PROJECT REPORT

Assessment of the Native Hawaiian Plant Society Restoration Projects on Kaho'olawe Island, Hawai'i

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A follow-up survey shows low survival rates—but plants that did survive are promoting recruitment of new plants and providing some protection from erosion.

Kaho'olawe Island, Hawai'i was once covered by dryland forest. Today, about one-third of the island is a largely barren plateau, commonly referred to as the "hardpan." Original dry forest vegetation may have initially given way to grassland in some areas as a result of agricultural practices of Hawaiians, especially burning (Kirch, 1982). However, severe vegetation loss probably did not begin until after the introduction of goats in 1793 or after the introduction of Western-style ranching in the 1850s. Ranching was discontinued after the U.S. Navy took control of Kaho'olawe for training purposes in 1941, but feral goats remained and continued to thwart vegetation recovery until they were finally eradicated in the early 1990s (Giambelluca and others, 1997). Severe soil loss prompted the first revegetation efforts shortly after the turn of the century, but these projects involved the introduction and planting of alien species, including *kiawe* (*Prosopis pallida*), *koa haole* (*Leucaena leucocephala*), ironwood (*Casuarina equisetifolia*), and Australian creeping saltbush (*Atriplex semibaccata*), rather than reintroduction of lost native species. In the late 1980s, the US Army Construction Engineering Research Laboratory (CERL) revegetation experiments were initiated to determine the long-term success of several revegetation strategies and to identify species (both native and exotic) best suited for future restoration of the highly eroded hardpan surface (Warren and Aschmann, 1993).

Some recent efforts have been directed at the exclusive establishment of native dryland forest species. For example, researchers of the Nitrogen Fixing Trees and Legumes (NiFTAL) experiment attempted to identify microbial and mineral constraints to reestablishing the *wiliwili* tree (*Erythrina sandwicensis*) (Nakao and others, 1993). Between 1985 and 1989, the Maui Native Hawaiian Plant Society (NHPS) initiated a demonstration project with the aim of reestablishing a native dryland forest similar to those currently on the islands of Maui and Lanā'i. The NHPS volunteer team situated the plantings in the most degraded, windswept area of the island to investigate whether native Hawaiian plants could be used for revegetating the island without fertilization, irrigation, or wind abatement—even in areas with harsh environmental conditions. They conducted informal surveys during and immediately following the planting years; however, they did not conduct a formal survey in the years subsequent to the project's end to ascertain the survival of the 34 species planted. In this work, we surveyed the NHPS sites to determine: (1) Which native species are most capable of surviving on the barren, windswept regions of Kaho'olawe; (2) Environmental constraints limiting survival of native species; and (3) How the plantings have contributed to site restoration. Although the NHPS project was not designed as a scientific investigation, the information gleaned from a formal assessment is valuable to future attempts to

Stripped to hardpan by erosion, vast areas on the island of Kaho'olawe, Hawai'i, now sustain only a few hardy exotics, such as Australian creeping saltbush, posing a challenge for restorationists working on the island. The cloud-wreathed mountain in the background is Mt. Haleakalā, on Maui, about 25 miles away. *Photo by Alan Ziegler*

establish dryland forests on Kaho'olawe, because vegetative growth in some areas is hindered by: (1) A semi-impermeable, highly eroded soil matrix depleted of available nutrients, organic matter, and microbial activity; (2) A harsh climate that includes low, seasonal rainfall, high solar radiation, and strong, persistent trade winds; and (3) A dearth of native seed sources. The work described in this paper is part of a larger survey of prior restoration projects on Kaho'olawe. That survey was intended to facilitate the Kaho'olawe Island Reserve Commission's development of a plan to restore the biological and physical condition of the island (Giambelluca and others, 1997).

The Native Hawaiian Plant Society Projects

The NHPS plantings were coordinated by Rene Sylva (Paia, Maui Island, Hawai'i) through the auspices of the Maui Native Hawaiian Plant Society, with the aid of personnel from the U.S. Navy, United States Department of Agriculture, Hawaii Department of Land and Natural Resources, the University of Hawai'i, and the Sierra Club (Kaho'olawe Island Conveyance Commission, 1993). The following background is based on conversations with Sylva and NHPS volunteer Linda Wilson, and from unpublished works by Sylva and the U.S. Navy (1989).

