Towards restoration of Hawaiian tropical dry forests: the Kaupulehu outplanting programme

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Hawaiian tropical dry forests contain diverse assemblages of woody canopy species, including many endemic and endangered species that warrant conservation attention before completely disappearing. Today, tropical dry forests in Hawaii are not viable ecosystems. Poor land use practices, fragmentation, non-native plant invasions, and inadequate native vegetation regeneration are all factors that have contributed to their endangerment. Only an ambitious restoration programme that includes non-native ungulate exclusion, weed control, fire management, and the outplanting of seeds and seedlings will be sufficient to enhance Hawaiian tropical dry forests. We selected a 25 ha preserve within the Kaupulehu Dry Forest Preserve, located in North Kona on the Island of Hawaii, to test dry forest restoration strategies. In 1997, the preserve was fenced and all non-native ungulates were removed. Altogether, 4892 outplants were planted from 1999–2006. In 2007, we surveyed all of the outplants. The survey found 1487 live plants, 3357 dead, and 48 plants missing. This equates to an overall survival rate of 30%. Survival by vegetation type indicated that vines had the highest rate of survival (63%) followed by trees (34%). Herbs had the lowest rate of survival (12%). Twelve of a total of 35 species that were outplanted in the Kaupulehu Dry Forest Preserve accounted for more than 90% of the total surviving plants species, while five federally listed species represent almost 60% of the total. The outplanting of dry forest species into the Kaupulehu Dry Forest Preserve considerably increased the population of many federally listed endangered species. However, the high mortality of many common and important plant species of tropical dry systems highlights the importance of an outplanting programme that emphasizes ecosystem sustainability rather that species success. In equal measure, the successes and failures of the Kaupulehu outplanting project have enhanced our ability to begin to restore this unique and endangered ecosystem.

Key words: Hawaii, Tropical dry forests, Endangered species, Seedling survival, Non-native species

INTRODUCTION

IN 1999, the North Kona Dryland Forest Working Group (Working Group) received funding from the United States Fish and Wildlife Service (USFWS) Private Landowner Incentive Program to outplant 10 federally listed endangered species in a tropical dry forest preserve (Kaupulehu) located in North Kona on the Island of Hawaii. This Working Group, in addition to government and non-governmental agencies, scientists, land owners, local citizens, and native Hawaiians, has been actively conducting dry forest preservation, restoration, and outreach programmes for over 10 years. Since 1999, over 5000 plants have been outplanted into this 25 ha preserve. We evaluated the outcome of this effort, and in particular, the long term sustainability of outplanting programmes in Hawaii.

The Kaupulehu dry forest is located approximately 17 km east of Kailua-Kona on the leeward side of the Island of Hawaii at 600 m elevation, and contains dry forest remnants that are owned by Kamehameha Schools. The outplanting preserve is a 25 ha area that was fenced for exclusion of non-native ungulates in 1997. The preserve is located on rough clinker-type lava flow from 1500–3000 BP (Moore and Clague 1992). Mean annual rainfall is < 750 mm, with the majority falling during intense winter storms (Giambelluca *et al.* 1986).

Currently, dry tropical forests are among the most endangered of all tropical forest ecosystems (Janzen 1988; Miles *et al.* 2006), due largely to the enormous pressure of human activities in the last 100 to 400 years. Tropical dry forests have suffered degradation mostly due to the impact of grazing animals, invasive species, fire, and land conversion (Hobdy 1993; Stemmermann and Ihsle 1993; Stratton *et al.* 1998; Cabin *et al.* 2000). As a consequence of this long-term degradation, most of the remaining tropical dry forests are isolated patches immersed in a matrix of pastureland and/or secondary forest. Hawaii is not an exception to this pattern. Mehrhoff (1996) estimates that the Hawaiian Islands have lost 90% of their dry forest since the arrival of humans (circa 400 A.D.). Today more than 25% of the officially listed endangered Hawaiian plant taxa are from dry forests or dry scrub habitats (Bruegmann 1996).

