12.

VEGETATION RESPONSE WITHIN EXCLOSURES IN HAWAI'I: A REVIEW

Lloyd L. Loope and Paul G. Scowcroft

ABSTRACT

Exclosure studies have been used to great advantage in the Hawaiian Islands to evaluate and demonstrate impacts of alien vertebrate herbivores upon native vegetation. Information presented for 50 exclosures, mostly on Hawai'i and Maui, shows a wide range of vegetation responses. In most situations, native biota hold their own or increase following removal of vertebrate damage, but the chance of recovery becomes reduced as the extent of degradation increases. Displacement by alien grasses appears to be the most significant factor inhibiting reproduction of native species in areas other than rain forest. The intact native vegetation in "natural exclosures" shows that damage by alien vertebrates is a prerequisite for large-scale invasion of alien plant species. Priorities for the future include continuing maintenance and evaluation of existing exclosures and establishment of new ones in leeward low and middle elevation ecosystems. Comprehensive monitoring should be carried out to document biological and physical changes resulting from vertebrate herbivore exclusion aided by large fencing projects.

INTRODUCTION

Construction of "exclosures" with fencing to exclude alien vertebrate herbivores from small areas has proved to be a highly useful tool in allowing, demonstrating, and/or determining vegetation recovery from grazing, browsing, trampling, digging, etc. by these animals. Exclosures are commonly used by land managers throughout the world, both on islands and in continental situations (Tiedemann and Berndt 1972; Jane and Pracy 1974; Marquis 1974; Lock 1977; Kightley and Smith 1978; Coblentz 1977). In Hawai'i, exclosures have most frequently been used in areas where native vegetation persists. We present in this paper an inventory of exclosures in the State of Hawai'i known to us; review objectives and accomplishments of their establishment; review methods and frequency of vegetation monitoring used; summarize vegetation response under protection; examine the special case of "natural exclosures;" and explore future needs.

INVENTORY OF HAWAIIAN EXCLOSURES

We have been able to obtain information on 51 exclosures in the State of Hawai'i, most of which are on the islands of Hawai'i (27) and Maui (18). These exclosures have been constructed by the U.S. National Park Service (NPS, 22 in number), the Hawai'i Department of Land and Natural Resources (DLNR, 20), and other institutions. Table 1 lists these exclosures and provides the following information: location (island, volcanic mass, and U.S. Geological Survey [USGS] quadrangle map); responsible agency; vegetation zone, according to the system of Ripperton and Hosaka (1942); year constructed; approximate size in hectares; purpose of establishment; brief characterization of vegetation response to date; and source of information. Table 2 gives a simplified version of the Ripperton and Hosaka (1942) classification scheme for zonal vegetation in Hawai'i.

EXCLOSURE OBJECTIVES AND THEIR ACCOMPLISHMENT

The reasons for building the exclosures listed in table 1 fall into broad and often overlapping categories. In this section, we discuss some prime examples of how the 4 objectives listed below were or were not met.

Demonstrate Impacts of Alien Vertebrate Herbivores

Exclosure HKi-1 was a major public relations success for Hawai'i Volcanoes National Park (HAVO) early in its fencing/feral goat (*Capra hircus*) eradication program. Within 2 years of its construction, an endemic species, *Canavalia kauensis* appeared, which had apparently survived 150 years of goat browsing through seeds lying dormant in the soil (St. John 1972; Baker and Reeser 1972). This discovery gave tremendous momentum to the goat control program, which was sustained even though the response of native species in other exclosures was less dramatic. Similarly, prompt and excellent recovery of vegetation damaged by feral pigs (*Sus scrofa*) in an exclosure (HKi-5) in a rain forest area near Napau Crater (Katahira 1980) gave impetus to an accelerated program of pig control at HAVO.

Study Recovery Potential of Animal-damaged Ecosystems

Included in this objective are studies of reproduction, survival, and growth of native plants; changes

Table 1. Inventory of exclosures in the Hawaiian Islands.

Name/Descriptor References/Sources	Purpose	Findings	
Sandalwood Sanctuary HMK-1-DLNR-E2-68-Ø.8-Ahumoa (NW)	Protection of concentration of sandalwood trees	Sandalwood trees have flourished and are reproducing by rootsuckers but not seedlings	DLNR-DOFAW (Hilo)
Kaluamakani HMK-2-DLNR/SCS-E2-63-Ø.4-`Umikoa (SW)	Demonstration area to show adverse effect of feral and mouflon sheep on vegetation	Mamane reproducing inside but not outside exclosure. Plant cover greater inside	Scowcroft and Giffin 1983
Pu`u Nanaha HMK-3-DLNR/SCS-E2-63-Ø.4-Ahumoa (NE)	Same as Kaluamakani	Same as Kaluamakani	Scowcroft and Giffin 1983
Pu`u Kole HMK-5-DLNR/SCS-E2-63-Ø.4-Mauna Kea (SE)	Same as Kaluamakani	Same as Kaluamakani	Scowcroft and Giffin 1983
Kahinahina HMK-5-DLNR/SCS-E2-63-Ø.4-Mauna Kea (SE)	Same as Kaluamakani	Little difference evident between protected and unprotected areas	DLNR-DOFAW files
Wailuku HMK-6-DLNR/FS-E2-Ø.9-Mauna Kea (SE)	Same as Kaluamakani; and test methods for regenerating silversword and mamane	Same as Kaluamakani; planting of silversword and mamane successful; direct sowing of mamane seeds a marginal practice	Scowcroft and Giffin 1983; Scowcroft 1981
Pu`u o Kauha HMK-7-FS-E2-72-Ø.3-Ahumoa (SE)	Determine effect of feral and mouflon sheep on mamane and other plant species	Feral sheep suppress mamane reproduction and other preferred browse species	Scowcroft and Giffin 1983

Table 1. Continued.