Between 1985 and 1989, NHPS volunteers established eight 1-acre plots in two planting sites on Kaho'olawe near K2 road, which we will refer to as NHPS3 and NHPS4. They planted more than 23,000 plants of 34 species, including two Polynesian introductions, to create a diverse dryland forest. Sylva grew seedlings from seeds collected from areas on Maui having climatic conditions similar to Kaho'olawe. Volunteers hand planted and watered all seedlings initially, but did not re-irrigate the plants. The NHPS team did not fertilize the seedlings because they believed fertilization would foster above-ground biomass growth rather than promote the establishment of root systems, which would be beneficial in

Table 1. **Physical and hydrological soil properties inside and outside the Native Hawaiian Plant Society restoration sites.**

Site	Sample size	Saturated hydraulic conductivity		Bulk density		Soil moisture at saturation	
		Value (mm h-1)	COV§	Value (g cm-3)	COV	Value (g cm-3)	COV
NPHS sites†	13	94.9*	0.68	1.05	0.12	0.51*	0.16
Control	8	47.1	0.60	1.15	0.10	0.43	0.12

† NHPS refers to areas inside the planting boundaries of both sites; control, the areas outside that were not affected by tillage or planting.

§ Coefficient of variation (COV) = standard deviation divided by the mean.

* Indicates a significant difference between the NHPS sites and the control (Mann-Whitney U-test, p = 0.05).

Table 2. **Soil Nutrients at the Native Hawaiian Plant Society restoration sites (Ziegler and Smith, 1997).**

	pH	EC†	P	K	Ca	Mg	Zn	TN	OC
	-	mmhos/cm	ppm	ppm	ppm	ppm	ppm	%	%
Mean	6.7	0.2	11.3	375	365	335	< 0.1	0.1	0.9
COV	0.1	0.2	0.5	0.3	0.3	0.2	2.8	0.3	0.3
Interpretation §	neutral	OK	Low	High	Very low	OK	Very low	*	*

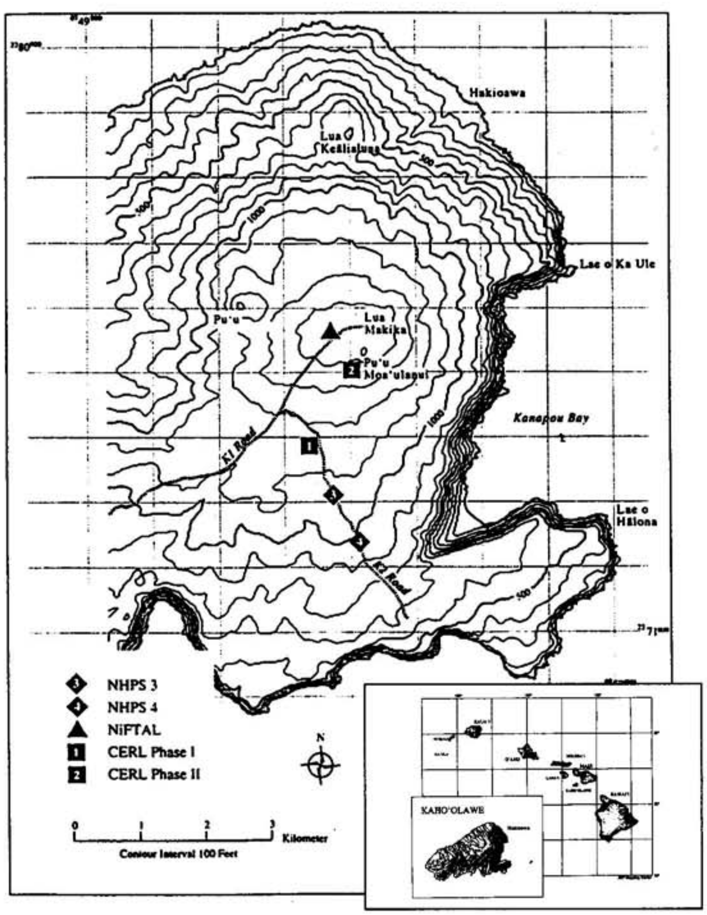
† EC is electrical conductivity; TN, total nitrogen, OC, organic carbon; sample size is 4 for all variables.