Even after successful efforts to eliminate ungulates and invasive species from protected dry forests, regeneration of native species has not been stimulated to the levels desired (Cabin

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PACIFIC CONSERVATION BIOLOGY Vol. **14:** 279–284. Surrey Beatty & Sons, Sydney. 2008.

et al. 2000; Stratton *et al.* 1998); less than 1% of the original extent of these forests are naturally regenerating. In most cases, the seed bank is saturated with non-native species and without further intervention, such as native outplanting and or seeding, following initial ungulate removal and invasive species control efforts, the ecosystem will quickly return to a non-native dominated forest (Cabin *et al.* 2000). Such is the case for the small Kaupulehu Dry Forest Preserve on the Island of Hawaii, where land managers have struggled to promote the growth of native forest stands and control invasive species.

Small reserves such as Kaupulehu are increasingly crucial in conserving biodiversity because they are often protected from non-native ungulates and can more easily be managed than larger areas of degraded forest. The extreme endangerment of the system demands safe sites or a refugia for species on the brink of extinction, as well as serving as a testing ground to facilitate and guide appropriate sustainable restoration prescriptions for Hawaiian tropical dry forests. Outplanting programmes can provide an invaluable resource towards conservation and restoration of these unique and culturally valuable ecosystems. Historically, the native Hawaiian dryland forests were an important source of diverse plants which provided materials used in vessels, implements, food gathering, fishing, shelter, medicines and rituals.

The purpose of this paper is to (1) document outplant survival, (2) analyse species specific and plant group specific patterns of mortality, and (3) make research recommendations for future dry forest restoration projects in Hawaii that may have broad application in other tropical dry forest settings.

METHODS

Altogether, 4892 outplants were planted from 1999–2006. We made the greatest number of outplants in 2002 and 2003 (n = 1485 and 1433 individuals, respectively), with the fewest planted in 1999 (79). Trees represented 2996 of the total number of outplants followed by shrubs (997), vines (237), herbs (33), and sedges (4). There were 625 unknown tagged individuals (i.e., a unique tag was initially associated with the plant at the time of planting but the outplant died before the tag and species information was recorded), but the data was not originally recorded during outplanting. A typical outplanting event from 1999–2006 consisted of several steps. The first step involved removal of the non-native grass *Pennisetum setaceum* by weedwhacking followed by applications of the herbicide glyphosate based Round-up® (Cordell *et al.* 2002a). Seeds were collected from within Kaupulehu or neighbouring remnant tropical dry forests and grown at an on-site nursery. Species selection was based on a number of factors ranging from plant availability, funding source, and previously known successful native species. All outplants were tagged and watered via drip irrigation for up to 6 months (Cordell *et al.* 2002b). Outplantings began in 1999 with 79 plants and continued through 2006, with a peak in 2002 when 1485 plants were outplanted. Monitoring censuses occurred in 2001, 2002, 2003, and 2007. In 2007, all of the outplants were surveyed.

RESULTS

Precipitation from 1999–2003 was 45–70% below normal; whereas 2004 had the highest rainfall recorded (1249 mm), with 2005–2006 considered to be within the normal range (Table 1). Out of a total of 4892 outplants, our survey

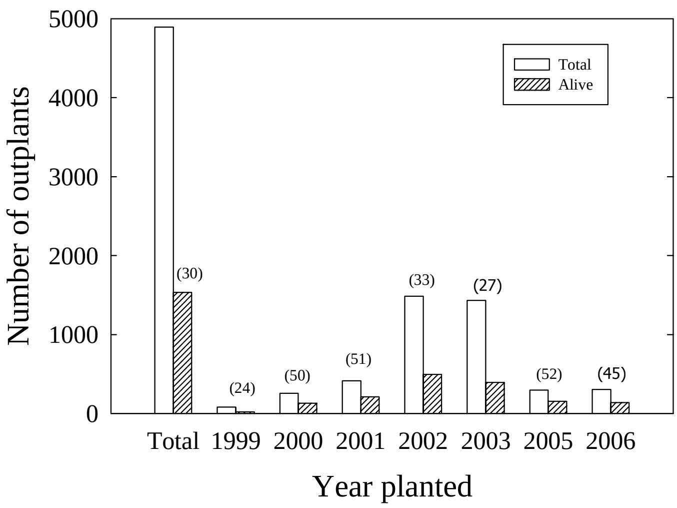

Fig. 1. Outplant totals from the 2007 census by planting year at the Kaupulehu Dry Forest Hawaii Preserve. The numbers in parentheses represent the percent survival.