Name/Descriptor References/Sources	Purpose	Findings	
Hale Pohaku HMK-8-FS-E2-72-0.3- Mauna Kea (SW)	Same as Pu`u o Kauha	Same as Pu`u o Kauha	Scowcroft and Giffin 1983
Pu`u La`au-Mauka HMK-9-DLNR-E2-73-0.1- Ahumoa (NW)	Demonstrate natural recovery of mamane forest freed from sheep browsing	Rapid growth of mamane sprouts and seedlings	DLNR-DOFAW files (Hilo)
Wailuku Pen HMK-10-DLNR-E2-63-0.1- Mauna Kea (SE)	Abandoned mouflon holding pen now a demonstration area for forest recovery	Vegetation more abundant inside pen	DLNR-DOFAW (Hilo)
Pu`u Nanaha-Mauka HMK-11-DLNR-E2-73-0.4- Ahumoa (NE)	Demonstrate response of vegetation to protection from sheep above tree line	Little change observed inside	DLNR-DOFAW (Hilo)
Pu`u o Kauha-Mauka HMK-12-DLNR-E2-78-2.0- Ahumoa (NE)	Test feasibility of reforesting by planting mamane seedlings	High survival and good growth of nursery stock	DLNR-DOFAW files (Hilo)
Pu`u Kaupakuhale HMK-13-DLNR-E2-72-0.4- Mauna Kea (SE)	Demonstration area above tree line to show vegetation recovery when sheep are excluded	No follow-up measurements	DLNR-DOFAW (Hilo)
Laupahoehoe HMK-14-FS-D3-75-0.1- Keanakolu (SW)	Study survival and growth of rooted cuttings, air-layers,and tissue culture seedlings from superior koa trees	All tissue culture seedlings died and all others lived. Some trees growing well	Skolmen 1978

Table 1. Continued.

Name/Descriptor References/Sources	Purpose	Findings	
Humu`ula HMK-15-FS-D3-77-Ø.1-Keanakolu (SW)	Test koa reforestation methods	Regeneration efforts negated by banana poka	USFS files (Skolmen, Honolulu)
Kukaiau #2 HMK-16-MKR/FS-D3-78-2.Ø-Keanakolu (NW)	Test koa reforestation methods	Excellent survival and growth of containerized koa seedlings Little natural regeneration	MKR/FS (Skolmen, Honolulu)
Koai`e Sanctuary HKo-1-DLNR-D2-5Ø-5.2-Kamuela (NW)	Protection and recovery of Acacia koaia and other dryland species	Seedlings of resident woody plants in the exclosure have grown well. Planted Hibiscadelphus barely alive	DLNR-DOFAW (Hilo)
Honua`ula HHu-1-DLNR-D3-82-Ø.4-Kailua (SE)	Study survival and growth of koa nursery stock	None to date	DLNR-DOFAW (Hilo)
Mauna Loa Strip HML-1-NPS-D3-68-Ø.1-Kilauea Crater (NE)	Determine effect of feral goats on koa reproduction. No longer maintained	Goat browsing/trampling leads to increase in production of koa suckers but suppresses their growth	Spatz and Mueller-Dombois 1973
Keauhou HML-2-BE/FS-D3-77-81.Ø-Kulani (SW)	Study stand development after soil scarification and test cultural practices	Abundant regeneration, even in unscarified areas; rapid growth; fertilization useful	Skolmen and Fujii 198Ø
Keauhou #2 HML-3-BE/DLNR-D3-8Ø-2.Ø-Kulani (SW)	Demonstrate ability of koa to recolonize a logged and grazed site	None to date	Bishop Estate (Honaunau)

Name/Descriptor References/Sources	Purpose	Findings	
Powerline HML-4-DLNR-bog-84-Ø.1	Protect declining population of Ka`u silversword, _Argyroxiphium kauense_	None to date	DLNR/DOFAW (Hilo)
Kukalau`ula HKi-1-NPS-A/B-68-Ø.1- Ka`u Desert (SW)	Determine recovery of lowland vegetation protected from goats	Appearance of new endemic species, _Canavalia kauensis_; annual alien grass replaced by alien perennials	Mueller-Dombois and Spatz 1975; Mueller-Dombois 1979, 1981
Fern Jungle HKi-2-NPS-D2-68-Ø.1- Volcano (NW)	Determine recovery of rain forest understory from pig damage	Modest increase of cover by native species and decrease of aliens after 13 years	Higashino and Stone 1982
Pu`u Kaone #1 HKi-3-NPS-A/B-71-Ø.1- Ka`u Desert (SE)	Determine recovery of lowland vegetation	Change in dominant alien grass species; large increase in the alien grass _Melinus_. Increase in total cover	Mueller-Dombois and Spatz 1975; Mueller-Dombois 1981
Pu`u Kaone #2 HKi-4-NPS-A/B-71-1.Ø- Ka`u Desert (SE)	Determine recovery of lowland vegetation. Used as nene pen starting in 1976	Same as above. Also large increase in the alien tree _Leucaena_	Mueller-Dombois and Spatz 1975; Mueller-Dombois 1979
Napau Crater HKi-5-NPS-D2-75-Ø.4- Makaopuhi Crater (NE)	Determine recovery of rain forest understory from feral pig damage	Dramatic recovery of native vegetation	Katahira (198Ø)
Thurston Lava Tube HKi-6-NPS-D2-812ØØ Volcano (NW)	Test feasibility of removal and exclusion of pigs	Pigs successfully excluded from area	NPS files (Hawaii Volcanoes N.P., Resources Mgmt.)

Table 1. Continued.

