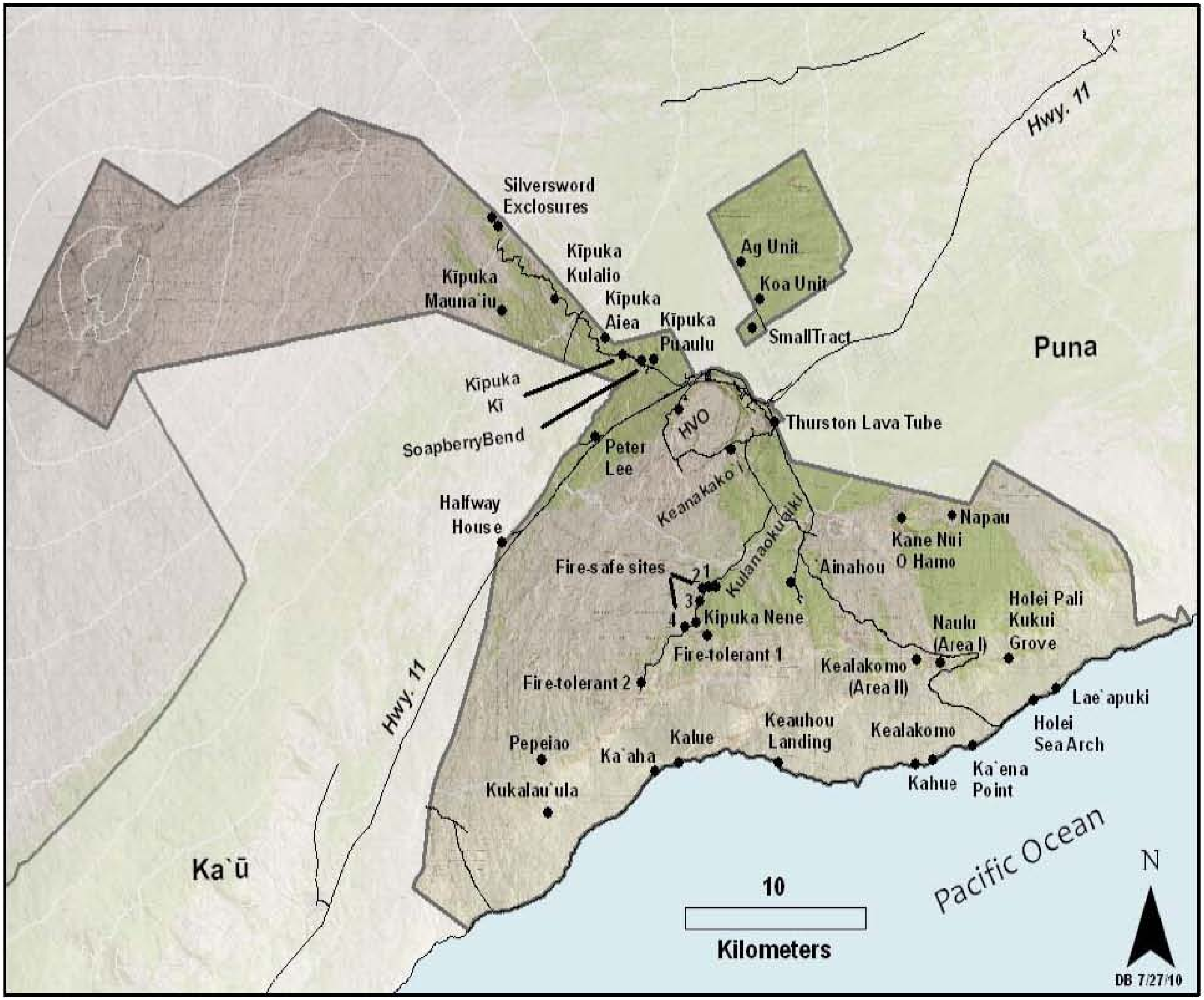

Figure 2. Specific planting locations within Hawai Volcanoes National Park.

COASTAL STRAND

Study Area and Methods

The coastal strand environment of Hawai`i Volcanoes National Park lies in a narrow band under the influence of salt spray, 15-100 m or more from the shoreline. In shoreline areas with high sea cliffs, the strand is typically narrow; in low bluff or beach areas, the strand may extend further inland. Rainfall declines from east to west along the coast in the park averaging approximately 1,500 mm per year to 500 mm per year (Mueller-Dombois and Fosberg, 1974). Summers tend to be driest time of the year at the coast.

The most well-developed stands of coastal strand vegetation at HAVO occur in small, disjunct sites with low bluff or beach environments on older substrates. These areas are separated by broad expanses of a highly simplified and narrow band of coastal strand, above higher shoreline cliff faces. Much of the eastern portion of the park's coastal lowlands was covered by the 1969-74 Mauna Ulu Lava flows and the Pu`u `Ō`ō lava flows from 1983 to the present. Very sparsely vegetated nineteenth century `ā`ā flows cover the dry coastal environments near the western boundary of the park.

The coastal strand community is not only one of the most fragmented, but it is also one of the most degraded and simplified native ecosystems in HAVO. The coastal lowlands of the park were occupied by Hawaiians for hundreds of years (Allen, 1979). In addition to dwelling areas, some of which were located in shoreline environment, the coastal lowlands were cleared for agriculture or burned to stimulate grass for thatching structures. Following Hawaiian occupation, the coastal strand and lowland environments were heavily impacted by the browsing and trampling of high numbers of feral goats from the mid-nineteenth century to the early 1970s when goats were removed (Mueller-Dombois and Spatz, 1975). The coastal lowlands of HAVO were the habitat for most of the park's nearly 20,000 goats (Baker and Reeser, 1972). One plant association in the park's coastal strand, the *Scaevola taccada (*naupaka kahakai*)/Sesbania tomentosa* (`ohai) or Coastal Dry Shrubland, at `Āpua Point is considered a rare plant community in Hawai`i (Pratt *et al*., 2011).

Plantings for community restoration and/or rare plant stabilization were carried out at seven sites: Ka Lae‘apuki (now covered by recent lava flows), Hōlei Sea Arch, Ka‘ena Point, Kealakomo, Kahue, Ka‘aha-Kaluē, and Keauhou Landing. The sites at Hōlei Sea Arch and Ka`ena Point can be characterized as high bluff environments. Here, the coastal strand is a narrow band often less than 20 meters wide (up to 50 m at Ka`ena Point) above a 10-20 m tall sea cliff. Native strand vegetation is comprised mainly of scattered clumps of the native sedge, *Fimbristylis cymosa,* a coastal strand specialist which is found in rocky and sandy soil directly affected by salt spray near the top of the sea cliff. The upper fringe of the narrow coastal strand merges with the characteristic coastal lowland vegetation of mixed native and alien shrubs, including *Osteomeles anthyllidifolia* (‘ūlei) and *Wikstroemia sandwicensis* (`akia) and alien shrubs such as *Schinus terebinthifolius* (Christmasberry*)*, *Lantana camara* (lantana), and *Pluchea caroliensis* (sourbush). In addition, there is a mix of native grasses, e.g., *Heteropogon contortus* (pili*),* the possibly indigenous grass *Chrysopogon aciculatus* (mānienie `ula), and the alien *Melinis repens (*Natal redtop*).*

Kealakomo and Kahue can be characterized as low bluff environments with sea cliffs approximately 1-3 m high. As a result, the coastal strand environment may extend up to 100-150 m inland. Immediately behind the low sea cliff, similar to the high bluff habitat, is an environment dominated by sand and rock outcrops with scattered *Fimbristylis cymosa*. Inland of this sparsely vegetated zone, the vegetation prior to the commencement of the project differed between Kealakomo and Kahue. At Kealakomo, there were patches of low *Scaevola taccada* for approximately 10-20 m transitioning on the inland side to stands of the alien shrubs *Pluchea caroliensis* and *Lantana camara* and a mix of native and alien grasses. At Kahue, inland of the mostly barred *Fimbristylis* zone, the native shrub *Scaevola taccada* is abundant along with the native grass *Heteropogon contortus*.

Ka‘aha and Kaluē are low bluff environments approximately one kilometer from each other. Both strand environments surround a large tide pool or lagoon. Ka`aha has a low rocky pāhoehoe beach with *Fimbristylis cymosa*. Inland of the large tide pool at Ka`aha, are spreading *Scaevola taccada* shrubs and the vine *Ipomoea pes-caprae* (pōhuehue). There is a sandy beach on the protected side of the lagoon at Kaluē with *S. taccada* just inland of the beach and below a steep pali. Typically plantings were placed at both sites during the same work sessions so the two sites were treated as one for monitoring and analysis purposes.

Keauhou Landing is a low sandy beach environment surrounding a large tide pool or lagoon. The high water table supports strand vegetation dominated by stands of putatively indigenous small tree, *Thespesia populnea (*milo*),* along with planted *Cocos nucifera (*coconu*t).* The strand community at Keauhou Landing also supports stands of non native trees, especially the shrub *Leucaena leucocephala* (koa haole), along with scattered *Scaevola taccada.*

The primary purpose of plantings in the coastal strand was for plant community restoration. The ultimate goal of the restoration project was to create a diverse, self-perpetuating native strand plant community. A specific objective of plantings for community restoration was to establish a closed to open low canopy of native spreading shrubs and vines characteristic of intact, native coastal strand. These matrix species would help suppress alien vegetation and create habitat for additional native coastal strand species, including uncommon and rare species. Another objective of plantings for community restoration was to increase biodiversity in the coastal strand by reintroducing and augmenting uncommon and rare species.

The relatively more intact coastal strand community at Kamilo outside the park in Ka‘ū and ‘Āpua Point in HAVO was used loosely as a reference (model or target) community and a primary source of founders. Seeds were collected from founder plants and grown in the Resource Management nursery facility. Seeds were used to propagate all coastal strand plantings except for *Portulaca villosa* (‘ihi) plantings and some *Myoporum sandwicense* (naio papa); cuttings were used in these cases.

Plantings in the coastal strand were carried out from 1998-2003 and in 2008 for one species, *Pritchardia affinis* (loulu) (Table 1). Twenty-one species were planted for community restoration and rare plant stabilization in the coastal strand. Four common species were planted largely as matrix species for community restoration (*Ipomoea pes-caprae* {pōhuehue}, *Osteomeles anthyllidifolia, Scaevola taccada*, and *Sida fallax* {ilima papa}). Four currently uncommon or rare species were planted as potential matrix species: *Myoporum sandwicense, Sesbania tomentosa*, *Jacquemontia ovalifolia (pā`uohi`iaka), and Vigna marina* (beach pea). Plantings would also stabilize the currently low populations of these species. Three other rare to uncommon species were planted to increase biodiversity in the coastal strand and to stabilize these species: *Boerhavia repens* (alena), *Chamaesyce celastroides* (`akoko*), Cyperus javanicus* (ahu awa), and *Plumbago zeylanica* (`ilie`e)*.*

Five target species were extirpated elements of the park’s coastal strand flora: *Capparis sandwichiana* (maiapilo), *Ipomoea tuboides* (Hawaiian moon flower), *Ischaemum byrone* (Hilo Ischaemum), *Lycium sandwicensis* (‘ōhelo kai), *Portulaca villosa*, and possibly *Pritchardia affinis*. *Ischaemum byrone* and *P. affinis* are endangered species; *P. villosa* and *C. sandwichiana* are species of concern. Reintroduction of these extirpated species was carried out with the intent of achieving interim stabilization.

There is no park documentation for the presence of final three target species: *Heliotropium anomalum* (hinahina)*, Melanthera* (formerly *Lipochaeta) integrifolia* (nehe), and *Panicum fauriei.* Because of the fragmented and degraded nature of the park coastal strand and the similarity of environments, these introduced species from the reference community could plausibly have occurred in the park’s coastal strand. They occur in coastal strand at Kamilo in Ka`ū near the park and have potential for community restoration and enhancement of biodiversity.

The results of plantings for all 21 target species, whether planted for community restoration or rare plant stabilization, are reported here. Considering the highly simplified and degraded nature of the coastal strand, there is considerable overlap of target species for rare plant stabilization and community restoration. Reintroducing or augmenting populations of most of the species above would serve both species stabilization and community restoration purposes. For example, *Sesbania tomentosa* is rare in the park and coastal strand. Increasing the number of individuals and creating new populations of this species would help stabilize this endangered species. As demonstrated by its behavior at `Āpua Point, this prostrate shrub can spread widely and act as a matrix species, thus serving an important role in community restoration. Many of the target species above were also recommended by Smith (1980) for coastal community ecosystem restoration.

Almost all of the restoration and rare plant stabilization work was done with plantings, seed additions were also used in one site. In 2004, the unused inventory of seeds for the coastal community restoration and rare plant stabilization projects was broadcast in one site, Hōlei Sea Arch. The seed additions included *Capparis sandwichiana*, *Cyperus javanicus*, *Heliotropium anomalum*, *Ipomoea pes-caprae, Ipomoea tuboides*, *Jacquemontia ovalifoila*, *Lycium sandwicensis*, *Melanthera integrifolia*, *Myoporum sandwicense*, *Osteomeles anthyllidifolia*, *Scaevola taccada*, *Sesbania tomentosa*, *Sida fallax*, and *Vigna marina*.

All coastal strand sites were monitored for a final time in 2009 or 2010 by systematically searching all planting sites for surviving individuals. Vigor and presence of flower or fruits were recorded for survivors. In most cases, size of surviving plantings was also recorded. Many of the plantings were spreading shrubs or vines and the longest dimension of the plants was recorded. Counting the number of surviving individuals of *Scaevola taccada*, *Ipomoea pes-caprae*, *Jacquemontia ovalifolia*, and *Myoporum sandwicense* was problematic in places; these plants tended to root at the nodes as they spread, in a few cases apparently dying back along the stem and losing their connection to the original planting. In some cases, metal plant identification tags could be located to determine the center of the plant. In other cases the nail holding the metal tags corroded in the salt spray environment, allowing the tags to be moved by wind or water. In the absence of metal tags, the rooting area with the largest stems was assumed to be the origin of the plants. Counting *Melanthera integrifolia* and *Ischaemum byrone* was confounded by the spreading tendencies of these planting; closely planted individuals grew and spread into each other at some sites. Denser clumps were counted as separate plantings.

Results by Species

Table 1. Survival of Coastal Strand Plantings

Species	Number Planted	Percent[a] Survival Early Monitoring	Percent Survival Last Monitoring	Number Surviving 2010
Holei Sea Arch				
Boerhavia repens	1	0 (5 mos.)	0% (83 mos.)	0
Ipomoea pes-caprae	0	NA	NA	1[c]
Ischaemum byrone	500	45% (15 mos.)	<1% (113 mos.)	15
Jacquemontia ovalifolia	68	0% (15 mos.)	0% (83 mos.)	0
Melanthera integrifolia	32	ND	22% (83 mos.)	7
Myoporum sandwicense	90	14% (15 mos.)	29% (113 mos.)	26
Plumbago zeylanica	64	ND	0% (83 mos.)	0
Portulaca villosa	729	74% (41 mos.)	0% (113 mos.)	0
Scaevola taccada	60	ND	143% (83-113 mos.)[b]	86
Sesbania tomentosa	45	4% (15 mos.)	2% (113 mos.)	1
Sida fallax	173	9% (15 mos.)	23% (83 mos.)	40
Vigna marina	0[c]	NA	NA	8[c]
Subtotal	**1642[e]**	NA	**5%**	**89[e]**
Ka`ena Point				
Portulaca villosa	400	50% (14-20 mos.)	0% (133-144 mos.)	0
Keauhou Landing				
Pritchardia affinis	59	25% (12 mos.)	19% (24 mos.)	10
Kealakomo				
Boerhavia repens	15	7% (19 mos.)	0% (92 mos.)	0
Cyperus javanicus	209	36% (19 mos.)	10% (92 mos.)	20
Heliotropium anomalum	67	36% (19 mos.)	0% (92 mos.)	0
Ipomoea pes-caprae	23	17% (19 mos.)	74% (92 mos.)	17
Ipomoea tuboides	6	50% (19 mos.)	0% (92 mos.)	0
Ischaemum byrone	287	17% (19 mos.)	0% (92 mos.)	0
Jacquemontia ovalifolia	17	41% (19 mos.)	0% (92 mos.)	0
Lycium sandwicensis	48	21% (29 mos.)	0% (92 mos.)	0
Melanthera integrifolia	79	30 (19 mos.)	0% (92 mos.)	0
Myoporum sandwicense	756	36% (19 mos.)	3% (92 mos.)	26
Ostoemeles anthyllidifolia	126	28% (19 mos.)	6% (92 mos.)	7
Plumbago zeylanica	40	23% (19 mos.)	0% (92 mos.)	0
Portulaca villosa	578	84% (19 mos.)	0% (92 mos.)	0
Scaevola taccada	220	52% (19 mos.)	11% (92 mos.)	24
Sesbania tomentosa	139	28% (19 mos.)	2% (92 mos.)	3
Sida fallax	33	3% (19 mos.)	0% (92 mos.)	0
Vigna marina	175	34% (19 mos.)	0% (92 mos.)	0
Subtotal	**2818**	NA	**3%**	**97**

Table 1 (continued). Survival of Coastal Strand Plantings				
Species	Number Planted	Percent[a] Survival ırly Monitoring (month	Percent Survival ıst Monitoring (month	Number Surviving 2009-2010
Kahue				
Boerhavia repens	15	33% (7 mos.)	0% (85 mos.)	0
Capparis sandwichiana	1	0% (7 mos.)	0% (7 mos.)	0
Chamaesyce celastroides	2	50% (7 mos.)	0% 85 mos.)	0
Cyperus javanicus	100	93% (7 mos.)	25% (85 mos.)	25
Heliotropium anomalum	147	95% (7 mos.)	10% (85 mos.)	14
Ipomoea pes-caprae	41	59% (7 mos.)	15% (85 mos.)	6
Ipomoea tuboides	3	0% (7 mos.)	0% (7 mos.)	0
Ischaemum byrone	132	58% (7 mos.)	0% (85 mos.)	0
Jacquemontia ovalifolia	126	80% (7 mos.)	4% (85 mos.)	5
Melanthera integrifolia	170	59% (7 mos.)	<1% (85 mos.)	1
Myoporum sandwicense	90	100% (7 mos.)	<1% (85 mos.)	3
Osetomeles anthyllidifolia	16	88% (7 mos.)	6% (85 mos.)	1
Panicum fauriei	28	0% (7 mos.)	0% (7 mos.)	0
Plumbago zeylanica	132	37% (7 mos.)	0% (85 mos.)	0
Portulaca villosa	504	30% (7 mos.)	0% (85 mos.)	0
Sesbania tomentosa	111	53% (7 mos.)	5% (85 mos.)	6
Sida fallax	148	66% (7 mos.)	10% (85 mos.)	15
Vigna marina	240	40% (7 mos.)	14% (85 mos.)	33
Subtotal	**2006**	NA	**5%**	**109**
Ka`aha-Kalue				
Capparis sandwichiana	6	0% (4 mos.)	0% (4 mos.)	0
Ischaemum byrone	211	<1% (33-51 mos.)	0% (118-141 mos.)	0
Jacquemontia ovalifolia	184	12% (33-42 mos.)	13% (118-131 mos.)	25
Myoporum sandwicense	70	51% (33-51 mos.)	31% (118-141 mos.)	22
Plumbago zeylanica	96	36% (42-51 mos.)	2% (131-141 mos.)	3
Portulaca villosa	575	28% (33-51 mos.)	0% (118-141 mos.)	0
Pritchardia affinis	22	14% (33-51 mos.)	9% (118-141 mos.)	2
Scaevola taccada	60[d]	32% (42 mos.)	ND[d]	ND[d]
Sesbania tomentosa	25	0% (33 mos.)	0 (33 mos.)	0
Sida fallax	80	20% (42 mos.)	21% (131 mos.)	17
Vigna marina	490	3% (23-42 mos.)	<1% (122-141 mos.)	2
Subtotal	**1639**	**NA**	**4%**	**71**
Total	**8559**	**NA**	**4%**	**376**

[a] *total numbers not presented because a subset of plants monitored for some species.*
[b] *a percentage greater than 100 was calculated because of seedling recruitment.*
[c] *counted plants resulted from seed additions, not plantings*
[d] *planting could not be distinguished from naturally occurring plants so not included in total count*
[e] *subtotal for Holei Sea Arch does not included totals for Scaevola taccada*
ND = no data

Boerhavia repens L., **Alena**
Family: Nyctanginaceae (Four-o'Clock family)
Status: Uncommon species in HAVO

Habitat and Distribution. This polymorphic, perennial herb is indigenous to the coastal strand and lower slopes on dry and leeward coasts throughout the Hawaiian Islands (Wagner *et al*., 1990). *Boerhavia repens* is an uncommon species or possibly rare species in HAVO, last documented from near Halapē in 1989 (Chai *et al.,* 1989).

Stabilization. *Boerhavia repens* seed was collected from Kamilo and propagated in the park greenhouse. Thirty-one individuals were planted at three sites, Hōlei Sea Arch, Kealakomo, and Kahue (Table 1). The one individual planted at Hōlei Sea Arch was not relocated after five months. Five of the 15 plantings at Kahue were alive after seven months; one of the 15 plantings at Kealakomo was alive at 19 months. When last monitored in 2010 after seven years, there were no surviving planted *B. repens* plantings in any of the three outplanting sites.

Capparis sandwichiana DC., **Maiapilo.**
Family: Capparaceae (Caper family)
Status: Species of Concern (Federal)

Habitat and Distribution. *Capparis sandwichiana* is a sprawling shrub found in the coastal strand and dry coastal lowlands of all the main Hawaiian Islands and some of the leeward Hawaiian Islands (Wagner *et al.,* 1990). It was last known from two sites in HAVO: Keaoi Island, just off the coast at Halapē and near the shoreline at the eastern boundary of the park. It was extirpated from Keaoi when this island was submerged following the subsidence associated with the 1975 earthquake. The individuals near the eastern park boundary in sites were inundated by lava flows in the 1980s. It is unlikely that *Capparis sandwichiana* is still extant in HAVO.

Stabilization: Six individuals were planted in the coastal strand at Ka`aha-Kālu`e (Table 1). These individuals were not located when monitored four months later or 11 years later when last monitored. One individual was planted at Kahue in 2003 and was not found six months later or when last monitored seven years after planting.

Chamaesyce celastroides (Boiss.) Crozat & Degener, **`Akoko**
Family: Euphorbiaceae (Spurge family)
Status: Rare in park coastal strand

Habitat and Distribution. *Chamaesyce celastroides* is an uncommon shrub or small tree found in coastal environments and mesic forest on all the main Hawaiian

Islands (Wagner *et al.*, 1990). At HAVO, it is found sparingly in lowland dry forest and the coastal lowlands.

Stabilization. Two plantings of *C. celastroides*, derived from founders at Kamilo, were planted at Kahue in 2003. One was alive when monitored seven months later; no live *Chamaesyce celastroides* were found seven years after planting.

***Cyperus javanicus* Houtt.** , **`Ahu`awa**
Family: Cyperaceae (Sedge family)
Status: Uncommon in coastal strand in HAVO

Habitat and Distribution. *Cyperus javanicus* is a large, perennial sedge found nearly throughout Hawai`i in coastal environments and low elevation wetlands (Wagner *et al*., 1990). In HAVO, it occurs uncommonly in coastal strand communities and is locally common at Hōlei Sea Arch, Ka`ena Point, and possibly other areas.

Stabilization. Seed was collected from founder plants at Kamilo and Hōlei Sea Arch. Plantings were made at Kealakomo and Kahue (Table 1). At Kealakomo, 75 of the 209 plantings were alive when monitored at 19 months; 10 plantings were alive after seven and one-half years. At Kahue, 93 of the plantings were alive when monitored after seven months; 25 plantings were alive when last monitored after seven years. When last monitored at all sites, 6% of the plantings were alive. The size and vigor of the plants varied greatly. Although this perception was not quantified, the most vigorous plants appeared to be growing in gaps in *Scaevola taccada* patches.

Heliotropium anomalum Hook. & Arnott., **Hinahina**
Family: Boraginaceae (Borage family)
Status: Introduction to HAVO?

Habitat and Distribution. *Heliotropium anomalum* is an indigenous, low-growing and occasionally mat-forming subshrub occurring throughout Hawai'i in sandy substrates of the coastal strand (Wagner *et al.*, 1990). There are no collections records from HAVO, but this is a common species in minimally disturbed coastal strand in Ka`ū. Based on this species broad distribution in Hawai`i and its presence in nearby coastal strand in Ka`ū, it is plausible that *Heliotropium anomalum* may have occurred in the park's coastal strand.

Stabilization. Founders of *Heliotropium anomalum* were derived from plants at Kamilo in Ka`ū and introduced to the coastal strand at Kealakomo and Kahue. At Kealakomo, 24 of the 67 plantings were alive at 19 months; one planting was alive after more than seven years (Table 1). At Kahue, 139 of the 147 plantings were alive after seven months; 14 were alive after seven years. Almost all plants were rated in poor or fair condition. Overall at all outplanting sites, 7% of the plantings were alive at last monitoring (2009).

Ipomoea pes-caprae (L.) R. Br., **Pōhuehue**
Family: Convolvulaceae (Morning glory family)
Status: Common in coastal strand

Habitat and Distribution. *Ipomoea pes-caprae* is a long-trailing, perennial vine found commonly in many coastal strand and sometimes more inland coastal areas (Wagner *et al*., 1990). At HAVO, *I. pes-caprae* is relatively common in the coastal strand in low bluff and beach coastal strand habitat including `Āpu`a Point, Keauhou Landing, and Halapē.

Stabilization: *Ipomoea pes-caprae* was planted at Kealakomo and Kahue, largely for community restoration purposes. At Kealakomo, 23 individuals of *I. pes-caprae* were planted (Table 1). After 19 months, while individual plantings still could be readily distinguished and counted, four plantings were found; after seven and one-half years, *I. pes-caprae* vines were abundant, but not reliably countable because they grew up to 20 meters long and rooting at the nodes. At Kahue, 24 of the 41 plantings were found after seven months. After seven years, six plants were found. One small *I. pes-caprae* was found at Hōlei Sea Arch in 2010, even though no plantings were made at this site. Recruitment of this individual was undoubtedly a product of seed additions made at this site in 2004.

Ipomoea tuboides Degener & Oostrstr. **Hawaiian moon flower**
Family: Convolvulaceae (Morning glory family)
Status: Extirpated in HAVO

Habitat and Distribution. *Ipomoea tuboides* is a perennial, trailing vine of dry, barren lava surfaces below 600 m elevation on the larger islands in Hawai`i (Wagner *et al*., 1990). At HAVO, it was collected in 1983 west of Kamoamoa (L. Pratt, pers. comm.), a site now under lava.

Stabilization. Founders were derived from *Ipomoea tuboides* plants at Kamilo. Six individuals of *I. tuboides* were planted at Kealakomo (Table 1). Three were alive at 19 months, but none were found after seven and one-half years. Three individuals were planted at Kahue. None were located during subsequent monitoring.

Ischaemum byrone (Trin.) Hitchc***.*, Hilo Ischaemum**
Family: Poaceae (Grass family)
Status: Endangered

Habitat and Distribution. *Ischaemum byrone* is a perennial grass which occurs near the shoreline on the windward shores of Moloka`i, Maui and Hawai`i Island. On Hawai`i Island, it occurs at scattered sites from Hilo along the Puna Coast to HAVO (Wagner *et al.,* 1990). In the early 1990s at HAVO, *I. byrone* was known primarily from Pu`u Manawalea, west of Kamoamoa. Some plants were also found in low numbers at High Castle and just east of Lae`apuki. All of these sites were overrun by lava flows in 1992-2006.

Stabilization. Prior to the destruction of these sites some *Ischaemum byrone* plants were salvaged and maintained *ex situ* at the HAVO nursery. Additional founders were derived from seed collected of plants east of the park at Kaimū. *I. byrone* was planted at Hōlei Sea Arch, Kealakomo, Kahue, and Ka`aha-Kālu`e (Table 1). At Hōlei Sea Arch, 500 *I. byrone* were planted. At 15 months, 225 plants were alive; after eight years, 61 plants were alive (S. McDaniel, unpublished data); after nine and one-half years, 15 plants were alive (Fig. 3).

At Kealakomo, 287 *I. byrone* were planted. When monitored after 19 months, 49 plants were alive; when monitored at seven and one-half years, no plants could be found. At Kahue, 132 plantings of *I. byrone* were made. After seven months, 77 plants were alive; after seven years, no *Ischaemum byrone* plants were found. At Ka`aha-Kālul`e, 211 plantings of *I. byrone* were made. When monitored after three years, only one individual was alive. After 10 years, no survivors were found. Collectively, at all

Figure 3. Planting of *Ischaemum byrone* (Hilo Ischaemum) at Hōlei Sea Arch. Less than one percent of the 1,130 plantings of *I. byrone* survived, all at Hōlei Sea Arch, the eastern-most and most mesic planting site for this species. The western most and driest naturally occurring site was at Kamoamoa, east of Hōlei Sea Arch in the park. The failed planting sites in HAVO may have been too dry for *Ischaemum byrone*.

sites at last monitoring, <1% of plantings survived, all at the eastern-most and more mesic site at Hōlei Sea Arch.

Jacquemontia ovalifolia subsp. ***sandwicensis*** A. Gray. K. Robertson, **Pā`ūohi`iaka**
Family: Convolvulaceae (Morning glory family)
Status: Uncommon in HAVO

Habitat and Distribution. *Jacquemontia ovalifolia* subsp. *sandwicensis* is a prostrate vine found in coastal environment and is more abundant in dry locations (Wagner *et al.*, 1990) In HAVO in recent decades it has been found at `Āpua Point and vicinity, Ka`aha, and Keauhou (Smith, 1980).

Stabilization. *Jacquemontia ovalifolia* subsp. *sandwicensis* was planted at Hōlei Sea Arch, Kealakomo, Kahue, and Ka`aha-Kalue (Table 1). The plantings were derived from founders within the park at Kealakomo. At Hōlei Sea Arch, 68 plantings were made; after 15 months, there were no survivors. At Kealakomo, 7 of the 17 planting were surviving after 19 months; however, there were no survivors after seven and one-half years. At Kahue, 126 plantings were made. After seven months, 101 of the plantings were alive; after seven years, five plantings were alive. At Ka`aha-Kālu‘e, 184 plantings were made. After 33-42 months, 22 plants were found; 25 plantings were counted after 10-12 years. Collectively at all sites at last monitoring, 9% of the plantings of *J. ovalifolia* subsp. *sandwicensis* survived.

Lycium sandwicense A. Gray, **`Ōhelo Kai**
Family: Solanaceae (Nightshade family)
Status: Rare in HAVO

Habitat and Distribution. *Lycium sandwicense* is a low-growing, spreading shrub growing in the coastal strand of all the main Hawaiian Islands (Wagner *et al.,* 1990). It was found at Halapē and Keauhou Landing in the late 1970s (Smith, 1980).

Stabilization. Forty-eight individuals of *Lycium sandwicense*, derived from founders at Kamilo, were planted at only one site, Kealakomo in 2002 (Table 1). When monitored 29 months later, 10 plants were alive. When monitored in 2010, nearly eight years after planting, no *L. sandwicense* were found.

Melanthera integrifolia (Nutt.) *W. L. Wagner & H. Rob*.**, Nehe**
Family: Asteraceae (Sunflower family).
Status: Introduction to HAVO?

Habitat and Distribution. This prostrate perennial shrub is found in the coastal strand on all the main Hawaiian Islands (Wagner *et al*., 1990). *Melanthera integrifolia* has never been collected in HAVO. It was included in the restoration project because of its occurrence near the park in Ka`ū.

Stabilization. Founders were derived from naturally occurring plants at Kamilo in Ka`ū. *Melanthera integrifolia* was planted as three sites in the park (Table 1). At Hōlei Sea Arch, 32 individuals were planted in 2003. They were not monitored until 2010 when seven spreading plants were found. At Kealakomo, 79 *M. integrifolia* were planted in 2002. When monitored nearly two years later, 30 plants were surviving. When last monitored in 2010, no live plants were located. At Kahue, 170 *M. integrifolia* were planted in 2003. After seven months 101 plants were alive. When monitored in 2010, only one live plant was found. The collective survival rate at last monitoring for all sites was 3%.

***Myoporum sandwicense* A**. Gray, **Naio papa**
Family: Myoporaceae ((Myoporum family)
Status: Rare in coastal strand of HAVO

Habitat and Distribution. *Myoporum sandwicense* is a highly polymorphic shrub to small tree growing in various habitats from the coastal to subalpine woodlands in wet to dry environments on all the main islands except Kaho`olawe (Wager *et al*., 1990). At HAVO, it is probably most common in mesic forest and the remnants of dry forest, but also occurs sparingly in the wet `Ōla`a Forest and upland forests and woodlands on Mauna Loa. The coastal strand form of *M. sandwicense,* called naio papa, is a low, spreading shrub (Fig. 4). It is rare at HAVO, occurring in the dry, southwest coastline at or near Papaleahau Point in the southwestern shoreline of the park. However, its spreading and mat-forming habit suggested its potential as a matrix species for community restoration.