§ Interpretations are based on Tamimi and others, (1994), using the assumption of general crops and a heavy soil.

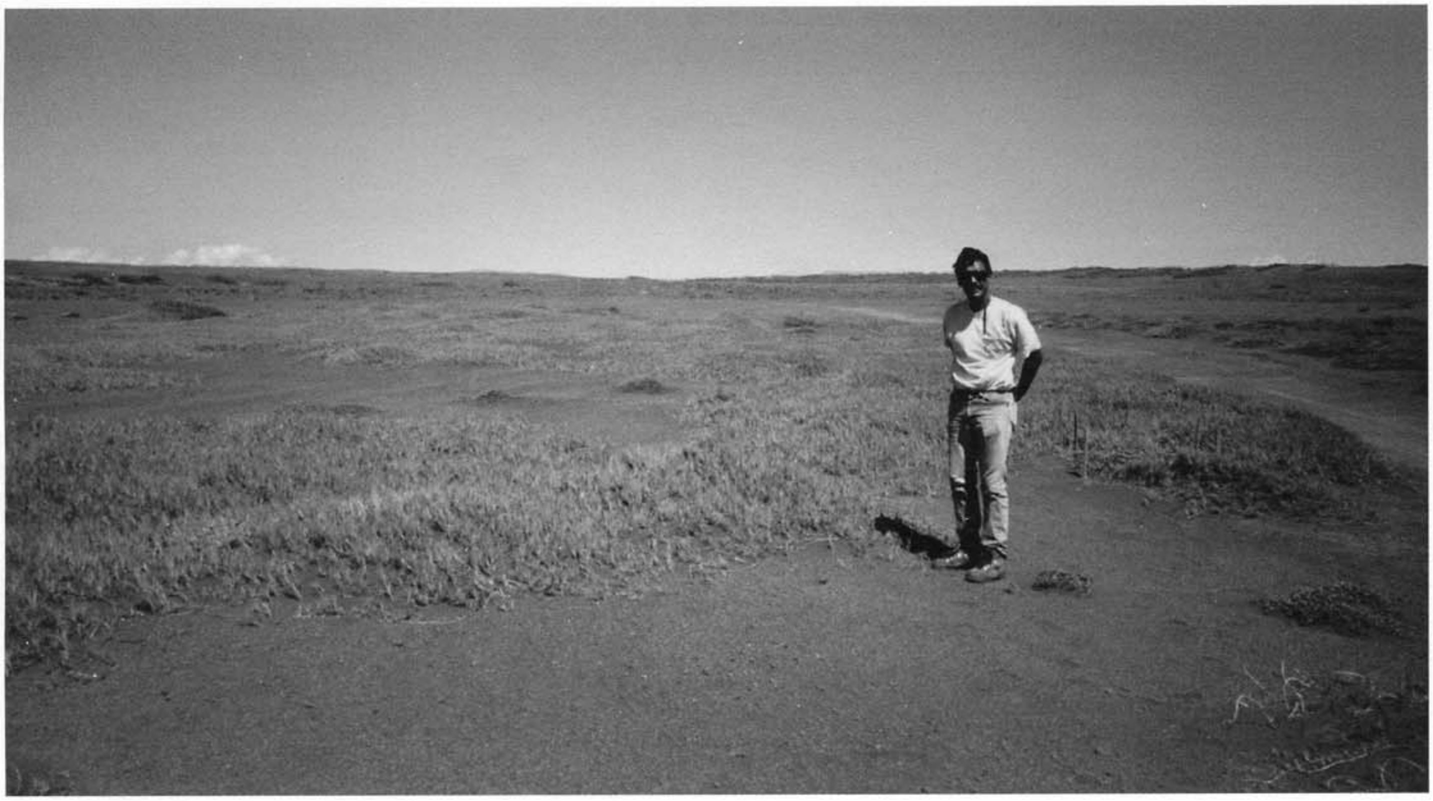
* The ratio of TN to OC is considered to be low.