Name/Descriptor References/Sources	Purpose	Findings	
Honokahua EMa-1-NPS-E2-65-0.1-Nahiku (SW)	Determine recovery of mamane stand under protection from goats	Disappearance of browse line on individual trees; no reproduction	Jacobi 1980
Auwahi EMa-2-TNC-C2-69-5-Luala`ilua Hills (SW)	Protection of concentration of rare dryland forest tree species; determine recovery under protection from cattle	Invasion by kikuyugrass prevented reproduction of trees; deterioration of stand continued	Medeiros, Loope, and Holt, in prep.
Kalapawili grassland EMa-3-NPS-E1-74-0.04-Nahiku (SE)	Determine result of competition between native and introduced grasses under protection after pig disturbance	Stable situation over 5-year period; native grass *Deschampsia* holding its own	Jacobi 1981
Healani EMa-4-DLNR-D3-76-0.2-Kaupo (NE)	Determine recovery of koa stand under protection from goat browsing	Good immediate reproduction of koa; simultaneous increase in alien grass *Melinus*	Scowcroft and Hobdy, in prep.
East Kaupo EMa-5-NPS-D3/ C2-77-3.0-Kaupo (NE)	Protect mixed forest from goats	Improved reproduction of *Myrsine*, *Coprosma stephanocarpa*; kikuyugrass has prevented reproduction of rare trees in lower portion	Loope, Medeiros, and Crivellone, in prep.
West Kaupo EMa-6-NPS-C2/ E2-78-0.1-Kaupo (NW)	Determine recovery potential of goat-damaged area	Initial dominance by alien grasses; gradual increase of native shrubs	Loope, Medeiros, and Crivellone, in prep.

Table 1. Continued.

Name/Descriptor References/Sources	Purpose	Findings	
Flattop Bog EMa-7-NPS-bog-79-0.2-Nahiku (SE)	Protect pig-damaged bog and allow recovery	Alien dominants have occupied bare ground and may have displaced some native bog vegetation since fencing	Loope, Medeiros, and Gagne, in prep.
Kipahulu (4750 ft) EMa-8-NPS-D3-79-0.1-Nahiku (SW)	Determine recovery of `ohi`a rain forest vegetation under protection from pigs	Recovery slow	Loope, Medeiros, and Crivellone, in prep.
Kipahulu (3200 ft) EMa-9-NPS-D2-79-0.1-Kaupo (NE)	Determine recovery of koa rain forest vegetation under protection from pigs	Not remeasured yet	Loope, Medeiros, and Crivellone, in prep.
Kipahulu (2200 ft) EMa-10-NPS-D2-79-0.1-Kipahulu (NW)	Determine recovery of low elevation rain forest vegetation under protection from pigs	Not remeasured yet	Loope, Medeiros and Crivellone, in prep.
Pu`u Mamane EMa-11-NPS-E2-81-0.4-Nahiku (SW)	Determine recovery potential of mamane stand under protection from goats	Good initial vegetative recovery; poor seedling growth and survival	Loope, Medeiros, and Crivellone, in prep.
Greensword Bog EMa-12-NPS-bog-81-0.2-Nahiku (SE)	Protect pig-damaged bog and allow recovery	Cover of native bog spp. increased from 4% to 39% in 2 years; no invasion of aliens as yet	Loope, Medeiros, and Gagne, in prep.

Name/Descriptor References/Sources	Purpose	Findings	
\`Iliahi EMa-13-NPS-E2-81-0.2- Kilohana (SE)	Determine recovery of stand of *Santalum haleakalai* under protection from goat browsing	Slow growth of vegetative root suckers; no new seedling establishment yet	Loope, Medeiros, and Crivellone, in prep.
Kaupo Dryland Ridge EMa-14-NPS-D3/ C2-81-0.1-Kaupo (NE)	Allow rare dryland forest to reproduce	Initial reproduction of more common tree species. Increase in alien grass cover	Loope, Medeiros, and Crivellone, in prep.
Polipoli/red Geranium EMa-15-DLNR-E2-83-0.5- Luala\`ilua Hills (NW)	Allow very rare *Geranium arboreum* to reproduce	Not re-evaluated yet	DLNR-DOFAW (Wailuku)
New Bog EMa-16-NPS-bog-83-0.2- Nahiku (SE)	Allow pig-damaged bog to recover before alien plants invade	Not remeasured yet	Loope, Medeiros, and Gagne, in prep.
Ko\`olau/orchid EMa-17-TNC/NPS-E1-84- 0.1-Nahiku (SW)	Protect small population of *Plantanthera holochila*, a very rare endemic orchid	Not re-evaluated yet	Loope, Medeiros, and Crivellone, in prep.
Manawainui/Remya WMa-1-DLNR-C-82-23- Ma\`alaea (NW)	Protect very rare *Remya mauiensis* and other species of dryland forest/shrubland	No formal re-evaluation as yet	DLNR-DOFAW (Wailuku)
Kaho\`olawe #3 Kah-1-DLNR/FS/USN-A- 71-0.2-Kaho\`olawe East (SW)	Study recovery of vegetation after goats excluded; test suitability of alien trees for erosion control	Only alien species present after fencing, mainly grasses	USFS files (Whitesell, Honolulu)

Table 1. Continued.

Name/Descriptor References/Sources	Purpose	Findings	
Kaho`olawe #4 Kah-2-DLNR/FS/USN-A-71-0.2-Kaho`olawe East	Same as Kaho`olawe #3	A few indigenous *Waltheria americana* inside only	USFS files (Whitesell, Honolulu)
Kaho`olawe #5 Kah-3-DLNR/FS/USN-A-71-0.2-Kaho`olawe West (NE)	Same as Kaho`olawe #3	Indigenous *Waltheria americana* and *Sida fallax* well represented inside and outside	USFS files (Whitesell, Honolulu)
Puhi`elelu Ridge L-1-private-C-82-.001-Lana`i Island	Protects last surviving plant of *Hibiscadelphus crucibracteatus* from axis deer	Initially effective, but plant appears dead as of 1/85	P. Connally; R. Hobdy
Mo-1-DLNR-C-84-4-Kaunakakai (SE)	Protect several hundred individuals of the very rare *Sesbania arborea* from axis deer and cattle	Not yet re-evaluated	Established by DLNR-DOFAW (Wailuku) with permission of Hawaii Home Lands Commission
Gardenia 0-1-DLNR/private-(Honolulu) C-35-0.004	Protects a single plant of *Gardenia brighamii* in pasture of private ranchland	Tree still survives, but no reproduction	DLNR-DOFAW

Descriptor format: Island and volcanic mass/reference #, based on order of exclosure establishment in each location/agency responsible/vegetation zone of Ripperton and Hosaka, 1942/ last two digits of year established/size in hectares/USGS Quadrangle in which the exclosure is located.