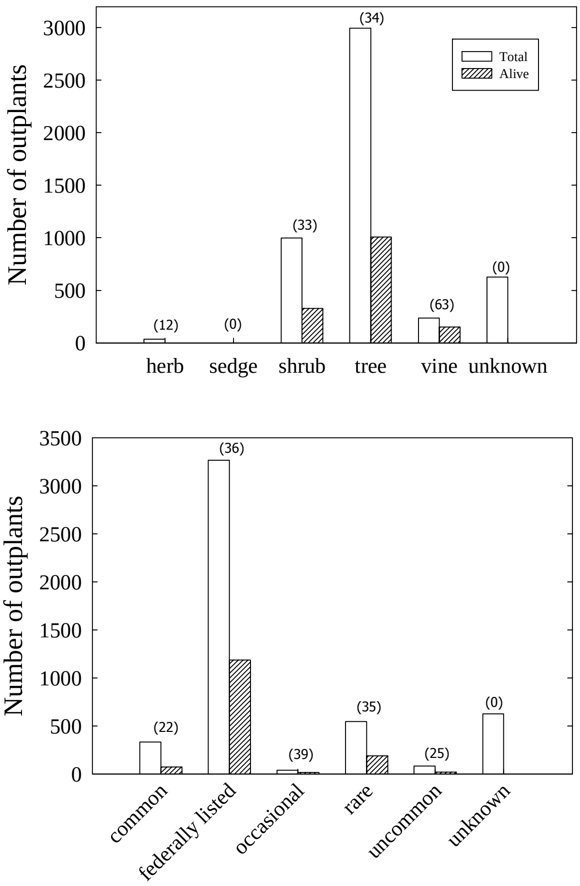

Fig. 2. Outplant totals by plant type (a) and abundance (b) from the 2007 census at the Kaupulehu Dry Forest Hawaii Preserve Type and abundance categories are as described in Cabin *et al.* (2000). The numbers in parentheses represent the percent survival.

found 1487 live plants, 3357 dead, and 48 plants missing (Fig. 1). This equates to an overall survival rate of 30%. Survival by vegetation type indicates that vines had the highest rate of survival (63%) followed by trees (34%) (Fig. 2a). Herbs had the lowest rate of survival (12%). The majority of the outplants (3266 plants or 77 %) were federally listed species (Fig. 2b). Only 7% of the total outplants were considered common species (Cabin *et al.* 2000) but this abundance category had the lowest rate of survival (22 %).

Thirty-five species were outplanted in the Kaupulehu Dry Forest Preserve but twelve species represent more than 90% of the total, and five federally listed species represent almost 60% of the total (*Kokia drynarioides* (n = 884), *Pleomele hawaiiensis* (574), *Nothocestrum breviflorum* (375), *Abutilon menziesii* (330), and *Colubrina oppositifolia* (307). Of those listed, *C. oppositifolia* and *P. hawaiiensis* had the highest rate of survival (56% and 55%, respectively) while *Nothocestrum breviflorum* had the lowest (16%) (Fig. 3). Outplanting efforts have substantially increased the populations of many of the federally listed species, ranging from 3% to almost 10,000% (Table 2).

Table 1. Total annual precipitation (mm) from 1996-2006 at the Kaupulehu Dry Forest Preserve, Hawaii.