the near-drought conditions on Kaho'olawe. Nor did they install wind-protection structures—although they designed the planting scheme to mitigate wind and fluvial erosion processes by generally following the topographic contours and positioning upwind the more wind-resistant species, notably *'akoko* (*Chamaesyce celastroides*). They planted low, creeping plants such as *'ākulikuli* (*Sesuvium portulacastrum*) three feet apart in parallel rows, themselves five feet apart, in anticipation that runners would join together, forming a continuous ground cover. The team excluded *'Ākulikuli* from the latter plantings after discovering a fungal infection on both seedlings and plants of this species already established on Kaho'olawe. Nevertheless, the NHPS volunteers planted more than 5,000 *'ākulikuli* sprigs in 1985 alone, before they discovered the fungus. The volunteers planted other grass, shrub, and tree species, including approximately 5,000 *'a'ali'i* (*Dodonaea viscosa*), in single-species patches throughout the planting units. They included in the plantings several salt-tolerant beach/coastal species, including *'akoko, hinahina* (*Heliotropium anomalum*), *Hilo ischaemum* (*Ischaemum byrone*), *nehe* (*Lipochaeta integrifolia*), *naio* (*Myoporum sandwicense*), *'iliahi* (*Santalum paniculatum*), and *milo* (*Thespesia populnea*).

The setting Sylva and his colleagues chose for these plantings was unusually challenging from a restoration perspective. The sites are located on the denuded hardpan plateau, roughly one mile from Kanapou Bay. Considerable salt spray reaches the sites because the winds are typically strong, northeasterly trades. The scarcity of vegetation in this area results in part from limited water availability, as the small island (about 45 square miles) lies in the rainshadow of Mt. Haleakalā on Maui, about 25 miles to the northeast. Mean annual rainfall is only about 14.6 inches, with almost 70 percent of this coming between November and March (Ziegler and Giambelluca, 1998). More importantly, the scarcity of vegetation results from historical overgrazing by feral goats and the ensuing large-scale erosion. Today this surface, which is probably lower than the original soil surface by more than six



Kaho'olawe Island



Natural Reserve Specialist inspects a large patch of *'aki'aki* grass with isolated clumps of the slightly taller *'ākulikuli*. Eight years after this photo was taken, in 1991, *'a'ali'i* seedlings are establishing in the existing vegetation. *Photo by Allison Chun*

feet, is the source area of significant overland flow, which erodes large gullies on the slopes extending down the plateau to the coastline (Loague and others, 1996). The soil in the planting areas is largely the Bw horizon of an exhumed paleosol, dominated by the Kaneloa soil series (Nakamura and Smith, 1995). Tables 1 and 2 include information about several soil and nutrient properties taken within the NHPS sites and immediate area. Sparse hardpan vegetation consists mainly of introduced species, including *kiawe*, tamarisk (*Tamarix aphylla*), buffelgrass (*Cenchrus ciliaris*), Natal red top (*Rhynchelytrum repens*), lantana (*Lantana camara*), *koa haole* (*Leucaena leucocephala*), and pitted beardgrass (*Bothriochloa pertusa*). In addition, native *pili* or twisted beardgrass (*Heteropogon contortus*), *'ilima* (*Sida fallax*), and indigenous (status uncertain) *'uhaloa* (*Waltheria indica*) are generally found on the hardpan.