Example:

EMa-4-DLNR-D3-76-0.2-Kaupo (NE) = East Maui, 4th exclosure established there, Hawai`i Department of Land and Natural Resources responsible, within Ripperton and Hosaka zone D3- open forest of Acacia koa, exclosure established in 1976, 0.2 hectares in size, located within northeast quadrant of USGS Kaupo Quadrangle.

Descriptors:

Location--HMK - Island of Hawai`i, Mauna Kea
HML - Island of Hawai`i, Mauna Loa
HHu - Island of Hawai`i, Hualalai
HKo - Island of Hawai`i, Kohala
HKi - Island of Hawai`i, Kilauea
EMa - Island of Maui, East Maui (Haleakala)
WMa - Island of Maui, West Maui (West Maui Mtns.)
Kah - Island of Kaho`olawe
L - Island of Lana`i
Mo - Island of Moloka`i
O - Island of O`ahu

Agency--
BE - Bishop Estate
DLNR - Hawai`i Department of Land and Natural Resources
DOFAW - Hawai`i Division of Forestry and Wildlife
FS - Forest Service
MKR - Mauna Kea Ranch
NPS - National Park Service
SCS - Soil Conservation Service
TNC - The Nature Conservancy
USN - U.S. Navy

Table 2. Simplified version of the Ripperton and Hosaka (1942) classification.[1]

Climatic Regime	Zone	Vegetation Class	Vegetation Association
Xerotropical (leeward lowland to submontane)	A	Savannah and dry grassland	_Prosopis_ savannah and _Heteropogon-Rhynchelytrum_ grassland
	B	Dryland sclerophyll forest (or scrub)	_Metrosideros-Diospyros_ open forests; replacement vegetation: _Leucaena_ scrub and forest
	C	Mixed mesophytic forest (woodland or scrub). C1 low phase, C2 high phase	_Acacia koa_ open forests; replacement vegetation _Psidium guajava_, _Eugenia cuminii_ forests or woodland
Pluviotropical (windward lowland to upper montane)	D1	Lowland rain forest	_Metrosideros_ forests
	D2	Montane rain forest	_Metrosideros-Cibotium_ and dominantly _Cibotium_ forests
	D3	Upper montane rain or cloud forest	_Cheirodendron_ or _Acacia koa-Metrosideros_ mixed forests

Climatic Regime	Zone	Vegetation Class	Vegetation Association
Cool tropical (upper montane to alpine); only on Maui and Hawai`i	E1	Mountain parkland and savannah	*Acacia koa*-*Sophora chrysophylla* tree communities, *Deschampsia* tussock grassland
	E2	Subalpine forest and scrub	*Sophora*-*Myoporum* tree communities, *Styphelia*-*Vaccinium*-*Dodonaea* scrub communities
	E3	Sparse alpine scrub	*Styphelia*, *Vaccinium* and moss desert *Rhacomitrium lanuginosum* var. *pruinosum*

1 Scheme for zonal vegetation in Hawai`i adapted from Mueller-Dombois and Gagne in Wagner, Herbst, and Yee (this volume).

in physical, chemical, and biotic characteristics of the soil; changes in associated fauna, etc. Exclosures built for this purpose show tremendous differences in recovery potential, related mainly to ecosystem type, degree of animal damage, and presence of one or more highly competitive exotic plant species. These exclosures also satisfy the first objective.

Provide Ungulate-free Areas for Biological Experiments

This objective has been used infrequently in Hawai'i. Scowcroft (1981) successfully used HMK-6 to determine if recovery of mamane (*Sophora chrysophylla*) forest could be enhanced by direct sowing of mamane seeds. Skolmen (1978) used a pig- and cattle-proof exclosure (HMK-14) to study survival, growth, and disease susceptibility of vegetatively-grown koa (*Acacia koa*) progeny.

Preserve Populations of One or More Rare Plant Species or Small Tracts of a Rare Plant Community Which Would Otherwise be Lost through Animal Damage

Several exclosures have been erected in the past few years primarily to protect localized populations of single species. Target species have included *Argyroxiphium sandwicense* subsp. *sandwicense*, *Remya mauiensis*, *Sesbania arborea*, *Pittosporum confertiflorum*, and *Platanthera holochila*. In each case the projects have been emergency efforts to save populations before they are extirpated. It is too early to say how successful these projects will be in protecting naturally reproducing populations over the long term, but most would appear to have been highly successful in the short run in preventing what appeared to be certain extirpation of the populations. In exclosure HMK-6, results of Mauna Kea silversword plantings appeared promising with some apparent natural regeneration as of 2/83 (LLL). The rare *Dubautia arborea* was observed to be thriving in this same exclosure.

ASSESSING VEGETATION CHANGE

A variety of methods and sampling intervals has been used for assessing vegetation change in Hawaiian exclosures. Parameters of interest have been plant cover, density, survival, and growth. No one has reported studying changes in phytomass, although we see merit in such an approach.

Cover

Mueller-Dombois and Spatz (1975), Jacobi (1981), Katahira (1980), Mueller-Dombois (1981), and Scowcroft and Hobdy (in prep.) and others have used a point-frequency sampling method for estimating percentage ground cover and species composition. The method has 2 basic variants. For herbaceous vegetation and other plants less than 0.5 m tall, one or more sharpened metal rods are lowered at predetermined sampling points. Species touched by the tip of the rod are tallied. The other variant is applicable to trees and tall shrubs and uses an optical device which enables the observer to superimpose a single crosshair or a grid on the reflected image of the overhead vegetation. The theory and limitations of the point-frequency method are discussed more fully by Mueller-Dombois and Ellenberg (1974).

Scowcroft and Giffin (1983) used the line-intercept method to estimate cover in exclosures located in sparse subalpine forest on Mauna Kea. The method is applicable where individual plants have compact, discrete canopies.

