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STUDIES IN MONTANE BOGS OF HALEAKALA NATIONAL PARK

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STUDIES IN THE MONTANE BOGS OF HALEAKALĀ NATIONAL PARK

77. Recovery of Vegetation of a Montane Bog Following Protection From Feral Pig Rooting

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ABSTRACT

The perimeter of a montane bog at 1860 m elevation on northeastern Haleakalā volcano was fenced in 1981 to provide protection from feral pig digging. This site had undisturbed native vegetation until introduced pigs arrived in the area some time after 1975 and extensively rooted the bog by early 1981. Prior to fencing, a large tract of vegetation, formerly a nearly intact turf dominated by *Oreobolus*, had been obliterated by pigs so that almost no vegetation cover remained. In a portion of the bog, the combined cover of native plant species increased from 6% to 95% after six years of protection. Most of the increase in cover, primarily by the dominant endemic sedges *Oreobolus furcatus* and *Carex echinata* and the grass *Deschampsia nubigena*, took place in the first three years after fencing. Recovery of non-dominants was incomplete after six years. Species which have failed to recover to pre-disturbance levels include *Plantago pachyphylla*, *Argyroxiphium grayanum*, and *Calamagrostis expansa*. Though they occur nearby, presence of alien plant species in the bog was minimal, and those present failed to increase their abundance, despite initially high levels of bare ground. In this instance, feral pig damage to the vegetation of an Hawaiian bog was largely reversible. This may be due to inherently low invasibility of native *Oreobolus* communities.

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INTRODUCTION

Like many Hawaiian habitats, montane bogs of the Hawaiian Islands offer excellent opportunities for the study of evolutionary patterns in isolation (Simon 1987). However, as with most native ecosystems of the Hawaiian and other oceanic islands (Loope *et al.* 1988), these bogs are threatened by alien species and require active management for their long-term conservation. Hawaiian ecosystems, having evolved without disturbance of hoofed mammals, are susceptible to large-scale disturbance by pigs, goats and other introduced ungulates. In order for recovery of native species to occur, the influence of ungulates must be greatly reduced or entirely removed. Depending on the characteristics of the ecosystem and the extent of the damage, even where ungulates have been removed from an area, recovery may be only partial (e.g. Mueller-Dombois 1981, Scowcroft and Hobdy 1986). This paper reports on the recovery of bog vegetation following protection after severe damage by rooting of feral pigs.

Montane bogs occur in level, frequently inundated sites on the otherwise precipitous, rain-drenched, stream-dissected windward slopes of Haleakalā volcano at 1450-2270 m elevation. The distinctive, largely endemic flora has affinities with Malesia, New Zealand, and the Andes (*Coprosma*, *Deschampsia*, *Metrosideros*, *Oreobolus*, *Plantago*, *Styphelia*, *Viola*), as well as with northern hemisphere bogs (*Carex*, *Deschampsia*, *Geranium*, *Rhynchospora*, *Vaccinium*). The dominant species of Haleakalā bogs are *Carex alligata*, *Carex echinata*, and *Oreobolus furcatus*[1]. *Oreobolus* occupies slightly raised bog areas, *Carex echinata* occurs in lower and wetter sites; *Carex alligata* characteristically occurs in the wettest, usually flooded, sites.

In this study, we document the recovery of a bog that was undisturbed by feral pigs as recently as 1973-1974 (B.H. Gagné and J.D. Jacobi, pers. obs., Figures 1, and 2). This small but biologically diverse site, with the local name Greensword Bog, is located in Haleakalā National Park at 1860 m elevation (Figure 3). The bog was named in the 1970s for the striking stands of the endemic Maui greensword (*Argyroxiphium grayanum*) at the margins, and to a lesser extent in the central bog (Figure 4). Minor pig rooting was present in the late 1970s (J.D. Jacobi and A.Y. Yoshinaga, pers. comm.) but severe damage occurred in May 1981 (R.J. Nagata, pers. comm.). In June 1981, a fence was constructed around the perimeter of this bog, excluding feral pigs (Figure 5). By that time, a large portion of the vegetation which was formerly a near solid turf of *Oreobolus* had been so damaged by pigs that almost no vegetation cover (only bare ground) remained (Figure 6). In an effort to document plant succession in the disturbed area, we set up a monitoring system in August 1981 and assessed the status of vegetation annually for six additional years.

[1] Nomenclature follows Wagner et al. 1990.