Stabilization. Founders were derived from *Myoporum sandwicense* plants are Kamilo and Kamehame in Ka`ū outside the park and near Papaleahau in HAVO. *M. sandwicense* was planted at all coastal sites except Ka`ena Point (Table 1). At Hōlei Sea Arch, 90 individuals were planted in 2000. After a little more than one year, 13 live plantings were found. After nearly 10 years, 26 live plantings were found. The increase may be an artifact of the difficulty of counting spreading vines rooting at the roots or seed additions to the site in 2004. At Kealakomo, 756 *M. sandwicense* were planted in 2002. After one and one-half years, 252 were alive; after nearly eight years, 26 plantings were alive. At Kahue, 90 plantings were placed in 2003. All were alive when monitored after seven months. Only three plantings were surviving at seven years. At Kaaha-Kālu‘e, 70 *M. sandwicense* were planted in 1998-2000. When monitored after 3-4 years, 36 plantings were alive. When monitored in 2009, 22 plants were found to be surviving. When last monitored, the average survival rate for all sites was 7%.

Figure 4. Low-growing, viney planting of *Myoporum sandwicense* (naio papa) in the coastal strand. The prostrate form of *M. sandwicense* is a rare plant in HAVO, found only in one site in the southwestern portion of the coast near Kūē`ē. Because of its spreading and mat-forming habit, *M. sandwicense* also has potential as a matrix species in community restoration. Stabilization of rare plants was carried out in the coastal strand in the context of a community restoration project.

Osteomeles anthyllidifolia (Sm.) Lindl. , **`Ūlei**
Family: Rosaceae (Rose family)
Status: Common in HAVO

Habitat and Distribution. *Osteomeles anthyllidifolia* is an upright to sprawling shrub occurring in a wide range of dry to mesic environments on all the main Hawaiian Islands except Kaho`olawe and Ni`ihau (Wagner *et al*., 1990). At HAVO, *O. anthyllidifolia* is common as an upright shrub in mid-elevation woodlands and remnants of the lowland dry-mesic forest. It is also common in the coastal lowlands, primarily as a low, spreading shrub. It is found in the higher reaches of the coastal strand community.

Stabilization. *Osteomeles anthyllidifolia* was included in the coastal plantings for community restoration purposes to provide structure and cover, particularly in the upper strand, and habitat for rare species. As a dense, low-growing shrub it seems to effectively diminish the role of invasive grasses in the coastal lowlands and strand. *O. anthyllidifolia* was planted in two sites in 2002, Kealakomo and Kahue (Table 1). According to a plant survey conducted in 2001, no *O. anthyllidifolia* was present at Kahue prior to outplanting. All of the plants were derived from founder in the park. At Kealakomo, 126 individuals were planted. After one and one-half years, 35 planting were alive. After seven and one-half years, seven planting were still surviving. Sixteen *O. anthyllidifolia* were planted at Kahue; 14 of these were alive after seven months. Only one planting was surviving at seven years. The survivorship when last monitored at both beaches was 6%.

Panicum fauriei, Hitch. (no common name)
Family: Poaceae (Grass family)
Status: Introduction to HAVO?

Habitat and Distribution. *Panicum fauriei* is a short, tufted annual grass in a wide range of dry coastal sites on all the main islands except Ni`ihau (Wagner *et al*., 1990). The species is not known from HAVO, but it is common in the coastal strand in nearby Ka`ū.

Stabilization. *Panicum fauriei* was included in the coastal strand project because of its proximity to the park and its occurrence in the coastal strand. All founders were derived from Kamilo and it was planted only at Kahue. None of the planted 28 individuals were surviving after seven months; no regeneration was observed (Table 1).

Plumbago zeylanica L., **`Ilie`e**
Family: Plumbaginaceae (Plumbago family)
Status: Rare in HAVO

Habitat and Distribution: *Plumbago zeylanica* is a low, spreading shrub found in dry and mid-elevation environments, including coastal strand, on all the main islands (Wagner *et al.* 1990). There is just one observation of this plant at HAVO from the lowlands in the 1960s (Fosberg, 1966). The absence of more recent observations suggests that it may be very rare or possibly extirpated from the park.

Stabilization. All *Plumbago zeylanica* founders were derived from naturally occurring plants at Kamilo in Ka`ū outside the park. It was planted at all sites except Ka`ena Point (Table 1). In 1998-1999, 96 individuals were planted at Ka`aha-Kālu'e. After 3-4 years, 35 surviving plants were found. Three plants were found after 11-12 years. The 64 *P. zeylanica* planted in 2003 at Hōlei Sea Arch were monitored just once, after seven years; no surviving plants were located. At Kealakomo, 40 individuals were planted in 2002. After one and one-half years, 9 plants were alive; no plants were found after seven and one-half years. At Kahue, 132 *P. zeylanica* were planted in 2003. When monitored at seven months 49 live plants were found; at seven years, no plantings were found. Altogether at last monitoring, less than 1% of the plantings of *Plumbago zeylanica* were alive.

Portulaca villosa Cham., **\`Ihi**
Family: Portulaceae (Purslane family)
Status: Species of Concern

Habitat and Distribution. *Portulaca villosa* is a prostrate perennial herb found in dry sites from the coast to approximately 300 m elevation on all the main Hawaiian Islands (Wagner *et al.,* 1990). It was known recently in the park from near Pu\`u Manawalea, west of Kamoamoa. This site was covered by lava shortly after 20 individuals of the 40 plants present were translocated to the park nursery as founder stock.

Stabilization. Cuttings were propagated in the park greenhouse from salvaged park founder plants. In 1997-1998, 400 *P. villosa* were planted at Ka\`ena Point in sandy swales similar to those in which it grew naturally in the park, from near the shoreline inland to nearly to the Puna Coast Trail (Table 1). When monitored one and one-half year later, 200 were still surviving. When monitored in 2004,125 individuals were alive. No surviving plants were found in a systematic survey in 2010, although some remnants of dead plants were found. In 1998-2000, 575 *Portulaca villosa* were planted at Ka\`aha-Kālu'e. When monitored after 3-4 years, 161 individuals were alive. At Hōlei Sea Arch 729 individuals were planted in the same habitat as the founder population. After three and one-half years, 539 live individuals were located. In 2002, 578 individuals were planed at Kealakomo; 486 were alive at three and one-half years. Finally, at Kahue 504 *P. villosa* were planted in 2003; 151 were alive seven months later. All of the outplanting sites in the park were monitored in 2009 or 2010; no surviving *Portulaca villosa* were found and no natural regeneration was observed at any site.

Pritchardia affinis Becc., **Loulu**
Family: Arececeae (Palm family)
Status: Endangered

Habitat and Distribution. *Pritchardia affinis* is a small to large palm found in leeward coastal areas on Hawai\`i Island (Wagner *et al.,* 1990). This species was known to be widely cultivated by Hawaiians, so individuals found in the wild may not be naturally occurring. At HAVO, *P. affinis* was known to occur in a small group of cultivated plantings at Waha\`ula and near the Kalapana Trail before these areas were covered by lava in the 1980s and 1990s. Plantings of *Pritchardia affinis* can feasibly be considered a reintroduction of an endangered species or re-establishment of a culturally significant native species.

Stabilization. In 2000, 14 *P. affinis,* derived from a founder in Hilo and another at Kaimū, Puna District, were planted at Kālu'e (Table 1). Two plantings were alive when last monitored in 2009. In 2008, 59 *P. affinis,* representing 10 founder lines from seed collected of plants occurring at sites along the Kona and Ka`ū coast, were planted in two sites at Keauhou Landing, in sand just above the high tide line. After one year 15 (25%) were alive; after two years, 10 were found to be surviving. Eight of these were located near or under *Thespesia populnea* trees.

Scaevola taccada Gaertn., **Naupaka kahakai**
Family: Goodeniaceae (Goodenia family)
Status: Common in coastal strand

Habitat and Distribution. Typically a low, spreading shrub, *Scaevola taccada* is found at the coast in all the Hawaiian Islands (Wagner *et al.,* 1990). At HAVO, it is locally abundant at Kealakomo, Kahue, `Āpua Point, Keauhou Landing, Halapē, and Ka`aha-Kālu'e.

Stabilization. *Scaevola taccada* was planted as a matrix species for community restoration and to provide habitat for rare species stabilization (Fig. 5). Founders were derived from naturally occurring plants in the park at Kahue. In 1999 at Ka`aha-Kālu'e, 69 *Scaevola taccada* were planted. When monitored at three and one-half years, 19 plantings were found. They could not be reliably counted and distinguished from naturally occurring plants when Ka`aha-Kālu'e was monitored in 2009. At Kealakomo, 220 *Scaevola taccada* were planted in 2002. At one and one-half years114 *S. taccada* were alive; 24 plantings were alive after eight and one-half years. Sixty *S. taccada* were planted at Hōlei Sea Arch in 2003. When monitored in 2010, 86 plants were counted and presumed to be plantings because of their size and the presence of metal identification tags on some plants of comparable size. In addition, there were 72 very small plants or seedlings, presumed to result from natural seedling recruitment or seed additions.

Figure 5. Patches of spreading *Scaevola taccada* (naupaka kahakai) plantings in the coastal strand at Hōlei Sea Arch. Over 86 patches of *S. taccada,* representing surviving plantings and natural recruitment, were found in this site, along with 72 small plants recently recruited from seed. *S. taccada* was essentially absent from this coastal strand planting site prior to outplanting. Common, mat-forming species such as *S. taccada* had 30% survival 7-12 years post- planting, suggesting the potential for community restoration in the coastal strand.

Sesbania tomentosa Hook. & Arnott, **`Ohai**
Family: Fabaceae (Pea family)
Status: Endangered

Habitat and Distribution. Ses*bania tomentosa* is a sprawling, sometimes upright shrub historically found at low, leeward elevations on all the main Hawaiian Islands (Wagner *et al.,* 1990). At HAVO, plants occur in the coastal strand at `Āpua Point, Kūē`ē, and one plant at Kālu’e. *Sesbania tomentosa* is also found more inland in the grass-dominated dry coastal lowlands and mid-elevation woodland at Kamo`oali`i, Kīpuka Pepeiao, Kukalau‘ula, Hilina Pali, and Kīpuka Nēnē. At least 200 `ōhai plants were mapped in these areas during rare plant surveys conducted in the mid-1990s. More recent stand structure studies indicate declining populations of *Sesbania tomentosa* in the park (Pratt *et al*. 2011)

Stabilization. *Sesbania tomentosa* was propagated from founders of the natural population at `Āpua Point and planted at Ka`aha-Kālu‘e, Hōlei Sea Arch, Kealakomo, and Kahue. At Ka`aha-Kahue, 25 *S. tomentosa* were planted in 2000. No survivors were detected when monitored nearly three years later. At Hōlei Sea Arch, 45 individuals were also planted in 2000. Two were alive after one year; one was alive after 10 years. At Kealakomo, 139 individuals were planted in 2002. After one year, 39 were alive; after nearly eight years, three were alive. At Kahue, 111 *Sesbania tomentosa* were planted in 2003. After seven months, 59 of these plantings were alive; after seven years six, vigorous, wide-spreading plants were alive. The collective survivorship at last monitoring across all sites was 3%.

Sida fallax Walp. , **`Ilima papa**
Family: Malvaceae (Mallow family)
Status: Common in coastal strand

Habitat and Distribution. *Sida fallax* is a prostrate to erect small shrub in leeward dry to mesic low elevation environments on all the main Hawaiian Islands (Wagner *et a*l., 1990). In HAVO, *S. fallax* is common in the coastal lowlands including the coastal strand. Here it s a diffuse, prostrate shrub referred to as `ilima papa.

Stabilization. Park plantings were derived from founders at Halapē, Kamilo, Kealakomo, and Punalu`u, and were planted largely for community restoration purposes. In 1999, 80 *S. fallax* were planted at Ka`aha-Kālu’e. After three and one-half years, 16 planting were alive. After 11 years, 17 *S. fallax* were counted; there may have been natural recruitment. There was a similar pattern of increasing numbers over time at Hōlei Sea Arch in 2000 and 2003 where 173 individuals were planted. After one year, 16 plantings were found. After nearly seven years, 40 individuals were found, undoubtedly reflecting local seedling recruitment. At Kealakomo, 33 S*. fallax* were planted in 2002. At one and one-half years, just one planting was found; no plantings were located after seven and one-half years. At Kahue, 148 *S. fallax* were planted in 2003; 98 survivors were found after seven months; 15 were found after seven years.

Vigna marina (J. Burma.) Merr*.,* **Beach pea**
Family: Fabaceae (Pea family)
Status: Uncommon in coastal strand

Habitat and Distribution. *Vigna marina* is a viney perennial herb typically found in the coastal strand or occasionally on sea cliff or dry lowland slopes (Wagner *et* *al.,* 1990). At HAVO, it is an uncommon component of the strand vegetation and is naturally occurring mostly at `Āpua Point.

Stabilization. All plantings in the park were derived from founders at `Āpua Point. In 1999-2000, 490 individuals of *Vigna marina* were planted at Ka`aha/Kālu'e. After two to three years, 15 were alive; after 10-12 years, only two plants were surviving. At Kealakomo in 2002, 175 *Vigna marina* were planted. After one and one-half years, 60 plantings were found; no plantings were found at seven and one-half years. At Kahue 240 planting were placed in 2003. At seven months, there were 96 plants surviving; 33 live plantings were found after seven years. At Hōlei Sea Arch, eight plants were located in a survey in 2010 (Fig. 6). No plantings were done at this site. However, *Vigna marina* seeds were broadcast at this site in 2004.

Figure 6. *Vigna marina* (beach pea) at Hōlei Sea Arch. The *V. marina* here resulted from seed additions rather than plantings. This was the only site in the coastal strand in which seed additions were attempted, a technique which may have potential for community restoration or rare plant stabilization for dry to mesic environments, especially with plants such as *V. marina* with hard seed coats and probably a persistent soil seed bank.

Discussion

The average survivorship of plantings in the coastal strand was ostensibly very low, 4% across all sites and species (Table 1). However, this low survival rate reflects to a degree the extremely low survivorship of two intensively planted rare plant species, *Ischaemum byrone* and *Portulaca villosa*. Over 48% of the total plantings at the six sites of coastal strand were individuals of these two species. Only 15 (1%) individuals of *I. byrone* survived long term; no surviving plantings of *P. villosa* were located in the final monitoring in 2009 or 2010. The overall survivorship of plantings of all other coastal strand species was 7%.

Ischaemum byrone, an endangered species, and *Portulaca villosa*, a species of concern, occurred naturally as recently as 1992 in small populations near Kamoamoa. A subset of individuals of both species was salvaged from the site just before they were inundadated by lava flows in 1992. The salvaged plants were readily propagated and planted in large numbers into remaining coastal strand habitat in the park. The high numbers of plantings reflect partly the ease of propagation and the urgency to re-establish these recently extirpated or rare species.

The Kamoamoa site was the western-most and presumably driest known natural site for *I. byrone*, which is still found from Puna to Hilo. It may be that the park sites where it was planted, all west of Kamoamoa, are too dry for *Ischaemum byrone*. *Portulaca villosa* is, in contrast, found in relatively dry coastal habitats. An alternative explanation for the absence *of Portulaca villosa* plants when monitored 11-12 years after planting may be the life span of *P. villosa* and failure of seedling recruitment. This small herbaceous plant is a short-lived perennial; the life-span is not known. However, short-lived perennials depend on seedlings recruitment to replace mature individuals. The occasional seedling recruitment of *Portulaca villosa* observed was ephemeral.

Another explanation for the failure of *Portulaca villosa* plantings may be the propagation techniques employed. *Portulaca* spp. can readily be propagated from cuttings, but propagation from seed is more difficult. All the planted material of *P. villosa* was made from cuttings. *Portulaca sclerocarpa*, a congener of *P. villosa,* was planted in the mid-elevation woodlands, mostly from cuttings. The plantings of *P. sclerocarpa* derived from seed appear to have noticeably greater survivorship than plantings made at the same time derived from cuttings (Table 3). An experiment in progress at HAVO comparing the survival of side-by-side plantings of *P. sclerocarpa* derived from cuttings and seed indicates, to date, significantly higher survivorship of seed derived plantings (L. Pratt, pers. comm.). Seedlings may have a higher root-to-shoot ratio at the time of planting and presumably greater tolerance to lower soil moisture, an important limiting factor in the dry to mesic coastal strand sites. In addition, cuttings of a short-lived perennial such as *Portulaca* spp. have the same life expectancy as the parent plant; seedlings should live longer.

In contrast to the failure of *Ischaemum byrone* and *Portulaca villosa* plantings, survivorship of plantings of common species in the coastal strand at HAVO was 30% (Table 1). These species include *Scaevola taccada, Ipomoea pes-caprae*, *Osteomeles* *anthyllidifolia*, and *Sida fallax.* Some of the apparent success may be due to over-counting of these species, all of which root at the nodes as they spread. However, their greater natural abundance is seemingly a logical predictor of the greater success of their plantings. Plantings of *Scaevola taccada* were the most successful of the common species: there was 36% survival with plants averaging 3.3 m in the longest dimension. Planting of *S. taccada* was particularly successful at Hōlei Sea Arch where just one small naturally occurring plant was present prior to outplanting. Seven to 10 years after the initial planting of *S. taccada*, 72 seedlings (defined here as plants< 0.5 m in longest dimension) were found in 2010. These seedlings may have resulted from either natural recruitment from the mature plantings or from seed additions in 2004.

The survivorship of other common park coastal strand species was also modestly high. The survivorship of *Ipomoea pes-caprae* at the two sites it was planted was 36%, although overcounting may have occurred in this spreading vine. The survivorship of *Sida fallax* was 17%. The survivorship of *Osteomeles anthyllidifolia* was 13%.

The plantings of a viney, spreading uncommon park strand species, *Jacquemontia ovalifolia*, were also modestly successful: 10% of the plantings were surviving after 7-12 years. One potential matrix species, *Vigna marina*, had 14% survival when planted at Kahue in a matrix of *S. taccada, but* lower survivorship in other sites. Plantings of *Myoporum sandwicense*, rare in the park, were 8%. Although the plantings of the endangered spreading shrub *Sesbania tomentosa* was low (5%) across all sites, where it survived, it formed, spreading dense mats of vegetation.

The modest or localized survivorship of common park strand species, *Scaevola taccada*, *Ipomoea pes-caprae*, *Osteomeles anthyllidifolia*, *Sida fallax*, and uncommon or rare species including *Vigna marina, Myoporum sandwicense*, and *Sesbania tomentosa* suggest the potential *of* community restoration in the coastal strand. All of these potential matrix species are low-growing and spreading and have varying abilities to form dense mats of native vegetation to suppress alien vegetation and presumably create habitat for other native species. Large numbers of seedlings would be needed for most of these species because only one to three of 10 plantings survive long term. Additional augmentation with the plantings of these species in the six restoration sites would accelerate the community restoration and create habitat for future plantings of rare species. There is extensive high bluff habitat to the west of Hōlei Sea Arch where restoration leading with *Scaevola taccada* might be successful.

The success of plantings of other rare species in the coastal strand beside *Ischaemum byrone* and *Portulaca villosa* was also, on average, very low and contributes to the low overall survivorship of plantings in the coastal strand. Rare species in this context include species currently with very small populations in the park or coastal strand (*Chamaesyce celastroides, Plumbago zeylanica, Lycium sandwicensis,)*; species extirpated from the park (*Capparis sandwichiana and Ipomoea tuboides)*; and species introduced to the park from nearby areas (*Heliotropium anomalum*, *Panicum fauriei, Melanthera integrifolia*, and possibly *Pritchardia affinis)*.

Five percent of the rare species in the park's coastal strand, as defined above, were surviving when last monitored.

The low survivorship of rare species plantings may require different approaches to achieve stabilization of these species in the coastal strand. Because the vegetation of the coastal strand is so degraded, restoring common or matrix species in the coastal strand plant communities as habitat may be an important first step prior to planting rare plant species for stabilization purposes. The value of a matrix of different native plant cover can be tested against plantings outside a matrix. Plantings were made at Kahue and other sites within and outside a *Scaevola taccada* matrix. However, the survivorship of these planting cannot be compared by microsite since this was not recorded at planting time and so cannot be used to inform this question. \`Āpua Point was not utilized as an outplanting site in the current project. However, its matrix of *Scaevola taccada* and *Sesbania tomentosa* provide opportunities for stabilization of rare plant species. Long-term maintenance of *S. tomentosa* as a matrix species at \`Āpua Point will probably require rodent control. Rodent predation on fruits and seeds has been demonstrated to be an important limiting factors contributing to the decline of this species (Pratt et al., 2011).

A number of the rare species plantings with low survivorship involved very small numbers of plantings. For example, only two *Chamaesyce celastroides*, seven *Capparis sandwichiana*, nine *Ipomoea tuboides*, 28 *Panicum fauriei*, and 31 *Boerhavia repens* were planted. Increasing the number of plantings in a diversity of habitats can enhance the prospects of plantings in different microsites and post-planting environments. Small planted populations are more vulnerable to extinction through unfavorable chance environmental events.

The use of seed additions may be another useful restoration and stabilization technique in the coastal strand. Seed additions were carried out only once in the project, at Hōlei Sea Arch, with seed broadcast of 14 coastal strand species. From monitoring conducted in 2010 and planting records, it can be inferred that the *Vigna marina* and the *Ipomoea pes-caprae* found in 2010 at Hōlei Sea Arch represents seedling recruitment from seed additions. No plantings were placed for these two species and the nearest known seed sources are at Kealakomo. Seedling recruitment may have taken place in other species from the seed additions, but these could not be distinguished from plantings.

At Hōlei Sea Arch, the amount of seed added was not quantified and sowing locations were not specified. No site preparation, e.g., removing alien grasses or covering seeds with soil, was done and no follow up monitoring was done. Experimentation with seed additions, including comparisons of microsite and site preparation, may have potential as a restoration technique in a dry, severely degraded environment such as the coastal strand with minimal seed sources or soil seed bank. However, it is recognized that seed collecting is time-consuming and minimal seed may be available for some species.

LOWLAND DRY-MESIC FOREST

Study Area and Methods

Small remnants of lowland dry-mesic forest persist in Hawai`i Volcanoes National Park on the steep, south-facing slopes of Hōlei Pali between 100 and 600 m elevation. They are found on 400-750 year old flows originating from Kāne Nui o Hamo Crater on the east rift of Kīlauea (Wolfe and Morris, 1996). Very little soil is present on these young pāhoehoe and `ā`ā substrates. The average rainfall at the top of Hōlei Pali, above and windward of the forest remnants, is approximately 1,200 mm per year with the summer months generally much drier than the rest of the year (HAVO Fire Cache, unpublished data). The sheltered pali faces supporting the relictual lowland dry-mesic forest stands below the rain gauge probably receive less rain. The lowland forest remnants in the park have been variously classified as either dry or mesic so in this treatment these sites will be identified as transitional or dry-mesic.

The vegetation of lowland dry-mesic forest in HAVO is characterized by an open to closed canopy of short *Diospyros sandwicensis* (lama) trees and, often emergent, *Metrosideros polymorpha* (`ōhi`a). *Metrosideros polymorpha* initially colonized the lava flows; *D. sandwicensis* dominates later seral stages of lowland dry-mesic forest like those found in the park (Stemmermann and Ihsle, 1993). The lowland dry-mesic forest in HAVO also includes low numbers of other native trees including *Santalum paniculatum* (iliahi), *Myoporum sandwicense* (naio), and *Sophora chrysophylla* (māmane), and stands of a naturalized Polynesian introduction, *Aleurites molluccana* (kukui), a medium-sized tree that can form dense, nearly monospecific stands. The widespread native shrub *Dodonaea viscosa* (`a`ali`i) is abundant in the understory; the tall native shrub, *Psydrax odorata* (alahe`e), found commonly in lowland dry forest in the state, is locally abundant. Some areas have a sparse ground cover of the native herbs *Peperomia blanda* (`ala`ala wai nui) and *Plectranthus parviflorus (*`ala`ala wai nui*)*. Many other understory areas are dominated by dense patches of the invasive fern *Nephrolepis multiflora* (sword fern*),* the invasive shrub *Lantana camara* (lantana*),* and invasive grasses.

The extent of lowland dry-mesic *Diospyros/Metrosideros* forest in HAVO was sharply reduced by lava flows since 1970. An extensive lowland dry-mesic forest north of Kamoamoa was covered by Pu`u `Ō`ō flows, 1997-1998. The Nāulu forest was formerly semi-continuous on Hōlei Pali west of the apex of the hairpin turn in the Chain of Craters Road. This forest was partly covered by the Mauna Ulu flows from 1970-1972 (Warshauer, 1974; Abbott and Pratt, 1996). The Mauna Ulu flows have undoubtedly modified the environment of the remnant kīpuka by increasing the edge-to-interior ratio of the stands and emplacing dry, barren, dark rock surfaces adjacent to the edge of the forest. The forest remnants on Hōlei Pali lie near the mean vector of volcanic gases, including sulfur dioxide, sulfates, and sulfuric acid, emitted from the Pu`u `Ō`ō vent.

Feral goats, centered in large herds in the nearby coastal lowlands, browsed the dry-mesic forest for many decades until controlled finally in the early 1970s (Katahira and Stone, 1982). Feral goats undoubtedly browsed on seedlings and interfered with the natural regeneration of native woody plants (Abbott and Pratt, 1996). Although there are patches of understory with some native understory herbs and few invasive plants, dense stands of invasive plants now occupy much of the forest understory and probably greatly inhibit the successful establishment of native trees. Little natural regeneration of uncommon and rare native trees was found (Abbott and Pratt, 1996)

Dry tropical forests are among the most endangered of all tropical forest ecosystems (Janzen, 1988). Hawaiian dry forests are similarly imperiled (Stemmermann and Itsle, 1993). The Hawaiian Heritage Program gives the park's lowland dry-mesic forest (*Diospyros sandwicensis/Metrosideros polymorpha* Mixed Lowland Mesic Forest) a global rank of G3, very rare and restricted range (Pratt *et al*., 2011).

The largest and most diverse remaining stands of lowland dry-mesic forest are located in two kīpuka of the Nāulu Forest in the Kealakomo ahupua`a. The 41 ha eastern most stand is identified as Area I after Abbott and Pratt (1996). It is often identified informally by park resource managers and researchers as Nāulu. The 34 ha western most stand is identified as Area II after Abbott and Pratt (1996); the formal place name is Kealakomo.

These two forest stands were the target sites for almost all the lowland plantings including the following rare 12 tree, shrub, and vine species (Table 2): *Alphitonia ponderosa (*kauila), *Antidesma pulvinatum* (hame), *Bobea timonioides*, *Canavalia hawaiiensis* (`āwikiwiki), *Erythrina sandwicensis* (wiliwili), *Nothocestrum breviflorum* (`aiea), *Nototrichium sandwicense* (kukuī), *Pleomele hawaiiensis* (halapepe), *Rauvolfia sandwicensis* (hao), *Reynoldsia sandwicensis* (`ohe makai), *Senna gaudichaudii* (kolomona), *Tetraplasandra hawaiensis (* `ohe mauka*)*, and *Xylosma hawaiiense* (maua). In addition, one of these species, *Erythrina sandwicensis*, was planted in dry forest habitat within an *Aleurites moluccana* stand on Hōlei Pali over five kilometers to the east of Nāulu and Kealakomo. This site is identified as Hōlei Pali Kukui Grove (Table 2).

Two of the planted species are endangered species; four others are species of concern. Two of the planted species were extirpated from lowland dry-mesic forest in the park in recent decades and were reintroduced by planting. Four planted species are represented by just 1-3 individuals (Abbott and Pratt, 1996). Three planted species were not historically collected or observed in Nāulu Forest. However, small numbers were found since 2000 north of Nāulu in the transition to mesic and wet forest or to the west on Poliokeawe Pali.

Invasive plant control was initiated in 2000 in both forest remnants and continues to the present in portions of Area II. In addition to rare species, potential matrix species, *Myoporum sandwicense* and *Santalum paniculatum*, along with the native shrub, *Sida fallax,* were planted in Area I. Outplanting data was recorded and thus reported here only for *M. sandwicense*. Successful augmentation of the populations of rare species also serve community restoration purposes.

Results by Species

Table 2. Survival of Plantings in Lowland Dry-mesic Forest.

Species	Number Planted[b]	Percent[a] Survival Early Monitoring	Percent Survival Last Monitoring)	Number Surviving 2010
AREA I (NAULU)				
Alphitonia ponderosa	19	63% (14 mos.)	0% (52-120 mos.)	0
Antidesma pulvinatum	18	100% (3 mos.)	6% (51-65 mos.)	1
Bobea timonioides	480	7% (18 mos.)	0% (60-107 mos.)	0
Canavalia hawaiiensis	31	ND	0% (67-70 mos.)	0
Erythrina sandwicensis	94	47% (14 mos.)	23% (62-77 mos.)	22
Myopoum sandwicense	191	54% (26 mos.)	40% (107 mos.)	51
Nothocestrum breviflorum	15	73% (26 mos.)	0% (62-77 mos.)	0
Nototrichium sandwicense	202	39% (21-29 mos.)	24% (83-91 mos.)	49
Pleomele hawaiiensis	51	84% (26 mos.)	88% (107 mos.)	45
Rauvolfia sandwicensis	253	90% (9-14 mos.)	10% (71-95 mos.)	25
Reynoldsia sandwicensis	220	63% (33-57 mos.)	9% (83-107 mos.)	19
Senna gaudichaudii	133	32% (18-29 mos.)	23% (80-91 mos.)	31
Tetraplasandra hawaiensis	15	ND	7% (72 mos.)	1
Xylosma hawaiiense	16	38% (18 mos.)	6% (88 mos.)	1
Subtotal	**1738**	**NA**	**14%**	**245**
AREA II (KEALAKOMO)				
Nototrichium sandwicense	97	78% (22 mos.)	3% (82 mos.)	3
Pleomele hawaiiensis	77	88% (22 mos.)	83% (82 mos.)	64
Rauvolfia sandwicensis	28	46% (20 mos.)	0% (40 mos.)	0
Reynoldsia sandwicensis	186	61% (22 mos.)	47% (82 mos.)	88
Senna gaudichaudii	95	22% (21mos.)	1% (82 mos.)	1
Xylosma hawaiiense	16	56% (17 mos.)	13% (78 mos.)	2
Subtotal	**499**	**NA**	**32%**	**158**
HOLEI PALI KUKUI GROVE				
Erythrina sandwicensis	77	75% (31 mos.)	4% (142 mos.)	3
TOTAL	**2314**	**NA**	**18%**	**406**

[a] *Counts were not included because subsets of plantings were monitored for some species.*
[b] *Number planted and monitoring. See text for additional plantings not monitored*
ND = no data

Alphitonia ponderosa Hillebr., **Kauila**
Family: Rhamnaceae (Buckthorn family)
Status: Species of Concern (Federal)

Habitat and Distribution. *Alphitonia ponderosa* is a small tree of dry and mesic forests on all the major islands except Ni`ihau and Kaho`olawe. It is rare except on Kaua`i (Wagner *et al*., 1990). Naturally occurring plants are now very rare at HAVO, consisting of scattered trees along the Great Crack. (R. Warshaurer, pers. comm.). The approximately 40 naturally occurring trees on Hōlei Pali and above Hilina Pali near Kīpuka Nēnē and the Hilina Pali Overlook (Abbott and Pratt, 1996; T. Tunison, pers. comm.) were destroyed by lava flows in the 1970s or wildfire in the 1980s and 1990. *Alphitonia ponderosa* was planted at Kīpuka Puaulu, Hilina Pali, and Kīpuka Nēnē from 1924-1957 (Morris, 1967) and in the 1970s at Kīpuka Puaulu, Kīpuka Kī, Kīpuka Nēnē, and lower `Āinahou (Zimmer, unpublished report).

Stabilization. Seeds were collected from naturally occurring trees inside the park at the Great Crack and from a single individual on the adjacent state land. Seed was also collected from the planted trees at Kīpuka Puaulu and from the single planted tree at Kīpuka Nēnē. Germination rates were low, and seedlings had a high mortality and slow growth rate in the nursery (Belfield, pers. comm.). As a consequence, only 18 seedlings were planted, all in Area I of Nāulu Forest (Table 2).

Eleven seedlings of *A. ponderosa* were planted in 2002. After 14 months seven of these plants were alive. Eight additional *A. ponderosa* seedlings were planted in 2005. No *A. ponderosa* were located in a survey of Nāulu in 2010.