Loope, Medeiros, and Crivellone (in prep.) and Loope, Medeiros, and Gagne (in prep.) used a network of relocatable transects of 1 m^2 plots as a standard technique for vegetation monitoring in Haleakala National Park (HALE). Cover for each species was estimated to the nearest 5%. This method introduces an undesirable element of subjectivity through need for estimation and resultant possibility of observer bias. However, the advantages of allowing precise relocation and resampling of identical areas were judged to outweigh disadvantages. The method seems particularly useful for understanding plant community dynamics on a micro-scale and lends itself well to combination with photo-documentation of changes.

Mueller-Dombois and Spatz (1975) used permanent 10 m^2 plots and the releve method of Braun-Blanquet to estimate cover/abundance in HAVO.

Basal area has also been used as a measure of cover in Hawaiian exclosures (Scowcroft and Giffin 1983). The method involves measuring the diameter or circumference at ground-line of each individual in a sample plot. It is a tedious technique and applicable only to perennials in areas with sparse vegetation.

<u>Density</u>

The density of individuals of a given species has been determined inside and outside exclosures by systematically examining every square meter (Scowcroft and Hobdy, in prep.). The method is applicable to trees, single-stemmed annuals and perennials, bunch grasses, and tufted ferns, because individuals are easily recognized (Mueller-Dombois and Ellenberg 1974). Counting individuals in randomly located quadrats has been used to estimate density of tree reproduction (Skolmen and Fujii 1980). In most cases, however, the exclosures have been generally small enough to permit complete counts.

Survival and Growth

The measure-tag-remeasure method has been used in exclosure studies to determine survival and growth of tree reproduction for preferred browse species (Skolmen and Fujii 1980; Scowcroft and Giffin 1983).

Statistical Analysis

Statistical analyses of cover, abundance, and other exclosure data have rarely been used. Scowcroft and Giffin (1983) used the Bonferroni t-test to compare changes in basal area cover inside exclosures with that outside and to test the hypothesis that protected plants were not significantly taller than unprotected ones. Those same authors reported using a procedure described by Draper and Smith (1966) to determine if growth rates of protected koa seedlings differed among exclosure sites.

Statistical treatment of point-frequency data is possible, but the use of normal statistical methods requires that each sampling point be located randomly and independently of every other point. Stratified random sampling may be desirable. Uniformly spaced sample points along uniformly spaced line transects are a design more often used because of its simplicity. However, this design fails to meet the criteria of randomness and independence. Nevertheless, some statisticians hold that point frame data can be analyzed with t-tests to indicate the degree of difference between fenced and unfenced areas and before and after fencing. Scowcroft and Hobdy (in prep.) used the t-test to analyze point frame data from EMa-4.

We suggest researchers consider using multivariant statistical methods (Stroup and Stubbendieck 1983) to determine the effect of protection from grazing and browsing on species composition.

Sampling Frequency

Sampling has typically been done when the exclosure is built and annually thereafter for 1 to 5 years. More frequent sampling during the first year after fencing may be desirable where conditions for rapid growth prevail. Sampling prior to erection of the exclosure has rarely been done but can help in the planning stage to assess the degree of similarity of areas slated for protection and control.

Adequacy of Methods

We conclude that methods used have, in general, been adequate to accomplish objectives. The difficulty of identifying plant species, especially non-flowering grasses, seems the greatest potential source of error. Another problem can be failure to precisely relocate and resample transects, plots, and individual plants. Adequate, durable marking is necessary. Statistical analyses of the data are desirable and existing analytical methods are applicable. We recommend consultation with a statistician during the early design stages of a study. However, we also recognize that the response of preferred browse species to release from browsing may be so dramatic that statistics are superfluous.

SUMMARY OF VEGETATION RESPONSE IN HAWAIIAN EXCLOSURES

Exclosures constructed in the Hawaiian Islands to date have, without major exception, enclosed vegetation damaged by feral animals for the purpose of allowing, studying, and/or demonstrating recovery (objectives 1 and 2). Some of these same exclosures have satisfied objectives 3 and 4. The degree to which recovery has actually occurred has varied tremendously, even within comparable stands of vegetation. In light of this variability, we suggest that it is unwise to base management recommendations and decisions on the results from 1 or even 2 exclosures in a given situation, especially if the exclosures are small. Findings on one island should not be extrapolated to another island even though the ecosystems are comparable.

The following discussion of vegetation response in Hawaiian exclosures, organized by broad vegetation zones, is necessarily simplified but indicates trends. Those interested in more detail should consult the references or sources given in table 1.

Leeward Low/Middle Elevation Shrubland/Grassland (Corresponds to Zones A, B of Table 2)

Mueller-Dombois and Spatz (1975) and Mueller-Dombois (1979, 1981) have reported on 10 years of vegetation recovery under protection from goats in HAVO. Dramatic vegetation changes occurred following removal from foraging pressure, but most of these involved changes in the dominant aliens. The major exception was the endemic vine, *Canavalia kauensis*, which was not seen prior to goat removal. The population size of this legume has fluctuated inside exclosure HKi-1 since establishment, with cover values ranging from 46% to 2%. Mueller-Dombois (1981) attributed the fluctuations of *Canavalia* to synchronized, life cycle-dependent death of cohorts, a process which may occur independent of climatic fluctuations, phenology, or succession.

Leeward Low/Middle Elevation Forest (Zones B, C)

The Nature Conservancy (TNC) exclosure at Auwahi at 975-1,035 m elevation on East Maui's south slope

(EMa-2) was one of the few constructed in these forests. The site was chosen following a survey by Lennox (1967) for its high concentration of very rare trees (Ochrosia haleakalae, Pelea multiflora, Streblus (Pseudomorus) sandwicensis, Tetraplasandra meiandra, etc.). Kikuyugrass (Pennisetum clandestinum), an aggressive alien, was becoming established in the area at the time the exclosure was built and greatly increased its dominance in the first year following construction (C.G. Lennox, pers. comm.). Due to exclusion of grazing, kikuyugrass became even denser inside the exclosure than out, preventing any seedling establishment and eventually leading to abandonment of the project.