Year	Total precipitation (mm)
1999	225
2000	382
2001	342
2002	309
2003	374
2004	1249
2005	761
2006	669

DISCUSSION

The outplanting of dry forest species into the Kaupulehu Dry Forest Preserve increased the populations of many federally listed endangered species. One species, *Kokia drynarioides*, still found in the wild at the time of the original outplantings, is now thought to be extinct in the wild. More than 60 individuals of *K. drynarioides* that were planted in 1999–2000 still survive, some over 4 m in height. However, a true metric of success of any outplanting is if the plants are reproducing and the recruits are surviving in the wild. To date we have not collected this information, although recent observations at Kaupulehu suggest that natural regeneration of many of the out-planted species has not yet occurred. The absence of regeneration in outplanted species may be the result of a loss of native pollinators and dispersers, unsuitable sites for germination, natural episodic patterns of dry forest species recruitment, and/or

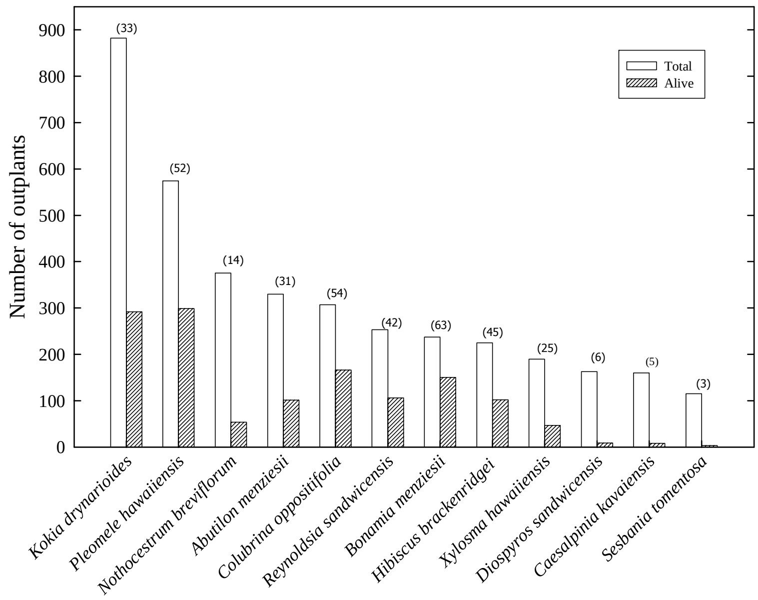

Fig. 3. Outplant totals from the 2007 census by species at the Kaupulehu Dry Forest Hawaii Preserve The numbers in parentheses represent the percent survival. These 12 species represent more that 90% of the total species outplanted at Kaupulehu between 1999-2006.

Table 2. Population increase of federally listed endangered species as a result of outplanting efforts at Kaupulehu Dry Forest Preserve, Hawaii.

Scientific name	Hawaiian name	Individuals remaining in the State (approximately #)	Increase of population from outplanting (%)
Abutilon menziesii	Ko‘oloa‘ula	450	*22*
Bonamia menziesii	no known name	200	75
Caesalpinia kavaiensis	Uhiuhi	42	20
Colubrina oppositifolia	Kauila	800	21
Hibiscus brackenridgei	Ma‘o hau hele	70	146
*Kokia drynarioides**	Koki‘o	3*	9733
*Nothocestrum breviflorum**	‘Aiea	100	54
*Pleomele hawaiiensis**	Halapepe	300	99
Sesbania tomentosa	Ohai	100	3

*Three individuals remained at the time of outplanting. Now this species is thought to be extinct in the wild

insufficient time to develop a viable seed bank. The germination requirements or pollination biology of most of these species is poorly understood.