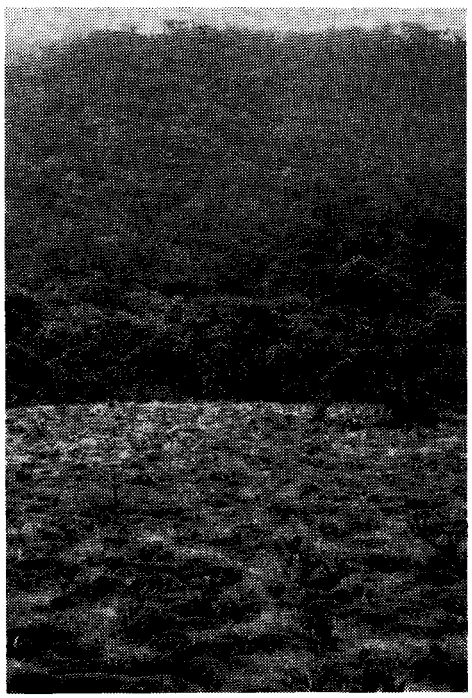


Figure 1: View of Greensword Bog, Haleakalā National Park, prior to pig damage, in April 1973. Tussocks of the sedge *Oreobolus furcatus* occur in a matrix of the wispy sedge *Carex echinata*. Rosettes of *Plantago pachyphylla* are conspicuous. (J.D. Jacobi photo)

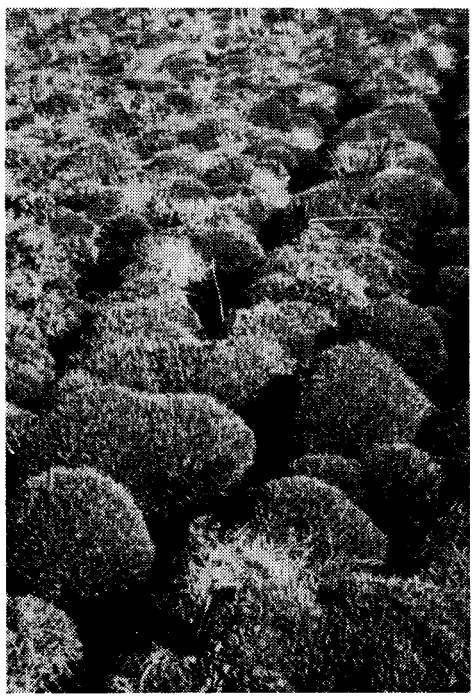


Figure 2: Undisturbed tussocks of the sedge *Oreobolus furcatus* in Greensword Bog, Haleakalā National Park, prior to pig damage. January 1974. (BHG photo)