Survey

In May 1996, we conducted a cover survey of species both inside and immediately outside the two planting sites. We established four and six sampling plots at the NHPS3 and NHPS4 sites, respectively. From each plot center, we established four 16.4-foot long transects in the four cardinal compass directions. At four-inch increments along each transect, we dropped a pole, recording the species touched. If the pole simultaneously touched more than one species, we gave a fractional presence weight to each (e.g., 0.33 for each of three species touched). Species coverage in each plot was calculated as the number of occurrences divided by the total number of times the pole was dropped. We established a total of eight control plots outside the restoration sites, but within 150 feet of the planting boundaries. We placed at least one control to the windward and leeward sides of each site. Recognizing that all existing species might not appear in the cover survey, we also conducted a comprehensive walk-through to identify all species present both inside and immediately outside the two planting sites.

We determined surface bulk density, the ratio of dry mass to the bulk volume of the soil, and soil moisture at saturation from soil cores collected from the upper 5 cm with a 90 cm^3 corer. The dry mass determinations were made after oven-drying for 24 h at 105°C. We determined saturated hydraulic conductivity (K_s), the rate at which water moves through a soil layer—and thus an important variable governing the generation of overland flow—from infiltration measurements taken on site with a Vadose Zone Equipment Corporation (Amarillo, TX) disk permeameter. Infiltration capacity was estimated roughly as $\frac{1}{2} K_s$ following the Philip (1957) infiltration model (see Ziegler and Giambelluca, 1997). Use of this permeameter on Kaho'olawe is described by Ziegler and Giambelluca (1997). We analyzed soil physical and percent cover data using the nonparametric Mann-Whitney U-test to assess differences between the restoration sites and the surrounding landscape.

Survival and Amelioration

During the walk-through at the NHPS3 site, we identified only eight of 34 species