The approximate overall survival rate of 30% of outplants at Kaupulehu was lower than expected. Initial censuses in 2000 and 2001 indicated a survival rate of over 80% (unpubl. data available from authors). No obvious correlative factor appears to be responsible for the high rates of mortality (i.e., drought, pest outbreaks, disease) and a summary of the data indicates that mortality of most species is highest several years after outplanting. Young rocky soil (i.e., <3000 year old lava substrate), extended periods of low precipitation, and competition with non-native, invasive, grass and weed species for resources, such as light, nutrients, and water may be independent and or cumulative factors associated with outplant mortality. Some of the species with very high mortality such as *Diospyros sandwicensis* and *Caesalpinia kavaiensis* (i.e., both with less than 5 % survival), may be differentially impacted by pests or disease, or in the case of *D. sandwicensis*, very slow rates of growth (Sandquist and Cordell 2007). Vines had the highest rate of success, and likely reflect their fast growing, light seeking physiology and architecture. They quickly top nearby trees and shrubs thereby reducing competition with re-emerging weeds for sunlight. In addition, the architecture and growth allocation patterns in vines are such that energy is focused on leaf production rather than support structures such as wood and roots. Given this suite of traits, vines should be preferentially outplanted in sites initially following disturbance (i.e., extensive weed removal, fire). Vines may rapidly alter the micro-habitat to favour future outplant survival by shading and thereby reducing the recolonization of non-native grasses, as well as providing a shade source for outplants. The positive influence of shade on outplant survival has been documented in numerous Hawaiian tropical dry forest studies (Cabin *et al.* 2002a,b; Cordell *et al.* 2002c; Cordell *et al.* 2004; Cabin *et al.* 2004). Another approach that may reduce mortality of slow growing tree species, such as *D. sandwicensis*, is to modify the germination techniques to promote faster growth, or allow more time in an on-site greenhouse until an adequate, competitive size has been obtained. Given the lack of natural recruitment of many common native species due to the complete conversion of the forest understorey by grasses, we believe future outplanting efforts should focus on creating a sustainable microenvironment that favours native species recruitment.

The observed high mortality rate of common species associated with this project is disturbing. High mortality highlights the importance of an outplanting programme with an emphasis on not only federally listed endangered species, but common species as well. Moreover, this project emphasizes the need to impose an effective monitoring plan at project onset. This project, as with many similar projects, has suffered from a lack of resources, continually changing personnel, and a lack of consistent planting and or data collection protocols. In particular, the monitoring efforts were sporadic and incomplete with no data collection occurring from 2003–2007. This deficiency significantly reduced our ability to discern the factors associated with species mortality, and in particular, species specific mortality that may have been caught and reversed if an observed trend had emerged. Additionally, the fate of the 625 individual plants that were documented as unknown would have been quickly discovered.

We consider the outplanting programme at Kaupulehu a success. This success is not necessarily related to the low rate of survival of many species but rather, the increased information generated by this study of Hawaiian tropical dry forests that is directly associated with our efforts. The enthusiasm and support of the volunteer groups and individuals dedicated to the protection of this highly endangered ecosystem has been encouraging. As with any programme characterized by initial early success, we have learned many lessons as a result of our mistakes. Our overarching general advice cannot emphasize enough the need for an outplanting plan to be implemented at the onset of a project. At a minimum, this plan would include the goals (i.e., habitat restoration, safe site for endangered species, educational garden), protocols for species selection, collection, germination, outplanting, monitoring, and indices of success. The species selection should be relevant and site specific. The collection should be broad and quantitative in terms of location information and collection amount, particularly if working with endangered species, for genetic purposes. Germination information must be documented and ought to include, at the very least, the time to germinate, scarification needs, soil or media used, and greenhouse or shadehouse conditions. It is essential that the outplanting protocol include planting maps, GPS locations, and a unique identification tag for each plant. It is best to plant areas with sequential numbers to ease locating them in the future. The monitoring protocol must be simple, consistent, and relatively frequent. Adequate monitoring will not only confirm the programmes success but information on failures can effectively re-route the program through adaptive management.

In the last decade we have learned an immense amount about Hawaii's tropical dry forests. Now we have a solid understanding of many of the barriers to restoration and how to overcome them. In equal measure, the successes and failures of the Kaupulehu outplanting project have enhanced our ability to continue restoring this unique and endangered ecosystem.

ACKNOWLEDGEMENTS

We would like to acknowledge the support and encouragement of the members of the Kona Dryland Forest Working Group, Kamehameha Schools for permission to use their lands, and to the numerous volunteers for their assistance, encouragement, and dedication to the preservation and restoration of Hawaii's dry forest ecosystems.

REFERENCES

Bruegmann, M. M., 1996. Hawaii's dry forests. *Endangered Species Bulletin* **21**: 26–27.

