Revegetation strategies for Kaho'olawe Island, Hawaii

STEVEN D. WARREN AND STEFANIE G. ASCHMANN

Abstract

Over the past 2 centuries, the island of Kaho'olawe has suffered the ravages of war, slash-and-burn agriculture, and overgrazing. Today, much of the island is barren and severely eroded. A research project initiated in 1988 has sought to identify effective, economical techniques to revegetate portions of the island. Treatments included drill seeding plus several rates of fertilization with monoammonium phosphate (11-52-0). Some treatments also include jute netting for soil moisture conservation and erosion control. The effect of windbreak fencing was evaluated across all treatments. Drill seeding plus broadcast application of at least 62 kg ha⁻¹ N plus 291 kg ha⁻¹ P₂O₅ was the most cost-effective treatment. Jute netting and windbreak fencing significantly enhanced plant production, but the high cost of materials and maintenance limits their use to critical areas. The planted species with greatest promise for the windy, semiarid conditions on Kaho'olawe were buffelgrass (Cenchrus ciliaris L.), bermudagrass [Cynodon dactylon (L.) Pers.] and weeping lovegrass [Eragrostis curvula (Schrad.) Nees]. Although not included in the seed mixture, Australian saltbush (Atriplex semibaccata R. Br.), a naturalized species, responded favorably to fertilization. A subsequent, larger-scale revegetation project using a specially modified chisel plow seeder to scarify, plant, and apply in-furrow fertilization in a single-pass operation reduced the cost and improved the results of the revegetation process.

Key Words: fertilization, jute netting, windbreak fence, drill seeding

Kaho'olawe, smallest of the 8 major islands of the Hawaiian Archipelago, suffers from a long history of natural and man-induced exposure to the forces of erosion. The island measures about 17.7-km long by 10.5-km wide, comprising some 11,340 ha. The highest point is the rim of an extinct volcano at 449 m above sea level. Kaho'olawe lies in the rain shadow of Haleakalā on Maui. Climatic records for the island are scant, but estimated annual precipitation is approximately 500 mm (Department of the Navy 1979), with most of it falling from November through March. In addition to the low precipitation, Kaho'olawe is the windiest of the Hawaiian Islands (Stearns 1940). Deflected by Haleakalā, the persistent northeasterly tradewinds accelerate across the intervening channel, reaching an average speed of about 9 m s⁻¹ at Kaho'olawe (Department of Geography, University of Hawaii 1973).

Much of Kaho'olawe may have been covered with a scrub forest at one time (Cuddihy and Stone 1990). Today, however, approximately a third of the island is barren, while the remainder is dominated by the introduced shrub kiawe [Prosopis pallida (Humb. & Bonpl. ex Wild.) Kunth] and a variety of introduced grasses and forbs. The only native species contributing significant...
biomass are pili grass or tanglehead [Heteropogon contortus (L.) P. Beauv. ex Roem. & Schult.], ma‘o or Hawaiian cotton (Gossypium tomentosum Nutt. ex Seem.), ‘ilima (Sida fallax Walp.), ‘uhaloa (Waltheria indica L.), and ma‘o or hoary abutilon [Abutilon incanum (Link) Sweet].

The disturbance of native vegetation on Kaho‘olawe probably began with slash-and-burn agriculture practiced by early Hawaiians (Kirch 1982). Intense intersi island warfare before the arrival of European explorers left the island "nearly overrun with weeds, and exhausted...of inhabitants" (Vancouver 1798). The population had declined from an estimated peak of 800 around 1500 A.D. to approximately 60 at the time of European discovery (Hommon 1980), presumably in response to a depleted natural resource base. In 1779 the crew of Captain Cook described the island as "barren," "desolate," and an "altogether poor island" (Beaglehole 1967). The same explorers that lamented the poor condition of the island unwittingly contributed to its further deterioration by introducing goats as gifts to native monarchy, thus accelerating soil erosion.

Reports over the next half-century place livestock populations as high as 20,000 sheep, 9,000 goats, and 200 head of cattle (Anonymous 1875, Bagot 1884). By 1916 approximately a third of the island was completely denuded, and from 1 to 3 m of topsoil had been blown or washed into the Pacific Ocean, leaving behind a wind-swept hardpan (Judd 1916).

With the entrance of the United States into World War II, Kaho‘olawe was acquired by the U.S. military and became a target for offshore gunnery and aerial bombing practice. While military use of the island may have caused further deterioration in areas of intense impact, there has been no apparent increase in the size of denuded hardpan areas since military training began (Department of the Navy 1979). The U.S. Navy has, nonetheless, undertaken the responsibility to improve the condition of the island.