Antidesma pulvinatum Hillebr., Hame
Family: Euphorbiaceae (Spurge family)
Status: Rare in HAVO

Habitat and Distribution. *Antidesma pulvinatum* is a small tree that occurs on O`ahu, Moloka`i, Maui, and Hawai`i Island in dry to mesic forest (Wagner *et al.*, 1990). On Hawai`i Island it grows in the South Kona and Ka`ū Districts. *Antidesma pulvinatum* is extremely rare at HAVO. Only one naturally occurring tree may now be present, at Nāulu on Hōlei Pali (Abbott and Pratt, 1996; L. Pratt, pers. comm.).

Stabilization. Similar to *Alphitonia ponderosa*, *Antidesma pulvinatum* has a low germination rate and high mortality in propagation. Therefore, only 18 *A. pulvinatum* were planted, all in Area I, Nāulu Forest, near the existing naturally occurring trees (Table 2). Because of the absence of seed from the *A. pulvinatum* in HAVO, seeds were collected from five trees growing in the Manukā Natural Area Reserve in South Kona. Eleven *A. pulvinatum* seedlings were planted in 2004. All 11 seedlings were alive when monitored three months later. However, the planted seedlings were defoliated by insects and leaves of the planting were also burned and discolored following vog events (T. Belfield, pers. comm.) An additional seven seedlings were planted in 2005. When Nāulu was surveyed in 2010, only one *A. pulvinatum* planting was found, a 40 cm tall plant with good vigor.

Bobea timonioides (J.D. Hook.) Hillebr., **`Ahakea**
Family: Rubiaceae (Coffee family)
Status: Species of Concern

Habitat and Distribution. *Bobea timonioides* is a tree that occurs in dry to mesic lowland forest in the Puna and Kona Districts of Hawai`i, as well as on Maui, O`ahu, and Kaua`i (Wagner *et al*., 1990). *Bobea timonioides* has become increasingly rare at HAVO in recent decades. Approximately 100 trees upslope of Kamoamoa (Warshauer, 1973) were covered by lava in the Pu`u `Ō`ō flows in 1997-1998. By the early 1990s, 21 of the 67 trees found in the early 1970s on Hōlei Pali had died and many of the remaining trees were in decline, with dead tops or branches and leaf tips burned by volcanic fumes. No natural regeneration was observed (Abbott and Pratt, 1996). Some trees persisted in mesic to wet forest above Hōlei Pali on the East Rift of Kīlauea (L. Pratt, pers. comm.)

Stabilization. Planting efforts for *B. timonioides* focused on recovery of the naturally occurring population in Area I, Nāulu Forest, the remnant stand with the largest number of remaining live trees in the park. Seeds were collected from five adult trees here in 2000 and 2002 and propagated at the HAVO nursery facility. Plantings were conducted in 2001, 2002, 2004, and 2005 totaling 480 seedlings (Table 2). A subset of 59 seedlings was monitored from the 2005 plantings. The survival rate of those seedlings was 7% over 18 months following planting (Pratt *et al*., 2011). Area I was surveyed in 2010; no *Bobea timonioides* plantings were found.

Canavalia hawaiiensis Degener, I Degener, & J. Sauer, **`Āwikiwiki**
Family: Fabaceae (Pea family)
Status: Rare in HAVO

Habitat and Distribution. *Canavalia hawaiiensis* is a large sprawling or climbing perennial vine which occurs in dry to mesic forest on Lana`i, Maui, and Hawai`i. On Hawai`i Island it is known from Hualālai, South Point, and Mauna Loa (Wagner *et al*., 1990). At HAVO, *C. hawaiiensis* is known from a naturally occurring small populations recruited after the construction of a small goat exclosure at Kūkalau`ula in the coastal lowlands and on Pūlama Pali where a number of dispersed groups of plants persist.

From 1975 to 1979, 381 *C. hawaiiensis* plants were planted at Pu`u Kaone, Pu`u Kapukapu, Hōlei Pali above Keauhou, and Halapē (Zimmer, unpublished report). A few vines were observed at Pu`u Kapukapu and Pu`u Kaone in the late 1980s when the exclosures in these areas were last monitored (Pratt, pers. comm.). *Canavalia hawaiiensis* seedlings were planted in the 2002 Kupukupu Fire area for rehabilitation purposes. After one year, 26% were alive.

Stabilization. Seeds were collected from plants on Pūlama Pali. In 2003, 31 *C. hawaiiensis* were planted in Area I of Nāulu Forest (Table 2). No monitoring was conducted until 2010 when no surviving *C. hawaiiensis* were found.

Erythrina sandwicensis Degener, **Wiliwili**
Family: Fabaceae (Pea family)
Status: Species of Concern (Federal)

Habitat and Distribution. *Erythrina sandwicensis* is a locally common tree in dry, lowland forests on all the main islands (Wagner *et al.*, 1990). The largest concentration of *E. sandwicensis* in HAVO occurred in a dry-mesic lowland *Diospyros sandwicensis* forest north of Kamoamoa. This forest was covered by lava flows from Pu`u `Ō`ō in 1997-1998, as were scattered, naturally occurring trees at Waha`ula in the early 1990s and a single naturally occurring individual on Paliuli north of Lae `Āpuki. Although no formal surveys have been conducted recently, it is thought that there are at least four naturally occurring *E. sandwicensis* extant in the park (L. Pratt, pers. comm.): a single tree at the base of Hōlei Pali below Nāulu, two to three trees near the Great Crack, and a single tree on Makahanu Pali west of the trail to Halapē. Planting records indicate 284 *E. sandwicensis* were planted in the park in the late 1970's of which a few individuals still persist at `Āpua Point and Pu`u Kaone (Zimmer, unpublished report).

The introduced Erythrina gall wasp (*Quadrastichus erythrinae),* whose rapid spread became noticeable in the state in 2005, has severe impacts on *Erythrina sandwicensis* throughout Hawai`i (HEAR website). In 2008, a biological control agent, *Eurytoma erythrinae*, was released to parasitize *Quadratichus erythrinae*. Preliminary monitoring indicates that this biocontrol agent is highly effective and *Erythrina sandwicensis* trees recover rapidly (P. Conant, pers. comm.) Although the biocontrol agent was released on Hawai`i Island in Kona and not HAVO, it is expected to disperse naturally to the park in the near future.

Stabilization. Just prior to the loss of the lowland dry-mesic forest north of Kamoamoa, seeds were collected from approximately 25 *E. sandwicensis* there and used in subsequent propagation and outplanting efforts in HAVO.

In 1998-2000, 55 *E. sandwicensis* were planted in the coastal lowlands above the coastal strand from Ka`aha to Kālu'e and on the unnamed, alien grass dominated pali above these coastal sites. Three individuals were alive in 2002; one *E. sandwicensis* was alive in 2009 at last monitoring, an individual on the pali. These data are not included in the tables for coastal strand or lowland dry-mesic forest.

In 1999, 77 *E. sandwicensis* seedlings were planted at the base of Hōlei Pali in lowland dry-mesic lowland forest environment within a dense *Aleurites molluccana* stand (Table 2). After 57 months there were 43 trees alive in late 2003, prior to the spread of the Erythrina gall wasp, in the Hawaiian Islands. In 2006, 21 trees were located; all were infected with Erythrina gall wasp (T. Belfield, pers. comm.). When monitored in 2010, only three surviving plants were found; two were infected with Erythrina gall wasp.

In 2003 and 2005, an additional 94 *E. sandwicensis* were planted in lowland dry-mesic forest at Area I, Nāulu Forest. When the plantings from 2003 were monitored 14 months later, 23 plants were alive. When Nāulu was surveyed in 2010, 22 (23%) *E. sandwicensis* were alive. Twenty were in poor or fair condition with signs of gall wasp damage. Two individuals were in good condition, without signs of gall wasp (Fig. 7). The presence of the biocontrol agent was not monitored.

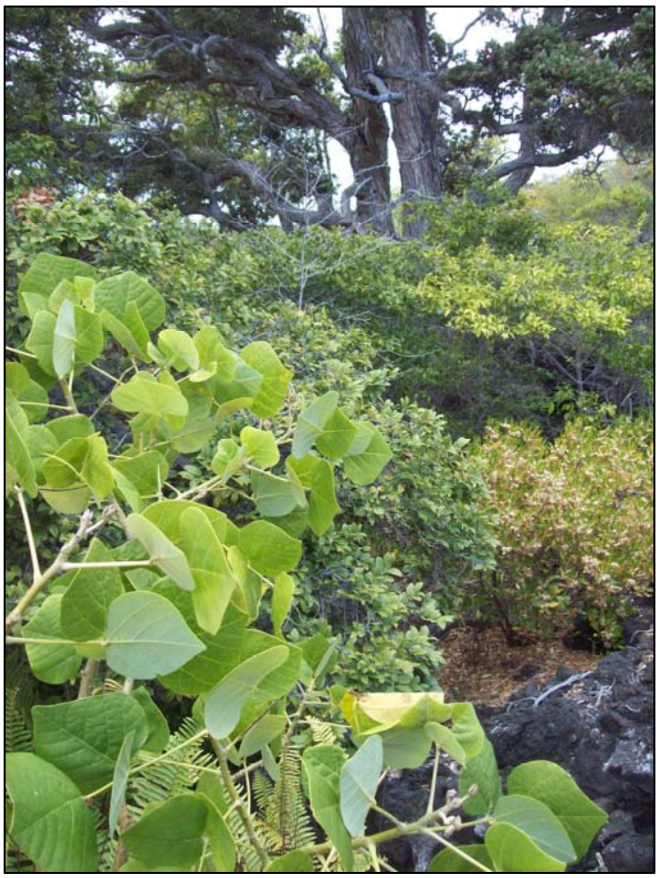

Figure 7. A planting of *Erythrina sandwicensis* (wiliwili) in dry-mesic lowland forest on the face of Hōlei Pali. This planting is vigorous with few signs of the Erythrina gall wasp, which severely infects 19 of the 22 surviving *Erythrina sandwicensis* plantings in lowland dry-mesic forest. This ecosystem is characterized by old, emergent *Metrosideros polymorpha* (\`ōhia\`a) (top right) and an open canopy of younger *Diospyros sandwicensis* (lama) (upper left and behind the *E. sandwicensis*). *Psydrax odoratum* (alahe\`e) is a locally abundant native shrub in the understory (right).

Myoporum sandwicense A. Gray, **Naio**
Family: Myoporaceae (Myoporum family)
Status: Uncommon in lowland dry-mesic forest in HAVO

Habitat and Distribution. *Myoporum sandwicense* is a shrub or small tree that grows on all the main islands except Kaho`olawe (Wagner *et al*., 1990). *Myoporum sandwicense* is ecologically and morphologically variable and is present at HAVO in many plant communities from the coastal strand to subalpine woodlands including dry, mesic, and wet forest. Although *M. sandwicense* is not a rare plant generally in HAVO, it was included in the stabilization project because of its uncommonness in lowland dry-mesic forest and because of its potential for facilitating community restoration.

There is a long history *of M. sandwicense* outplanting in the park, including Kīpuka Puaulu in the 1920s (Morris, 1967) and 1970s, lower `Āinahou, `Āinahou house, Kīpuka Nēnē, and Muliwai o Pele in the 1970s (Zimmer, unpublished report). *Myoporum sandwicense* has been included in recent post-fire restoration projects at HAVO because it is a fast-growing species that thrives in early successional environments (McDaniel *et al.,* 2009; Loh *et al*., 2007).

Stabilization. Source material for the plantings was seed taken from approximately 25 *M. sandwicensis* in the Nāulu Forest area. In 2001, 127 seedlings were planted in Area I (Table 2). After 26 months, 69 plantings were alive; after 45 months, 60 plantings were alive. In 2004, an additional 64 seedlings were planted. When all plantings were monitored in 2010, 51 (40%) plantings were found.

Nothocestrum breviflorum A Gray., **`Aiea**
Family: Solanaceae (Nightshade family)
Status: Endangered

Habitat and Distribution. *Nothocestrum breviflorum* is a dry to mesic forest tree endemic to Hawai`i Island. It occurs on the leeward side of the island from Ka`ū to Kona, including populations at Ka'ūpūlehu and Pu`uwa`awa`a (Wagner *et al.*, 1990). In HAVO it occurred historically in lowland dry-mesic forest at Nāulu and mesic forest at Kīpuka Puaulu and Kīpuka Kī (Fosberg, 1966), although naturally occurring plants may have become extinct by the 1960's in mesic forest (Mueller-Dombois and Lamoureux, 1967).

Stabilization. All plantings were propagated from seed collected of 15 founders at Pu`uwa`awa`a in the Kona District. In 2003, 15 *Nothocestrum breviflorum* were planted in Area I of Nāulu Forest (Table 2). When monitored 26 months later, 11 plantings were alive. In 2010, no surviving *N. breviflorum* were found.

Nototrichium sandwicense (A. Gray) Hillebr., **Kulu`ī**
Family: Amaranthaceae (Amaranth family)
Status: Rare in HAVO

Habitat and Distribution. *Nototrichium sandwicense* is a small tree or shrub occurring on exposed ridges and lava fields from sea level to 750 m on all the main islands (Wagner *et al.*, 1990). On Hawai`i Island it is abundant in localized populations in North and South Kona. At HAVO, *N. sandwicense* is known historically as a rare plant on Poliokeawe and Hilina Pali (Abbott and Pratt, 1996). Growing in lowland habitat with native woody plants impacted by high populations of goats, *N. sandwicense* has not been seen since 1974 and is now thought to be extirpated from the park. In the 1970s, 17 *N. sandwicense* were planted at `Āinahou and near the end of the Hilina Pali Road. All of these plantings failed (Zimmer, unpublished data).

Stabilization. *Nototrichium sandwicense* was propagated in the Resource Management nursery facility using mixed seed representing over 20 founders from naturally occurring plants at Hawaiian Ocean View Estates, the nearest known populations to the park. In 2002-2003, 202 *N. sandwicense* were planted at Area I of Nāulu Forest (Table 2). After 21-29 months, 78 of these plants were still present; after nearly seven to seven and one-half years, 49 plantings were alive. In 2003, over 10,000 seeds were broadcast at three sites in Nāulu. No seedling recruitment was observed (Belfield, pers. comm.).

At Area II of Nāulu Forest, 97 *N. sandwicense* were planted in 2003 (Table 2). After nearly two years, 76 of these plants were present. After nearly seven years, only three *N. sandwicense* plantings were found. Across all sites, the survival rate in 2010 was 17%.

Pleomele hawaiiensis Degener & I. Degener, **Hala pepe**
Family: Agavaceae (Agave family)
Status: Endangered

Habitat and Distribution. *Pleomele hawaiiensis* is a rare tree-like shrub endemic to the leeward slopes of Hawai`i Island from 300-860 m elevation (Wagner *et al.,* 1990). At HAVO, the 19-20 naturally occurring individuals of *P. hawaiiensis* are known from the Great Crack and lowland dry forest on the talus slopes of Poliokeawe and Hōlei Pali (Abbott and Pratt, 1996). The presence of a few smaller individuals at Poliokeawe Pali and Kealakomo suggest some limited natural regeneration (Abbott and Pratt, 1996)

At least 10 *P. hawaiiensis* were planted at Area I, Nāulu Forest, Great Crack, and a pali east of `Āinahou in the 1970s (Zimmer, unpublished report). Some of these plantings, derived from cuttings of naturally occurring *P. hawaiiensis* at Nāulu Forest, are still alive. The plantings at Nāulu have been observed to flower, seed, and produce long-lived seedlings (Abbott and Pratt, 1996).

Stabilization. A total of 128 individuals of *P. hawaiiensis* were planted representing 10 founder lines, which included material from the plants at the Great Crack and Kaloko and Ka'ūpūlehu, Kona. In 2001, 51 *P. hawaiiensis* were planted in Area I, Nāulu Forest (Table 2). After 26 months, 43 plantings were alive. After nearly 9 years, 45 *Pleomele sandwicensis* were found.

At two sites in Area I, natural regeneration was found near two larger, mature *P. hawaiiensis*. At one site, five seedlings less than 30 cm tall were found. At the second site there were nine untagged individuals approximately two meters in height, 2 untagged individuals 0.5-1.0 m tall, and 25 untagged seedlings less than 25 cm. tall.

At Area II (Kealakomo) 77 individuals were planted in 2003 (Table 2). After 11 months, 76 plantings were alive; after 22 and 41 months, 68 plantings were alive. At last monitoring, nearly seven years after planting, 65 *P. hawaiiensis* were alive. Two had flowered and set fruit. The survival rate across both sites in 2010 was 85% (Fig.8).

Figure 8. Three successful plantings of *Pleomele hawaiiensis* (hala pepe) in beneath a lama tree canopy in lowland dry-mesic forest. Across the two planting sites on Hōlei Pali, 85% of the 128 plantings of this species were alive after 7-9 years.

Rauvolfia sandwicensis A. DC, **Hao**
Family: Apocynaceae (Dogbane family)
Status: Rare in HAVO

Habitat and Distribution. *Rauvolfia sandwicensis* is a large shrub or small tree occurring on all the main islands except Kaho`olawe. It grows primarily in mesic forests and also in remnant dryland forest at low elevations (Wagner *et al.,* 1990). At HAVO, *R. sandwicensis* has been found in recent decades at Nāulu Forest, Poliokeawe Pali, and Waha`ula (Abbott and Pratt, 1996; Warshauer, 1974; Zimmer, unpublished report). *R. sandwicensis* does not seem to be naturally regenerating (Abbott and Pratt, 1996).

Stabilization. In 2002, 235 *R. sandwicensis* representing five founder lines from Area I of Nāulu Forest were planted in Area I (Table 2). An additional 13 individuals were planted in 2004. After 9-14 months, 227 plantings were alive. In 2010, after nearly 6-8 years, 25 plantings were alive. In 2003, 28 *R. sandwicensis* were planted in Area II (Table 2) After 20 months, 13 were alive; after 40 months, all were dead. Survivorship over both planting sites at final monitoring in 2010 was 9%.

Reynoldsia sandwicensis A. Gray, **`Ohe makai**
Family: Araliaceae (Ginseng family)
Status: Species of Concern

Habitat and Distribution. *Reynoldsia sandwicensis* is a small to medium sized tree found in dry to occasionally mesic, low elevation forest on all the main Hawaiian Islands except Ni`ihau and Kaho`olawe (Wagner *et al*., 1990). At HAVO, the largest concentration of approximately 150 trees grew in *Diospyros* forest north of Kamoamoa (Warshauer, 1973). This stand and scattered individuals in the eastern part of the park lowlands were destroyed by the Pu`u `Ō`ō lava flows, 1997-1998.

Stabilization. Plantings of *Reynoldsia sandwicensis* at HAVO represent seed from16 founder lines, including one tree from Pu`uwa`awa`a and 15 founders from Kaloko, North Kona, one of the last significant remaining populations on Hawai`i Island (Belfield, pers. comm.) From 2001-2003, 220 individuals of *R. sandwicensis* seedlings were planted in Area I of Nāulu Forest (Table 2). A total of 138 plantings were alive at 33-57 months. In 2010, 19 *R. sandwicensis* plantings were found.

In 2003, 186 seedlings of *Reynoldsia sandwicensis* were planted in Area II of Nāulu Forest (Table 2). After 22 months 114 plantings were alive; after 41 months 94 were alive. In 2010, 38 *R. sandwicensis* were alive. Across all planting sites at final monitoring, survivorship was 26% (Fig. 9).

Figure 9. A planting of *Reynoldsia sandwicensis* (`ohe makai) in lowland dry-mesic forest. The most successful plantings of this species were in Area II (Kealakomo) where 47% of the 186 plantings were alive after 7 years. Although not quantified, the most productive microsite seemed to be in ash pockets on `ā`ā flows, in the shade of trees or shrubs, and away from alien shrubs, ferns, and grasses.

Senna gaudichaudii (Hook. & Arnott) H. Irwin & Barneby, **Kolomona**
Family: Fabaceae (Pea family)
Status: Rare in HAVO

Habitat and Distribution. *Senna gaudichaudii* is found in dry coastal lowlands of all the islands except Ni`ihau and Kaho`olawe (Wagner *et al*., 1990). At HAVO, it was present in *Diospyros* forest in the coastal lowlands north of Kamoamoa. This site was covered by lava in the late 1990s. Naturally occurring *S. gaudichaudii* is now known from only Nāulu Forest where a single individual was located during survey work in the 1990s (Abbott and Pratt, 1996).

Stabilization. Seeds were collected from 10 naturally occurring founder *S. gaudichaudii* at Ka'ūpūlehu, Kona. In 2002 and 2003, 133 *S. gaudichaudii* were planted at Area I, Nāulu Forest (Table 2). When monitored after 18 or 29 months, 43 were alive; one third of the remaining plants were flowering or fruiting. When monitored in 2010 after six and one-half to seven and one-half years, 31 plants were surviving.

In 2003, 95 *S. gaudichaudii* were planted in Area II of Nāulu Forest (Table 2). After 21 months, 21 were alive; all were flowering or fruiting. After 41 months, 11 plants persisted. In 2010 after six and one-half years, only one live *S. gaudichaudii* plant was found. The survival rare at last monitored, collected for both sites, was 14%.

Tetraplasandra hawaiensis A Gray, **`Ohe Mauka**
Family: Araliaceae (Ginseng family)
Status: Rare in HAVO

Habitat and Distribution. *Tetraplasandra hawaiensis* is a large tree that occurs in mesic to wet forest on Moloka`i, Lāna`i, Maui, and Hawai`i (Wagner *et al.*, 1990). At HAVO, *T. hawaiensis* is known from `Ōla`a Forest, East Rift forests, and Kahuku. The largest concentration of *T. hawaiensis* occurs in the East Rift. However, many *T. hawaiensis* have been covered by the Mauna Ulu and Pu`u Ō`ō lava flows or destroyed by associated fires. During the Kupukupu fire of 2002 seed was collected from several *T. hawaiensis* trees on the East Rift in the vicinity of the fire. In post-fire restoration, 199 seedlings propagated from these seeds were planted with 49% survivorship after one year (McDaniel *et al.*, 2008).

Stabilization. In 2004, 15 seedlings from the same source material in nearby mesic forest were planted at Area I (Table 2). When monitored in 2010, just one survivor was found.

Xylosma hawaiiense Seem., **Maua**
Family: Flacourtiaceae (Flourcourtia family)
Status: Rare in lowland dry-mesic forest

Habitat and Distribution. *Xylosma hawaiiense* is a small to medium sized tree found on all the main Hawaiian Islands except Ni`ihau and Kaho`olawe (Wagner *et al.*, 1990). It occurs primarily in mesic forest but also known from dry and wet forest. In HAVO it occurs as widely scattered trees in the wet forest of `Ōla`a (Pratt and Abbott, 19967) and in the montane mesic forest of Kīpuka Puaulu. It is rare in dry forest, known only from six trees on Hōlei and Poliokeawe Pali and vicinity (Abbott and Pratt, 1996).

Stabilization. Because fruit with viable seed did not seem to be available from park trees (Belfield, pers. comm.), fruit was collected from two trees at Ka'ūpūlehu and a single tree at Pu`uwa`awa`a.

Sixteen *Xylosma hawaiiense* were planted each at Nāulu Forest, Area I and Area II (Table 2). At Area I, six plantings were alive after 18 months, and one was alive at six and one-half years. At Area II, 9 plantings were alive after 17 months, five plantings after 37 months, and two plantings after the last monitoring at six and one-half years. Survivorship at last monitoring across both sites was 9%.

Discussion

Stabilization of rare plant species was modestly successful in lowland dry-mesic forest. Eighteen percent of the plantings were surviving after the 5-9 year monitoring time-frame of the project (Table 2). Even when the one matrix species, *Myoporum sandwicense*, is excluded from the calculation, the survivorship of the 13 target species averaged 16%. Survival of one species, *Pleomele hawaiiensis*, was highly successful; 85% of the plantings survived with flowering and fruiting found on a few plants. Numerous seedlings were found around two large, mature plants, extant in the kīpuka prior to the current planting efforts.

The average survivorship (32%) over all species planted in Area II was more than double the average survivorship (14%) in Area I, in spite of the successful establishment of large numbers of plantings of the matrix species *Myoporum sandwicense* in Area I. The higher survivorship in Area II is attributable to successful plantings of two intensively planted species, *Pleomele hawaiiensis* and *Reynoldsia sandwicensis*. The survival rate of the four other species planted in Area II, *Nototrichium sandwicense*, *Rauvolfia sandwicensis*, *Senna gaudichaudii*, and *Xylosma hawaiiense,* was collectively less than 1%. The nearly complete failure of nearly 500 plantings of *Bobea timonioides* in Area I partly accounts for the lower overall survivorship of Area I. The complete or nearly complete failure of plantings of *Alphitonia ponderosa*, *Antidesma pulvinatum*, *Canavalia hawaiiensis*, *Nothocestrum breviflorum*, *Tetraplasandra hawaiensis*, and *Xylosma hawaiiense,* along with low survival of *Reynoldsia sandwicensis*, also account for lower overall survivorship in Area I.

The higher mortality among the Area I rare species plantings may be partly due to substrate. Many of the plantings in Area I were placed in a pāhoehoe substrate on the west side of the kīpuka (T. Belfield, pers. comm.). This substrate has thin soil and little accumulation of organic matter. The thin soil over pāhoehoe may become drier in extended periods with little rain. In contrast, the \`ā\`ā substrate in the east part of Area I and much of Area II seems to have accumulate some ash soil and certainly organic matter between the clinkers.

In Area 1, the very low survivorship of *Alphitonia ponderosa*, *Antidesma pulvinatum*, *Nothocestrum breviflorum*, *Tetraplasandra hawaiensis*, and *Xylosma hawaiiense* occurred in a context of very low numbers of plantings. Smaller populations such as these vulnerable to extinction form chance environmental stressors. There might be greater survivorship with additional, higher numbers of plantings and greater utilization of Kealakomo as a planting site.

Curiously, some species had higher survivorship in one of the two planting sites in no consistent pattern. For example, survivorship of *Nototrichium sandwicense*

(24%) and *Senna gaudichaudii* (23%) was higher than their survivorship in Area II, 0% and 3% respectively. Conversely, survivorship of *Reynoldsia sandwicensis* was higher in Area II (47%) than Area I (9%). These patterns may suggest that greater success may be expected with future plantings in the same sites.

Some mortality of plantings may be expected from the more xeric conditions in the forest remnants brought about by fragmentation of the forest habitat. This resulted from the Mauna Ulu lava flows in 1970-1973. These flows dissected Nāulu Forest and created a much more extensive forest edge environment. This exposed the forest margin to strong, drying winds blowing across dark, warm, sparsely vegetated lava flows. As a result, there are now increased levels of light and reduced moisture, certainly on the margins of the kīpuka. The current lowland forest sites may be more xeric than the habitats in which many of the extant rare species, e.g. *Bobea timonioides* and *Antidesma pulvinatum* became established.

Limiting factors were studied and partly determined for one species in Nāulu Forest, *Bobea timonioides* (Pratt *et al*., 2011.). The stabilization, planting program for this species was the least successful of the 13 target rare species in the lowland dry-mesic forest: no surviving plantings were found of the 480 seedlings planted. Stand structure analysis and observation of mortality in adult trees indicate that this species has a senescing, declining population with no regeneration, probably for decades. Fruit and viable seeds are produced and rodents are not seed predators of *B. timonioides*. The lack of success of planted seedlings suggests that environmental factors, possibly soil moisture, may be a factor in the lack of regeneration of *Bobea timonioides* (Pratt *et al*., 2011). This species is growing near the xeric end of its ecological range in Nāulu Forest. It is also found in the park in mesic and wet forest on the East Rift of Kīlauea. It may have become established when this site was less fragmented and more mesic (L. Pratt., pers. comm.). Continued plantings should focus on more mesic sites than Nāulu Forest, or at least until community restoration makes Nāulu Forest a more mesic environment. A similar recommendation can be made for *Tetraplasandra hawaiensis*, whose founders grew in mesic *Metrosideros polymorpha* forest to the east and at higher elevation than Nāulu Forest.

The development of dense stands of invasive ferns, shrubs, and grasses may also partly account for declining populations of extant species and lower survivorship of plantings. The low, alien shrub, *Lantana camara*, grows in sparse to dense stands, especially in high light understory sites. Finally, a suite of alien grasses occupy canopy gaps and edges in Nāulu Forest. The invasive fern *Nephrolepis multiflora* forms dense understory stands in some areas, in shadier environments than *Lantana camara* and alien grasses. The invasive species, especially the ferns and grasses undoubtedly restrict native plant species regeneration and establishment because they form thick mats on the forest floor. *Nephrolepis multiflora*, *L. camara*, and alien grasses should not only be controlled in forest understory, but also in gaps and the forest margin to allow for forest establishment in those areas.

Natural recruitment of common and rare plant species, as well as survivorship of plantings will undoubtedly be higher following implementation of an intensive community restoration program, including both invasive species control and planting of matrix understory plants. Nāulu Forest is a Special Ecological Area to be managed intensively. Control of invasive alien plants was initiated in 2000 in both Area I and Area II. Control efforts were discontinued in Area I in 2003, but continue to the present at least in portions of Area II.

Effective, long-term control of invasive shrubs, ferns, and grasses is logistically and ecologically challenging. Water for herbicide use must be transported to the site and the terrain is steep and rocky with extensive `ā`ā substrate. Long-term removal of invasive plants is confounded by the open nature of the canopy, the slow growth rates of most native woody species, and large populations of weedy species in the vicinity and in the soil seed bank. Herbicidal treatments of invasive species are not resulting in rapid recovery of a native plant canopy to inhibit the establishment of invasive understory species.

Developing a restoration plan integrating the controlling of weeds and planting of matrix species and rare species should be considered. This plan should also address infrastructure to deliver water for herbicidal control of invasive planting and the nurturing of native species plantings. Dense plantings of *Dodonaea viscosa* could be considered in sites after invasive plants are controlled. Planting of *D. viscosa* at high density has have been effective in early stages of restoration of lowland dry forest on Maui (A. Medeiros, pers. comm., Medeiros and vonAllen, 2005). The *Dodonaea viscosa* plantings suppressed the reestablishment of invasive grasses, facilitated the natural recovery of native woody species from the seed bank, and provided habitat for additional native species plantings. The planting of the prostrate form of *Osteomeles anthyllidifolia,* found in the nearby coastal areas, could also be considered. This form of *O. anthyllidifolia* is highly effective in suppressing alien grasses in the nearby coastal areas. Additional plantings of the small, bushy tree, *Myoporum sandwicense,* should be expanded. Nearly four of out 10 of these plantings survived, many developing into vigorous, bushy shrubs or small trees, averaging two meters in height after 8-9 years. A community restoration plan involving natural recovery and plantings of understory species may also help mitigate the effects of fragmentation and help increase soil moisture, reduce wind speeds, and shield seedlings and saplings of native species from vog effects.

Although the plantings and the survival rate of *Santalum paniculatum* and *Sida fallax* were not quantified, vigorous planted individuals were conspicuous components of the understory. These species, because of their more open growth form, probably cannot contribute as much as *Dodonaea, Osteomeles*, and *Myoporum sandwicense* to community restoration, at least to invasive species suppression. A few naturally occurring individuals of the small tree, *Sophora chrysophylla*, were growing near the upper margin of Area I, Nāulu Forest. Undoubtedly these were a component of the forest prior to the presence of feral goats and are recovering now that these feral ungulates are no longer present. Plantings of *Sophora chrysophylla* would expedite the recovery of this native tree as a matrix species and reintroduce it to Area II.

MID-ELEVATION WOODLAND

Study Area and Methods

The mid-elevation woodland ecosystem lies in the extensive leeward areas of Hawai`i Volcanoes National Park from the tops of Hilina Pali and Poliokeawe Pali to the eastern edge of Kīlauea Caldera. It transitions into rain forest, just east of the upper Chain of Craters Road. It include the Ka`ū Desert, the Hilina Pali Road area, the `Āinahou Ranch area, and the mosaic of recent lava flows and kīpuka to the east of Āinahou. This ecological zone of the park has also been called the seasonal submontane (Doty and Mueller-Dombois, 1966).

The mid-elevation woodland is beyond the reach of much of the rainfall supplied by the nearly daily trade wind showers experienced by the more windward rain forest areas. At the eastern transition from mid-elevation woodland to rain forest the average annual rainfall is approximately 2,000 mm per year. Rainfall amounts decline further leeward toward Hilina Pali and toward the western park boundary. The average rainfall from 2000-2009 at Kīpuka Nēnē, near the center of the mid-elevation woodland and scrub, is 1,200 mm per year (HAVO Fire Cache, unpublished data). Summers tend to be the driest season (Doty and Mueller-Dombois, 1966).

The lower rainfall and younger lava flows of the Ka`ū Desert in the western portion of the mid-elevation woodland favor shorter, more dispersed scrub vegetation. Scrub vegetation is characterized by short, scattered *Metrosideros* (`ōhi`a) trees, typically with a clustering at the base of native shrubs and herbaceous plants including *Leptecophylla tameiameiae* (pūkiawe), *Dodonaea viscosa* (`a`ali`i), *Osteomeles anthyllidifolia* (`ūlei), *Wikstroemia* spp. (`akia), *Morelotia ghaniiformis*, and *Dianella sandwicensis* (`uki`uki). The areas between the small islands of native vegetation are generally sparsely vegetated.