More recently constructed exclosures within HALE (EMa-5, -14), located at the upper elevational limits of this forest zone, have shown modest success in reproduction of some native species, but mainly the more common ones (Loope, Medeiros, and Crivellone, in prep.). Reproduction of common native trees in the lowland zone of HAVO following goat removal has been good (Williams 1980). In general, it is clear that displacement by introduced grasses and forbs poses a major problem for reproduction of leeward native tree species of Hawai'i. Other problems may exist as well, including predation on seeds by rodents, loss of pollinators, changes in microclimate due to forest destruction, etc. (Medeiros, Loope, and Holt, in prep.).

Acacia koa Forest (Zones C, D, E1)

This vegetation type can be separated into montane koa parkland and moist koa and koa-'ohi'a forests. Two feral goat exclosures exist in koa parkland. Data from EMa-4 showed that when goat browsing was eliminated, koa and other native woody reproduction became established and grew rapidly (Scowcroft and Hobdy, in prep.). No such reproduction was observed outside the fenced area. Molassesgrass (Melinus minutiflora) became the dominant ground cover inside EMa-4. In HAVO, results from HML-1 showed that goat browsing pressure stimulated root suckering but suppressed sucker growth (Spatz and Mueller-Dombois 1973). Following goat control in that area in the mid-1970's, koa has reproduced well both by seed and vegetatively.

Data from a cattle exclosure in a moist koa-'ohi'a forest (HML-2) showed that elimination of cattle alone results in the establishment of koa seedling regeneration sufficient to restock the area (Skolmen and Fujii 1980). Scarifying the soil surface greatly enhances seedling emergence and establishment. Reintroducing cattle before koa are tall and sturdy enough to resist being walked down results in severe browsing damage.

In another moist koa forest, the failure of planted koa seedlings inside a cattle- and pig-proof exclosure (HMK-14) indicated that competition with banana poka (Passiflora mollissima) and other plants rather than animal damage were inhibiting reestablishment of koa (R.G. Skolmen, pers. comm.).

Metrosideros Rain Forest (Zones D1, D2, D3)

Few exclosures have been built in this forest type. As a result, we know little about the impact of feral pigs on understory vegetation and ecosystem processes and we have little information about forest response to protection from feral pigs. Katahira (1980) found dramatic recovery of native vegetation in exclosure HKi-5 after 4.5 years. 'Ama'u fern (Sadleria pallida) increased from 4.9% to 47.8% cover; hapu'u (Cibotium spp.) increased from 1.0% to 6.0%; and Clermontia parviflora, initially absent, attained a 3.4% cover.

On the other hand, relatively modest changes in rain forest understory were found by Higashino and Stone (1982) in HKi-2 after 13 years and Loope, Medeiros, and Crivellone (in prep.) in EMa-8 after 4 years of protection from pigs.

Subalpine Forest/Shrubland (Zones E2, E3)

This forest type occurs only on Mauna Kea, Mauna Loa, Hualalai, and Haleakala, but most exclosures have been built on Mauna Kea and Haleakala. A series of exclosures built on Mauna Kea in the 1960's (HMK-2, -3, -4, -5) and the 1970's (HMK-6, -7, -8) clearly showed that feral sheep (Ovis aries) suppress reproduction of mamane and other native browse species (Scowcroft and Giffin 1983). Photos of HMK-4 showed that mature mamane trees inside stayed healthy and lost their browse-line, while many trees of comparable size outside died. Suppression of regeneration and the death of old mamane appear to account for the gradual thinning of the forest in the vicinity of HMK-3 and HMK-7 (Scowcroft 1983). Judging from the mamane recovery inside the exclosures, we suspect that in the absence of browsing the ecosystem will recover with little help from land managers. Monitoring is needed to assess recovery and show managers where reforestation efforts are needed.

Results from the Honokahua exclosure (EMa-1) in Haleakala Crater are not as encouraging. Jacobi (1980) found no mamane seedling reproduction after 11 years of protection from goats, despite the presence and continued production of viable seed and the occasional emergence of seedlings. He hypothesized that because harsh environmental conditions inhibited seedling establishment, vegetative regeneration was the more important mechanism for maintaining the species in this habitat. Data from outside the exclosure indicated that only 50% of the dead mamane still had basal sprouts capable of replacing the parent tree if released from goat browsing.

Preliminary results after 3 years from the Pu'u Mamane exclosure (EMa-11) in Haleakala Crater showed good vegetative recovery of mamane and *Dubautia menziesii*, but no recruitment of seedlings. Mamane seedlings are not uncommon within the exclosure, but grow very slowly and have high mortality rates. Competition with the introduced grass *Holcus lanatus* appears to be a major deterrent to germination, growth, and survival of mamane seedlings (Loope, Medeiros, and Crivellone, in prep.).

Subalpine Grassland (Zone E1)

The *Deschampsia australis*-dominated grasslands of Kalapawili Ridge on the north rim of Haleakala Crater are a unique vegetational feature in Hawai'i (Vogl and Henrickson 1971). A survey in 1973 showed that damage by feral pigs had resulted in exposure of 23% bare ground and 18% cover of alien species (mainly *Holcus lanatus* and *Hypochaeris radicata*; Jacobi 1976, 1981). A small exclosure (EMa-3) was constructed in 1974 to determine the potential of the native *Deschampsia* vegetation to survive and/or recover in the absence of pig digging (Jacobi 1976). Sampling at intervals since (most recently in 6/83) showed that the native grass holds its own against the aliens in the absence of further disturbance (Jacobi 1981, pers. comm.).

Montane Bogs (Azonal)

East Maui's high elevation bogs occur as small habitat islands surrounded by rain forest or (in one case) grassland. These and other Hawaiian bogs contain a unique assemblage of endemic plant species derived from ancestors in bogs, wet forests, and alpine habitats in Hawai'i and elsewhere in the world (Loope, Medeiros, and Gagne, in prep.). Damage to East Maui high elevation bog vegetation by rooting of feral pigs has become severe in the past decade and has prompted fencing of 3 bogs in HALE. In Flattop Bog (EMa-7), 2 aggressive alien species (*Holcus lanatus*, *Hypochoeris radicata*), which were well established prior to fencing, increased substantially during the 4 years following fencing, occupying bare ground exposed by pig digging and displacing some of the native vegetation. In Greensword Bog (EMa-12), where these introduced plants were not established prior to fencing, the cover of the endemic sedges *Oreobolus furcatus* and *Carex svenonis* increased from 5% to 40% in 2 years after fencing. Although much bare ground remained after 2 years, the native sedges appeared capable of reoccupying their former habitat through seedling establishment and vegetative growth. Failure of the aliens to establish in the bog after fencing suggests that their dispersal into a new area is very slow without the aid of feral pig movement.