Transplanted grass and legume seedlings have not survived well on Kaho‘olawe (Whitesell et al. 1974), perhaps due to their dependence on adequate rainfall soon after transplanting. Attempts to establish vegetation by broadcast seeding have likewise met with little success (author’s observation). This manuscript describes a study, begun in 1988, aimed at identifying effective, economical measures to revegetate portions of the island.

**Materials and Methods**

The study site was in a broad, relatively flat swale near the center of the island. The area supported less than 2% plant cover, composed primarily of isolated clumps of Australian saltbush (Atriplex semibaccata R. Br.). Since its introduction to Kaho‘olawe around 1918 (Stearns 1940), Australian saltbush has become one of the dominant plants on the hardpan area. Soil analyses indicate that the soil of the central hardpan is predominantly of clay loam texture (Warren et al. 1988). Iron and aluminum hydrous oxides, well known for phosphorus fixation (Sanchez 1976), dominate the clay component. Nitrogen, extractable phosphorus, and organic carbon levels are very low, while potassium content is very high. Soil pH tends to be slightly acidic. The soil surface is very hard and often polished and/or striated by blowing soil particles.

To create soil surface conditions suitable for planting, the entire hardpan area was chiseled to a depth of approximately 10 cm during November 1988. The surface soil was very dry at the time of planting in December of that year. However, subsurface soil moisture conditions were surprisingly good; moisture was evident to a depth of at least 45 cm, due to previous rains.

Five experimental blocks were established adjacent and parallel to each other. Within each block, 7 adjacent strips 60-m long and 1.8-m wide were laid out to accommodate 6 revegetation treatments and an unplanted control. All strips were oriented parallel to each other and parallel to the prevailing wind direction.

Each strip except the control was planted with a single longitudinal pass of a rangeland drill. The drill planted 5 rows in a total swath of 1.5 m. A mixture of 6 grasses and 1 legume (Table 1) was planted at a depth of 2.5 cm. Species selection was limited to the following species included in a mixture evaluated for revegetation on Kaho‘olawe.

<table>
<thead>
<tr>
<th>Grasses</th>
<th>Seeding rate</th>
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<tbody>
<tr>
<td>T-4464 buffelgrass</td>
<td>1.1 kg ha⁻¹</td>
</tr>
<tr>
<td>'WW Ironmaster' yellow bluestem</td>
<td>0.6</td>
</tr>
<tr>
<td>Plains bristlegrass</td>
<td>1.1</td>
</tr>
<tr>
<td>Buffalo grass</td>
<td>1.7</td>
</tr>
<tr>
<td>Green panicgrass</td>
<td>0.7</td>
</tr>
<tr>
<td>Glycine</td>
<td>7.1</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Legume</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>*De-wedgew</td>
<td></td>
</tr>
</tbody>
</table>

Introduced species because seeds of native species were not commercially available. Cracked corn was mixed with the seed prior to planting to improve uniformity of distribution. Seeds were covered by dragging 6 cm diameter steel pipes behind the drill.

Four strips in each block were selected for fertilizer treatments. One strip was fertilized with 3.6 kg ha⁻¹ nitrogen (N) plus 17.1 kg ha⁻¹ phosphorus (P₂O₅) applied in-furrow by the drill. Two strips were fertilized by broadcast application of 62 kg ha⁻¹ N plus 291 kg ha⁻¹ P₂O₅, and 1 strip was broadcast at 123 kg ha⁻¹ N plus 582 kg ha⁻¹ P₂O₅. All fertilizer was applied as a granular form of monomanoium phosphate (11-52-0). The use of a high ratio of phosphorus to nitrogen is common in subtropical and tropical regions where phosphorus-fixation by iron and aluminum hydroxides is a problem (Sanchez 1976). Within each block, 1 unfertilized strip and 1 strip fertilized at 62 kg ha⁻¹ N plus 291 kg ha⁻¹ P₂O₅ were covered with woven jute netting. The fabric, supplied in rolls 1.2 m wide, provided approximately 35–40% coverage of the soil surface. It was secured to the soil surface with 15 cm long staples immediately following seeding and fertilization.

To evaluate the potential benefits of wind abatement on plant establishment, a single 1.2 m tall, high-density polyethylene plastic windbreak fence was erected across the entire study site. The fence was attached to galvanized steel posts and situated perpendicular to the prevailing wind direction, approximately 12 m downwind of the windward edge of the experimental blocks. This configuration allowed an evaluation of the effects of wind abatement in each treatment strip on both the windward and leeward sides of the fence. Elliptical apertures in the windbreak fence provided approximately 37% porosity, which is ideal for a wind barrier (van Eimern et al. 1964). To avoid disturbance associated with wind turbulence at the ends of windbreaks, the fence was extended 4.5 m beyond the edge of the study site on both sides.