The older substrates and higher rainfall of the area between upper Hilina Pali Road and `Āinahou Ranch house to the transition with rain forest support taller, denser, woodland vegetation. These woodlands are dominated by open stands of *Metrosideros polymorpha* in discontinuous understory stands of largely the same native shrubs and herbs found in the mid-elevation *Metrosideros* scrub. Native understory plants persist in a matrix of alien grasses, including *Schizachrium condensatum* (beardgrass)*, Andropogon virginicus* (broomsedge) (Mueller-Dombois and Fosberg, 1974), and now increasingly *Melinis minutiflora* (molasses grass) (D`Antonio *et a*l., 1998). These grasses invaded the park in the 1960s. Mid-elevation woodland was widely invaded by the nitrogen-fixing alien tree *Morella faya* (faya tree) in the 1970s (Camrath *et al*, unpublished report).

Mid-elevation *Metrosideros* dominated woodland and scrub also occurs adjacent to each other in a mosaic or gradient pattern with woodland favored in sites with more extensive and deeper ash soil. Mosaics of woodland and scrub are evident along portions of Hilina Pali Road and the western park boundary with Kapāpala

Ranch. For the purposes of this report, both scrub and woodland are referred to as mid-elevation woodland.

Invasive species have highly altered the composition of most of the mid-elevation woodland in the park and degraded habitat for rare plant species. The invasive grasses are fire-promoting species that have altered the natural low frequency fire regime of the mid-elevation woodland. Fire frequency has increased three-fold and fire size over 60-fold (Tunison *et al.,* 2001) since their introduction in the 1960s, converting many woodlands into savannas dominated by alien grass, particularly *Melinis minutiflora* (molasses grass), with little regeneration of native trees and shrubs (Hughes *et al*., 1991). *Morella faya* now forms dense or continuous stands in the understory of many areas of the mid-elevation woodland, especially in the higher elevation transition to rain forest, displacing native understory species (Tunison *et al*., unpublished report).

Rare plant management, including stabilization efforts, is carried out in the context of strategies to address invasive species and fire impacts in the mid-elevation woodland and scrub. The park's main strategy for controlling invasive plants such as *Morella faya* and *Grevillea robusta* (silk oak) is to focus control efforts in the most intact, manageable, and biologically diverse sites or Special Ecological Areas (Tunison and Stone, 1992).

Invasive grasses cannot be feasibly controlled manually, mechanically, or chemically, even in small areas (D`Antonio *et al*., 1998). However, HAVO Resource Managers are developing a strategy to restore native woodlands in the mid-elevation woodland zone altered by invasive species and fire. The goal in the woodland is to establish fire-tolerant native trees and shrubs that are appropriate to this ecosystem and that can recover after the inevitable fires and spread in alien grass dominated savannas (Tunison *et al.*, 2001). This is done by rehabilitating areas burned by wildfires or prescription through plantings and seed additions of fire-tolerant, common species such as *Sophora chrysophylla* (māmane), *Dodonaea viscosa* (`a`ali`i), *Santalum paniculatum* (iliahi), *Osteomeles anthyllidifolia* (`ūlei), and other species that can recover after fire in spite of the rapid recovery of invasive grasses.

One of the main constraints of a restoration program involving extensive or intensive planting and seed additions of native plants, some of which are uncommon or rare, is the limited availability of propagules for propagation purposes. To this end, funding was secured to develop seed orchards of restoration species whose seed or cuttings were needed in rehabilitation and restoration projects. Six seed orchard sites were developed for planting along or near the Hilina Pali Road. Two of these sites were located in grassy areas subject to wildlife and were characterized as fire-tolerant sites. Most plantings in the fire-tolerant sites were common or uncommon species with known fire tolerance. Also, included were rare plants targeted for stabilization with known or suspected fire-tolerance or ability to compete with invasive grasses. These included *Bidens hawaiensis* (ko`oko`olau), *Canavalia hawaiiensis* (`āwikiwiki), *Chamaesyce celastroides* (`akoko), *Erythrina sandwicensis* (wiliwili), *Pittosporum* *terminalioides* (hōʻawa*), Rhus sandwicensis* (neneleau*)*, *Scaevola Kīlaueae* (huahehili uka), and *Senna gaudichaudii* (kolomona) (Table 3).

Four additional seed orchard sites were located in isolated kīpukas not subject to wildfire and were thus characterized as fire-safe sites. Competition from invasive grasses was minimal in these sites. The following rare plant species were planted in these sites: *Bidens hawaiiensis*, *Canavalia hawaiiensis*, *Erythrina sandwicensis, Myrsine lanaiensis* (kōlea*)*, *Neraudia ovata*, *Nototrichium sandwicensis* (kuluʻī), *Portulaca sclerocarpa (`ihi mākole)*, *Pittosporum glabrum* (hōʻawa), *Rhus sandwicensis* (neneleau), *Senna gaudichaudii* (kolomona), and *Sesbania tomentosa* (`ohai).

Most of the plantings of rare plants in the fire-tolerant sites were carried out from February to April, 2007, with some plantings in 2006. These plantings were monitored one time, November, 2009. The plantings of rare plants in the fire-safe sites were mostly carried out from February, 2006 through June, 2006, with a few plants placed in 2007 and 2008. All the plantings in the fire-safe sites were monitored October, 2008 and for a final time, May, 2010.

The 16 rare species targeted for stabilization in the mid-elevation woodland and scrub include eight listed species: four endangered species (*Portulaca sclerocarpa, Neraudia ovata, Sesbania tomentosa, and Spermolepis hawaiiensis*) and four species of concern (*Bidens hawaiensis, Erythrina sandwicensis*, *Exocarpos gaudichaudii* (hulumoa) and *Scaevola Kīlaueae*. While not listed, *Canavalia hawaiiensis*, *Chamaesyce celastroides*, *Myrsine lanaiensis*, *Nototrichium sandwicensis, Pittosporum glabrum*, *Pittosporum terminalioides*, *Rhus sandwicensis*, and *Senna gaudichaudii* are either rare or uncommon in HAVO, or are extirpated from the park.

Results by Species

Table 3. Survival of Plantings in Mid-elevation Woodland

Species	Number Planted[b]	Percent[a] Survival Early Monitoring	Percent Survival Last Monitoring	Number Survivors 2009-2010
Fire-Safe Sites				
Bidens hawaiensis	239	84% (29 mos.)	64% (48 mos.)	153
Canavalia hawaiiensis	158	44% (28 mos.)	<1% (47 mos.)	1
Myrsine lanaiensis	284	62% (18 mos)	33% (37 mos.)	94
Neraudia ovata	116	84% (32 mos.)	2% (45 mos.)	2
Nototrichium sandwicense	138	74% (32 mos.)	0% (51 mos)	0
Pittosporum glabrum	19	95% (19 mos.)	37% (38 mos.)	7
Portulaca sclerocarpa				
Planted 7/2006	71	94% (28 mos.)	68% (45 mos.)	48
Planted 3/2008	77	100% (7 mos.)	73% (25 mos.)	56
Rhus sandwicensis	83	30% (30 mos.)	7% (49 mos.)	6
Senna gaudichaudii	12	8% (31 mos.)	17% (50 mos.)	2
Sesbania tomentosa	177	37% (32 mos.)	13% (25-51 mos.)	23
Subtotal	**1374**	**NA**	**29%**	**392**
Fire-Tolerant Sites				
Bidens hawaiensis	460	24% (32 mos.)	NA[c]	112
Canavalia hawaiiensis	129	9% (32 mos)	NA[c]	11
Chamaesyce celastroides	180	18% (32 mos.)	NA[c]	32
Erythrina sandwicensis	18	0% (mos.)	NA[c]	0
Pittosporum terninalioides	89	4% 32 mos.)	NA[c]	4
Rhus sandwicensis	675	16% (38-50 mos.)	NA[c]	111
Scaevola kilaueae	26	15% (32 mos.)	NA[c]	4
Senna gaudichaudii	262	0% (46-50 mos.)	NA[c]	0
Subtotal	**1839**	**NA**	**15%**	**274**
Other Sites				
Neraudia ovata	109	88% (9-19 mos.)	43% (60-72 mos.)	47
Portulaca sclerocarpa				
Kalanaokuaiki	483	3% (51 mos.)	0% (140 mos.)	0
Footprints	500	10% (42 mos.)	0% (131) mos.)	0
Crater Rim Trail	455	91% (20-22 mos.)	0% (72-74 mos.)	0
Observatory	504	90% (14 mos.)	<1% (71 mos.)	1
Subtotal	**2051**		**2%**	**48**
Total	**5264**	**NA**	**14%**	**714**

[a] Percent survivorship is presented for early monitoring because subsets of plantings monitored for some species

[b] Number planted and monitoring. See text for additional plantings not monitored

[c] Fire-tolerant sites monitored just once, in 2009

Bidens hawaiensis A. Gray. **Ko`oko`olau**
Family: Asteraceae (Sunflower family)
Status: Species of Concern (State)

Habitat and Distribution. *Bidens hawaiensis* is an erect shrubby, perennial herb found from 600-1,400 m elevation in three disjunct locations on Hawai`i Island: Kohala, Puna, and Kīlauea (Wagner *et al*., 1990). At HAVO, it is known formerly from mid-elevation woodland near Kīpuka Puaulu, Ko`oko`olau Crater (Degener, 1975), and `Āinahou (Fosberg, 1966). It has been successful planted in mid-elevation woodland in low numbers at `Āinahou, upper Hilina Pali Road, and Kīpuka Nēnē (Zimmer, unpublished report). Although not an especially strong fire-tolerant species, the potential of this rare subshrub as a rehabilitation species was demonstrated by significant recruitment from seed in controlled post-burn environments (Loh *et al.* 2009) and high one year survivorship of plantings and seedlings recruited from seed additions in the mesic *Metrosideros* woodlands in the Broomsedge fire (Loh *et al*., 2007) and the Kupukupu Fire (McDaniel *et al*., 2008). Short-term survival in burn rehabilitation sites was high.

Stabilization. *Bidens hawaiensis* was planted in both fire-tolerant and fire-safe sites along Hilina Pali Road. In the fire-tolerant sites, 460 individuals were planted (Table 3). After 32 months, 112 (24%) individuals were surviving. In the fire-safe sites, *B. hawaiensis*, 239 individuals were planted. After 29 months, 201 plantings were alive; after four years, 153 plantings were alive (Fig. 10). Survivorship at last monitoring was 64%.

Figure 10. *Bidens hawaiensis* (ko`oko`olau) (mid-foreground) in mid-elevation woodland. Sixty-four percent of the 239 *B. hawaiiensis* planted in the four fire-safe sites such as the example above were surviving after four years. Eighty percent of the surviving plants had set fruit, although no seedling recruitment was observed. The plantings are growing in an ash pocket at the base of a tumulus. In the mid-elevation woodland, larger, more closely spaced *Metrosideros polymorpha* (`ōhi`a) trees are found in deeper ash pockets. Plantings of *B. hawaiiensis* had the highest survivorship and frequency of fruiting of the 16 species planted in the mid-elevation woodland.

Canavalia hawaiiensis Degener, I Degener, & J. Sauer, **`Āwikiwiki**
Family: Fabaceae (Pea family)
Status: Rare in HAVO

Habitat and Distribution. *Canavalia hawaiiensis* is a large sprawling/climbing perennial vine that occurs in dry to mesic forest on Lana`i, Maui, and Hawai`i. On Hawai`i Island it is known from Hualālai, South Point, and Mauna Loa (Wagner *et al*., 1990). In HAVO, C. *hawaiiensis* is growing naturally in dry grasslands of Kukalau`ula below Hilina Pali west of Pepeiao and in more mesic environments on Pūlama Pali to the east of the mid-elevation woodlands and scrub. The potential of *C. hawaiiensis* as a post-fire rehabilitation species was suggested by modest survivorship (49% after one year) (McDaniel *et al*., 2008), following planting in the 2002 Kupukupu Fire area, in mesic *Metrosideros* woodland and forest just windward of the mid-elevation woodlands.

Stabilization. Seed for all of the *Canavalia hawaiiensis* plantings in lowland dry-mesic forest was derived from vines on Pūlama Pali in the park. In 2006, 129 *C. hawaiiensis* were planted along Hilina Pali Road in fire-tolerant sites as part of the seed orchard project (Table 3). When monitored after two and one-half years, 11 plantings were alive. In fire-safe sites, 158 individuals were planted. After two and one-half years, 70 plants were surviving; after nearly four years, only one 10 cm long planting with poor vigor was found. Numerous dead vines were observed.

Chamaesyce celastroides (Boiss.) Crozat & Degener **`Akoko**
Family: Euphorbiaceae (Spurge family)
Status: Uncommon in HAVO

Habitat and Distribution. *Chamaesyce celastroides* is an uncommon shrub or small tree found in coastal environments and mesic forest on all the main Hawaiian Islands (Wagner *et al.*, 1990). At HAVO, it is a low growing shrub found sparingly in mid-elevation woodland in the `Āinahou area. It has also been observed in the coastal lowlands near the Kalapana Trail in an area probably now covered by lava (L. Pratt, pers. comm.). A small sample of *C. celastroides* plantings had very high survivorship (92%) after one year following planting in the 2002 Kupukupu Fire (McDaniel *et al.*, 2008).

Stabilization. A total of 180 *Chamaesyce celastroides* were planted in two fire-tolerant sites along Hilina Pali Road. After 32 months, 32 plantings (18%) were alive.

Erythrina sandwicensis Degener, **Wiliwili**
Family: Fabaceae (Pea family)
Status: Species of Concern (Federal)

Habitat and Distribution. *Erythrina sandwicensis* is a locally common tree in dry, lowland forests on all the main islands (Wagner *et al.*, 1990). The largest concentration of *E. sandwicensis* in the park north of Kamoamoa was covered by lava in 1997-1998. Only four naturally occurring trees are thought now to occur in HAVO in the coastal lowlands and lower fringe of the mid-elevation woodlands and scrub (L. Pratt, pers.comm.).

Stabilization. Just prior to the loss of the dry lowland forest north of Kamoamoa, seeds were collected from approximately 25 *E. sandwicensis* as founders. In 2007, 18 *E. sandwicensis* were planted in a fire-tolerant site near the lower end of Hilina Pali Road (Table 3). When monitored in 2009, no surviving plants were found.

Exocarpos gaudichaudii A. DC, **Hulumoa**
Family: Santalaceae (Sandalwood family)
Status: Species of Concern

Habitat and Distribution. *Exocarpos gaudichaudii* is a hemiparasitic small tree or shrub occurring between 250 and 1,550 m elevations on all the main Hawaiian Islands except Kaua`i. This species is rare on Hawai`i Island (Wagner *et al.*, 1990). At HAVO, three individuals are known from two nearby sites at 850 m elevation near the `Āinahou Ranch area. They occur in mid-elevation woodland with native shrubs and abundant alien grass including increasing cover of molasses grass (*Melinis minutiflora*).

Stabilization. Seeds of *E. gaudichaudii* were collected from the plants at `Āinahou. Germination was not achieved so no seedlings were planted.

Myrsine lanaiensis Hillebr., **Kōlea**
Family: Myrsineaceae (Myrsine Family)
Status: Rare in HAVO

Habitat and distribution. *Myrsine lanaiensis* is a small tree that occurs in leeward dry forest and sometimes mesic forest on all the main islands except Kahoʻolawe and Niʻihau (Wagner *et al.,* 1990). In HAVO just one small root-sprouting cluster of trees is found in mid-elevation woodland at approximately 850 m elevation in lower ʻAinahou, along with other rare woody plants such as *Exocarpos gaudichaudii* and *Pittosporum terminalioides. M. lanaiensis* was identified as a potential fire tolerant species because of a relatively high germination of oven-heated seeds (Loh *et al.*, 2009); it is also able to resprout from the roots after fire.

Stabilization. Seed was collected from an unknown number of founders at Puʻuwaʻawaʻa. In 2007**,** 284 seedlings of *M. lanaiensis* were planted in four fire-safe, mid-elevation woodland sites along Hilina Pali Road (Table 3). After 18 months, 176 individuals were (62%) were alive; after 37 months, 94 (33%) were found to be surviving (Fig. 11).

Figure 11. Planting of *Myrsine lanaiensis* (kōlea) (center of photo) in mid-elevation woodland. The planting was placed in an ash pocket at the base of the pāhoehoe tumulus. *M. lanaiensis* was one of the most successful plantings in the mid-elevation woodland; 33% of the 284 planting were alive when last monitored after 37 months.

Neraudia ovata Gaud., **Maʻaloa**
Family: Urticaceae (Nettle family)
Status: Endangered

Habitat and Distribution. *Neraudia ovata* is a sprawling shrub endemic to the leeward slopes of Hawai`i Island between 300 and 1,450 m elevation (Wagner *et al*., 1990). It is currently restricted to six naturally occurring populations in North and South Kona and Pōhakuloa Training Area. It was historically present at HAVO near the park boundary near Halfway House at approximately 900 m elevation (Fosberg, 1966).

Stabilization. Plantings were derived from cuttings of 13 founders, including both male and female plants, collected at Pōhakuloa Training Area. One hundred forty-six *N. ovata* individuals were planted in multiple sessions along the park boundary with Kapāpala Ranch in a site near Halfway House and another site near Peter Lee Road (Table 3). These sites were small kīpuka of *Metrosideros polymorpha* and shorter *Sophora chrysophylla* above a dense native shrub understory, located within *Metrosideros* scrub on `ā`ā. The kīpuka appeared to be the edges of deep ash substrate covered by a think layer of rocks on the edge of the Keamoku `ā`a flow. At 9-19 months, 88% of these plantings were alive. Planting sites for only 109 plants were located with confidence when monitored in 2010. After 60-72 months, 47 (43%) of the monitored plantings were alive. The vigor of only two of these plants was characterized as good; the rest were rated as fair or poor. During early monitoring, flowering was observed on both male and female plants, and fruit on some female plants at the Halfway House and Kīpuka Kī sites. No natural regeneration was observed at any site.

In 2006, 116 *N. ovata* were planted in fire-safe sites. After 32 months, 97 plantings were alive; only two plants were found in 2010 after nearly four years. Plantings in Kīpuka Kī are reported in the section of the technical report on montane mesic forest.

Portulaca sclerocarpa A. Gray, **`Ihi mākole**
Family: Portulacaceae (Purslane family)
Status: Endangered

Habitat and Distribution. *Portulaca sclerocarpa* is a prostrate, succulent, short-lived perennial herb found only on Hawai`i Island and an islet off the coast of Lāna`i (Wagner *et al.*,1 990). It typically grows in dry, open habitats from 1,030-1,630 m elevations. In HAVO, the largest known population is from the Puhimau hydrothermal area also called the "Puhimau Hotspot." *P. sclerocarpa* grows here in the sparsely vegetated, warm soil. The population of *P. sclerocarpa* decreased sharply from about 4,000 to less than 1,000 plants between 1984 and 1994, (Pratt *et al*, 2011). A survey in 2007 revealed only about 300 plants (Pratt *et al*., 2011) There is a much smaller park population in sparsely vegetated cinder near Keanakako`i Crater. *P. sclerocarpa* was also known historically from dry *Metrosideros* scrub in the Ka`ū Desert at the Footprints area and dry *Metrosideros* woodland near Ko`oko`olau Crater and upper Hilina Pali Road below KulanaokuaiKī Pali.

Stabilization. Between 1998 and 2006, over 2,500 individuals of *P. sclerocarpa* were planted near historically known sites in the mid-elevation woodland (Table 3). All plantings were derived from founder lines belonging to the natural population at Puhimau hydrothermal area in HAVO and were propagated exclusively from cuttings except for some seedlings in the fire-safe sites along Hilina Pali Road.

Survivorship was high after 1-2 years, but declined sharply by four years, except in the Hilina Pali Road sites. In 1998, 483 *P. sclerocarpa* were planted at the base and on the top of Kulanaokuaiki Pali east of Hilina Pali Road. After nine months, 437 were alive, with many plants flowering; after 27 months 223 plants were alive; after 51 months, 16 plants were alive. When monitored for a final time after nearly 12 years, no surviving plants were found. In 1999, 500 cuttings were planted north of the Mauna Iki Trail between Highway 11 and Footprints in mid-elevation scrub. After 11 months, 326 plantings were alive; after 42 months, 52 plantings were alive. When monitored for a final time after nearly 11 years, no surviving plants were found. In 2004, 455 cuttings were planted near the Crater Rim Trail just west of Chain of Craters Road in closed, mesic *Metrosideros* forest with a native shrub understory The soil was deep cinder from the 1959 Pu`u Puai eruption. When monitored after 10 months, 412 plantings were alive; after six years, no surviving plants were found. Also in 2004, 504 cutting of *P. sclerocarpa* were planted one kilometer southwest of the Hawaiian Volcano

Observatory. After 10 months, 473 plants were alive; after six years, only one surviving plant was located.

Two cohorts of plantings were made at three fire-safe sites along Hilina Pali Road. Many of these were seedlings, rather than cuttings. In 2006, 71 plantings were made across all three sites. After two years, 67 were still alive; after nearly four years, 45 plants were alive. In 2008, 77 plantings were made in two of the sites. After seven months, all were alive; after two years, 56 were alive.

Seedling recruitment was observed at Kulanaokuaiki and Footprints. However, the seedlings did not persist.

Rhus sandwicensis A. Gray, **Neneleau**
Family: Anacardiaceae (Mango family)
Status: Rare in HAVO

Habitat and Distribution. *Rhus sandwicensis* is a root-suckering shrub or small tree growing typically in disturbed, open areas at a few locations on Kaua`i, O`ahu, Moloka`i, Maui, and Hawai`i Island, where it is the most abundant (Wagner *et al.,* 1990). In HAVO, *R. sandwicensis* is rare, known from a small number of plants in two populations near the upper Kalapana Trail at approximately 750 m elevation. Because of its root-sprouting tendencies, *R. sandwicensis* was evaluated as a potential fire-tolerant species for post-burn rehabilitation purposes. *Rhus sandwicensis* was planted in the 2002 Kupukupu Fire area. After one year, 71% of the subset of plantings monitored were alive (McDaniel *et al*., 2008).

Stabilization. Seeds were collected from a mix of approximately 75 founders on the Hāmākua Coast**.** In 2005-2006, *R. sandwicensi*s was planted along Hilina Pali Road as part of the seed-orchard project (Table 3). In the fire-tolerant sites, 675 seedlings of *R. sandwicensis* were planted in 2005 and 2006. When monitored 38-50 months after planting, 111 individuals were alive. In the fire-safe sites, 26 plantings were surviving after 30 months; six were alive after 49 months.

Scaevola Kīlaueae Degener, **Huahehili uka**
Family: Goodeniaceae (Goodenia family)
Status: Species of Concern

Habitat and Distribution. *Scaevola Kīlaueae* is a low, usually upright shrub found in dry to mesic forest from 1,000-1,500 m elevation only on Hawai`i Island. Outside the park it occurs in three disjunct locations: near Pāhoa, in Ocean View Estates, and in Kapāpala Ranch. The park supports a fourth disjunct population of scattered shrubs in mid-elevation woodland on Kīlauea, south of the caldera from Chain of Craters Road west to the Keā`moku flow (Pratt *et al*., 2011). Over 400 *Scaevola Kīlaueae* seedlings were planted as part of a vegetative rehabilitation project after the 2000 Broomsedge Fire in mesic mid-elevation woodland. After one year, 84% were alive (Loh *et al.,* 2007).

Stabilization. In 2007, 26 *Scaevola Kīlaueae* seedlings were planted in one of the fire-tolerant sites along Hilina Pali Road (Table 3). When monitored after nearly three years, four plantings were still alive.

Senna gaudichaudii (Hook. & Arnott) H. Irwin & Barneby, **Kolomona**
Family: Fabaceae (Pea family)
Status: Rare in HAVO

Habitat and Distribution. *Senna gaudichaudii* is found in dry coastal lowlands of all the islands except Ni`ihau and Kaho`olawe and occasionally as high as 950 m elevation in mesic environments (Wagner *et al*., 1990). At HAVO, it was present in dry-mesic *Diospyros* forest in the coastal lowlands north of Kamoamoa. This site was covered by lava in the late 1990s. Naturally occurring *S. gaudichaudii* is now known from a single plant in Nāulu Forest (Abbott and Pratt, 1996). Over 500 *S. gaudichaudii* seedlings were planted after the 2002 Kupukupu fire. After one year, 26% of the plantings were alive (McDaniel *et al*., 2008).

Stabilization. Because of the paucity of naturally occurring *Senna gaudichaudii* in HAVO, seed for propagation of this species was collected from 10 naturally occurring founder *S. gaudichaudii* plants at Ka'ūpūlehu, Kona. In 2006, 12 *S. gaudichaudii* seedlings were planted in one fire-safe seed orchard site; after four years, two seedlings with poor vigor were found (Table 3). In 2005-2006, 262 individuals of *S. gaudichaudii* were planted in fire-tolerant sites along Hilina Pali Road. No live plantings were found after four and one-half years.

Sesbania tomentosa Hook. & Arnott, **`Ohai**
Family: Fabaceae (Pea family)
Status: Endangered

Habitat and Distribution. Ses*bania tomentosa* is a sprawling, sometimes upright shrub historically found at low, leeward elevations on all the main Hawaiian Islands (Wagner *et al.*, 1990). At HAVO, plants occur naturally in the coastal strand at `Āpua Point, Kūē`ē, and one plant at Ka`aha (L. Pratt, pers. comm.). *S. tomentosa* also occurs in small populations more inland in dry coastal lowlands and mid-elevation woodlands at Kamo`oali`i, Kīpuka Pepeiao/Kukalau`ula, Hilina Pali, and Kīpuka Nēnē. Approximately 200 *Sesbania tomentosa* plants were mapped in these areas during rare plant surveys conducted in the mid-1990s (Pratt *et al*., 2011).

Stabilization. Because of phenotypic and probable genetic differences among the different populations of *S. tomentosa* in the park, only seed from nearby populations at Kīpuka Nēnē and above the top of Hilina Pali were used as founder material in the mid-elevation woodland. In 2006, 128 *S. tomentosa* seedlings were planted in the four fire-safe sites; an additional 49 plants were added into two of these sites in 2008 (Table 3). After 32 months, 47 (37%) of the 2006 plantings were alive. When all fire-safe sites were monitored in 2010, 23 (13%) plantings were alive. Twenty of these were in Sites 3 and 4 where plantings were added in 2008.

Spermolepis hawaiiensis Wolf (no common name)
Family: Apiaceae (Parsley family)
Status: Endangered

Habitat and Distribution. *Spermolepis hawaiiensis* is a short, annual herb occurring in open lowland and mid-elevation sites and even cultivated fields on Kaua`i, O`ahu, Moloka`i, Maui, and Hawai`i (Wagner *et al.*, 1990) *S. hawaiiensis* occurs on Hawai`i Island at several sites at Pōhakuloa Training Area and Pu`u Anahulu. At HAVO, *S. hawaiiensis* is documented from only one locality; at 610 m elevation in *Metrosideros* woodland west of Kīpuka Kahali`i (Fagerlund and Mitchell, 1944). This site was probably covered by lava flows or cinder from the Mauna Ulu eruption, 1969-1974.

Stabilization. Seeds collected at Pōhakuloa Training Area in 2004 provided multiple founder lines. These were propagated in the Resource Management nursery facility to develop an *ex situ* supply of stock plants from which seed was subsequently collected for broadcasting. Approximately 20,000 seeds were broadcast into plots in mid-elevation woodland at Kahue near the Chain of Craters Road, Kīpuka Kahali`i, and Hilina Pali. At all sites, germination was observed, but the seedlings did not recruit into mature plants (Belfield, pers. comm.). Similar results have been reported from seed broadcast efforts conducted with this species at Pōhakuloa Training Area.

Discussion

The majority of plantings for the mid-elevation woodland were in the seed orchard planting sites near Hilina Pali Road. Survivorship at last monitoring was approximately twice as great in the fire-safe sites (29%) as in the fire-tolerant sites (15%) (Table 3). The disparity in survivorship is even greater when length of monitoring is considered. The fire-safe sites were monitored twice, first at about 2 and one-half years for most species, and then again at approximately four years for most species. The fire-tolerant sites were monitored just once, at two and one-half years. The survivorship of the plantings in the fire-safe sites averaged 65% at two and one-half years; after the same length of time, the survivorship of the fire-tolerant sites was 15%. The greater survivorship in the fire-safe sites may be partly due to a difference in composition of target species at the two sites. Three of the eight species in the fire-tolerant sites were not planted in the fire-safe sites and six of the 10 species planted in the fire-safe sites were not planted in the fire-tolerant sites. Differential survivorship may be also due to differences in the environments of the sites. Three of the four fire-safe sites are located at higher elevation and slightly more windward environments. These sites may receive slightly more moisture. A major difference between the two sites is the abundance of dense stands of alien grasses in the fire-tolerant sites.

Plantings were made into dense grass swards with no subsequent control of grasses. Alien grasses are sparse in the fire-safe sites and were avoided when placing plantings. The disparity in survivorship of the two sites may reinforce the intuitively obvious assumption, that rare plants survival should be higher in more intact environments with minimal invasive grasses.

The plantings of *Portulaca sclerocarpa* at Kulanaokuaiki Pali, Footprints, Crater Rim Trail, and Hawaiian Volcano Observatory account for over one-third of the plantings in the mid-elevation woodland. Only one planting survived in these sites when last monitored in 2010, 6-12 years following outplanting. All of the failed planted populations of *Portulaca sclerocarpa* had high initial survivorship, generally around 90% at 1-2 years (Table 3). Populations then declined steeply by four years after outplanting. Environmental factors may be responsible for the failure of *Portulaca sclerocarpa* to persist after three years. Although it was planted near sites where this species was found historically, these sites differ from the site where *P. sclerocarpa* has persisted in the largest population at HAVO (Pratt *et al*., 2011), the Puhimau hydrothermal area. The latter site has numerous steam vents that may maintain higher soil and atmospheric moisture at this site than in the planting sites.

Another factor possibly accounting for low survivorship of *P. sclerocarpa* may be propagation techniques. All of the plantings in the failed planting sites were derived from cuttings. The ratio of root mass to shoot mass appears to be lower in cuttings than in nursery grown seedlings (L. Pratt, pers. comm.). In dry extremes, plantings derived from cuttings may be more subject to drought stress than plantings derived from seedlings. The current survival of *P. sclerocarpa* plantings in fire-safe sites may also suggest that propagation technique may be a factor in survivorship of plantings. A subset of these plantings, planted in 2006 at fire-safe Sites 3 and 4, were seedlings, rather than cuttings. Remonitored in 2010, these plantings had a much higher survivorship (68%) after nearly four years than plantings at Kulanaokuaiki and Footprints (<10%) (Table 3). Results from a controlled experiment along Hilina Pali road comparing plantings derived from cuttings with plantings derived from seed demonstrated that cuttings had significantly higher mortality (40%) versus seedlings (3%) (Pratt *et al*., 2011). *Portulaca sclerocarpa* is a short-lived perennial. Cuttings have the life expectancy of the parent plant from which they are taken. Planted cuttings should have a shorter life expectancy that planted seedlings.

Rodent predation of fruits and seeds appears to be a limiting factor of *Portulaca sclerocarpa* (Pratt *et al*., 2011). As a short-live perennial, *P. sclerocarpa* depends on sufficient seedling recruitment to maintain population size. Seedlings have been observed in the outplanting sites at Footprints and Kulanaokuaiki; they did not persist. If seedling recruitment is limited significantly by seed predation, then populations may decline and disappear in a matter of years.

In spite of the high mortality and complete failure of most of the plantings of *Portulaca sclerocarpa*, knowledge gained from limiting factors study suggest the potential for successfully stabilizing the declining population of this species. Higher vigor and possibly long-term survivorship may result by planting seedlings rather than cuttings. Rodent control would increase seed rain and potentially seedlings recruitment. More mesic open sites, if any can be found, may provide opportunities for long term survival of recruited seedlings. Speculatively, seedlings may recruit at irregular intervals, in wet years without summer or winter/spring *El Niño* drought periods. In more mesic environments dry periods may be less limiting.

In contrast to the results with *Portulaca sclerocarpa* throughout the mid-elevation woodland, there was relatively high survivorship of plantings of *Myrsine lanaiensis* (33%) and *Bidens hawaiensis* (75%) in fire-safe sites (Table 3). Both species were planted in relatively large numbers, so that surviving plantings were noticeable. *Bidens hawaiensis* plantings were 88 cm tall on average and 88% had good vigor, as opposed to poor or fair vigor. Nearly all plants had fruit. Although no seedlings resulting from natural recruitment were found, seedlings are present in the small populations along upper Hilina Pali Road (M. Johnson, pers. comm.). The *Myrsine lanaiensis* plantings were 44 cm tall on average; 41% were rated in good condition.