Cabin, R. J., Cordell S., Sandquist, D. R., Thaxton, J. and Litton, C.M., 2004. Restoration of tropical dry forests in Hawaii: Can scientific research, habitat restoration and educational outreach happily co-exist within a small private preserve? *In* 16th International Conference, Society for Ecological Restoration, pp. 1-8, Victoria, Canada.

Cabin, R. J., Weller, S. G., Lorence, D. H., Cordell S. and Hadway, L. J., 2002a. Effects of microsite, water, weeding, and direct seeding on the regeneration of native and alien species within a Hawaiian dry forest preserve. *Biological Conservation* **104**: 181–190.

Cabin, R. J., Weller, S. G., Lorence, D. H., Cordell, S., Hadway, L.J., Montgomery, R., Goo, D. and Urakami, A., 2002b. Effects of light, alien grass, and native species additions on Hawaiian dry forest restoration. *Ecological Applications* **12**: 1595–1610.

Cabin, R. J., Weller, S. G., Lorence, D. H., Flynn, T. W., Sakai, A. K., Sandquist, D. and Hadway, L. J., 2000. Effects of long-term ungulate exclusion and recent alien species control on the preservation and restoration of a Hawaiian Tropical Dry Forest. *Conservation Biology* **14**: 439–453.

Cordell, S., Cabin, R. J. and Hadway, L. J., 2002a. Physiological ecology of native and alien dry forest shrubs in Hawaii. *Biological Invasions* **4**: 387–396.

Cordell, S., Cabin, R. J., Weller, S. G. and Lorence, D. H., 2002b. Simple and cost-effective methods control fountain grass in dry forests (Hawaii). *Ecological Restoration* **20**: 139–140.

Cordell, S., Sandquist, D. R., Litton, C. M., Cabin, R. J., Thaxton, J., Hadway, L. J., Castillo, M. and Bishaw D., 2004. An invasive grass has significant impacts on tropical dry forest ecosystems in Hawaii: the role of science in landscape level resource management and native forest restoration in West Hawaii. *In* 16th International Conference, Society for Ecological Restoration, pp. 1–4, Victoria, Canada.

Giambelluca, T. W., Nullet, M. A. and Schroeder, T. A., 1986. Rainfall atlas of Hawaii. State of Hawaii, Department of Land and Natural Resources, Division of Water and land Development, Honolulu.

Hobdy, R. 1993. Lanai-a case study: the loss of biodiversity on a small Hawaiian Island. *Pacific Science* **47**: 201–210.

Janzen, D., 1988. Tropical dry forests, the most endangered major tropical ecosystem. Pp. 130–144 *in* Biodiversity ed by E.O. Wilson. National Academy Press, Washington, D.C.

Mehrhoff, L., 1996. Reintroducing Endangered Hawaiian Plants. Pp. 101–120 *in* Restoring Diversity ed by D. A. Falk, C. Millar and M. Olwell. Island Press, Washington, D.C.

Miles, L., Newton, A. C., DeFries, R. S., Ravilious, C., May, I., Blyth, S., Kapos, V. and Gordon, J. E., 2006. A global overview of the conservation status of tropical dry forests. *Journal of Biogeography* **33**: 491–505.

Moore, J. and Clague, D., 1992. Volcano growth and evolution of the island of Hawaii. *Geological Society of America Bulletin* **104**: 1471–1484.

Sandquist, D. R. and Cordell, S., 2007. Functional diversity of carbon-gain, water-use, and leaf-allocation traits in trees of a threatened lowland dry forest in Hawaii. *Am. J. Bot.* **94**: 1459–1469.

Stemmermann, L. and Ihsle, T., 1993. Replacement of *Metrosideros polymorpha*, 'Ohi'a, in Hawaiian dry forest succession. *Biotropica* **25**: 38–45.

Stratton, L., Hudson, L., Suenaga, N. and Morgan, B., 1998. Overview of Hawaiian dry forest propagation techniques. *Newsletter of the Hawaiian Botanical Society*, pp. 13–27.