"NATURAL EXCLOSURES" AND THEIR IMPLICATIONS

Feral animals have had an overwhelming, but not ubiquitous, influence on Hawaiian vegetation. As a result of some very steep topography, some areas have remained untouched by herbivores. Most of these areas are on cliff faces and provide only atypical samples of pristine Hawaiian vegetation, although they are important in allowing survival of certain vulnerable native species. A few kipukas surrounded by rough lava flows on Hawaii (Stone, pers. comm.) and a few gently-sloping areas have escaped the effects of feral animals as a result of adjacent steep topography, just as a few mesa tops of Zion National Park, Utah, have escaped livestock grazing (Madany and West, 1984). Such Hawaiian areas known to us include Oloku'i on Moloka'i and Lihau and Mt. 'Eke on West Maui. No one has yet published information on the vegetation of these sites, although some detailed vegetation data were gathered by the U.S. Fish and Wildlife Service Hawaii Forest Bird Survey in 1980 on Oloku'i. Observations by L.L. Loope, R. Hobdy, and A.C. Medeiros on Lihau and Mt. 'Eke suggest that the pristine vegetation of these undisturbed sites is essentially intact and introduced species are almost lacking. On these sites, there has been no displacement of native vegetation by introduced species. Although more rigorous evaluation is clearly needed, the conclusion that introduced flowering plant species require feral animals or direct human influence as a vector for significant displacement of native Hawaiian species appears warranted.

NEEDS FOR THE FUTURE

It appears to us that almost every exclosure in Hawai'i has served to demonstrate impacts of vertebrate herbivores (objective 1). We see no pressing need for establishment of additional exclosures solely for this purpose, although improved documentation in published ecological literature is desirable. Exclosures built to study recovery potential (objective 2) will automatically demonstrate the impacts of vertebrate herbivores. Determination of recovery potential is being fairly well achieved in subalpine forest/shrubland, but is not being met in most other ecosystems due to small sample size and variability of local conditions. Establishment of additional exclosures appears most urgently needed in leeward mid- and low-elevation areas to gain a better understanding of possibilities for preserving representative tracts of this quickly disappearing vegetation in carefully chosen areas (e.g., Medeiros, Loope, and Holt, in prep.). Small exclosures appear satisfactory for predicting vegetation recovery over large areas, provided enough are built to sample the range of habitat conditions. Continued maintenance and monitoring of existing exclosures are as important as establishment of even urgently needed new ones.

Continued and expanded use of exclosures to test experimental manipulation as a management tool in the absence of alien herbivores (objective 3) shows promise. One useful application involves experimental control of alien species within exclosures to determine whether certain native plant species can reproduce when potential "safe sites" (Harper 1977) for seedling establishment are released from dominance by these aliens. Another application involves testing hypotheses about population dynamics and plant succession in koa-'ohi'a forests.

We have difficulty making predictions regarding the future role or success of exclosures in the protection of rare plant species (objective 4). We suspect that as the native Hawaiian flora continues to dwindle (see Wagner, Herbst, and Yee, this volume), what is left will be perceived as more valuable, and pressures will arise to do what is possible to save dwindling populations. Fencing, in spite of its very serious limitations and often prohibitive costs, seems to provide the only immediate hope for saving populations and communities impacted by feral or domestic ungulates. We suggest that such projects be well thought out and based on the best available information (usually from results of exclosure studies in comparable situations) to assure that the best sites are protected and at least a moderate chance of success exists. An accumulation of failures will undoubtedly lead to loss of enthusiasm, followed by loss of moral and financial support.

Experience (especially that from "natural exclosures") indicates that the sooner alien ungulates are removed from Hawai'i's wildlands, the greater the likelihood of ecosystem recovery. The more a site has been degraded by feral animals, the less the chance of success. The chance for recovery also becomes smaller as the extent of degradation becomes greater. With these thoughts in mind, we recommend that action to protect Haleakala's Kipahulu Valley from feral pigs be taken as soon as possible if it is to be taken at all. We also caution that recovery potential of a certain ecosystem type demonstrated within an exclosure today may be greatly reduced after years of continuing damage by alien ungulates.

Finally, we recommend that comprehensive monitoring be carried out to document biotic and physical changes resulting from large fencing projects in national parks and other sites for purposes of preservation of native biota and watershed protection. A firm scientific basis will be necessary to objectively evaluate the benefits in relation to costs of such endeavors.

ACKNOWLEDGEMENTS

We thank S. Conant, J.D. Jacobi, J.M. Scott, C.W. Smith, and C.P. Stone for helpful comments on the manuscript. R. Hobdy, P. Higashino, and C. Corn kindly provided information on exclosure locations.

LITERATURE CITED

Baker, J.K., and D.W. Reeser. 1972. Goat management problems in Hawaii Volcanoes National Park: a history, analysis, and management plan. Natl. Park Serv. Nat. Resour. Rep. 2.

Coblentz, B.E. 1977. Some range relationships of feral goats on Santa Catalina Island, California. J. Range Manage. 30:415-419.

Draper, N.R., and H. Smith. 1966. Applied regression analysis. New York: John Wiley Sons, Inc.

Harper, J.L. 1977. Population biology of plants. New York: Academic Pr.

Higashino, P.K., and C.P. Stone. 1982. The Fern Jungle exclosure in Hawaii Volcanoes National Park: thirteen years without feral pigs in a rain forest. [Abstract] Proc. 4th Hawaii Volcanoes Natl. Park Nat. Sci. Conf., 86. Honolulu: Univ. Hawaii.