The proximity of naturally occurring plants of *Bidens hawaiensis* and *Myrsine lanaiensis* in nearby mid-elevation woodland should be a predictor of survivorship along Hilina Pali Road. *Myrsine lanaiensis* is extremely rare in HAVO. The relictual, naturally occurring population of possibly one, root-sprouting clone is found in mid-elevation woodland in the former `Āinahou Ranch at an elevation close to that of the lowest planting site for *M. lanaiensis.* The planting sites were located to the west and presumably drier sites. They were also located on younger Kīpuka Nēnē lava flows. However, the plantings of *Myrsine lanaiensis* were placed in pockets of ash soil. *Bidens hawaiensis* is not as rare and was successfully planted along upper Hilina Pali Road in the 1970s.

Exocarpos gaudichaudii occurs naturally near the *Myrsine lanaiensis* in lower `Āinahou. This is one of the rarest plant species in HAVO. Fruits were present, but seeds collected did not germinate. Additional potential founders outside the park are known from South Kohala or may be available from other islands.

Spermolepis hawaiiensis, an endangered species, is one of the few annual plants in the native plant flora of Hawai`i. Seeds were sown into plots in 2006 and 2007, germination occurred, but seedlings died before the plants matured. In the spring of 2008, a large number of seedlings were observed at the Hilina Pali site from seeds that were broadcast in 2007, and perhaps from 2006, indicating that *S. hawaiiensis* may retain a short lived seed bank; seed banks of annual plants may be long-lived (Harper, 1977). Continued monitoring would indicate further seedling recruitment and recruitment into mature plants in the seed addition plots. More seed addition plots can be developed by maintaining seed stock plants in the Resource Management nursery facility.

By the criteria of presence and similarity of habitat, higher survivorship of *Chamaesyce celastroides, Pittosporum terminalioides,* and *Scaevola Kīlaueae* might be predicted. These species are uncommon to rare in mid-elevation woodland near or along Hilina Pali Road. They were placed in the fire-tolerant sites, not for stabilization purposes, but for their potential as fire rehabilitation species. However, survivorship was low in these species, possibly because all were planted only in stands of dense, alien grass. They are typically found naturally occurring in sites without thick stands of alien grass. Some natural recruitment of *Pittosporum terminalioides* and *Scaevola Kīlaueae* was observed incidental to monitoring. Distribution and stand structure of the small populations of these species should be determined to evaluate the necessity of augmentation and reintroduction into additional areas of their potential range.

There was a modest measure of success with plantings of *Pittosporum glabrum* and *Sesbania tomentosa*. Although 37% of the *P. glabrum* were alive after three years, taxonomic uncertainties with this species should be clarified before further stabilization work is carried out. All plantings were derived from a single founder located on northern margin of the mid-elevation woodland in the park. This founder was apparently not *Pittosporum terminalioides* (L. Pratt, pers. comm.) and was tentatively identified as *P. glabrum*, a taxon not previously collected in HAVO or on Hawai`i Island. The systematics of *Pittosporum* in Hawai`i are complex.

Sesbania tomentosa occurs naturally in a few small populations in the mid-elevation woodland. *Sesbania tomentosa* was planted at all fire-safe sites north of the natural populations. When monitored in 2010, 13% of the plantings were still alive with an average length of 2.7 m. Twelve of the 23 surviving *S. tomentosa* plantings were growing close together in Site 4. Additional seedlings were planted in Site 4 and also Site 3 in 2008, nearly two years after than other plantings (L. Pratt, pers. comm.). On the other hand, Site 4 where most of the surviving planting were located, at the base of Kulanaokuaiki Pali in Site 4, appeared to have deeper soil than many of the other plantings sites. Many failed plantings were placed in shallower ash deposits as the base of pāhoehoe and `ā`ā flows, sites selected because they mighty receive additional run-off during rain events. A site with deep soil and run off from vertical faces above site may also facilitate seedling recruitment. No natural seedling recruitment was observed in recent studies of *S. tomentosa* limiting factors; mortality of planted seedlings was also very high (Pratt *et al*., 2011).

Canavalia hawaiiensis, *Erythrina sandwicensis*, *Nototrichium sandwicensis*, *Rhus sandwicensis*, and *Senna gaudichaudii* had very low survivorship, with a sharp decline taking place between two and one half years and four years. There are two potential founder locations for *Canavalia hawaiiensis,* one in a more xeric environment in the park coastal lowlands at Kukalau`ula. The founders for the Hilina Pali plantings came from mesic forest on Pūlama Pali to the east of the mid-elevation woodland. The *C. hawaiiensis* plants in the old goat exclosure at Kukalau`ula differ phenotypically enough from of other *C. hawaiiensis* that they were initially described as a new species (St. John, 1972). Founders from Kukalau`ula might provide founders better adapted to the drier environmental conditions of the mid-elevation woodland than founders from Pūlama Pali.

Unlike *Myrsine lanaiensis* and *Bidens hawaiensis*, the current or recent historical ranges of *Erythrina sandwicensis*, *Nototrichium sandwicense*, *Rhus sandwicensis*, and *Senna gaudichaudii* in the park may not include mid-elevation woodland. *Erythrina sandwicensis* is known from lowland dry-mesic lowland forest in the park and state. *Nototrichium sandwicense* and *S. gaudichaudii* were found in lower and drier environments in the park, but, on a state-wide basis, include elevations as high as the mid-elevation woodlands. *Rhus sandwicensis* is found in the park in more mesic environments, but in the state from also wet to dry environments. Planting these species in the mid-elevation woodlands was experimental, based on a broader ecological range in the islands or the more mesic nature of the mid-elevation woodlands than its typical lowland, more xeric environment. *Erythrina sandwicensis*, *Nototrichium sandwicense*, and *Senna gaudichaudii* had much higher survivorship in lowland dry-mesic forest (Table 2). Stabilization and recovery may have greater potential there for these three species.

Neraudia ovata had very low survivorship along Hilina Pali Road, 2% after 45 months. There was much higher survivorship over a longer time period (43% after 5-6 years), closer to where it was found historically in the park in mid-elevation woodland and scrub near the Kapāpala Ranch boundary. However, only 10% of the surviving plantings had good vigor; the others were rated as poor or fair. The planting site near Peter Lee Road appeared to be the edge of a formerly extensive montane mesic forest on deep soil, now highly degraded by cattle ranching. Scattered *Sapindus saponaria* (mānele) trees were still extant on nearby steep slopes of the pasture. Rainfall data is not available for this site, but it may be similar to the mid-Hilina Pali Road seed orchard sites. However, there is ash soil and a closed canopy of *Metrosideros polymorpha* and *Sophora chrysophylla*. The Halfway House planting sites *for N. ovata* have similar vegetation, but are kīpuka surrounded by \`ā\`ā and appear to be rockier with less ash soil.

The kīpuka near Peter Lee Road and Halfway House, along with other kīpuka near the Kapāpala Ranch boundary may be favorable sites for stabilizing a range of rare plant species of the mid-elevation woodland. The upper Special Ecological Area at \`Āinahou and possibly areas with ash soil in Kīpuka Kahali\`i or Kahue may also be favorable stabilization sites. These areas are more windward of the current planting sites and may receive greater rainfall. The lower Special Ecological Area at \`Āinahou, that supports relict individuals of *Myrsine lanaiensis* and *Exocarpos gaudichaudii*, could also be considered. This site would require intensive invasive species control work and native shrub plantings to inhibit the reestablishment of alien grasses. This Special Ecological Area is on an older lava flow and may have deeper soil than the Hilina Pali Road fire-safe sites.

Experiments to date with seed additions are not definitive in clarifying the value of using seeds versus plantings for the target rare plants in the mid-elevation woodlands and scrub. Only a small subset of species was tested in a narrow range of habitats. Testing seed additions for other rare species in a range of sites may be an ecologically appropriate strategy for a dry to mesic environment.

MONTANE RAIN FOREST

Study Area and Methods

Montane rain forest at Hawai`i Volcanoes National Park is found in windward areas typically receiving an average of greater than 2,200 mm of rainfall per year, with nearly daily trade wind showers. Generally, wetter months occur in the winter and drier months in the summer, but monthly mean rainfall does not drop below 100 mm in any month (Giambelluca *et al.*, 1986). There is a narrow band of rain forest along the windward margin of Kīlauea Caldera and a one to several kilometer wide expanse on the East Rift of Kīlauea, much of it covered by lava flows since 1983. The most extensive tract of rain forest in HAVO is the approximately 4,000 ha `Ōla`a Forest, a disjunct tract separated from the Kīlauea area of HAVO by the community of Volcano.

All rain forest plantings were placed in `Ōla`a Forest. This is the oldest and most floristically diverse rain forest in the park. The western half has been fenced and protected from feral pigs for 20-30 years, depending on management unit. There is also an active invasive plant control program underway. Recovery of this habitat after ungulate removal is noticeable and well-documented (Pratt *et al*., 1999; Loh and Tunison, 1999; Belfield, 1998). In addition, `Ōla`a Forest is highly accessible because it is bisected by a state Highway (Wright Road). Finally it is secure because it is little visited by the public. All the plantings were located within 400 m of Wright Road.

The vegetation in the planting sites of `Ōla`a Forest is a *Metrosideros polymorpha* (`ōhi`a) forest with a secondary canopy primarily composed of *Ilex anomala* (kāwa`u) and *Cheirodendron trigynum* (`ōlapa) (Fig. 12). The emergent *M. polymorpha canopy* is made up of large, open to scattered trees resulting from a wave of natural dieback (Mueller-Dombois *et al.*, 1980). There is a dense, closed tree fern canopy of *Cibotium* spp*.* beneath the trees and above an open understory of native shrubs and a diverse ground cover of fern, bryophytes, and herbs. Removal of feral pigs in the 1980s and early 1990s has resulted in an increase in native plant cover, especially of understory ferns and shrubs, and a flush of native tree seedlings and saplings. Removal of pigs did not inhibit the spread of certain aggressive alien plants such as *Hedychium gardnerianum* (kahili ginger) (Loh and Tunison, 1999). Although invasive alien plants such as *Hedychium gardnerianum* and *Psidium cattleianum* (strawberry guava) are present, the cover of aggressive invasive plants that can form monotypic understory stands is generally less than 1%.

Figure 12. Forest floor of the planting habitat in `Ōla`a Forest with closed canopy of tree ferns and an understory of ferns and shrubs.

The rainfall of the planting sites in `Ōla`a Forest averages 3,200 mm per year. As much as one-third of the precipitation for plants is from cloud interception (D. Foote, pers. comm.) Some planting locations are on Mauna Loa flows and others on younger Kīlauea flows. Both flows are overlain by deep deposits of ash explosively erupted from Kīlauea Volcano. The thickest layers near the surface in which the forest vegetation is rooted are approximately 2,000 years old (Vitousek, 2004). The forest present at the site represents a later successional stage of the vegetation that pioneered on these ash deposits and currently found in the rain forest communities at the summit of Kīlauea Caldera and the East Rift.

Eleven montane rain forest species were selected for stabilization. All are either federal or state listed species: two endangered species (*Clermontia peleana* subsp. *peleana* and *Sicyos alba*); three candidate endangered species (*Cyanea tritomantha, Joinvillea ascendens* subsp*. ascendens,* and *Phyllostegia floribunda);* and six species of concern (*Anoetochilus sandvicensis*, *Eurya sandwicensis*, *Schidea diffusa*, *Stenogyne macrantha*, *Stenogyne scrophularioides,* and *Phyllostegia vestita)*. Six of the 11 target species are rare in the park; five are thought to be extirpated from the park.

Results by Species

Table 4. Survival of Plantings in Montane Rain Forest

Species	Number Planted[b]	Percent[a] Survival Early Monitoring	Percent Survival Last Monitoring	Number Surviving 2009-2010
Anoetochilus sandvicensis	300[c]	NA	NA	NA[c]
Clermonia peleana	390	NA	31% (17-59 mos.)	124
Cyanea tritomantha	68	40% (17-28 mos.)	31% (81-92 mos.)	21
Eurya sandwicensis	7	86% (18 mos.)	71% (27 mos.)	5
Joinvillea ascendens	111	5% (18-21 mos.)	0% (74-79 mos.	0
Phyllostegia floribunda	171	85% (21 mos.)	21% (53-74 mos.)	36
Phyllostegia vestita	76	97% (14-17 mos.)	9% (70-78 mos.)	7
Schiedea diffusa	136	90% (6-17 mos.)	7% (69-74 mos.)	10[d]
Sicyos alba	3	0 (15 mos.)	NA	0
Stenogyne macrantha	21	67% (15-28 mos.)	38% (79-81 mos.)	8
Stenogyne scrophularioides	93	79% (15 mos.)	17% (53-81 mos.)	16[d]
Total	**1076**		**21%**	**227**

[a] *Percent survivorship is presented for early monitoring because subsets of plantings monitored for some species*
[b] *Number planted and monitoring. See text for additional plantings not monitored may have been monitored*
[c] *Number planted for this species not included in total planted since individuals not countable at final monitoring*
[d] *Counting of surviving plantings confounded by viney habit and rooting at the nodes*

Anoectochilus sandvicensis Lindl.**, Jewel Orchid**
Family: Orchidaceae (Orchid family)
Status: Species of Concern

Habitat and Distribution. *Anoectochilus sandvicensis* is a creeping perennial herb that is usually found growing terrestrially from rhizomes. It is known to occur on all the main Hawaiian Islands except Ni`ihau and Kaho`olawe (Wagner *et. al.*, 1990). Very small numbers of *A. sandvicensis* are known currently from `Ōla`a Forest, Koa Unit (Pratt and Abbott, 1997) and formerly in the 1990s from the East Rift at Kāne Nui o Hamo crater and west and south of Nāpau Crater (Belfield,1998; Pratt *et al*., 2011).

Stabilization. *Anoectochilus sandvicensis* plantings were derived from cuttings taken from the wild population in the Koa Unit. No other founders were available from Hawai`i Island (T. Belfield, pers. comm.). In 2002 and 2003, 100 cuttings were planted in each of three small plots in `Ōla`a Forest: two sites in the Koa Unit and one site in the Small Tract Unit (Table 4). When first monitored at 18-24 months, survivorship was high and the planting plots had expanded in area by as much as one-third. Because the plantings grew into each other forming discontinuous small patches at final monitoring after 6-7 years, it was not possible to quantify survivorship of individual plantings. The one planting plot in Small Tract Unit could not be relocated and was presumed to have no survivors. Flowering has been observed through multiple years.

Clermontia peleana subsp. ***peleana*** Rock, **`Ōhā wai**
Family: Campanulaceae (Bellflower family)
Status: Endangered

Habitat and Distribution. *Clermontia peleana* subsp. *peleana* is an extremely rare epiphytic shrub or small tree known from the windward slopes of Mauna Kea and Mauna Loa between 530 and 1150 m elevation (Wagner *et al.*, 1990). Six naturally occurring plants were found recently from the mid-elevation Wailuku River drainage (K. Bio, pers. comm.) *Clermontia peleana* was historically known either from the park's `Ōla`a Forest or vicinity, but collection records do not address location specifically enough to determine this. *Clermontia peleana* has not been found in recent surveys of the park's `Ōla`a Forest (Jacobi and Warshauer, 1975; Anderson *et al.*, unpublished report, 1988; Pratt and Abbott, 1997).

Stabilization. All the HAVO plantings, to date, are the progeny of a selfed, single founder under propagation at the Volcano Rare Plant Facility, thought at the time to be the only extant individual. Additional propagation material for future plantings is now available from the recently discovered founders. The first plantings in the park were six large *C. peleana* transferred from the Volcano Rare Plant Facility in the Koa Unit (Table 4). In 2006, an additional four *C. peleana* were planted in Koa Unit. Nine of the 10 plantings were alive in 2009.

In 2005, five small C. *peleana* were planted in a permanent monitoring plot in Small Tract Unit. In 2009, three of these plantings were still alive. In 2008, more extensive plantings of seedlings in Small Tract Unit were carried out in collaboration with the Three Mountain Alliance, the Preventing Extinction in Plants program, the Volcano Rare Plant Facility, and the Hawaiian Silversword Foundation. Forty-four seedlings were planted in March, 2008; 18 of these were alive when monitoring 14 months later; 10 were alive 24 months later. In October, 2008, 331 seedlings were planted. When last monitored 18 months later, 102 live plants were found. All but four of the surviving plants were judged to be in good condition, even though the central stem of nearly one-third of the plants was arched and leaning, rather than upright. The collective survival rate of *Clermontia peleana* in `Ōla`a Forest at last monitoring was 29%.

Cyanea tritomantha A. Gray, **`Akū**
Family: Campanulaceae (Bellflower family)
Status: Candidate Endangered Species

Habitat and Distribution. *Cyanea tritomantha* is a large shrub or small tree endemic to wet forest on Hawai`i Island (Wagner *et al*., 1990). Historically, it occurred broadly across the island including populations on Mauna Loa, Mauna Kea, Kohala Mountains, and Kīlauea. At HAVO, *C. tritomantha* is known from `Ōla`a Forest, primarily in the Koa and Ag Units, and formerly in the Small Tract Unit (Pratt *et al*., 2011).

Stabilization. In 2001 and 2002, a total of 68 *C. tritomantha* were planted in `Ōla`a Forest (Table 4). The plants were propagated from seed representing two founder lines of naturally occurring plants in `Ōla`a Forest. Forty-three *C. tritomantha* were planted in the Koa Unit. Seventeen of the 43 plantings were alive after 17-28 months; 15 were surviving at last monitoring after 6-7 years. Twenty-five plantings were placed in the Small Tract Unit (Fig. 13). Ten of the 25 plantings were alive after 26 months; six were alive seven and one-half years after planting. Across all sites and planting sessions, survivorship was 31% at last monitoring. Five of the six surviving plants in Small Tract Unit had heights greater that 2.0 m and had been observed flowering and fruiting.

Figure 13. Planting of *Cyanea tritomantha* (`akū) in `Ōla`a Forest. This large lobelioid with prickly stems and leaves was planted over seven years ago and is producing fruit; however, no seedling recruitment has been observed.

Eurya sandwicensis A. Gray, **Ānini**
Family: Theaceae (Tea family)
Status: Species of Concern

Habitat and Distribution. *Eurya sandwicensis* is a shrub or small tree that grows scattered to rare in mesic to wet montane forest. It occurs on all the main islands except Ni`ihau and Kaho`olawe (Wagner *et al.*, 1990). *Eurya sandwicensis* has not been documented at HAVO in the last 50 years except for a recent sighting in the Kahuku acquisition near the park boundary adjacent to Ka`ū Forest Reserve (Benitez *et al.*, 2008). Historically, *E. sandwicensis* was found in wet forest near Makaopuhi Crater on Kīlauea's East Rift. It was not relocated in surveys of the East Rift site in the 1990s (Belfield, 1998). It also grew in Ōla`a Forest along the park boundary shared with privately-owned pastureland (Fosberg, 1966) in an area now identified as the Koa Unit.

Stabilization. The plantings were derived from cuttings and seed of two founders in Pu`u Maka`ala Natural Area Reserve. In 2007, seven *E. sandwicensis*

Figure 14. *Eurya sandwicensis* (`ānini) planted in montane rain forest at Small Tract Unit, `Ōla`a Forest. Limited by availability of propagation material, only seven individuals were planted of this species that have not been documented from HAVO in 50 years except for a recent sighting in the newly acquired Kahuku unit. Five plantings with good vigor are surviving after two years. Photo courtesy of Carol Johnson.

were planted in a cluster in Small Tract `Ōla`a (Table 4). Five plantings, all with good vigor, were alive in 2010 (Fig. 14). However, based on mortality patterns of other plantings, it is premature to conclude that survivorship will be high. Greater reconnaissance and searching is needed in the range of *E. sandwicensis* to increase founder number and propagation material to develop stabilized populations in the park.

Joinvillea ascendens subsp. **ascendens** Gaud. ex Brongn. & Gris, **`Ohe**
Family: Joinvilleaceae
Status: Candidate Endangered Species

Habitat and Distribution. *Joinvillea ascendens* subsp. *ascendens* is a tall, grass-like perennial up to five meters tall. It occurs in wet forest habitat on Kaua`i, O`ahu, Moloka`i, Maui, and Hawai`i at elevations from 300 to 1,250 m elevation (Wagner *et al.*, 1990). At Hawai`i Volcanoes National Park, the only documented collection was made in the early 1980s from near the middle of `Ōla`a Forest, south of the trench and crater features.

Stabilization. In 2003, a total of 111 *J. ascendens* subsp. *ascendens* seedlings were planted in `Ōla`a Forest, 81 in the Koa Unit and 30 in Small Tract Unit (Table 4). After one year, only six of the 85 plantings were alive in the Koa Unit; only three of the 38 plantings in Small Tract Unit were found alive when monitored after two years. No live *Joinvillea ascendens* plantings were found in `Ōla`a Forest in 2009.

Liparis hawaiensis H. Mann, **`Awapuhi a kanaloa**
Family: Orchidaceae (Orchid family)
Status: Species of Concern

Habitat and Distribution. *Liparis hawaiensis* is a terrestrial or epiphytic, perennial herb found on all the main Hawaiian Islands, except Ni`ihau and Kaho`olawe (Wagner *et al*., 1990). At HAVO, *L. hawaiensis* is known most recently from`Ōla`a Forest (Pratt and Abbott, 1997). Historically it was found in a number of locations in the park including Kīlauea's East Rift near Nāpau Crater (Fosberg, 1966), mesic *Metrosideros* forest near Keanakako`i Crater, and mid-elevation woodland along upper Hilina Pali Road. These individuals or populations have not been relocated so currently, there are no known populations of *Liparis hawaiensis* in HAVO (L. Pratt, pers. comm.).

Stabilization. One individual was collected and successfully propagated in the Resource Management nursery facility from the last known population `Ōla`a Forest, while still extant, in the park. This plant was later damaged by rats and then died before seed could be collected from it. Consequently, no planting of *Liparis sandvicensis* has been conducted in HAVO.

Phyllostegia floribunda Benth. (No common name)
Family: Lamiaceae (Mint family)
Status: Candidate Endangered Species

Habitat and Distribution. *Phyllostegia floribunda,* endemic to Hawai`i Island*,* is an erect subshrub of mesic and wet forest (Wagner *et al.*, 1990). In HAVO, *P. floribunda* was found in the 1990s in `Ōla`a Ag Unit, (Pratt and Abbott, 1997) and the East Rift of Kīlauea where four plants were observed in 1995 near Nāpau Crater (Belfield,1998).

Stabilization. In 2000, seeds and cuttings were obtained from 12 individuals of *P. floribunda* in Waiākea Forest Reserve. Between 2002 and 2004, 171 individuals were planted in Koa Unit (Table 4). After 21 months, 71 of 84 plantings were alive. Nearly one-third of the plants had flowers or fruits. After final monitoring at six years, 15 individuals were alive. In Small Tract, 87 *P. floribunda* were planted. Short term monitoring was not conducted. At last monitoring after four and one-half years, 21 individuals were alive. Collectively, 21% of the plantings were found to be surviving when last monitored in 2009.

Phyllostegia vestita Benth. (No common name)
Family: Lamiaceae (Mint family)
Status: Species of Concern (State)

Habitat and Distribution. *Phyllostegia vestita* is a climbing vine that occurs in wet forests on Hawai`i Island (Wagner *et al.*, 1990). It has been found in HAVO rain forest as recently as the 1990s. In `Ōla`a Forest, eight plants were found growing in three sites (Pratt and Abbott, 1997). In the East Rift a small population was located within the crater of Kane Nui O Hamo (Belfield, 1998).

Stabilization. Plantings *of P. vestita* were derived from cuttings of eight founders in the Waiākea Forest Reserve. In 2002, four plantings were placed in Small Tract Unit (Table 4). After 14 months, three of the plantings were alive. All plantings were dead by 2009 when last monitored. In 2003, 72 *P. vestita* were planted in the Koa Unit. After 17 months, 68 of the plantings were alive. At last monitoring in 2009, seven surviving plants were found. The collective survival rate at 6-7 years was 9%. Despite multiple years of fruit production, no natural regeneration has been observed near the plantings.

Schiedea diffusa subsp. ***macraei*** A. Gray (No Common Name)
Family: Caryophyllaceae
Status: Species of Concern

Habitat and Distribution. *Schiedea diffusa* is a partly wood vine found in wet forest on Moloka`i, East Maui, and Hawai`i Island (Wagner *et al.*, 1990). The *S. diffusa* on Hawai`i Island is a distinct variety, var. *macrei*, known only from Kohala Mountains until a single individual was found in 1985 within the Ag Unit of `Ōla`a Forest. The individual of *S. diffusa* var. *macraei* in `Ōla`a Forest could not be found in a survey in 2008, suggesting that naturally occurring *S. diffusa* var. *macraei* may no longer be present in the park (Pratt *et al*., 2011).

Stabilization. In 2003, a total of 136 *S. diffusa* were propagated from cuttings and seeds collected from the only known plant occurring in the park. Propagules were also collected from a founder in the Kohala Mountains. Eighty-three individuals were planted in the Koa Unit (Table 4). After 17-21 months, 68 individuals were surviving. After 6-7 years, 10 individuals were alive. Also in 2003, 53 plants were planted in Small Tract. After six months, 48 plantings were alive. However, at last monitoring after six and one-half years, all plantings had died. The collective survivorship across all sites as last monitoring was 7%. No flowering or fruiting was observed.

Sicyos alba (St. John) Telford, **`Ānunu**
Family: Cucurbitaceae (Gourd family)
Status: Endangered

Habitat and Distribution. *Sicyos alba* is an annual vine found only in wet forest on the windward slopes of Kīlauea, Mauna Loa, and Mauna Kea (Wagner *et al.*, 1990). It has been located in the last two decades in only three areas: Pu`u Maka`ala Natural Area Reserve, `Ōla`a Forest Reserve, and the park's `Ōla`a Forest. In `Ōla`a Forest, it was found in the 1990s in over six sites in the Koa Unit (Pratt and Abbott, 1997). Naturally occurring seedlings have also been observed in this pig-free management unit, and these have persisted for at least a year (VanDeMark *et al*., 2010)

Stabilization. Three *S. alba* were planted in the Koa Unit in 2007 (Table 4). These were individuals obtained from germination trials conducted as part of a study to determine limiting factors of selected park rare plants. Twelve to 14 months later, the three plantings had died (VanDeMark *et al*., 2010).

Stenogyne macrantha Benth., (No Common Name)
Family: Lamiaceae (Mint Family)
Status: Species of Concern

Habitat and Distribution. *Stenogyne macrantha* is a climbing or decumbent vine found in wet forests on Hawai'i Island (Wagner *et al*., 1990). At HAVO, *S. macrantha* occurs in small numbers in the Ag and Koa Units of `Ōla`a Forest (Pratt and Abbott, 1997).

Stabilization. Cuttings were collected from two plants in `Ōla`a Forest and from a single plant in Pu`u Maka`ala Natural Area Reserve. A total of 21 individuals of *S. macrantha* were planted in `Ōla`a Forest in 2002 -2004 (Table 4). Eleven plants were planted in the Koa Unit. After 28 months, nine plants were alive. At last monitoring after nearly seven years, three *S. macrantha* were alive. Ten individuals of *S. macrantha* were planted in the Small Tract Unit. After 15 months, five were alive. At last monitoring after six and one-half years, these five plants were still alive. The collective survivorship for *Stenogyne macrantha* at last monitoring was 38%. Flowering and fruiting was observed on many plants, but no seedling recruitment (T. Belfield, pers. comm.).

Stenogyne scrophularioides Benth., **Mōhihi**
Family: Lamiaceae (Mint family)
Status: Species of Concern (State)

Habitat and Distribution. *Stenogyne scrophularioides* is a climbing or decumbent vine in wet forests on Hawai`i Island. It is found on Mauna Loa and a single collection from Mauna Kea (Wagner *et al.*, 1990). At HAVO, 15 *S. scrophularioides* plants were located along survey transects in the Pu`u Unit, Koa Unit and Small Tract Unit of `Ōla`a Forest in the 1990s (Pratt and Abbott, 1997). Since those surveys a few scattered plants have been located in the Koa and Small Tract Units away from survey transects (Belfield, pers. com.). Although *S. scrophularioides* and *S. macrantha* are thought to hybridize freely in most locations where their ranges overlap, collections from the `Ōla`a Forest suggest that they do not intergrade here (Wagner *et al*., 1990) so plantings can be carried out without the potential for introgression.

Stabilization. Cuttings were taken from naturally occurring plants in Small Tract and Koa Units and one plant from Waiākea Forest Reserve. Between 2002 and 2004, a total of 141 *S. scrophularioides* were planted in Small Tract and Koa Units (Table 4). In the Koa Unit, after 28 months, 47 of the 51 plantings were alive. Seven plantings were alive when last monitored after nearly seven years. Ninety *S. scrophularioides* were planted in Small Tract Unit. A subset of 25 plantings was monitored after 15 months; 15 were alive. When all plantings sites were monitored in 2009, nine surviving individuals were found. The collective survivorship of *Stenogyne scrophularioides* after nearly seven years was 17%.

Discussion

Rare plant stabilization began in recovering, montane rain forest environments in the park including the Thurston and the East Rift Special Ecological Areas. The results of these efforts will be published in subsequent reports. Rare species plantings there are being placed in younger rain forest environments with lower tree fern cover, higher light levels near the forest floor, less leaf litter, and less damage to plantings from falling fern fronds. Even though plantings were placed in `Ōla`a Forest in a number of separate locations, site features were homogenous and all planting areas were within a few hundred meters of each other. Surviving plantings at the Thurston and East Rift sites may enhance stability by increasing population size and establishing additional populations.

Stabilization of montane rain forest rare plant species was perceived at the outset as challenging because of the high degree of rarity of all the target species. The state-wide rarity of all 11 target species is recognized by the listing of all species by the US Fish and Wildlife Service or the Hawai`i Department of Land and Natural Resources. Five of the species have probably been extirpated from the park. All target species are perennial herbs, vines, or shrubs of the forest understory or forest floor. This is the most vulnerable stratum of rain forest to the impacts of feral pigs (*Sus scrofa*) and also to competition from invasive plants. The target planting site, the `Ōla`a Forest, has a closed canopy of tree ferns. Significant mortality of tree seedlings has been documented in `Ōla`a Forest from falling tree fern fronds (Drake and Pratt, 2001).

The average survivorship (21%) of the plantings in montane rain forest at Ōla`a was similar to that of lowland dry-mesic forest (18%) and mid-elevation woodland (14%), even though rain forest plantings typically do not have to contend with dry extremes that occur in the lowland dry-mesic forest and mid-elevation woodland and the plantings were placed in a partly restored habitat. Moreover, lower survivorship of the current plantings in `Ōla`a Forest might be expected over time because of the anticipated decline of the most intensively planted species, *Clermontia peleana* subsp. *peleana.* Plantings of this species account for over one-third of the total plantings in `Ōla`a Forest and 55% of the surviving individuals. However, approximately one-third of the surviving plantings had noticeably arched, rather than erect, stems. This condition was found to be a precursor of reduced vigor and mortality in other sites (L. Pratt, pers. comm.). Localized high, patchy mortality of planted *C. peleana* in other locations is possibly a result of slug damage (R. Robichaux, pers. comm.), although the impact of slugs has not been demonstrated experimentally or even directly observed. Furthermore, most of the plantings of *C. peleana* were made approximately 18 months before the final monitoring. The survivorship of five other planted rare rain forest plant species declined sharply after this time-frame.

The average survivorship of all planted species other than *C. peleana* was 15%. However, four target rain forest species had modest survivorship that would warrant further propagation and outplanting to increase their numbers and stability. In addition, several target species were limited by the availability of founder material and were planted at very low numbers. Stabilization would be enhanced with the addition of more founder material.

Plantings of *Cyanea tritomantha, Phyllostegia floribunda, Stenogyne macrantha, and Stenogyne scrophularioides* had modest levels of plantings, survivorship, and reproduction. Thirty-one percent of 68 plantings of *Cyanea tritomantha* were surviving after seven years. Flowering and fruiting were observed in the largest *C. tritomantha,* although no seedling recruitment was reported during surveys of planting survival.

Twenty-one percent of 171 plantings of *Phyllostegia floribunda* were surviving after four and one-half to five and one-half years and flowering and fruiting were observed in one-quarter of the plantings as early as 21 months. Some *Phyllostegia* species are relatively short-lived so survivorship of plantings, relative to the average life-span of this species, may have been higher. During a study of limiting factors of *P. floribunda*, (VanDeMark *et al*., 2010), there was relatively high fruit production and seed germination in the greenhouse, a relatively pest-free environment. Natural seedling recruitment was observed, but with very high mortality within the first few months, suggesting that limiting factors, possibly slugs, act on this stage of the life cycle. This limiting factor would undoubtedly need to be addressed in a recovery program. However, planting additional larger seedlings may allow resource managers to avoid limiting factors and implement at least interim stabilization of *P. floribunda*. This species is historically known from lower elevations so that higher survivorship may occur with planting in the East Rift rain forest (L. Pratt, pers. comm.).