Table 3. **Species Present or Planted in NHPS Project sites in 1996**

Description[1]		Species name[3]	Common name	NHPS3	NHPS4	Control
PLANTED BETWEEN 1985 AND 1989						
N	S	*Abutilon menziesii* Seem.	*ko'oloa'ula*			
N	T	*Acacia koa* A. Gray	*koa*			
N	T	*Acacia koaia* Hillbr.	*koai'a, koa*			
I	T	*Aleurites moluccana* (L.) Willd.	*kukui*			
N	T	*Alphitonia ponderosa* Hillbr.	*kauila*			
N	H	*Argemone glauca* (Nutt. ex Prain) Pope var. *glauca*	prickly poppy, *pua kala*	*		
N	S	*Artemisia australis* Less.	*āhinahina*			
N	V	*Bonamia menziesii* A. Gray	-			
N	S/T	*Canthium odoratum* (G. Foster) Seem.	*alahe'e*			
N	S	*Chamaesyce celastroides* (Boiss.) Croizat & Degener	*'akoko*[2]	*	*	
N	S	*Chenopodium oahuense* (Meyen) Aellen	*'āheahea*			
N	S	*Colubrina asiatica* (L.) Brongn.	*'anapanapa*	1.4	*	
N	T	*Diospyros sandwicensis* (A. DC) Fosb.	*lama*			
N	S	*Dodonaea viscosa* Jacq.	*'a'ali'i*		3.8	
N	G	*Eragrostis variabilis* (Gaud.) Steud.	*'emoloa, kāwelu*	*	*	
N	T	*Erythrina sandwicensis* Degener	*wiliwili*		*	
N	S	*Gossypium tomentosum* Nutt. ex Seem.	Hawaiian cotton, *ma'o*	*	*	
N	S	*Heliotropium anomalum* var. *argenteum* A. Gray	*hinahina*[2]	*	*	
N	T	*Hibiscus brackenridgei* A. Gray	*ma'o hau hele*		*	
N	T	*Hibiscus tiliaceus* L.	*hau*		*	
N	G	*Ischaemum byrone* (Trin.) Hitchc.	*Hilo ischaemum*[2]			
N	H	*Lipochaeta integrifolia* (Nutt.) A. Gray	*nehe*[2]		*	
N	SG	*Mariscus javanicus* (Houtt.) Merr. & Metcalfe	*'ahu'awa*			
I	T	*Morinda citrifolia* L.	Indian mulberry, *noni*			
N	T	*Myoporum sandwicense* A. Gray	bastard sandalwood, *naio*[2]			
N	S	*Osteomeles anthyllidifolia* (Sm.) Lindl.	*'ūlei*		*	
N	T	*Pleomele aurea* (H. Mann) N.E. Brown	*hala pepe*		*	
N	S/T	*Santalum paniculatum* Hook & Arnott	sandalwood, *'iliahi*[2]		*	
N	S	*Scaevola coriacea* Nutt.	dwarf *naupaka*[2]		*	
N	S/T	*Senna gaudichaudii* (Hook. & Arnott) H. Irwin & Barneby	*kolomona*			
N	H	*Sesuvium portulacastrum* (L.) L.	*'ākulikuli*	0.1	3.7	
N	T	*Sophora chrysophylla* (Salisb.) Seem.	*māmane*			
N	G	*Sporobolus virginicus* (L.) Kunth	seashore rushgrass, *'aki'aki*	15.0	4.9	
N	T	*Thespesia populnea* (L.) Sol. ex Corrêa	Portia tree, *milo*[2]		*	
VOLUNTEERING IN 1996						
A	T	*Acacia implexa* Benth.	twisted wattle		*	
A	S	*Atriplex semibaccata* R. Br.	Australian creeping saltbush	2.1	3.0	0.4
A	G	*Bothriochloa pertusa* (L.) Camus	pitted beardgrass	*	*	
A	T	*Casuarina equisetifolia* L.	common ironwood		*	
A	G	*Cenchrus ciliaris* L.	buffelgrass		*	*
A	G	*Cenchrus echinatus* L.	common sandbur	0.5		
A	H	*Chamaecrista nictitans* (L.) Moench	partridge pea	0.1		
A	G	*Digitaria insularis* (L.) Mez ex Ekman	sourgrass		*	
A	H	*Emilia fosbergii* Nicolson	*pualele*	*	*	
A	S	*Lantana camara* L.	*lākana*, lantana	*		
A	G	*Rhynchelytrum repens* (Willd.) Hubb.	Natal redtop	9.4	*	*
A	S	*Salsola kali* L.	Russian thistle, tumbleweed		*	
N	S	*Sida fallax* Walp.	*'ilima*		*	
A	H	*Sonchus oleraceus* L.	sow thistle, *pualele*	0.1	*	
A	H	*Tridax procumbens* L.	coat buttons	0.1	*	
N	H	*Waltheria indica* L.	*'uhaloa*	1.4	*	
A	H	*Xanthium strumarium* var. *canadense* (Mill) Torr. & A. Gray	cocklebur	*		
		Planted species		**16.5**	**12.4**	**-**
		Volunteering species		**13.7**	**3.0**	**0.4**
		Total coverage		**30.2**	**15.4**	**0.4**

1 N = native; A = alien; I = Polynesian introduction; G = grass; S = shrub; T = tree; SG = sedge; V = vine; H = herb.
2 Coastal or beach species.
3 Modified from Giambelluca and others, 1997
* indicates present in the walk-through, but did not appear in the formal cover survey.

planted (Table 3). Of these eight, we found three in the ground cover survey, comprising a little more than half of the total vegetative cover. The dominant species was *'aki'aki* (*Sporobolus virginicus*) grass, having a coverage of 15.0 percent. Forty-five percent of the cover in NHPS3 was made up of 11 volunteering species, with exotic Natal redtop comprising almost one-third of the total cover. Native volunteer *'uhaloa* had coverage of only 1.4 percent. More total species were present at NHPS4 (30) than in NHPS3 (19), but total cover was significantly less (15.4 versus 30.2 percent; Mann-Whitney U-test, $p = 0.05$). In the NHPS4 walk-through, we found 17 of the 34 planted species. Of 13 volunteers identified, two—*'uhaloa* and *'ilima* (*Sida fallax*)—were natives. Three planted native species, *'a'ali'i*, *'ākulikuli*, and *'aki'aki*, and Australian creeping saltbush, a volunteering exotic, were the only species found in the cover survey. *'Aki'aki* grass cover was about one-third of that in NHPS3. We did not find Natal red top, the dominant alien in NHPS3 in the NHPS4 cover survey, although we did find this species in the walk-through.