Data were collected at the study site during January 1991, approximately 25 months after planting. A 0.25-m² quadrat was placed on the ground at 2-m intervals along the central axis of each treatment strip, beginning at the windbreak fence and proceeding to the end of the strip in both the windward and leeward directions. Percent foliar cover in each quadrat was visually estimated by species and as a total, and recorded by cover class (Daubenmire 1959). Data were summarized using class midpoints. A 3-way analysis of variance (ANOVA) was used to determine differences between treatments, blocks, and distances from the windbreak.
fence. Duncan's multiple range test was used to separate means where differences were shown to be significant in the ANOVA. The relative success of plant species across all treatments, blocks and distances from the windbreak fence was evaluated by paired comparison t-tests (SAS Institute Inc. 1988). The difference in percent foliar cover between any given pair of species was calculated for every quadrat, and the mean difference was tested to determine if it was significantly different from zero. The analysis was repeated for all possible combinations of species. A 95% level of probability was used for all analyses.

Results and Discussion

Twenty-five months after planting, treatments that included fertilization with at least 62 kg ha⁻¹ N plus 291 kg ha⁻¹ P₁₀₅ produced significantly more foliar cover than other treatments (Fig. 1). Treatment strips fertilized at 3.6 kg ha⁻¹ N plus 17.1 kg ha⁻¹ P₁₀₅ had no more vegetation than the unplanted strips. Foliar cover increased as fertilization increased. The rate of increase, however, appeared to diminish between the 2 higher rates of fertilization, indicating that elevated levels of fertilization would not greatly enhance vegetation response. When applied at the maximum rate, the cost of fertilizer was approximately $560 ha⁻¹.

The most effective treatment was the combination of seed, jute netting, and 62 kg ha⁻¹ N plus 291 kg ha⁻¹ P₁₀₅. Overall, this treatment produced 61% foliar cover. Jute netting apparently conserved soil moisture and provided protection from soil erosion. Unusually heavy precipitation during the 2nd year of the study generated large volumes of runoff that concentrated primarily on 2

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**Table:**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Foliar Cover (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unplanted control</td>
<td>AB</td>
</tr>
<tr>
<td>Seed only</td>
<td>A</td>
</tr>
<tr>
<td>Seed &amp; jute netting</td>
<td>A</td>
</tr>
<tr>
<td>Seed &amp; fertilization rate 1</td>
<td>B</td>
</tr>
<tr>
<td>Seed &amp; fertilization rate 2</td>
<td>C</td>
</tr>
<tr>
<td>Seed &amp; fertilization rate 3</td>
<td>D</td>
</tr>
<tr>
<td>Seed, jute netting &amp; fertilization rate 2</td>
<td>E</td>
</tr>
</tbody>
</table>

**Fig. 1.** Percent foliar cover by treatment, averaged across all blocks and distances from the windbreak fence, 25 months after planting on Kaho'olawe. Fertilization rate 1 = 3.6 kg ha⁻¹ N plus 17.1 kg ha⁻¹ P₁₀₅, rate 2 = 62 kg ha⁻¹ N plus 291 kg ha⁻¹ P₁₀₅, and rate 3 = 123 kg ha⁻¹ N plus 582 kg ha⁻¹ P₁₀₅. Means followed by the same letter are not significantly different at P=0.05, according to Duncan's multiple range test.

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Of the remaining species, only weeping lovegrass [*Eragrostis curvula* (Schrad.) Nees] contributed greater than 1% cover. This species was not included in the seeding mixture, and probably arrived as a contaminant with one of the other grasses. The relative success of weeping lovegrass, despite the extremely low input, indicates that it is a species deserving attention as a candidate for future revegetation efforts on Kaho'olawe. Siratpo [*Macroptilium atropurpureum* (DC) Urb.], another twining legume that arrived as an apparent contaminant with one of the other grasses. The relative success of weeping lovegrass, despite the extremely low input, indicates that it is a species deserving attention as a candidate for future revegetation efforts on Kaho'olawe.
Fig. 2. Percent foliar cover by distance upwind or downwind from the windbreak fence, averaged across all treatments and blocks, 25 months after planting on Kaho'olawe. Means with the same letter are not significantly different at P = 0.05, according to Duncan's multiple range test.

Fig. 3. Percent foliar cover of various plant species, averaged across all treatments, block, and distances from the windbreak fence, 25 months after planting on Kaho'olawe. Means followed by the same letter are not significantly different at P = 0.05, according to paired comparison t-tests for all possible combinations of species.
woody species. Yellow bluestem, plains bristlegrass, buffalograss, and green panicgrass showed little promise for Kaho'olawe.

Literature Cited