The modest survival of *Stenogyne macrantha* (21 plantings and 38% survival) and *S. scrophularioides* (93 plantings and 17% survival) indicates the potential to expand stabilization efforts. Both species can be propagated from cuttings, both of successful plantings in the park and additional naturally occurring founders from `Ōla`a Forest or nearby areas.

Greater stabilization of the two orchid species might be achievable by utilizing founder material from out of the park or even other islands. *Anoectochilus sandvicensis* is naturally occurring in very small numbers in `Ōla`a Forest. Additional material from outside the park has been under propagation in the recent past at the Volcano Rare Plant Facility and *A. sandvicensis* may also be available from additional locations on Hawai`i Island. Attempts to propagate and plant *Liparis hawaiensis* failed basically because of the paucity of founder material. There are currently no known *L. hawaiensis* in HAVO or even on Hawai`i Island (L. Pratt, pers. comm.). Founder material may be available outside the park, including Moloka`i and Maui (Mehrhoff, 1996). In the past, there has been a reluctance to use founder material from other islands, even of the same recognized taxon. However, it may be necessary to utilize these sources when local sources are not available, to provide founder material for reintroductions and genetic diversity for long-term survival. Translocations of pests and diseases between islands can be mitigated by quarantine, inspection, and sanitation.

There was complete failure of over 100 *Joinvillea ascendens* subsp. *ascendens* plantings. No obvious causes of mortality were observed when the plantings were monitored. However, one can speculate that the outplanting sites may be at the upper elevational range of this species. The nearest naturally occurring plants closest to the park are at lower elevations, in `Ōla`a Forest Reserve and Wao Kele o Puna. Stabilization efforts currently underway on the East Rift may have greater potential for success than those conducted in `Ōla`a Forest.

Sample sizes of *Sicyos alba* (three plantings) and *Eurya sandwicensis* (seven plantings) were too small to make inferences about the success of further stabilization efforts. Many more plantings are needed for stabilization, but may be limited by the paucity of propagules or founder material. Limiting factors studies of *Sicyos alba* (VanDeMark *et al*., 2010) indicate that seeds of this species are difficult to germinate.

Developing techniques to improve germination rates would increase the number of plantings for stabilization. *Eurya sandwicensis* propagates readily from seeds and cuttings, but naturally occurring source plants are rare and widely scattered; more founders need to be discovered.

Schiedea diffusa, var. *macraei* had an apparently low rate of establishment (7%). Additional plantings are needed to stabilize this recently extirpated species. In contrast to plantings in the wild, plants maintained in the greenhouse flowered and fruited (T. Belfield, pers. comm.) to serve as a propagule source for rearing plantings in a greenhouse setting for outplanting.

MONTANE MESIC FOREST

Study Area and Methods

Montane mesic forest at Hawai`i Volcanoes National Park consists of floristically diverse kīpuka on deep ash soil from 1,180-1,280 m elevation on the lower Mauna Loa Strip. The largest of these are Kīpuka Puaulu and Kīpuka Kī. Smaller kīpuka of less diverse montane mesic forest are found on patches of deep ash along the park boundary with Keauhou Ranch. One kīpuka along the ranch boundary included in the stabilization project has been informally called "Kīpuka `Aiea" by resource management staff because of the presence of remnant *Nothocestrum longifolium* (`aiea) plants. The montane mesic forest zone has a summer-dry seasonal climate with rainfall averaging 1,525 mm per year (Giambelluca *et al*., 1986). The soil of most sites is comprised of more than two meters of ash deposits from explosive eruptions of Kīlauea volcano. The underlying Mauna Loa flows beneath Kīpuka Puaulu and Kīpuka Kī are mostly 8,500 years old (F. Trusdell, pers. comm.).

The forest vegetation of Kīpuka Puaulu and Kīpuka Kī is dominated by mixed stands of *Acacia koa* (koa), *Metrosideros polymorpha* (`ōhi`a), and *Sapindus saponaria* (mānele), with an open understory of diverse native trees, shrubs, and ferns. Common native understory species are *Pisonia brounoniana* (pāpala kēpau), *Coprosma rhynchorcarpa* (pilo), *Nestegis sandwicensis* (olopua), *Alyxia stellata* (maile), and *Microlepia strigosa* (palapalai). This rare plant community has been described as *Acacia koa*/*Metrosideros polymorpha*/*Sapindus* (Koa/`Ōhi`a lehua/Mānele) montane mesic forest (Mueller-Dombois and Lamoureux, 1967). It has been given the rank of G1, critically imperiled globally, by the Hawai`i Heritage Program (Pratt *et al*., 2011). The only relatively intact examples remaining in the Islands are Kīpuka Puaulu, Kīpuka Kī, and Pu`uwa`awa`a, all on Hawai`i Island. The native woody plant flora of Kīpuka Puaulu, per hectare, is the richest vascular plant assemblage in HAVO. As a mesic environment, montane mesic forest supports floristic elements from not only wetter and more xeric environments, but also plant species characteristic of mesic forest. In addition, species richness may be greater with the late successional status of the forest.

The plant diversity of Kīpuka Puaulu was recognized early in the twentieth century (Rock, 1913) and initial efforts to exclude domestic cattle (*Bos Taurus*) and plant rare species began in the 1920s, much earlier than at Kīpuka Kī and the other montane mesic forest stands. A partially effective cattle fence was constructed around Kīpuka Puaulu around 1930 and a goat and pig-proof fence in 1968. Removal of stray cattle and feral goats (*Capra hircus*) was accomplished at Kīpuka Kī and other remnants of montane mesic forest in the early 1970s. Feral pigs (*Sus scrofa*) were excluded from these areas by the mid-1980s. Kīpuka Kī has lower species diversity, and the montane mesic forest stands on deep ash soil along the park boundary with Keauhou Ranch have only suggested remnants of the diversity found in Kīpuka Puaulu. Later initiated ungulate and weed management may partially account for these differences.

Sustained alien plant control began in Kīpuka Puaulu in the mid-1980s when it was designated a Special Ecological Area. Control work was carried out on *Hedychium gardnerianam* (kahili ginger), *Psidium cattleianum* (strawberry guava), *Solanum pseudocapsicum* (Jerusalem cherry), and *Tropaeolum majus* (nasturtium). Alien plant management was initiated at Kīpuka Kī in 1990 with control of extensive understory stands of *Rubus argutus* (Florida prickly blackberry), *Solanum pseudocapsicum* (Jerusalem cherry), and a number of alien grasses including *Ehrharta stipoides* (meadow ricegrass) and *Pennisetum clandestinum* (Kikuyu grass). The systematic reforestation of large canopy gaps created by cattle grazing activities was undertaken in Kīpuka Puaulu by chemical control of alien grasses and *Rubus argutus* that dominated these old pastures. Restoration relied largely on natural recovery of native woody species and in some cases planting of fast-growing native woody plants such as *Acacia koa*, *Coprosma rhynchocarpa*, and *Pipturus albidus* (māmaki). Intensive plantings of not only woody canopy species, but understory species was carried out in old pastures disjunct and west of Kīpuka Puaulu on deep ash soil, lying along either side of the Mauna Loa Road, an area called informally “Soapberry Bend” by park staff.

By the early 1990s, it was apparent that ungulate and alien plant removal had resulted in abundant natural recovery of common native plant species in Kīpuka Puaulu and Kīpuka Kī where alien plant management began in 1990. An inventory of rare plants was undertaken in Kīpuka Puaulu from 1992-1994 (Pratt and Abbott, unpublished data) and in Kīpuka Kī in 1998 (Belfield and Pratt, unpublished data).

Twenty-two plant species were propagated and planted in the montane mesic forest. Ten of the 22 species are listed by the US Fish and Wildlife Service and include four endangered species, *Hibiscadelphus giffardianus* (hau kuahiwi), *Melicope zahlbruckneri* (alani), *Nothocestrum breviflorum* (\`aiea), and *Neraudia ovata* (ma\`aloa); two candidate endangered species, *Ochrosia haleakalae* (hōlei) and *Sicyos macrophyllus* (\`ānunu); and four species of concern, *Embelia pacifica* (Kīlioe), *Melicope hawaiensis* (mokihana kūkai), *Zanthoxylum dipetalum* var. d*ipetalum* (kāwa\`u), and *Zanthoxylum kauense* (a\`e). Eight of the 22 species are rare in mesic forest and/or rare in the park. These include *Cheirodendron trigynum* (\`ōlapa), *Kadua affinis* (manono), *Nothocestrum longifolium* (\`aiea), *Phytolaccca sandwicensis* (pōpolo kū mai), *Rumex giganteus* (pāwale), *Urera glabra* (pōhue), *Clermontia hawaiiensis* (`ōhā kēpau), and *Xylosma hawaiiense* (maua). Propagation and planting were conducted on listed and rare species to augment existing small populations and, when sufficient planting material was available, to reintroduce or augment populations in additional kīpuka of the montane mesic forest. This increased stability and evenness-diversity.

The other five plant species propagated and planted were uncommon in montane mesic forest or even common in one of the kīpuka: *Psychotria hawaiiensis* (kōpiko `ula) and *Rubus hawaiiensis* (`ākala), *Nestegis sandwicensis* (olopua), *Pittosporum hosmeri* (hōʻawa), and *Charpentiera obovata* (pāpapa). Propagation and outplanting was also done to increase population size and evenness-diversity by planting in other montane mesic forest kīpuka where they were absent or rare. The uncommon to common species were typically found in the more floristically rich Kīpuka Puaulu, but rare or absent in the longer impacted Kīpuka Kī. Twenty-one species were planted in Kīpuka Kī, 14 in Kīpuka Puaulu, and one in "Kīpuka `Aiea."

Results by Species

Table 5. Survival of Plantings in Montane Mesic Forest

Species	Number Planted[b]	Percent[a] Survival Early Monitoring	Percent Survival Last Monitoring	Number Survivors
Kipuka Ki				
Charpentiera obovata	151	89% (28 mos.)	51% (49 mos.).	77
Cheirodendron trigynum	16	69% (16 mos.)	50% (37 mos.)	8
Clermontia hawaiiensis	341	58% (23-37 mos.)	39% (40-49mos.)	132
Embelia pacifica	33	76% (16 mos.)	61% (39 mos.)	20
Hibiscadelphus giffardianus	100	NA	83% (84-96 mos.)	83
Kadua affinis	126	70% (23-28 mos.)	49% (44-52 mos.)	62
Melicope hawaiensis	3	NA	67% (30 mos.)	2
Melicope zahlbruckneri	4	100% (44 months)	100% (43-87 mos.)	4
Neraudia ovata	52	82% (19-24 mos.)	37% (62-88 mos.)	17
Nestegis sandwicensis	122	74% (27 mos.)	48% (27-46 mos.)	58
Nothocestrum longifolium	108	78% (21-29 mos.)	33% (36-50 mos.)	36
Ochrosia haleakalae	39	97% (5-27 mos.)	69% (22-48 mos.)	27
Phytolacca sandwicensis	87	71% (14 mos.)	47% 28 mos.)	41
Pittosporum hosmeri	156	97% (28 mos.)	73% (49 mos.)	114
Psychotria hawaiiensis	16	73% (23-27 mos.)	69% (39-48 mos.)	11
Rubus hawaiensis	84	44% (13-23 mos.)	26% (38-44 mos.)	22
Rumex giganteus	63	ND	57% (28 mos.)	36
Sicyos macrophyllus	11	72% (18-20 mos.)	55% (29-31 mos.)	6
Urera glabra	38	75% (23-27 mos.)	71% (23-48 mos.)	27
Xylosma hawaiiense	64	83% (23 mos.)	33% (39-44 mos.)	21
Zanthoxylum dipetalum	86	79% (21-23 mos.)	37% (42-44 mos.)	32
Subtotal	**1700**		**47%**	**804**
Kipuka Puaulu				
Cheirodendron trigynum	49	82% (5-35 mos.)	73% (27-49 mos.)	36
Clermontia hawaiiensis	280	76% (21-23 mos.)	55% (40-49 mos.)	154
Embelia pacifica	10	100% (28 mos.)	80% (39 mos.)	8
Hibiscadelphus giffardianus	100	NA	63% (84-96 mos.)	63
Kadua affinis	152	62% (24 mos.)	24% (46 mos.)	37
Nothocestrum breviflorum	123	88% (16-23 mos.)	49% (19-62 mos.)	67
Phytolacca sandwicensis	137	34% (15 mos.)	15% (29 mos.)	20
Rubus hawaiensis	15	80% (2-6 mos.)	67% (15-19 mos.)	10
Rumex giganteus	93	86% (15 mos.)	45% (29 mos.)	42
Sicyos macrophyllus	7	72% (18-20 mos.)	14% (29-31 mos.)	1
Urera glabra	43	20% (21-27 mos.)	20% (24-49 mos.)	7
Xylosma hawaiiense	22	55% (6-26 mos.)	55% (41-63 mos.)	12
Zanthoxylum dipetalum	12	NA	25% (62 mos.)	3
Zanthoxylum kauense	10	60% (13-16 mos.)	0	0
Subtotal	**1053**		**49%**	**460**
Total[c]	**2753**		**46%**	**1264**

[a] *Percent survivorship is presented for early monitoring because subsets of plantings monitored for some species*

[b] *Number planted and monitoring. See text for additional plantings not monitored*

[c] *The total does not include the planting of 75 Hibiscadelhyus giffardianus and monitored for 19 months.*

Charpentiera obovata Gaud., **Pāpala**
Family: Amaranthaceae (Amaranth family)
Status: Uncommon in HAVO

Habitat and Distribution. *Charpentiera obovata* is a small tree found on all the larger islands except Ni`ihau and Kaho`olawe (Wagner *et al.*, 1990). It occurs sparingly in the wet forest of `Ōla`a (Pratt and Abbott, 1997). Natural occurrence of *C. obovata* in mesic forest at Kīpuka Puaulu was documented in the 1960s (Fosberg, 1966). It was also planted in Kīpuka Puaulu and Kīpuka Kī between 1947 and 1964 (Morris, 1967) and in the 1970s (Zimmer, unpublished report). Planted *C. obovata* trees occurring in Kīpuka Puaulu can no longer be distinguished from naturally occurring plants that may still persist there. Rare plant surveys conducted in the early 1990s (Pratt *et al.*, unpublished data) located 121 trees in Kīpuka Puaulu. Surveys in the late 1990s (Belfield and Pratt, unpublished data) located 19 trees planted along the Mauna Loa Strip road corridor in Kīpuka Kī. All trees occurring in Kīpuka Kī were planted.

Stabilization. Seeds were collected from over 20 founder trees in Kīpuka Puaulu and Kīpuka Kī. Plantings were used to augment the small population of previously planted *C. obovata* in Kīpuka Kī. In 2002, 151 seedlings were planted into forested sites that had been cleared in recent years of dense understory swards of invasive alien grasses and shrubs (Table 5). After two years, 135 plantings were alive. After the last monitoring at four years, 77 (51%) of the plantings were alive.

Cheirodendron trigynum (Gaud.) A. Heller, **`Ōlapa**
Family: Araliaceae (Ginseng family)
Status: Rare in HAVO montane mesic forest

Habitat and Distribution. *Cheirodendron trigynum* is a polymorphic, medium-sized tree species that occurs in wet and mesic forests on all islands except Kaho`olawe (Wagner *et al.*, 1990). At HAVO, *C. trigynum* is abundant in mid-elevation montane rain forest. It was also documented from mesic forest of Kīpuka Puaulu from 1911 (Rock, 1913) into the 1960s (Mueller-Dombois and Lamoureux, 1967) and from Kīpuka Kī in the 1970s. It was not found in surveys conducted in Kīpuka Puaulu and Kīpuka Kī in the 1990s (Pratt and Abbott, unpublished data; Belfield and Pratt, unpublished data). *Cheirodendron trigynum* was included in the rare plant stabilization project because it was a rare tree in montane mesic forest.

Stabilization. Seeds were collected from 25 founder *Cheirodendron trigynum* in three kīpuka north of Kīpuka Puaulu near the Keauhou Ranch. In 2003, 16 seedlings were planted at Kīpuka Kī (Table 5). After 16 months, 11 (69%) of the 16 planted trees at Kīpuka Kī were alive; after 37 months, eight (50%) of the plantings were alive (Table 5). Forty-nine seedlings were planted at Kīpuka Puaulu in five sessions from 2002-2004. At first monitoring, 40 trees were alive. At last monitoring from 27-49 months, 36 plantings were found to be surviving. Across both kīpuka, the survivorship at final monitoring was 68%.

Clermontia hawaiiensis (Hillebr.) Rock, **`Ōhā kēpau**
Family: Campanulaceae (Bellflower family)
Status: Rare in HAVO

Habitat and Distribution. *Clermontia hawaiiensis,* a shrub or small tree of mesic to wet forests, is a Hawai`i Island endemic known from the Puna and Ka`ū Districts (Wagner *et al.*, 1990). It is rare in HAVO where it is known from small disjunct populations in `Ōla`a Forest, wet montane forest along the east Kīlauea summit, and in the East Rift rain forest where it is locally abundant within the crater of Pu'u Huluhulu, along the Nāpau Trail, and near the rim of Nāpau Crater (Pratt *et al.*, 1997). It was documented from Kīpuka Puaulu in very small numbers in 1911 (Rock, 1913) to the 1960s (Mueller-Dombois and Lamoureux, 1967). *Clermontia hawaiiensis* was not found in Kīpuka Puaulu in the early 1990s (Pratt and Abbott, unpublished data). Recently, a single large adult tree of *Clermontia hawaiiensis*, with several saplings nearby, was found in a montane mesic forest kīpuka on the Keauhou/HAVO boundary near Kīpuka Puaulu (S. McDaniel, pers. comm.).

Stabilization. Material for propagation was collected from 20 naturally occurring plants at Sulphur Banks, Pu`u Huluhulu, Crater Rim Trail, and near Nāpau Crater. Three different sets of plantings were combined in Table 5, but are described separately below. In October, 1999, 200 *C. hawaiiensis* seedlings were planted each in Kīpuka Kī and Kīpuka Puaulu. In Kīpuka Kī, 93 plantings were alive when last monitored at 40 months. In Kīpuka Puaulu, 128 plantings were alive after 40 months. In January, 2000, 45 large plants were placed each in Kīpuka Kī and Kīpuka Puaulu. In Kīpuka Kī, 29 plantings were alive after 23 months; 9 were alive after 49 months. In Kīpuka Puaulu, 33 plantings were alive after 23 months; 8 were alive after 49 months. Plants left over from the rat toxicant study were planted in 2002 and 2003. In Kīpuka Kī, 96 seedlings were planted. After 27 months, 53 were alive; after 49 months, 30 plantings were found to be surviving. In Kīpuka Puaulu, 41 plants were placed; only 35 of these were monitored. After 21 months, 28 were alive; after 41 months, 18 were alive. At last monitoring, across the three sets of plantings in Kīpuka Kī, 132 (39%) of 341 plantings were found to be surviving at 40-49 months. For the three sets of plantings in Kīpuka Puaulu at last monitoring after 40-49 months, 154 (55%) of the 280 plants were found to be surviving. Additional plantings were made in 2004 and 2007; however these have not been monitored. Many plantings at both Kīpuka Puaulu and Kīpuka Kī have been observed flowering and fruiting; however, no natural regeneration has been observed to date

Embelia pacifica Hillebr., **Kīlioe**
Family: Myrsineaceae (Myrsine family)
Status: Species of Concern

Habitat and Distribution. *Embelia pacifica* is a climbing vine found scattered in wet to mesic forests on all the Hawaiian Islands except Ni`ihau and Kaho`olawe (Wagner *et al*., 1990). At HAVO, *E. pacifica* is found sparingly in the wet forest of `Ōla`a. Surveys in the early 1990s of Kīpuka Puaulu and Kīpuka Kī documented the presence of small numbers of *E. pacifica* in both sites (Pratt and Abbott, unpublished data). In 1998, only two spreading vines were found in Kīpuka Puaulu and no plants were found in Kīpuka Kī (Belfield and Pratt, unpublished data).

Stabilization. In 2001, cuttings were collected from plants in two large clusters growing in Kīpuka Puaulu and from plants in the Ag Unit of `Ōla`a Forest. Fruiting was observed in just one plant, in Kīpuka Puaulu; ripe fruit was collected, but did not germinate. Thirty-three *E. pacifica* were planted in Kīpuka Kī from 2002-2003 (Table 5). Twenty-five plants (76%) were alive after 16 months and 20 plants (61%) were found to be surviving after 39 months. Ten *E. pacifica* were planted in Kīpuka Puaulu in 2003. All plantings were alive when monitored after 28 months. When monitored at 39 months, 8 plantings (80%) were alive. Across both planting sites in montane mesic forest, 65% of the plantings were alive at last monitoring.

Hibiscadelphus giffardianus Rock, **Hau kuahiwi**
Family: Malvaceae (Mallow family)
Status: Endangered

Habitat and Distribution. *Hibiscadelphus giffardianus* is a small tree known only from the montane mesic forest of Kīpuka Puaulu (Wagner *et al*., 1990). A single, remaining individual was documented there in 1911 (Rock, 1913). Before this individual died seed was collected and propagated by Giffard, a local Volcano resident. Seed collected from this propagated tree was eventually transferred to the Territorial Nursery in Hilo where it was propagated and specimens kept *ex situ*. Between 1951 and 1964, 60 *H. giffardianus* were planted from these specimens in Kīpuka Puaulu and Kīpuka Kī (Morris, 1967). By 2008, only seven of the 1951-1964 plants remained (Pratt *et al*., 2011).

Stabilization. The remaining trees in Kīpuka Puaulu became the seed source and founders for propagation and plantings from 1997-2008 in Kīpuka Puaulu, Kīpuka Kī, and "Kīpuka Aiea." Approximately 340 *H. giffardianus* were planted in the three mesic forest kīpuka during this period.

The largest sample monitored for short-term survival is available from the 75 *H. giffardianus* planted in "Kīpuka `Aiea" in 2004 (not presented in Table 5). After 19 months, only one tree was dead. The largest sample of long-term survival is available from the monitoring of the 200 *H. giffardianus* planted 2000-2001 in Kīpuka Puaulu and Kīpuka Kī as part of the small mammal toxicant research program (Spurr *et al.*, unpublished report) (Table 5). In 2008, the overall survival rate was 73%, with higher survival in Kīpuka Kī (83%) than in Kīpuka Puaulu (63%) (Pratt *et al.*, 2010). Fewer than 10 *Hibiscadelphus giffardianus* planted in the late 1990s and 58 trees planted in Kīpuka Puaulu and Kīpuka Kī from 2002-2006 have not been monitored consistently enough to report**.**

***Kadua affinis* [**formerly ***Hedyotis terminalis*]** (Hook. & Arnott) W.L. Wagner & Herbst, **Manono**
Family: Rubiaceae (Coffee family)
Status: Rare in HAVO montane mesic forest

Habitat and Distribution. *Kadua affinis*, the most polymorphic species in the Hawaiian flora after *Metrosideros polymorpha*, is a shrub or small tree occurring on all the main islands except Ni`ihau and Kaho`olawe (Wagner *et al.*, 1990). In HAVO, it is a locally common species of wet forest. It is currently rare in mesic and dry areas of the park. Only one naturally occurring individual is known from Kīpuka Puaulu and two from Kīpuka Kī. These trees appear to be of great age with large diameters and little observed flowering and fruiting (T. Belfield, pers. comm.). *Kadua affinis* was included in the rare plant stabilization project because their low numbers and senescence may lead to local extinction in Kīpuka Puaulu and Kīpuka Kī.

Stabilization. Seed source for propagation were collected from trees found along the Nāulu and Kalapana Trails. In 2002, 126 *Kadua affinis* were planted in Kīpuka Kī (Table 5). After 23-28 months 70% of a monitored subset of plantings were alive. After 44-52 months, 62 (49%) of all the plantings were found to be surviving. At Kīpuka Puaulu in 2003, 152 individuals of *K. affinis* were planted. After 24 months, 94 (62%) plantings were alive; after 46 months, 37 plants (24%) were found to be surviving. Collectively, in montane mesic forest, the survivorship of plantings was 36% at last monitoring. Many flowering and fruiting plants were found after three years.

Melicope hawaiensis *Wawra*, **Mokihana kūkai**
Family: Rutaceae (Citrus family)
Status: Species of Concern

Habitat and Distribution. *Melicope hawaiensis* is large shrub or small tree occurring in mid-elevation and upland dry to mesic forest on the islands of Moloka`i, Lanai, Maui, and Hawai`i. On Hawai`i Island outside the park, *M. hawaiensis* is found at Pōhakuloa Training Area, Pu`uwa`awa`a, Manukā, and Keauhou. In HAVO, it is known from Kīpuka Puaulu and a separate population of six plants at lower elevation along the boundary of the park with Kapāpala Ranch. The *Melicope hawaiensis* population in Kīpuka Puaulu is in decline. Botanical surveys in the early 1990s located 150 *M. hawaiensis*. By 2008, 40% of these had died, with mortality occurring largely among the youngest and oldest trees, although at least 10 new young trees had recruited into the population (Pratt *et al.,* 2010).

Stabilization. There was limited success propagating *Melicope hawaiensis*. In 2001, 200 cuttings were collected from trees in Kīpuka Puaulu and propagated in the Resource Management nursery facility. Also in 2001, 400 fruits were collected from two trees in Kīpuka Puaulu, with only a single seed germinating. Germination rates improved markedly with collection of fruit from two mature trees of the recently discovered disjunct population along the park boundary with Kapāpala Ranch. The larger two trees of this small outlying population exhibited vigorous flowering and fruiting. These trees became the founders for three seedlings planted at Kīpuka Kī in 2007. Two surviving plantings were located in 2010 (Table 5).

Melicope zahlbruckneri Rock, **Alani**
Family: Rutaceae (Citrus family)
Status: Endangered

Habitat and Distribution. *Melicope zahlbruckneri* is a small to medium sized tree known from three locations on Hawai`i Island. It was collected once in wet forest “between Glenwood and 29 mile” (Wagner *et al.*, 1990). A small population has been recently located in Laupāhoehoe Natural Area Reserve, but the largest population still extant is in park mesic forest at Kīpuka Puaulu (Pratt *et al.,*2010). However, the park population is in decline. In the early 1990s, 37 *M. zahlbruckneri* were located by systematic surveys (Pratt and Abbott, unpublished data). During repeat surveys in 2006-2008, only 19 live trees, with only one small, presumably younger individual, were found (Pratt *et al*., 2010).

Stabilization. Planting of *Melicope zahlbruckneri*, like that of *M. hawaiensis*, has been constrained by limited propagation success. Tissue culture and air layers were unsuccessful; cuttings produced three plantings and seed germination produced one. From this effort only four plants, representing three founder lines, were planted, all in Kīpuka Kī (Table 5). All four plants, in vigorous condition, were located in 2010.

Neraudia ovata Gaud., **Maʻaloa**
Family: Urticaceae (Nettle family)
Status: Endangered

Habitat and Distribution. *Neraudia ovata* is sprawling shrub endemic to the leeward slopes of Hawai`i Island between 300 and 1,450 m elevation (Wagner *et al*., 1990). It is currently restricted to six populations in North and South Kona and Pōhakuloa Training Area. It was historically present at HAVO near the park boundary close to Halfway House at approximately 900 m elevation (Fosberg, 1966).

Stabilization. Plantings were derived from cuttings of 13 founders, including both male and female plants, collected at Pōhakuloa Training Area. Between 2003 and 2005, 44 *N. ovata* were planted in montane mesic forest at Kīpuka Kī (Table 5). The planting site at Kīpuka Kī was in an ecotone between *Acacia koa*)/*Sapindus saponaria* forest and a more sparsely vegetated `ā`ā flow. The plantings were placed on the very edge of the `ā`ā where it thinly covered the deep ash substrate of Kīpuka Kī. This planting site was more mesic than the other outplanting sites and more closely resembled the environment of the founder plants at PTA (T. Belfield, pers. comm.). After 19-24 months, 82% of the plantings were alive with many plants flowering. After 62-88 months, 17 (39%) of the plantings were alive. The plantings were organized in three clusters. The cluster adjacent to the Mauna Loa road had the most surviving individuals (86%), the largest plants 3.3 m (longest dimension) and the most vigorous plants (11 with good vigor and one with poor vigor). Survival was low (17%) and only one plant had good vigor in the other clusters.

Nestegis sandwicensis (A. Gray), **Olopua**
Family: Oleaceae (Olive family)
Status: Uncommon in HAVO

Habitat and Distribution. *Nestegis sandwicensis* is a tree found on all the main Hawaiian Islands except Ni`ihau and Kaho`olawe in lowland to mid-elevation dry and mesic forest (Wagner *et al.*, 1990). At HAVO, it was found sparingly on the mesic slopes above the coastal plain near the eastern park boundary. These areas were covered by lava in the 1980s and 1990s. Now it occurs only in the mesic forests of Kīpuka Puaulu and Kīpuka Kī. In Kīpuka Puaulu, *N. sandwicensis* occurs commonly in thickets, but also as scattered individuals. It is represented by all size classes from seedlings to large adult fruit-bearing trees. *Nestegis sandwicensis* is much less common in Kīpuka Kī, only occurring in one large patch just below the Mauna Loa Road. Augmenting the small population in Kīpuka Kī enhances the long-term viability of this species in HAVO.

Stabilization. In 2002 and 2003, 122 *N. sandwicensis* seedlings were planted in Kīpuka Kī from seed collected of over 50 founders at Manukā (Table 5). After 27 months, 90 (74%) of these plantings were found to be surviving. After 27-46 months, 58 (48%) of the plantings were alive.

Nothocestrum breviflorum A Gray. , **`Aiea**
Family: Solanaceae (Nightshade family)
Status: Endangered

Habitat and Distribution. *Nothocestrum breviflorum* is a dry to mesic forest tree endemic to Hawai`i Island. It occurs on the leeward side of the island from Ka`ū to Kona, including populations at Ka'ūpūlehu and Pu`uwa`awa`a (Wagner *et al.*, 1990). In HAVO, it occurred historically in lowland dry forest at Nāulu and mesic forest at Kīpuka Puaulu and Kīpuka Kī (Fosberg, 1966), although naturally occurring plants may have become extinct in mesic forest by the 1960's (Mueller-Dombois and Lamoureux, 1967).

Stabilization. All plantings were propagated from seed of 15 founders collected at Pu`uwa`awa`a in the Kona District. In 2001-2005, 123 *N. breviflorum* seedlings were planted at Kīpuka Puaulu in three outplanting sessions (Table 5). After 16-23 months, 88% of a subset of plantings was alive. After 19-62 months, 67 (49%) of all the plantings were found to be surviving.

Nothocestrum longifolium A. Gray, **`Aiea**
Family: Solanaceae (Nightshade family)
Status: Rare in montane mesic forest

Habitat and Distribution. *Nothocestrum longifolium* is a mesic to wet forest tree found on all the main Hawaiian Islands except Ni`ihau and Kaho`olawe (Wagner *et al*., 1990). In HAVO rain forest, *N. longifolium* is uncommon and grows scattered in `Ōla`a Forest (Pratt and Abbott, 1997). It also occurs naturally in very low numbers in park mesic forest: one tree in Kīpuka Kī (T. Belfield, pers. comm.); two trees in Kīpuka Puaulu (Pratt and Abbott, unpublished data); and 30 trees in "Kīpuka `Aiea" (T. Belfield, pers. comm.). Zimmer (unpublished report) planted 19 seedlings in "Kīpuka `Aiea" in 1980-1981.

Stabilization. The park plantings were derived from seed of 27 founders at Ka'ūpūlehu and Pu`uwa`awa`a, Kona District. One hundred and eight individuals were planted in Kīpuka Kī (Table 5). After 21-29 months, 78% of the plantings were alive. After 36-50 months 36 plantings (36%) were found to be surviving.

Ochrosia haleakalae St. John, **Hōlei**
Family: Apocynaceae (Dogbane family)
Status: Candidate Endangered Species

Habitat and Distribution. *Ochrosia haleakalae* is a small tree that occurs naturally in dry to mesic forest from 700 m to 1,200 m elevation only on Maui. It was introduced to HAVO in 1954 when 21 individuals were planted in Kīpuka Puaulu and two individuals were planted in Kīpuka Kī. In addition, from 1974 to 1980, 183 individuals of *O. haleakalae* were planted at Kīpuka Puaulu. Rare plant surveys in the early 1990s located 136 *O.* haleakalae with some natural regeneration occurring (Pratt and Abbott, unpublished data). The plantings in the 1950s and 1970s were intended as a reintroduction of the *Ochrosia* species found in 1911 by Rock (1913) in Kīpuka Puaulu. At the time, the taxonomic treatment of the genus *Ochrosia* recognized 11 native species of the genus *Ochrosia* occurring in Hawai`i, with *Ochrosia sandwicensis* on both Maui and Hawai`i Island, including its occurrence at Kīpuka Puaulu.