'Anapanapa, *'a'ali'i*, *'aki'aki*, and *'ākulikuli* appear to be the four most persistent native species planted. *'Aki'aki* (grass) accounted for half the vegetative cover at NHPS3. The two shrubs, *'anapanapa* and *'a'ali'i*, and the herb *'ākulikuli* combined for more than 80 percent of the cover at NHPS4. Mr. Sylva told us of the early success of *'emoloa* (*Eragrostis variabilis*); however, this success was not long-term, as we did not find this grass in the cover surveys at either site. In general at both sites, species tended to be grouped together in sparse clumps of vegetation, indicating that the grasses and low creeping species depended on each other for survival, and have so far been unable to form a continuous protective cover across the site. We found no native species outside of the planting sites during the walk-through. The inability of natives to spread beyond the original planting sites suggests that most plants within the site boundaries are survivors rather than new recruits—or that if propagation has occurred, growing conditions within the NHPS sites are now more favorable to plant establishment and growth than those outside. If the first alternative is true, then the cover percentages are not merely a function of survivorship, but also of total species planted—information that was not well-documented. We do know that at least 5,000 seedlings of both *'a'ali'i* and *'ākulikuli* were planted.

Dwarf beach naupaka (*Scaevola coriacea*), one of 34 native species included in trial plantings, on the NHPS3 site in September 1999. *Photo by Allison Chun*

Mean ground cover in the control areas was less than one percent (Table 3). Alien species buffel grass, Natal red top, and Australian creeping saltbush—three stalwart species of the barren, windswept hardpan—were the only species we found immediately outside the planting areas. These species also volunteered within the planting sites, along with 12 other exotic and two native species, *'ilima* and *'uhaloa*. Thus, these latter 14 species were apparently recruited from somewhat distant seed sources. The presence of the volunteering exotics demonstrates the presence of nonnative seed sources on the island, and makes it clear that these species are capable of pioneering in sites where growing conditions are or become favorable. We did not find two invasive species, glycine (*Neonotonia wightii*) and siratro (*Macroptilium atropurpureum*), that were found in the nearby CERL experiment site (Warren and Aschmann, 1993; Ziegler and others, in press). Their absence suggests these species were not dispersed to the CERL site from on-island seed sources as was originally considered (Ziegler and others, in press), but were most likely contaminants in the CERL seed mixtures. Finally, Australian creeping saltbush, an exotic pioneer that dies back after producing seed at roughly two years, was probably more abundant in the years following the plantings, but has now decreased in extent.

Environmental Constraints

Although vegetation at both sites is subject to salt spray under windy conditions, there is no indication that the salt-tolerant species were more successful than other species. None of the eight coastal or beach species planted have substantial coverages today (Table 3). In addition, the electrical conductivity data in Table 2 do not indicate soil salinity to be a limiting factor. Soils at both sites are very low in zinc and calcium. Phosphorus and the ratio of carbon to nitrogen are also low. Again, when Sylva and his colleagues set up the NHPS study they used no fertilizer. Here, comparison with the NiFTAL and CERL studies is interesting. Results of the NiFTAL study showed that relatively small inputs of phosphorus and zinc greatly enhanced survival and growth of the *wiliwili* tree. Plantings of the CERL experiments receiving no fertilization were far inferior to plantings receiving moderate to high rates of nitrogen and phosphorus fertilization.

It appears to us that the plantings have been more successful on NHPS3 than on NHPS4 in part because the former lies recessed in the landscape, protected from the wind, while the latter site is more exposed. Sylva, in fact, commented in his unpublished notes on the general benefits of wind protection at these sites. Recent interpretations of the NiFTAL experiment (Nakao and others, 1993, 1997) and CERL plantings (Warren and Aschmann, 1993; Ziegler and others, in press) emphasize the importance of providing wind abatement for establishing some native plants. For example, survival of *wiliwili* at the NiFTAL site was considerably higher than in the CERL Phase I study where the wind-protection structure failed. Other data from CERL Phase I are especially suggestive, as none of the 228 native seedlings planted, including *'a'ali'i*, *'ūlei* (*Osteomeles anthyllidifolia*), *koa* (*Acacia koa*), *ko'oloa'ula* (*Abutilon menziesii*), and *ma'o* (*Gossypium tomentosum*) survived without some form of wind protection.