Jacobi, J.D. 1976. The influence of feral pigs on a native alpine grassland in Haleakala National Park. Proc. 1st Hawaii Volcanoes Natl. Park Nat. Sci. Conf., 107-112. Honolulu: Univ. Hawaii.

Jacobi, J.D. 1980. Problems with the long-term maintenance of mamane (Sophora chrysophylla) in the central crater area of Haleakala National Park. Proc. 3rd Hawaii Volcanoes Natl. Park Nat. Sci. Conf., 167-171. Honolulu: Univ. Hawaii.

Jacobi, J.D. 1981. Vegetation changes in a subalpine grassland in Hawaii following disturbance by feral pigs. Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit Tech. Rep. 41. Honolulu: Univ. Hawaii.

Jane, G.T., and L.T. Pracy. 1974. Observations on two animal exclosures in Haurangi Forest over a period of twenty years (1951-1971). New Zealand J. For. 19:102-113.

Katahira, L. 1980. The effects of feral pigs on a montane rain forest in Hawaii Volcanoes National Park. Proc. 3rd Hawaii Volcanoes Natl. Park Nat. Sci. Conf., 173-178. Honolulu: Univ. Hawaii.

Kightley, S.P.J., and R.I.L. Smith. 1978. The influence of reindeer on the vegetation of South Georgia: I. Long term effects of unrestricted grazing and the establishment of exclosure experiments in various plant communities. Brit. Antarct. Surv. Bull. 44:57-76.

Lennox, C.G. 1967. Auwahi forest survey report. The Nature Conservancy, Honolulu. Typescript.

Lock, J.M. 1977. Preliminary results from fire and elephant exclusion plots in Kabalega National Park, Uganda. East Africa Wildl. J. 15:229-232.

Loope, L.L., A.C. Medeiros, and C.F. Crivellone. In prep. A review of results of exclosure studies in Haleakala National Park and vicinity. Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit Tech. Rep. Honolulu: Univ. Hawaii.

Loope, L.L., A.C. Medeiros, and B.H. Gagne. In prep. Montane bogs of East Maui. Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit Tech. Rep. Honolulu: Univ. Hawaii.

Madany, M.H., and N.E. West. 1984. Vegetation of several relict mesas in Zion National Park. J. Range Manage. 37(5):456-461.

Marquis, D.A. 1974. The impact of deer browsing on Allegheny hardwood regeneration. U.S. For. Serv. Res. Pap. NE-308. Upper Darby, Penn.: Northeast. For. Exp. Stn.

Medeiros, A.C., L.L. Loope, and R.A. Holt. In prep. Status of native flowering plant species on the south slope of Haleakala, East Maui. Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit Tech. Rep. Honolulu: Univ. Hawaii.

Mueller-Dombois, D. 1979. Succession following goat removal in Hawaii Volcanoes National Park. Proc. 1st Conf. Sci. Res. Natl. Parks, 2:1149-1154. Washington, D.C.: Govt. Print. Off.

Mueller-Dombois, D. 1981. Vegetation dynamics in a coastal grassland of Hawaii. Vegetatio 46:131-140.

Mueller-Dombois, D., and H. Ellenberg. 1974. Aims and methods of vegetation ecology. New York: John Wiley Sons, Inc.

Mueller-Dombois, D., and G. Spatz. 1975. The influence of feral goats on the lowland vegetation in Hawaii Volcanoes National Park. Phytocoenologia 3:1-29.

Ripperton, J.C., and E.Y. Hosaka. 1942. Vegetation zones of Hawaii. Hawaii Agric. Exp. Stn. Bull. 89.

St. John, H. 1972. Canavalia kauensis (Leguminosae), a new species from the island of Hawaii. Pac. Sci. 26:309-414.

Scowcroft, P.G. 1981. Regeneration of mamane: effects of seedcoat treatment and sowing depth. For. Sci. 27:771-779.

Scowcroft, P.G. 1983. Tree cover changes in mamane (Sophora chrysophylla) forests grazed by sheep and cattle. Pac. Sci. 37:109-119.

Scowcroft, P.G., and J. Giffin. 1983. Feral herbivores suppress mamane and other browse species on Mauna Kea, Hawaii. J. Range Manage. 36:638-645.

Scowcroft, P.G., and R. Hobdy. In prep. Recovery of montane koa parkland vegetation protected from feral goats. U.S. For. Serv., Honolulu.

Skolmen, R.G. 1978. Vegetative propagation of Acacia koa Gray. Proc. 2nd Hawaii Volcanoes Natl. Park Nat. Sci. Conf., 260-273. Honolulu: Univ. Hawaii.

Skolmen, R.G., and D.M. Fujii. 1980. Growth and development of a pure stand of koa (Acacia koa) at Keauhou- Kilauea. Proc. 3rd Hawaii Volcanoes Natl. Park Nat. Sci. Conf., 301-310. Honolulu: Univ. Hawaii.

Spatz, G., and D. Mueller-Dombois. 1973. The influence of feral goats on koa tree reproduction in Hawaii Volcanoes National Park. Ecology 54:870-876.

Stroup, W. W., and J. Stubbendieck. 1983. Multivariate statistical methods to determine changes in botanical composition. J. Range Manage. 36:208-212.

Tiedemann, A.R., and H.W. Berndt. 1972. Vegetation and soils of a 30-year deer and elk exclosure in central Washington. Northwest Sci. 46:59-66.

Vogl, R.J., and J. Henrickson. 1971. Vegetation of an alpine bog on East Maui, Hawaii. Pac. Sci. 25(4): 475-483.

Wagner, W. L., D.R. Herbst, and R. S. N. Yee. Status of the native flowering plants of the Hawaiian Islands. [This volume]

Williams, J. 1980. Native vs. exotic woody vegetation recovery following goat removal in the eastern coastal lowlands of Hawaii Volcanoes National Park. Proc. 3rd Hawaii Volcanoes Natl. Park Nat. Sci. Conf., 373-382. Honolulu: Univ. Hawaii.