However, the current treatment of the genus *Ochrosia* recognizes four species: *O. compta* on Oahu, *O. kauaiensis* on Kauai, *O. haleakalae* on Maui, and *O. Kīlaueaensis* on Hawai`i Island. *Ochrosia Kīlaueaensis* was known from Hawai`i Volcanoes National Park where Giffard last collected it in 1927 at Kīpuka Puaulu. It has not been seen since then at this site and is now thought to be extinct. *Ochrosia Kīlaueaensis* was also known from Pu`uwa`awa`a where it persisted longer, but now is also presumed to be extinct (Wagner *et al*., 1990). Because of its planting history and the changes in taxonomic treatment of the genus *Ochrosia*, the rationale for outplanting *O. haleakalae* differs from all other target species in the rare plant stabilization project. *Ochrosia haleakalae* is treated as a surrogate species for the extinct *O. Kīlaueaensis* that it closely resembles phenotypically except for minor floral characteristics (Pratt *et al*., 2011). *Ochrosia haleakalae* is now a rare species in its native range on Maui and warrants protection.

Stabilization. Thirty-nine *O. haleakalae,* all derived from planted founders were planted at Kīpuka Kī in three planting sessions (Table 5). After 5-27 months, 38 (97%) were alive; after 22-48 months, 27 plantings (69%) were still alive. Flowering and fruiting was observed on some individuals.

Phytolacca sandwicensis Endl., **Pōpolo kū mai**
Family: Phytolaccaceae (Pokeweed family)
Status: Rare in HAVO

Habitat and Distribution. *Phytolacca sandwicensis* is a perennial, scandent vine or shrub occurring in mesic to wet forests from 120 m to 1,980 m elevation. It is found on all the main Hawaiian Islands except Kaho`olawe and Ni`ihau (Wagner *et al.*, 1990). At HAVO, where it is rare, *P. sandwicensis* is known from a few scattered individuals in `Ōla`a Forest and three plants in "Kīpuka Aiea" along the Keauhou boundary.

Stabilization. Fruit was collected from the four plants located in `Ōla`a Forest and the two plants in "Kīpuka Aiea." In 2002 from these six founders, 87 plantings in Kīpuka Kī and 137 plantings were made at Kīpuka Puaulu (Table 5). After 14 months in Kīpuka Kī, 62 plants (71%) were alive; after 28 months, 41 plantings (47%) were still alive. In Kīpuka Puaulu, after 15 months, 46 (34%) of the plantings were alive; after 29 months, 20 (15%) of the plantings were found to be alive. Flowering and fruiting were observed in over 90% of the initial plantings after the first year and the remaining plants at last monitoring. Across both montane mesic forest sites, survivorship of *Phytolacca sandwicensis* was 27%.

Pittosporum hosmeri Rock, **Hō`awa**
Family: Pittosporaceae (Pittosporum family)
Status: Uncommon in montane mesic forest

Distribution and Abundance. *Pittosporum hosmeri* is a small to medium sized tree that grows from 380 m to 1,070 m elevation in leeward mesic to wet forest on Hawai`i Island from the Kohala Mountains to Ka`ū (Wagner *et al*., 1990). This species was observed in 1911 by Rock (1913), growing in a small kīpuka between Kīpuka Kī and Kīpuka Puaulu. No natural occurring trees have been documented from the montane mesic forest area of the park since that time. *Pittosporum hosmeri* were planted in Kīpuka Puaulu in the 1920s through the 1970s and in 1970s in Kīpuka Kī, as well as along the Mauna Loa Road between Kīpuka Puaulu and Kīpuka Kī.

Stabilization. In 2002, seed from founders at Kīpuka Puaulu was used to propagate and plant 156 *P. hosmeri* at Kīpuka Kī (Table 5). After 28 months, 147 (97%) were alive. When monitored after four years, 114 plants (73%) were alive (Fig 15).

Figure 15. A thriving planting of *Pittosporum hosmeri* (hōʻawa) in Kīpuka Kī in a stand of *Sapindus saponaria* (mānele)/*Acacia koa* (koa). Seventy-three percent of the 156 plantings of *P. hosmeri* were alive after four years.

Psychotria hawaiiensis (A. Gray) Fosb., **Kōpiko \`ula**
Family: Rubiaceae (Coffee family)
Status: Uncommon in Kīpuka Kī

Distribution and Abundance. *Psychotria hawaiiensis* is a small tree occurring in wet, mesic, and dry forests of Moloka\`i, Maui, and Hawai\`i (Wagner *et al*., 1990). In mesic forest at HAVO it is known from Kīpuka Kī and Kīpuka Puaulu. It occurs in scattered stands or as individuals commonly at Kīpuka Puaulu where it appears to be regenerating by seedling recruitment. *Psychotria hawaiiensis* is uncommon in Kīpuka Kī so plantings were placed there to increase evenness-diversity in montane mesic forest.

Stabilization. Seed was collected from a small number of founder trees at Kīpuka Puaulu. Sixteen seedlings were planted in Kīpuka Kī in 2002-2003 (Table 5). After 23-27 months, 73% of a subset of the plantings were found to be surviving. After 38-49 months, 11 (69%) of the plantings were alive.

Rubus hawaiensis A Gray, **`Ākala**
Family: Rosaceae (Rose Family)
Status: Uncommon in montane mesic forest

Habitat and Distribution. *Rubus hawaiensis* is a shrub growing mostly in mesic forest, wet forest, and subalpine woodland on Kaua`i, Moloka`i, Maui, and Hawai`i (Wagner *et al.*, 1990). In HAVO, *R. hawaiensis* is common in the wet forest at `Ōla`a; however, it is uncommon in subalpine and uncommon to rare in montane mesic forest. In Kīpuka Puaulu, *R. hawaiensis* is known from only a single site. Furthermore, *Rubus hawaiensis* was not observed during surveys of Kīpuka Kī in 1998 (Belfield and Pratt, unpublished data). Augmentation was initiated for *R. hawaiiensis* in montane mesic forest because of its scarcity here.

Stabilization. In 2002-2003, 84 *R. hawaiensis* were planted in four sessions at Kīpuka Kī (Table 5). After13-23 months, 44% of a monitored subset of plantings were alive. After 38-44 months, 22 of the total plantings were found to be surviving. At Kīpuka Puaulu 15 *R. hawaiensis* were planted. After 2-6 months, 12 (80%) were alive; after 15-19 months, 10 plantings (67%) were alive. The overall survivorship of *R. hawaiensis* in montane mesic forest at last monitoring was 32%.

Rumex giganteus W.T. Aiton, **Pāwale**
Family: Polygonaceae
Status: Rare in HAVO

Habitat and Distribution. *Rumex giganteus* is a scandent shrub or liana that occurs in wet, mesic, and subalpine woodland on Moloka`i, Maui, and Hawai`i (Wagner *et al.*, 1990). At HAVO, *Rumex giganteus* is known from wet and mesic forest in `Ōla`a Forest, mesic *Metrosideros polymorpha* woodland near Pu`u Puai, montane mesic forest at "Kīpuka `Aiea", and montane *Metrosideros/Sophora* woodland near the Mauna Loa Road. *Rumex giganteus* was not located during surveys of Kīpuka Puaulu in the early 1990a (Pratt and Abbott, unpublished data) and during a survey of Kīpuka Kī in the late 1990s (Belfield and Pratt, unpublished data).

Stabilization. In 2002, 63 *R. giganteus* were planted at Kīpuka Kī (Table 5). Fifteen of the plantings were flowering at the time of planting. Monitored only once at 28 months, 36 plantings (57%) were alive. Nine plantings exceeded five meters in length. Ten seedlings were found associated with one of the plantings (T. Belfield, pers. comm.). In Kīpuka Puaulu, 93 individuals of *R. giganteus* were planted, also in 2002. After 15 months, 80 (86%) of the plantings were found to be surviving. After 29 months, 42 (45%) were alive.

Sicyos macrophyllus A. Gray, **`Ānunu**
Family: Cucurbitaceae (Gourd family)
Status: Candidate Endangered Species

Habitat and Distribution. *Sicyos macrophyllus* is a fast-growing, perennial herbaceous vine found in a few disjunct locations in montane wet forest and subalpine woodlands of Hawai`i Island from 1,200-2000 m elevation (Wagner *et al.*, 1990). At HAVO, *S. macrophyllus* is known from a few plants in Kīpuka Kī and lower Kīpuka Mauna`iu. At Kīpuka Kī, plants have been observed to persist for more than 10 years, dying back and replacing themselves, apparently from a localized seed bank. A persistent seed bank is suggested by the recruitment of seedlings in *S. macrophyllus* sites several years after the death of the seed producing plants, the hard seed coat that seems to require scarification, and presence of *S. macrophyllus* seed in the soil seed bank (L. Pratt, pers. comm.).

Stabilization. Seed from remnant plants in the Kīpuka Kī population of *Sicyos macrophyllus* were used as founders for all the montane mesic forest plantings. Most of the seedlings planted resulted from germination trials in the rare plant limiting factors study (Pratt *et al., 2010*). Thirty-six individuals of *S. macrophyllus* were planted in Kīpuka Kī and Kīpuka Puaulu from 2006-2007 or earlier (T. Belfield, pers. comm.). Of the 11 seedlings planted and monitored in Kīpuka Kī in 2006 (Table 5), eight plantings were alive after 18-20 months; six were alive after 29-31 months (Pratt *et al*., 2010). Of the seven plantings monitored in Kīpuka Puaulu, five were alive after 18-20 months; only one plant was alive after 29-31 months. Most of the surviving plants exceeded lengths of 5.0 m and were flowering and fruiting at last monitoring (T. Belfield, pers. comm.).

Urera glabra (Hook. & Arnott) Wedd., **`Ōpuhe**
Family: Urticaceae (Nettle family)
Status: Rare in HAVO

Habitat and Distribution. *Urera glabra* is a dioecious shrub or small tree growing occasionally in mesic or wet forest from 150 m to 1,700 m elevation on all the main Hawaiian Islands except Ni`ihau and Kaho`olawe (Wagner *et al.*, 1990). At HAVO, *U. glabra* is rare to uncommon in the `Ōla`a Forest's Koa Unit and Small Tract Unit with less than 20 known individuals; all but one of these are mature trees (Pratt and Abbott, 1997). In the East Rift, *U. glabra* is only known to occur within the crater of Kane Nui O Hamo (T. Belfield, 1998) and another site in the lower East Rift (Pratt, pers. com.). It is rare in park montane mesic forest at Kīpuka Puaulu, Kīpuka Kī, and "Kīpuka `Aiea". Moreover, it can be considered to be functionally extinct in this environment because male and female plants are not present together in any of these kīpuka.

Stabilization. Because fertile seeds were not available, all material for planting was derived from cuttings representing 18 founder lines (including two male plants). Material was taken from mature individuals in `Ōla`a Forest's Koa Unit, Small Tract, and Kīpuka Puaulu, Kī, and "`Aiea." The strategy for this species was to plant male and female plants in clustered groupings to facilitate pollination.

One-hundred sixty-three cuttings of *Urera glabra* were planted in Kīpuka Kī in four sessions from 2002-2006 (Table 5). At 5-7 months, 100% of the plantings were alive. At 23-27 months, 75% of a subset of 16 plantings were alive. After 23-48 months, 71% of a subset of 38 monitored plantings were found to be surviving. One-hundred ninety-three *U. glabra* were planted in Kīpuka Puaulu in three sessions from 2002-2004; only 43 of these were monitored. After 21-27 months, 20% were alive; after 24-49 months, 7 (16%) were alive. Phenology was monitored in 2005; 100% of the surviving plants, both male and female plants, flowered. Female plants produced large clusters of fruit that were collected and successfully germinated in the greenhouse with a 90% germination rate (T. Belfield, pers. comm.).

Xylosma hawaiiense Seem., **Maua**
Family: Flacourtiaceae (Flourcourtia family)
Status: Rare in montane mesic forest

Habitat and Distribution. *Xylosma hawaiiense* is a small to medium sized tree found on all the main Hawaiian Islands except Ni`ihau and Kaho`olawe (Wagner *et al.*, 1990). It occurs primarily in mesic forest, but also is known from dry forests and wet forests. In HAVO, *X. hawaiiense* occurs as widely scattered trees in the wet forest of `Ōla`a (Pratt and Abbott, 1997) and in the montane mesic forest of Kīpuka Puaulu. Kīpuka Puaulu, with approximately 30 trees (Pratt and Abbott, unpublished data), has the highest concentration of *X. hawaiiense* in the park.

Stabilization. Because fruit with viable seed did not seem to be available from park trees (T. Belfield, pers. comm.), fruit was collected from two trees at Ka'ūpūlehu and a single tree at Pu`uwa`awa`a, Kona. At Kīpuka Kī, 64 seedlings were planted in 2003 (Table 5). After 23 months, 53 plantings were alive; after 44 months, 21 plantings were found to be surviving. At Kīpuka Puaulu, 22 seedlings were planed in 2001 and 2003. After 6-26 months, 12 (55%) of the plantings were alive; after 41-63 months, the 12 plantings were still alive.

Zanthoxylum dipetalum var. ***dipetalum*** H. Mann, **Kāwa`u**
Family: Rutaceae (Rue family)
Status: Species of Concern

Habitat and Distribution. *Zanthoxylum dipetalum* var. *dipetalum* is a short to medium-sized tree that occurs in dry to mesic forest, and sometimes in marginally wet forest, on Kaua'i, O`ahu, Moloka`i, and Hawai'i (Wagner *et al.*, 1990). On Hawai`i Island outside HAVO, it is known from Kawaihae, Kohala Mountains, windward Mauna Loa, and Manukā Natural Area Reserve. At HAVO, it is found only in montane mesic forest at Kīpuka Puaulu where it is naturally rare and augmented by plantings (Pratt *et al.*, 2010). Rock (1913) observed two trees. Park planting records (Morris, 1967;

Zimmer, unpublished report) indicate that over 50 seedlings were planted from the 1940s through the 1970s. Sixty-two *Z. dipetalum* var. *dipetalum* trees were found in the early 1990s (Pratt and Abbott, unpublished data). These included naturally occurring individuals and regeneration as well as plantings (Pratt *et al*., 2010). Three adult trees, apparently undocumented plantings, were found in a survey in Kīpuka Kī in 1998 near the Mauna Loa Road (T. Belfield and Pratt, unpublished data).

Stabilization. Founders were taken from both naturally occurring and planted trees in Kīpuka Puaulu. In 2003, 86 *Z. dipetalum* var. *dipetalum* were planted in Kīpuka Kī over four sessions (Table 5). After 21-23 months, 68 plantings were alive. At final monitoring after 42-44 months, 32 plantings were found to be surviving (Fig. 16).

In 2005, 12 individuals of *Zanthoxylum dipetalum* var. *dipetalum* were planted in Kīpuka Puaulu. Three of these were found to be surviving in 2010 after 62 months.

Figure 16. Planting of *Zanthoxylum dipetalum* var. *dipetalum* (a`e) (foreground) in *Sapindus saponaria* (māmele)/*Acacia koa* (koa) stand in Kīpuka Kī, montane mesic forest. Thirty-seven percent of the 86 plantings in Kīpuka Kī were alive after nearly four years. Most of the surviving plantings of his species were in portions of the forest with open understory such as the one illustrated, cleared of alien plants in the last two decades, mostly of *Solanum pseudocapsicum* (Jerusalem cherry) and *Rubus argutus* (Florida prickly blackberry).

Zanthoxylum kauense A Gray., **A`e**
Family: Rutaceae (Rue family)
Status: Species of Concern (federal)

Habitat and Distribution. *Zanthoxylum kauense* is a small to medium-sized tree that occurs on all the main Hawaiian Islands except Ni`ihau and Kaho`olawe (Wagner *et al*., 1990). *Zanthoxylum kauense* is one of the rarest plant species in HAVO. It was documented from Kīpuka Puaulu in the 1940's (Fagerlund and Mitchell, 1944). It was not found in surveys in the 1960s (Mueller-Dombois and Lamoureux, 1967) and in the early 1990s (Pratt and Abbott, unpublished data). A single tree was located in 2001 (T. Belfield, pers. comm.) and another tree was located in the park's `Ōla`a Forest, Koa Unit (Pratt *et al*., 2011). The nearest known population of *Z. kauense* is in the `Ōla`a Forest Reserve where five trees were located in 2001 (Pratt *et al*., 2010).

Stabilization. Because collected seed did not germinate, seedlings from `Ōla`a Forest Reserve were transplanted to the park plant nursery. Ten surviving seedlings were planted in Kīpuka Puaulu in 2003 (Table 5). After 16 months, four plants had died. Kalij pheasant browsing was evident on the leaves and growing tips (T. Belfield, pers. comm.). The remaining live plants were caged to protect them from kalij pheasants. No live plants were found at last monitoring in 2010 after 77-80 months. The cages found near the naturally occurring *Z. kauense* containing dead *Z. kauense* plantings were completed covered with invasive *Ehrharta stipoides* grass.

Discussion

Survivorship of plantings at final monitoring (46%) was higher in montane mesic forest than in any other planting environment of the rare plant stabilization project. Habitat recovery may be an important factor responsible for high survivorship. Kīpuka Puaulu and Kīpuka Kī Special Ecological Areas have been managed intensively for invasive species for several decades; natural recovery of common native plants species is evident and even dramatic in some areas. Recovering ecosystems provide habitat for establishment and growth of rare plants or plantings. Soil moisture in the deep ash, mesic forest environment was undoubtedly less limiting than in more xeric planting environments. Watering after planting was facilitated by road access to these kīpuka. The majority of the plantings, including 21 of the 22 target species for the montane mesic forest, were placed in Kīpuka Kī where restoration created favorable conditions for survival and growth of plantings. The *Acacia koa*/*Metrosideros polymorpha*/*Sapindus* tree canopy was intact. The subcanopy of native shrubs and small trees was patchy, unlike the often dense subcanopy in Kīpuka Puaulu. In addition, the forest floor understory was also largely open because of the recent control of *Rubus argutus*, *Solanum pseudocapsicum*, and alien grasses.

Another factor that may also partly account for the apparently higher survivorship of plantings in montane mesic forest is the time-frame for monitoring.

Final monitoring for most species was conducted after three to four years. Survivorship declined sharply in coastal strand, lowland dry-mesic forest, mid-elevation woodland and scrub, and montane rain forest between two years after planting and final monitoring at six to seven or more years. The last monitoring for most species was conducted in 2006 in the montane mesic forest. A comprehensive monitoring of plantings here would provide monitoring data more comparable in time-frame to monitoring in other ecosystems and detect if a similar “shake-out” of species occurred.

Stabilization efforts with both common and rare species contributed about equally to the high survivorship of plantings in montane mesic forest. Common planted species include those species currently common in either Kīpuka Puaulu or Kīpuka Kī or other parts of the park: *Charpentiera obovata, Cheirodendron trigynum, Kadua affinis, Nestegis sandwicensis, Pittosporum hosmeri, Psychotria hawaiiensis*, and *Rubus hawaiiensis.* The abundance of these species in some environments of the park, especially in montane mesic forest, suggests that limiting factors for their establishment and growth are not as constraining as limiting factors are for more rare species. Plantings of these species accounted for 36% of the total plantings in the montane mesic forest and the average survivorship of the plantings was 49%.

The survivorship of plantings of listed and rare species contributed as much as common species to the high survivorship of plantings in montane mesic forest. The listed species were *Hibiscadelphus giffardianus*, *Melicope zahlbruckneri*, *Nothocestrum breviflorum*, *Neraudia ovata*; *Ochrosia haleakalae, Sicyos macrophyllus, Embelia pacifica*, *Melicope hawaiensis*, *Zanthoxylum dipetalum* var. d*ipetalum*, and *Zanthoxylum kauense*. The rare species are either rare in montane mesic forest or rare throughout the park. These include *Clermontia hawaiiensis, Nothocestrum longifolium*, *Phytolaccca sandwicensis*, *Rumex giganteus*, *Urera glabra*, and *Xylosma hawaiiense*. Plantings of these species accounted for 74% of the total plantings; the average survivorship was 46%.

The survivorship and scope of stabilization efforts with *Hibiscadelphus giffardianus* is greater than with any other species in the montane mesic forest and rare plant stabilization project. This species was reduced early in the twentieth century to one known individual under propagation. All the individuals in the wild at the beginning of the stabilization project were in Kīpuka Puaulu and were planted. By 2008, there were just seven of these plantings surviving. In the stabilization project, approximately 340 *H. giffardianus* were planted in the park and there is monitoring data for 200 of these over 7-8 years; 73% were surviving with flowering and fruiting. Stabilization also involved planting in three montane mesic forest kīpuka including “Kīpuka `Aiea” along the Keauhou/HAVO boundary. These plantings had little mortality when monitored at 19 months; no longer-term monitoring has been done.

Among the listed and rare species, survivorship of several species was also relatively high, at least in comparison to survivorship in other target ecosystems. These species included *Ochrosia haleakalae* (69%), *Embelia pacifica* (65%), *Rumex giganteus* (50%), *Nothocestrum breviflorum* (49%), *Clermontia hawaiiensis* (46%), *Sicyos macrophyllus* (39%), *Zanthoxylum dipetalum* var. *dipetalum (37%)*, and

Xylosma hawaiiense (33%). These results predict that greater stabilization of these species can be achieved with additional plantings without change in propagation or planting methodology. Planting them in additional montane mesic forest sites such as "Kīpuka `Aiea" will also enhance stabilization by reducing loss through chance demographic or environmental events. Restoration of "Kīpuka `Aiea" and a nearby site on deep ash informally called "Kīpuka Alani" is underway. Restoration also includes plantings of rare montane mesic forest species.

Stabilization efforts were not as successful with some of the most vulnerable and rarest species including *Melicope hawaiensis*, *M. zahlbruckneri*, and *Zanthoxylum kauense*. Survivorship was high in *Melicope hawaiensis* (67%) and *M. zahlbruckneri* (100%). However, propagation resulted in limiting number of individuals to be planted; only three *M. hawaiensis* and four *M. zahlbruckneri* were planted. Since these planting efforts, it has been discovered that *M. hawaiensis* seeds have delayed dormancy or require after-ripening; germination rates are higher if the seeds are stored for a period (L. Pratt, pers. comm.). For *M. zahlbruckneri*, few fruit were found and seed germination rates were very low. In addition, cuttings and air layering failed. Successful air layering is now in progress by the staff of the Volcano Rare Plant Facility. None of the plantings of *Zanthoxylum kauense* survived. However, the sample size was small (10 plantings). If propagules become available, new plantings can be protected from kalij pheasant at the outset and a wider range of microsites can be tested, including those without dense swards of alien *Ehrharta stipoides* grass.

The most successful *Neraudia ovata* plantings in the stabilization project were in Kīpuka Kī, in the planting cluster just below the Mauna Loa Road. In spite of being set back by spray drift from alien plant control operations with herbicides, 12 of 14 plantings were alive, averaging 3.3 m in longest dimension. Eleven of the plantings had good vigor. The differences in site quality of the three planting areas were subtle since they shared the same *Acacia koa* and *Sapindus saponaria overstory*. The successful site was less rocky and the `a`a layer may have been thinner. The other sites appeared to be more centered on the sides of the `ā`ā flow. Also, the successful site was located just below the pavement of Mauna Loa Road that sloped toward the site, possibly providing additional run off from precipitation. There are additional similar sites in Kīpuka Kī below the Mauna Loa Road along the central `ā`ā and the flow on the east side of the kīpuka.

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UPPER MONTANE/SUBALPINE WOODLAND/SCRUB

Study Site and Methods

The upper montane environment extends from approximately the Powerline Road at 1,150 m elevation to 1,900-2,000 m elevation on the Mauna Loa Strip. At its upper extent, it grades into the subalpine that extends to tree line at approximately 2,600 m elevation. Because of the modest number of rare species planted in these two intergrading communities (Table 6), stabilization efforts are reported and analyzed together.

The upper montane and subalpine environments lie within or above the trade wind zone temperature inversion. As a result, precipitation decreases with increasing elevation. The average annual rainfall at the top of the Mauna Loa Strip Road, located in the transition between the two ecosystems, has averaged 1,190 mm over the last 11 years (HAVO Fire Cache, unpublished data). Summer is the driest season. Interception of cloud moisture from low clouds is an important source of moisture for plants in this zone (Doty and Mueller-Dombois, 1966). All of the plantings were placed in Kīpuka Kulalio, 1,500-3,000 year old pāhoehoe flows with ash pockets and exposed rock.

The vegetation of the upper montane environment is a complex mosaic of small, intergrading stands of *Acacia koa* (koa) forest, *Acacia koa-Dodonaea viscosa* (\`a\`ali\`i)-*Sophora chrysophylla* (māmane) forest, *Leptecophylla tameiameiae* (pūkiawe)-*Dodonaea viscosa* shrublands, and *Deschampsia nubigena* grasslands. Subalpine vegetation is characterized by *Metrosideros polymorpha* (\`ōhi\`a) scrub, with small, scattered to open trees of *Metrosideros* typically each with a localized understory of native shrubs and herbs (Fig. 17). More scattered shrubs and herbs occur away from *M. polymorpha*. The ecotone between the upper montane and

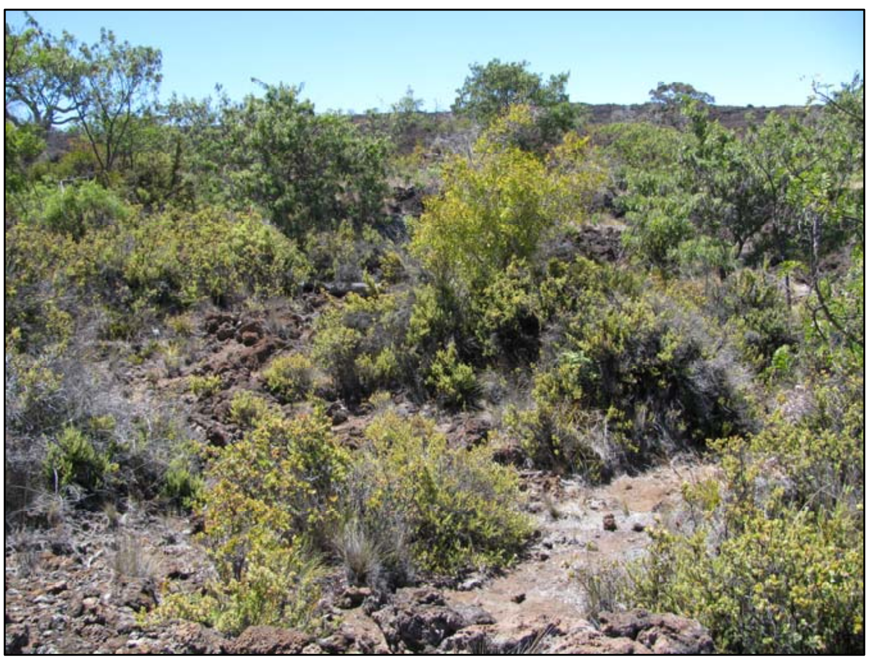

Figure 17. Typical subalpine woodland planting site. Vegetation is characterized by scattered *Sophora chrysophylla* trees in a matrix of *Metrosideros polymorpha* (\`ōhi\`a) scrub, with a localized understory of native shrubs, herbs and grasses.

subalpine, where many plantings were placed, is characterized by a mosaic of small stands of *Acacia koa* and scattered trees of *Sophora chrysophylla* in a matrix of *Metrosideros* scrub.

The vegetation of the upper montane and subalpine is recovering from the recent removal of feral ungulates, particularly feral goats (*Capra hircus*), that were controlled by exclusionary fences and systematic hunting in the upper montane in the early 1970s and the subalpine in 2000. Feral pigs (*Sus scrofa*) were removed from the upper montane in the mid-1980s and the subalpine in 2000. The few mouflon sheep (*Ovis musimon*) that had taken up residence in the upper montane and subalpine in late 1990s were excluded in 2000.

Now that feral ungulates have been eradicated, *Acacia koa* is expanding into the other communities in upper montane, mostly by root-sprouting (Tunison *et al*., 1995). *Sophora chrysophylla* is regenerating noticeably in both the upper montane and lower subalpine (R. Loh, unpublished data), and native grasslands are slowly recovering (Tunison *et al.,* 1994). Removal of feral ungulates has also noticeably benefited the rare subshrub, *Geranium cuneatum,* (nohoanu) (Belfield and Pratt, 2002). More subtle recovery patterns of other native plant species following feral ungulate removal await further monitoring and analysis.

Invasive plants have probably had less impact in the upper montane and subalpine ecosystems than they have at lower elevations at HAVO (Doty and Mueller-Dombois, 1966; Smith, 1985); these environments are dominated by native vegetation, although certain invasive species such as *Pennisetum setaceum* (fountain grass) (Tunison, 2002) and *Verbascum thapsus* (common mullein) (Ansari and Daehler, 2000) remain threats. Ungulate-free upper montane and subalpine ecosystems with recovering native vegetation and minimal competition from alien plants, and possibly a more intact community of arthropod and avian pollination vectors, should provide a favorable environment for the stabilization of rare plants.

Recent systematic surveys of the upper montane and subalpine (Belfield and Pratt, 2002) located populations of three endangered plant species, *Asplenium peruvianum* var*. insulare*, *Phyllostegia racemosa (= cf. stachyoides)* (kīpanapona), and *Plantago hawaiensis* (laukahi kuahiwi*);* one threatened species, *Silene hawaiiensis* (Hawaiian catchfly); and one species of concern, *Sisyrinchium acre* (mau`u lāli`i). These surveys also revealed the presence of five species rare in the park: *Exocarpos menziesii* (heau), *Geranium cuneatum* subsp. *hypoleucum* (nohoanu), *Tetramalopium humile*, *Pittosporum confertiflorum*, and *Rumex giganteus* (pāwale) (Belfield and Pratt, 2002). The relatively low number of rare species may reflect the floristic simplicity of the upper montane and subalpine and recovery of some native species following feral goat removal.

Rare plant stabilization in the upper montane and subalpine addressed seven species. Reintroduction of the endangered *Argyroxiphium kauense* (Ka`ū silversword) began in 1999 with the eventual planting of over 11,000 seedlings (Robichaux *et al.,* 2008). Six other listed or rare plant species were reintroduced or augmented by plantings including two endangered species (*Plantago hawaiensis* and *Stenogyne angustifolia*); three species of concern (*Fragaria chiloensis* subsp. *sandwicensis*, *Phyllostegia* cf. *stachyoides*, and *Scaevola Kīlaueae)*, and one species rare in the park (*Exocarpos menziesii*).

Results by Species

Table 6. Survival of Plantings in Upper Montane/Subalpine Woodlands/Scrub

Species	**Number Planted[b]**	**Percent[a] Survival Early Monitoring**	**Percent Survival Last Monitoring**	**Number Survivors**
Exocarpos menziesii	10	0% (12 mos.)	NA	0
Fragaria chiloensis	37	NA	0% (81-94 mos.)	0
Phyllostegia cf. stachyoides	158	24% (29 mos.)	10% (38-58 mos.)	16
Plantago hawaiensis				
Upper Exclosure	351	100% (12 mos)	0% (109 mos.)	0
Lower Exclosure	201	NA	46^ (109 mos.)	92
Scaevola kilaueae	59	48% (7 mos.)	3% (78-83 mos.)	2
Stenogyne angustifolia	204	91% (4 mos.)	1% (35-50 mos.)	3
Total	**1020**		**11%**	**113**

[a] *Percent survivorship is presented for early monitoring because subsets of plantings monitored for some species*
[b] *Number planted and monitoring. See text for additional plantings not monitored*

Exocarpos menziesii Stauffer, **Heau**
Family: Santalaceae (Sandalwood family)
Status: Rare in HAVO

Habitat and Distribution. *Exocarpos menziesii* is a low growing, semi-parasitic woody shrub that occurs from 1,400 to 2,100 m elevation almost exclusively on Hawai`i Island from Pōhakuloa, Hualālai, and Mauna Loa, where it is the most abundant (Wagner *et al*., 1990). At HAVO, *E. menziesii* occurs only in subalpine shrublands at the Mauna Loa Strip and Kahuku (Fig. 18). Only 11 plants have been located in the Mauna Loa Strip (Pratt and Belfield, 2002; Belfield, pers. comm.); well over 200 plants were widely distributed through the subalpine in Kahuku.

Stabilization. Seeds were collected from founder plants in the subalpine on the Mauna Loa Strip the population. Germination occurred seven months after seeds were sown and the growth rate of seedlings was slow. In 2003, 10 seedlings, all less the 5 cm in height were planted in the lower silversword exclosure within subalpine *Metrosideros* scrub (Table 6). All plantings died.

Figure 18. Natural indivduals of *Exocarpus menziesii* in subalpine woodland. Seeds of *Exocarpos menziesii* were collected; however propagation was difficult producing only 10 seedlings, none of which survived planting.