As there were no control groups for the NHPS project, it is impossible to ascertain which of the environmental constraints were most detrimental to survivorship. Collectively, the NiFTAL and CERL studies suggest survival of woody species would be low without strategies combining inoculation with mycorrhizal fungi (when appropriate), windbreak fencing, the presence of protective vegetation, and fertilization. There is also evidence that these strategies will have to be tailored to meet the needs of some species. The low species presence and coverage data indicate that future restoration efforts that do not take this into account are likely to fail.

Restoration

The high percentage of species volunteering within the NHPS sites compared with the paucity of recruits outside demonstrates that the plantings and site preparation actually did improve conditions for seedling establishment—particularly by pioneering exotics. Improved growing conditions probably result from the breakup of the hardpan surface crust during pre-planting tillage and the trapping of sediment by plants once they became established. Trapped sediment provides loose material for seed germination. Tillage, trapping of sediment, and plant growth all promote better infiltration of rain water, mainly by increasing the macroporosity of the surface soil. The physical data indicate that bulk density (an index of compaction) is lower, and soil moisture at saturation (a proxy for porosity) is significantly higher (Mann-Whitney U-test, $p = 0.05$) within the NHPS plots than immediately outside them (Table 1). In addition, saturated hydraulic conductivity—and hence infiltration capacity—is twice as high inside the experiment site as outside (95 vs. 47 mm h^{-1}). Thus, more rainwater enters the soil where it can be accessed by plant roots, and less overland flow is produced, thereby reducing the risk of fluvial erosion. However, vegetation cover in the plots is still very low and discontinuous. Generally, a cover of 40 to 60 percent is needed to provide significant protection from erosion (De Ploey and others, 1976; Morgan and others, 1986; Rogers and Schumm, 1991). The 15 to 30 percent cover in the NHPS sites are below this critical threshold, and may be too low to provide much protection from erosion. This seems especially likely because, although infiltration capacity within the experiment sites has increased since planting, erosion is exacerbated by surface runoff from areas outside the plots where infiltrability has not improved. Infiltration capacity is probably not high enough to absorb both on-site rain water and overland flow from upslope. The plantings therefore remain at risk to large-scale erosion processes that could eventually destroy the site.

> **Strategies have to be tailored to meet the needs of some species. The data indicate that future restoration efforts that do not take this into account are likely to fail.**

Conclusion

Our results suggest that establishment of native species on the barren, windswept plateau region of Kaho'olawe may not be feasible without strategies combining wind abatement, fertilization, irrigation, and rhyzobial inoculation in appropriate ways. Our assessment of the NHPS demonstration plots revealed that some planted native species were surviving, but were generally not propagating. The four planted, native species showing the greatest ability to persist on the hardpan were *'anapanapa*, *'a'ali'i*, *'aki'aki*, and *'ākulikuli*. Salt-tolerant species did not prove to be better survivors than more common natives, indicating that soil salinity is not a major constraint. The emergence of alien pioneer species within the experiment sites together with physical soil data suggest that, despite the disappointing short-term results, the planting has improved growing conditions and has increased the infiltration capacity of the soil. However, plant coverage is probably still too low to provide effective protection from erosion, which is exacerbated on these sites by overland flow from adjacent areas. Thus, low subsidy plantings, such as those attempted at the NHPS sites, are vulnerable in two ways. First, individual plants may not survive in the harsh environment. And second, because of low survivorship and recruiting, the site as a whole is likely to remain vulnerable to erosion for a long period, at least until the vegetation reaches some critical threshold coverage—if, indeed, it ever does.

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