Fragaria chiloensis subsp. ***sandwicensis*** (L.) Duchesne, **`Ōhelo papa**
Family: Rosaceae (Rose family)
Status: Species of Concern (Federal)

Habitat and Distribution. *Fragaria chiloensis* subsp. *sandwicensis* is a perennial herb that grows from rhizomes or long stolons. It occurs only at high elevations on Maui and Hawai`i Island (Wagner *et al.,* 1990). In HAVO, *F. chiloensis* subsp. *sandwicensis* is only known from the recently acquired Kahuku addition. Here is occurs within subalpine scrub north of the boundary with Ka`ū Forest Reserve in an estimated population totaling nearly 600 plants (Benitez *et al*., 2008). *Fragaria chiloensis* may have been present in the Mauna Loa Strip area of the park since it is known to occur on adjacent lands (Pratt *et. al.,* in prep.).

Stabilization. Cuttings from 25 founder plants at the Pu`uwa`awa`a Forest Reserve were collected prior to the acquisition of Kahuku. From these founders, 37 *Fragaria chiloensis* plants were planted in 2003 into seven plots located in the lower silversword exclosure in subalpine scrub at approximately 2050 m elevation and three plots in upper montane woodland along the Mauna Loa Road at approximately 1,700 m elevation (Table 6). An additional, undocumented number, possibly 15-20, were also planted in two plots at 1,800 m elevation west of the Mauna Loa Road, but these could not be relocated. The first eight plots mentioned above were relocated and monitored in 2010; no live *Fragaria chiloensis* were found.

Phyllostegia cf. stachyoides A. Gray, (no common name)
Family: Lamiaceae (Mint family)
Status: Species of Concern

Habitat and Distribution. *Phyllostegia cf. stachyoides* is a perennial herb known from Moloka`i, Maui, and Hawai`i Island (Wagner *et al*., 1990*).* At HAVO*, P.* cf. *stachyoides* was collected from Kīpuka Puaulu in 1915. Individuals of *Phyllostegia* were discovered in 1987 from five sites near the1,800 m contour in Kīpuka Mauna`iu of the Mauna Loa Strip. These specimens of *Phyllostegia*, a problematic taxon, were provisionally identified as *Phyllostegia racemosa* (Belfield and Pratt, 2002) or *Phyllostegia parviflora* (Pratt *et al*., 2011). They are now identified tentatively as *Phyllostegia* cf. *stachyoides* (L. Pratt, pers. comm.). In Kīpuka Mauna`iu where it is naturally occurring, *Phyllostegia* cf. *stachyoides* is an understory component in a dry to mesic upper montane forest of *Acacia koa*, S*ophora chrysophylla,* and *Myoporum sandwicense* (Pratt *et al*., 2011).

Stabilization. Cuttings and seed from the recently discovered *Phyllostegia. cf. stachyoides* in HAVO were used as founder material. Four plots with a total of 183 plantings were established in 2005 and 2007 within Kīpuka Kulalio along the Mauna Loa Road near 1,800 m elevation in mixed stands of *Acacia koa*, *Dodonaea viscosa*, and *Sophora chrysophylla*, a similar environment to the natural population (Table 6) (Fig. 19). Three of the plots were part of a rare plant limiting factors study (L. Pratt, pers. comm.). After 29 months, 24% of the individuals in a large subset of 133 plantings were alive. Many plants were flowering and fruiting. At final monitoring after 38-58 months, 16 of the total of 183 plantings from the four plots (10%) were found to be surviving (L. Pratt, pers. comm.). No natural seedling recruitment was observed.

Figure 19. Planted *Phyllostegia* cf. *stachyoides* within Kīpuka Kulalio in a mixed stand of *Acacia koa, Dodonaea viscosa,* and *Sophora chrysophylla*.

Plantago hawaiensis (A. Gray) Pilg., **Laukahi kuahiwi**
Family: Plantaginaceae (Plantain family)
Status: Endangered

Habitat and Distribution. *Plantago hawaiensis* is a perennial herb endemic to Hawai`i Island. It typically grows on upper leeward slopes between 1,800 and 1,950 m elevation (Wagner *et al.*, 1990). In HAVO, *P. hawaiensis* is found in the subalpine of the Mauna Loa Strip section of the park above 1,800 m elevation in both Kīpuka Kulalio and Kīpuka Mauna`iu (Belfield and Pratt, 2002). At Kahuku, the species is known from a single small population in the subalpine zone above the Ka`ū Forest Reserve (Benitez *et al*., 2008). The vulnerability of small *P. hawaiensis* populations was documented by Belfield and Pratt (2002) who recorded the loss of most individuals from a naturally occurring population of over 300 plants in Kīpuka Kulalio, possibly from erosion following heavy winter rains.

Stabilization. Seeds were collected from founder individuals in the lower subalpine at Kīpuka Mauna`iu. From 2001-2005, over 700 *Plantago hawaiensis* seedlings were planted in Kīpuka Kulalio inside and near the upper and lower silversword exclosures near the Mauna Loa Trail between 2,000 and 2,200 m elevation. Short-term monitoring is available only for 120 *P. hawaiensis* planted in 2003 inside the upper silversword exclosure to determine the effects of Kalij Pheasant herbivory on *P. hawaiensis*. No mortality was observed over one year (K. Postelli, unpublished data). Long-term monitoring is available for the 552 plantings placed in the two silverswords exclosures in 2001. Both exclosures were censused in 2010. In the lower exclosures, where 201 silverswords were planted, 91 surviving plantings were found, almost all in good condition. Thirty percent of the surviving *P. hawaiensis* had flowers or fruits. Sixteen percent had clusters of smaller plants adjacent to a larger plantings or metal identification tags, suggesting the presence of recruited seedlings. No live *Plantago hawaiensis* were found in the upper silversword exclosure where 351 plantings were placed. Survivorship across both at final monitoring after nine years was 17%.

Scaevola Kīlaueae Degener, **Naupaka kuahiwi**
Family: Goodeniaceae (Goodenia family)
Status: Species of Concern

Habitat and Distribution. *Scaevola Kīlaueae* is endemic to Hawai`i Island between 1,000 and 1,500 m elevation (Wagner *et al*., 1990). Outside HAVO, it is known from several disjunct sites in Ka`ū at Hawaiian Ocean View Estates and Kapāpala Ranch and in Puna north of Pāhoa. In HAVO, it is found in mid-elevation woodland and scrub in the Ka`ū Desert south of Kīlauea Caldera from the upper Chain of Craters to the Keā`moku Flow; it is relatively common in the Hilina Pali Road area.

Stabilization. Seed was collected from a founder population growing at approximately 1,850 m elevation in Kapāpala Ranch to the west of the park. The discovery of this population in 2001 was the basis of an introduction to the park in the upper montane; there were no park record of this species on the Mauna Loa Strip. In 2003, 59 seedlings of *Scaevola Kīlaueae* were planted in upper montane seasonal at 1900 m elevation (Table 6). After seven months, 50 plantings were alive. When last monitored at 78-83 months, only two surviving plants, both with good vigor, were found.

Stenogyne angustifolia A. Gray, (No common name)
Family: Lamiaceae (Mint family)
Status: Endangered

Habitat and Distribution. *Stenogyne angustifolia* is a rare plant found on Moloka`i, Maui, and Hawai`i Island (Wagner *et al.*, 1990). There is now only one extant naturally occurring population on Hawai`i Island, at 1,500-2,100 m elevation in Pōhakuloa Training Area (Pratt *et al*., 2011). *Stenogyne angustifolia* was apparently growing in or near the park, based on a historical collection from the nineteenth century (Fosberg, 1966). No other sightings of this species in proximity to the Mauna Loa Strip section of the park have been reported (Pratt *et al*., 2011). There are two historical collection records from Kahuku, one from the 1930's (Benitez *et al*., 2008) and one from the 1970s (L Pratt, pers. comm.).

Stabilization. All planted material at HAVO was propagated from cuttings representing over 10 found lines of naturally occurring plants at Pōhakuloa Training Area. A total of 204 plantings were placed in two locations in the upper montane: 1,900 m elevation near the Mauna Loa Road and 2,000 m elevation in lower subalpine environments adjacent to the Mauna Loa Trail (Table 6). These plants were monitored just once, in 2010. After four years, 3 of the 48 plantings in the upper montane were still surviving. None of the 156 planting in the subalpine planting site were alive after 3-4 years.

Discussion

The average survivorship (11%) of all planted species in the upper montane/subalpine environments (Table 6) was similar to survivorship of plantings in dry to mesic environments such as the lowland dry-mesic forest and mid-elevation woodland (Tables 2 and 3). Without the relatively high survivorship of the fairly large number of plantings of *Plantago hawaiensis* in the lower silversword exclosure, the average survivorship of the upper montane/subalpine would have been 3%, similar to the very low survivorship of the plantings in the coastal strand.

Stabilization work in the lower silversword exclosure with *Plantago hawaiensis* was productive. Over 90 plantings were established with small plants resulting from seedling recruitment found adjacent to 15 of these plantings. The disparity of survivorship between the two silversword exclosures is counterintuitive. The exclosures are only one kilometer apart and in the same subalpine *Metrosideros* scrub habitat. Microsites utilized in the two exclosures could not be compared since flags and tags had been removed from the dead *P. hawaiensis* plantings in the upper exclosure. The survivorship of *Argyroxiphium kauense* (Ka`ū silversword) has not been monitored recently so survivorship cannot be quantitatively compared. However, the remaining silverswords appeared to be much larger and more vigorous in the lower exclosure, even though they were planted in approximately the same years as the ones in the upper exclosure. One speculation that can be offered is that the lower exclosure is more windward and lower and may receive more precipitation and moisture from cloud water, an important source of moisture in the subalpine (Doty and Mueller-Dombois, 1966). Another speculation is that there are more sites in the lower silversword exclosure with greater soil depth, particularly next to the ā`ā flow in the exclosure and in the bottom of lava flow channels. Silverswords tended to be largest in these sites and many of the surviving and recruiting *Plantago hawaiensis* seedlings were found in these sites. There is similar habitat along this flow above the lower exclosure and in nearby flow channels; these may provide favorable sites for future plantings.

The small number of plantings of *Fragaria chiloensis* and *Exocarpos menziesii* failed altogether. Plantings of *Exocarpos menziesii* and *Fragaria chiloensis* were carried out in 2003, the same year Kahuku, with its extensive upper montane and subalpine environments, was acquired. When stabilization efforts began, *Exocarpos menziesii* was known only from 11 individuals in the subalpine on the Mauna Loa Strip. Survey work at Kahuku has located about 200 plants in the eastern subalpine woodland and additional plants in the central and western subalpine. *Fragaria chiloensis* was observed at 21 sites in the eastern upper montane and subalpine at Kahuku. The location of relatively robust populations of *Exocarpos menziesii* and *Fragaria chiloensis* at Kahuku makes stabilization efforts less urgent or even unnecessary, unless there is a compelling need to augment or reintroduce disjunct populations on the Mauna Loa Strip, away from Kahuku.

Less than 2% of the plantings of *Scaevola Kīlaueae* and *Stenogyne angustifolia* were alive when last monitored. Kahuku might be an alternative location for future efforts to reintroduce (or introduce) *Stenogyne angustifolia.* Only three of over 200 planted *S. angustifolia*, placed in the upper montane woodland and subalpine scrub in 2007, survived into 2010. It was found in the 1930s somewhere between Kīlauea and Kapāpala in the mid-nineteenth century, possibly in or near the park. There are more specific and recent collection records from Kahuku including collections in the 1930s (Pratt *et al*., 2011) and the 1970s (L. Pratt, pers. comm.). A second factor in the low survivorship of *Stenogyne angustifolia* might be that all the plantings were derived from cuttings. These might have a lower root-to-shoot ratio thus be less capable to surviving in a seasonally dry environment such as the upper montane and subalpine; cuttings also may have a shorter life span than seedlings. Planting seedlings might increase the survivorship of *Stenogyne angustifolia.* Mesic planting sites may also increase survival. Plantings devirved from cuttings planted at Puu Huluhulu (off saddle road) have thrived in the koa understory (K. Kawakami, pers. comm.).

Only two of the 59 plantings of *Scaevola Kīlaueae* were alive after nearly eight years. The site or the microsites selected might be inhospitable and other sites should be chosen for future plantings. This species appears to be stable in some areas of the mid-elevation woodland, especially the middle Hilina Pali Road area. Mapping and demographic information about this population of *S. Kīlaueae* would inform decisions about the need to stabilize this species.

DISCUSSION

Achieving Stabilization

The ultimate goal of the stabilization projects was to achieve Hawai`i/Pacific Plant Restoration Coordinating Committee (HPPRCC) standards for interim stabilization. These prescribe a minimum of three populations, of 25 reproductive individuals each for long-lived perennials, three populations of 50 individuals each for short-lived perennials, and five populations of 100 reproductive individuals each for annuals (USFWS, 1994).

HPPRCC standards were mostly achieved for only one species in the project, *Hibiscadelphus giffardianus,* a relatively long-lived perennial. The population in Kīpuka Puaulu was augmented, and populations in Kīpuka Kī and "Kīpuka `Aiea" were established, all with greater than 25 individuals. Many of these plantings were observed to be flowering and fruiting. However, limiting factors research has revealed that, even though flowers are produced, that few viable seeds are produced (Pratt *et al*., 2010).

Stabilization efforts with the short-lived perennials *Clermontia hawaiiensis*, *Bidens hawaiensis*, and the long-lived perennial, *Pleomele hawaiiensis*, were also partly achieved to HPPRCC standards. The number of surviving plantings per population met or nearly met the standard of established plants per populations and flowering and fruiting were occurring or beginning to occur. Two of the three prescribed planted populations were established for these species. A greater degree of stabilization can be achieved for these species by establishing additional populations.

In any case, HPPRCC standards should be regarded as guidelines. They are not empirically based for Hawaiian plants and the target numbers are arbitrary. It is improbable that a single standard for population size and distribution would apply to a broad range of diverse species with different breeding systems, life spans, amounts of genetic variability, potential for reproduction and regeneration, and vulnerability to environmental or demographic stochasticity. The HPPRCC guidelines for stabilization and recovery are currently under review (M. Bruegmann, pers. comm.). A more achievable and practical guideline may be to establish as many individuals of a target species as feasible and practicable without undue emphasis on target numbers. In any case, feasibility and practicability are probably the overriding constraints in rare plant stabilization projects and tend to control the outcomes.

In spite of the fact that stabilization efforts approximated HPPRCC standards for only a few species, the knowledge gained in augmenting and reintroducing rare plant species was a highly productive outcome of the stabilization projects. A great deal was learned about propagating and planting rare plant species. Probably the most important factor determining survivorship is site conditions that can inform future site selection. Successful stabilization sites were found for species with high survivorship; sites to be avoided, reconsidered, or modified were determined for species with low survivorship.

Future Plantings

A number of rare species had plantings with relatively high survivorship (>30%) in at least one site. Some of these species may have had low survivorship in one or two other planting sites. These species include *Clermontia peleana*, subsp. *peleana*, *Cyanea tritomantha*, *Embelia pacifica, Neraudia ovata, Phytolacca sandwicensis, Nothocestrum longifolium*, *N. breviflorum, Plantago hawaiensis, Stenogyne macrantha*, *Pittosporum hosmeri*, *Urera glabra, Xylosma hawaiiense*, and *Zanthoxylum dipetalum*. Not included in this list are species with high survivorship but very small sample size (e.g., *Melicope zahlbruckneri*), species planted for community restoration purposes (e.g. *Scaevola taccada*), and species common in non-target planting sites (e.g. *Psychotria hawaiiensis*). Stabilization might be achievable in the future for these species with additional plantings in multiple sites. Survivorship might be enhanced by modifying propagation or planting techniques (e.g., using seedlings instead of cuttings), improving the planting environment (e.g., alien grass control), or altering site selection or microsite selection. These modifications have been suggested in the previous discussion sections. Higher survivorship might also occur because of changed, more favorable weather following planting.

Some rare plant species targeted in the 1998-2008 stabilization projects urgently need additional plantings and stabilization. These species are extremely rare or extirpated from the park; they are also very rare in the Hawaiian Islands, as indicated by their by USFWS listing. Survivorship was low in most of these species or the number of plantings was limited and provided a very small sample size to judge survivorship of future plantings. Species urgently needing additional plantings include *Alphitonia ponderosa*, *Anoectochilus sandvicensis*, *Bobea timonioides, Capparis sandwichiana, Eurya sandwicensis, Exocarpos gaudichaudii, Joinvillea ascendens* subsp. *ascendens, Liparis hawaiensis*, *Melicope zahlbruckneri*, *Portulaca villosa, Schiedea diffusa, Sicyos alba*, *S. macrophyllus*, *Spermolepis hawaiiensis*, and *Zanthoxylum kauense*. Three other rare species have larger, but documented declining populations that also urgently need stabilization, including *Melicope hawaiensis, Portulaca sclerocarpa*, and *Sesbania tomentosa*. Management considerations for higher survivorship, including site selection and propagation techniques, are offered for some of these species in the preceding discussion sections.

Nine other rare plant species in HAVO, not included in the 1998-2008 stabilization projects, are also very rare or extirpated and potential candidates for future stabilization. Some of these are found only in Kahuku and were not addressed by the

1998-2008 stabilizations projects. These additional target species include: *Andophorus periens* (endangered and probably extirpated); *Cyanea* cf. *shipmanii* (endangered with one individual at Kahuku); *Cyanea stictophylla* (endangered, planted in two exclosures, and naturally occurring in a pit crater in Kahuku); *Cyrtandra giffardii* (endangered and occurring sparingly in parts of `Ōla`a Forest*); Cyrtandra menziesii* (species of concern, a few plants in Pu`u `Akīhi and nearby ravine); *Cyrtandra tintinnabula* (endangered and just one small population in `Ōla`a Forest); *Phyllostegia velutina* (endangered and extirpated); *Ranunculus hawaiensis* (candidate endangered species and only one population in Kahuku); and *Sanicula sandwicensis* (species of concern with one population in Kahuku) (L. Pratt, pers. comm.).

Other rare but not listed species, some with declining populations, can also be considered in future stabilization projects. These include *Antidesma pulvinatum*, *Dubautia linearis*, *Ipomoea tuboides*, *Labordia hirtella*, *Pittosporum confertiflorum*, *Plumbago zeylanica*, *Stenogyne sessilis*, and *Tetraplasandra oahuensis* (L. Pratt, pers. comm.). Rare ferns in this category include *Ctenitis latifrons*, *Gonocormus prolifer*, *Huperzia erosa*, *Microlepia speluncae*, *Ophioglossum polyphllum*, *Pneumatopteris pendens*, and *P. hudsonsiana*.

An ongoing program to plant and stabilize may be needed for some short-lived perennials species such *Phyllostegia* spp. With little or no seedling recruitment, planted populations will not replace themselves. Other relatively short-lived target species are probably dependent on frequent seedling recruitment. These include *Rumex giganteus*, *Sicyos macrophyllus*, *Sicyos alba*, and *Phytolacca sandwicensis.* Although their life spans have not been quantified, stabilization of these species may also require planting every few years, unless other management practices, e.g., rodent control, can bring about seedling recruitment.

Mortality Patterns Over Time

For many target species, mortality of plantings over time followed a pattern unexpected at the outset of the project. It was anticipated that species with high mortality would die soon after planting. However, this happened with very few species such as *Bobea timonioides* in the lowland dry-mesic forest. After 18 months, 93% of the *B. timonioides* plantings had died; no live plants were found when monitored after five years. A more common pattern of mortality over time for many species with eventual high mortality was high initial survivorship for one to two or even three years, followed by a sharp drop in survivorship by last monitoring at four to seven years after planting. The survivorship of *Rauvolfia sandwicensis* in Area I of Nāulu Forest illustrates this pattern. After 9-14 months, 90% of the *R. sandwicensis* were alive. When monitored after seven to eight years, only 10% of the plantings were surviving. In the mid-elevation woodland along Hilina Pali Road, after 32 months, 84% of the planted *Neraudia ovata* were alive; after 48 months, only 2% were surviving. This pattern of high survivorship for the first one to three years, followed by continuing declines in subsequent years, was also observed in *Argyroxiphium kauense* plantings in the subalpine of the Mauna Loa Strip (R. Robichaux, pers. comm.). Other species, particularly those with relatively high survivorship over several years experienced a more gradual decline. For example, *Reynoldsia sandwicensis* in Area II of Nāulu Forest had 61% survivorship at 22 months and 47% after 82 months. In the montane rain forest, *Stenogyne scrophularioides* had 67% survivorship after 15-28 months and 38% survivorship at 6-7 years.

Supplemental watering during the first few months after planting may account for high survivorship for at least part of the first year. Higher mortality after two or more years may result from eventual exposure to environmental extremes over time. A possible limiting factor influencing mortality for most sites may be soil moisture. The coastal, lowland forest, mid-elevation woodland, and upper montane/subalpine are dry to mesic environments with summer dry climates; dry periods may also occur at other times of years such as the occasional *El Niño* droughts in late winter/early spring. The temporal pattern of mortality in montane rain forest, where soil moisture is less likely to be limiting, is highly variable among the planted species.

Monitoring was not done frequently enough to correlate extended dry periods with pulses of mortality. For example, it is tempting to speculate that the *El Niño* drought of early 2010 may be a factor in the high mortality observed with many species in the fire-safe seed orchard plots along Hilina Pali Road. The steep decline in survivorship here occurred after October, 2008 when first monitored, and before May, 2010 when last monitored. However, no monitoring of plant morality was done between these two dates when plantings were dying.

Furthermore, monitoring was not done frequently enough to determine if there was a consistent temporal pattern of decline across planting environments or a predictable "shake out" phase. The "shake-out" in the mid-elevation woodland example above occurred generally between two and four years. It is not known if this pattern applies to other planting environments because the next and final monitoring was typically done after five to seven years in those environments. There seemed to be less of a sharp decline in the montane mesic forest from monitoring at an average of two years to the next and final monitoring at generally three to four years. Annual monitoring could help elucidate temporal patterns of mortality across different ecosystems, including correlating mortality with drought events.

The lesson learned from the temporal patterns of mortality observed in the stabilization projects is that early survivorship does not predict longer term survivorship; periodic monitoring needs to be continued on plantings. An additional monitoring should be conducted on rare species plantings in the montane mesic forest. The final monitoring was carried out at three to four years for most species, before the known or monitored decline in other planting sites. Most of this monitoring was conducted in 2006 or 2007. On the other hand, longer-term monitoring is not useful for short-lived species that may live for two or three years, produce copious amounts of fruit, and then depend on seedling recruitment for perpetuation of their populations.

Planting and Monitoring Protocols

An important lesson learned from conducting a final monitoring of planting sites with personnel new to the projects is the need for more detailed and standardized protocols for documenting and identifying plantings. Final monitoring occurred in the rare plant stabilization projects 4-12 years after plantings were placed on site.

The criteria or rationale for selecting planting sites should be articulated. The success or failure of plantings is largely a function of the ecological appropriateness of the planting site. These were mostly selected by well-informed intuition, based on perceived similarities with the sites of founder plants, historic range, or, more broadly, ecological range. Other sites were experimental, testing possible suitable sites beyond the known historic ranges. Historic range or ecological range can be interpreted broadly for rare plant species because known ranges are undoubtedly just a subset of the former range of these species (Mehrhoff, 1996). If the site features used in the selection process were characterized, then the site could be replicated if the plantings were successful or different sites could be selected if the plantings were a failure.

Microsite selection should also be characterized and thus potentially associated with mortality or survivorship. For example, plantings in grass swards can be compared to plantings in non-grassy areas; or plantings in shallow soil can be compared to deep ash pockets. In short, all plantings done for the purpose of stabilizing rare plant species can be carried out in a deliberate, experimental fashion to inform future planting efforts. The informational value of an experimental approach is demonstrated by plantings of *Neraudia ovata*. Some plantings were done near the historic collection site, others in a more xeric site along Hilina Pali Road with shallower soil, and still others in a more mesic community at Kīpuka Kī. The plantings near the known historic site had modest survivorship with fair to poor vigor after five to six years. One of the planting locations in the more mesic site at Kīpuka Kī had very high survivorship and vigor. In the Halfway House sites, one set of plantings was located in an exposed microsite away from forest cover. All the plantings placed in microsites away from forest cover died.

To help relocate plantings, besides GPS coordinates and dates of planting, metadata for plantings should include personnel doing the planting to utilize their recollections or experience. Most importantly, metadata should include detailed descriptions of the planting locations and the most efficient approach routes to the site. Hand-drawn field maps to planting sites and routes can be very useful for relocation, especially if annotated with notable landmarks. Field tactics can be suggested for locating all plantings while monitoring; these descriptions can complement shape files to locate plantings on the perimeter of the planting area. Metadata should also describe the methodology used for identifying individual plantings, including metal tags, flagging, and how these are associated with the plantings,

Protocols for monitoring should include recording of the monitoring dates, names of monitors, and a description of the methodology for measuring size of and evaluating vigor. Supplementary notes should indicate difficulties in finding and monitoring plants, discrepancies between plants found and plants recorded on previous occasions, and how the failure to find plants was addressed in calculating survivorship. Planting and monitoring protocols should be included on the spread sheets for data or a standardized protocol or metadata sheets can be developed.

Metal identification tags often could not be relocated, especially if they were attached to the ground with a nail or wire flag placed near the planting. Sometimes these tags were lost when the wire flags or nails corroded, especially near the shoreline or in vog-prone areas. The most consistently found metal identification tags were attached loosely to the target plant with flagging tape that also helped to locate target plants. Flagging tape may not persist for the desired 10 years monitoring time-frame. Twine may be a more resilient material to attach the metal tag to the target plant.

Vascular plants of a planting site, at least all native species, should be inventoried prior to planting. A problem encountered in monitoring was to distinguish plantings from naturally occurring plants of the same species. This was more of a problem with longer-term monitoring when metal identification tags had become disassociated from plantings.

Propagation and Outplanting Success

For *Portulaca sclerocarpa*, the effect of propagation technique and outplanting survivorship was demonstrated by the higher survivorship of plantings derived from seedlings than plantings derived cuttings. A technical report about propagation methods for plant species grown in the Resource Management nursery facility, including species propagated for the rare plant stabilization projects is in preparation. Comparing the results of this report with planting success may lead to insights about more effective propagation techniques for some species. For example, there may be relationships of survivorship and propagation techniques such as types and sizes of pots, potting media used, or cuttings versus seedlings.

Stabilization and Recovery

A stabilized species is not necessarily a recovering or recovered species. *Hibiscadelphus giffardianus* has been established in the numbers and a metapopulation structure prescribed for achieving HPPRCC standards for interim stabilization. Augmenting a very small existing population and creating new populations are undoubtedly effective in perpetuating this species in the short-term to minimize losses to demographic and environmental chance events. However, these planted populations are not recovered or recovering populations; no natural regeneration has been observed in *H. giffardianus.*

In contrast, signs of recovery are suggested in one of the partly stabilized, planted populations of *Pleomele hawaiiensis.* Two of the three prescribed populations of plantings have been established, respectively with 49 and 64 surviving plantings, a few of which are flowering and fruiting. Plantings from the 1970s are consistently fruiting and natural regeneration is occurring around these plants, with seedlings and individuals recruiting into taller size classes. *Plantago hawaiensis*, although only established in one planted population, is regenerating by seedling recruitment.

Stabilization is just the first step toward recovery. In spite of landscape-level removal of alien ungulate disturbance, reduction of cover of invasive plants, and recovery of common native plant species, many rare plant species are limited by factors, such as rodent predation on fruits or loss of pollinators, factors that are not addressed by landscape-level restoration. Stabilization, if effective, can preclude loss or extirpation while limiting factors are elucidated and management strategies are developed to address them. It is premature to dismiss the prospects for natural regeneration in the planted, partly stabilized populations of the other target species in the 1998-2008 rare plant stabilization projects. Most of the long-lived perennials have not reached reproductive maturity. The short-lived perennials with flowers and fruits have been established for just a few years. The only signs to date of natural regeneration have been ephemeral seedling recruitment was observed in a few species *Portulaca sclerocarpa* and *Phyllostegia floribunda*, but no recruitment into larger size classes.

Stabilization, Recovery, and Research Needs

Research lead by Linda Pratt, Botanist with the Pacific Island Ecosystems Research Center—US Geological Survey, has clarified limiting factors for 13 rare plant species in HAVO including *Hibiscadelphus giffardianus*, *Melicope hawaiensis*, *M. zahlbruckneri*, *Sicyos macrophyllus*, and *Zanthoxylum dipetalum* var. *dipetalum* in montane mesic forest (Pratt *et al*., 2010); *Cyrtandra giffardii*, *Phyllostegia floribunda*, and *Sicyos alba* in montane rain forest (VanDeMark *et al*., 2010); *Bobea timonioides*, *Portulaca sclerocarpa*, and *Sesbania tomentosa* in the coastal lowland and mid-elevation woodland (VanDeMark *et al.,* 2011); and *Phyllostegia* cf. *stachyoides and Silene hawaiiensis in the upper montane* (L. Pratt, pers. comm.). These species would benefit from more detailed studies of limiting factors such as rats, slugs, pollination, seed banks, and insect damage (L. Pratt, pers. comm.). Detailed research on limiting factors of additional rare plant species, with populations large enough to study, would provide recommendations for management to stabilize and recover these species. In fact, recovery may not be possible for many species until these kinds of studies are conducted.

Limiting factors more often affect reproduction and regeneration rather than established plants, such as plantings placed for stabilization (Mehrhoff, 1996, Pratt *et al*., 2010; Pratt *et al.,* 2011; VanDeMark *et al*., 2010). However, the survivorship of populations planted for stabilization purposes can be enhanced by understanding limiting factors. For example, understanding the cause of distorted growth and mortality of *Clermontia peleana* subsp. *peleana* plantings may confirm that slugs (or other arthropods) are a limiting factor of planted seedlings. Knowing this information might lead to at least slug control measures in localized areas when plants are most vulnerable.

Site selection or environment is often the overriding factor in the survivorship of plantings and in achieving stabilization. Although sites are typically selected based on historic range, knowledge of the limiting factors can help with site selection in some cases. Limiting factors studies on *Bobea timinoides* in lowland dry-mesic (Pratt *et al.*, 2011), for example, indicate that fruit and viable seed are produced and that rodents do not predate seeds on the plant or in the soil. However, there was little or no artificial or natural seedling recruitment, suggesting that site conditions, probably moisture, are now unfavorable in this altered, disturbed forest site and that more mesic sites within its range should be selected.

Another example is the low germination rate of *Sicyos alba* seeds (L. Pratt, pers. comm.). Determining techniques to increase the germination rate would increase the number of greenhouse-propagated plantings available for stabilization. Furthermore, controlling rats in planting environments of *S. alba* would reduce fruit and seed predation and may increase natural seedling recruitment. This would reduce or eliminate the need for periodic plantings to maintain population numbers of this stabilized species. Rat control may, in fact, lead to recovery of this species.

An understanding of limiting factors may also help in stabilizing another short-lived perennial, *Portulaca sclerocarpa*. Research indicates that this species is limited by rodent predation on fruits and poor seedling recruitment (Pratt *et al.*, 2011). To stabilize this species beyond just a few years and preclude replanting, controlling rodents would increase natural recruitment by increasing fruit and seed production to enhance the potential of seedling recruitment to replace short-lived mature plants. Research also suggests more mesic sites should be selected for the stabilized populations to improve opportunities for the growth and survival of naturally recruited seedlings. These measures for stabilizing, if carried out on a long-term basis, would also lead to recovery of this species.

Beyond Stabilization

Research of limiting factors will be needed to develop recovery programs for many rare species. One of the purposes of the stabilization projects was to allow time for this kind of research to take place. For example, multiple factors were found limiting reproduction and regeneration in *Hibiscadelphus giffardianus* (Pratt *et al*., 2010). It was determined that low fruit production was limiting reproduction and seedling recruitment; this resulted mostly from a paucity of mates in this self-incompatible species. Loss of pollinators and rat predation of fruits also reduce fruit and viable seed production. Alien grasses are partly responsible for suppression of natural seedlings recruitment. In order for *H. giffardianus* to recover, fruit production and seedling recruitment must resume. Management actions implied are systematic control of rats in the sites of the planted populations during peak fruiting times and control of invasive grasses in areas of potential seedlings recruitment. If these fail, consideration could be given to increasing genetic variability and the availability of mates by backcrossing hybrids between *H. giffardianus* and *H. hualalaiensis* with F_1 *H. giffardianus* may be considered (Pratt *et al*., 2010).

One theme of the research findings is that rodents limit fruit and seed production and availability of seed in the soil for many species studied. Registration for area-wide rat control is in process. Once registered, managers will have to develop strategies for implementing rat control for stabilization and recovery of rare species that would be affected. Registration or field strategies may need to be developed for mice control; mice may be the problem in drier areas. Another theme is that slugs may be important limiting factors especially in the rain forest environment. Research on slug effects and control methods would needed to develop tools to address this limiting factor. Managers would need to develop strategies to implement slug control in an affordable and practicable manner.

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