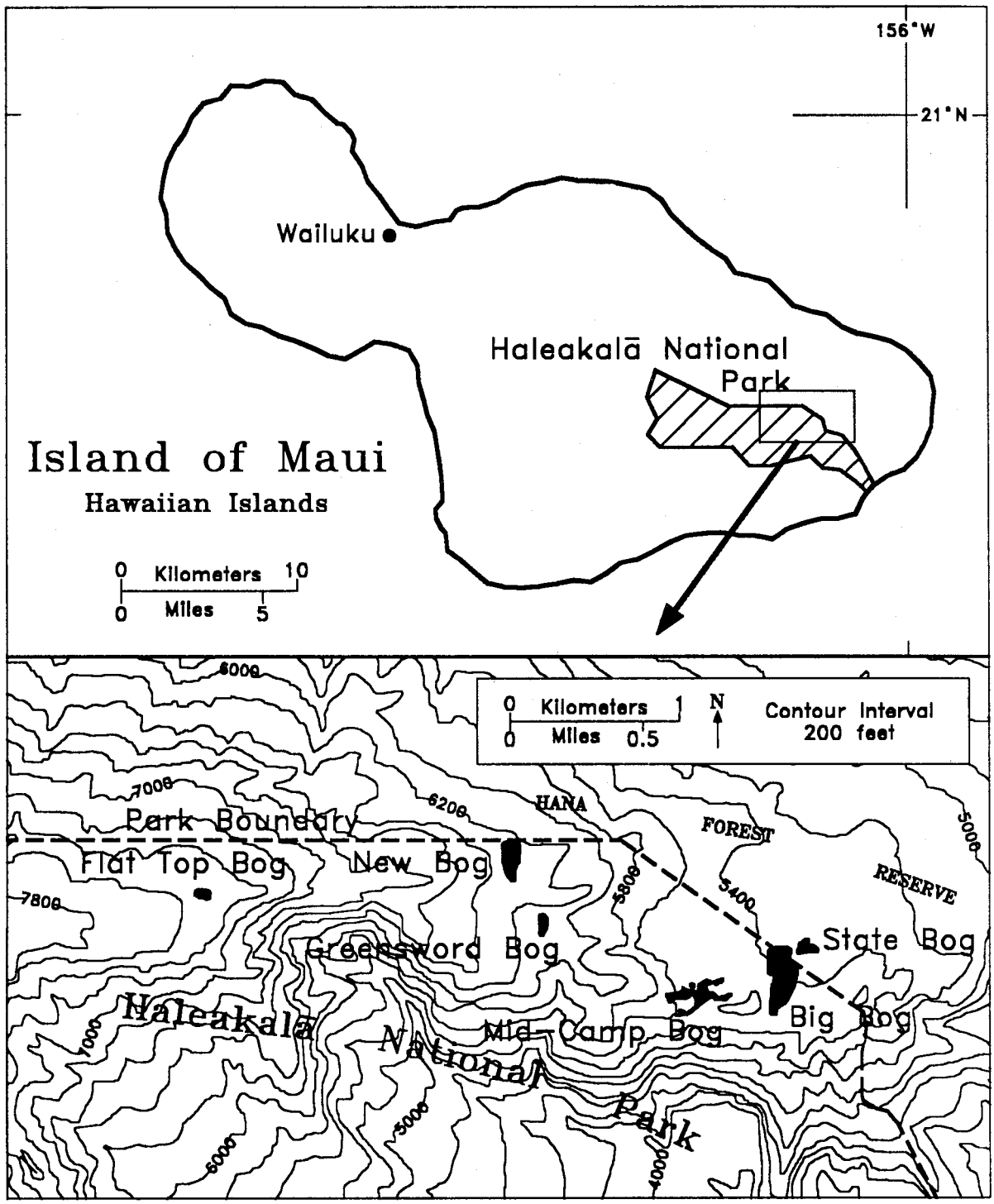


Figure 3: Location of Greensword Bog, Haleakalā National Park, Maui, Hawaiian Islands.

Figure 4: Flowering greenswords (*Argyroxiphium grayanum*) at the margin of Greensword Bog, Haleakalā National Park. (BHG photo)

Figure 5: Newly constructed hogwire fence around central portion of Greensword Bog, Haleakalā National Park. Pig damage is apparent on both sides of fence. August 1981. (ACM photo)

Figure 6: Heavily damaged vegetation in central portion of Greensword Bog, Haleakalā National Park. Newly constructed fence in background. Undamaged tussocks of *Oreobolus furcatus* in left foreground. August 1981. (ACM photo)

METHODS

We established five 10 m transects in the central, severely disturbed portion of Greensword Bog. End points of each transect were marked with a 5/8-inch PVC pipe. At each sampling date, a metric tape was stretched between the marked ends of each transect. A 1-meter square PVC plot frame, placed sequentially at 1 m intervals along the tape, was used to define plots. A total of 20 plots were sampled, 10 plots on each side of the 10 m long transect. Using this procedure, it was possible to resample virtually identical 1 m^2 areas in subsequent years.

Within each 1 m^2 plot, cover was visually estimated to the nearest 5% for each vascular plant species. Estimated cover less than 2.5% was recorded as 1%. Two workers made estimates independently, then reached a consensus on values to be recorded. In practice, the technique worked reasonably well and appeared repeatable in this unlayered type of vegetation. To supplement this information, photographs (35mm slides) were taken of plot #5 of each transect, as well as of the overall transect from each end.

Sampling was initially carried out six weeks after the fencing and repeated annually from 1981 through 1987 (seven times). All data and photographs are on file at the Research Office, Haleakalā National Park.

For comparison, the pristine condition of Greensword Bog was approximated using data from Yoshinaga (1977 and unpublished field data). Yoshinaga used 100 point-intercept points to evaluate cover and 50 1 m^2 plots to evaluate frequency. Photographs taken by Yoshinaga and Jacobi in 1973 also verified the substantial cover of *Argyroxiphium*, *Plantago*, and *Calamagrostis* in the central bog area sampled by our present transects.

RESULTS AND DISCUSSION

Recovery of the dominant native sedges and grasses in Greensword Bog began slowly, accelerating through the second and third years (Figures 7-12, Table 1). After nearly continuous vegetation cover was attained in the third year, changes became more subtle.

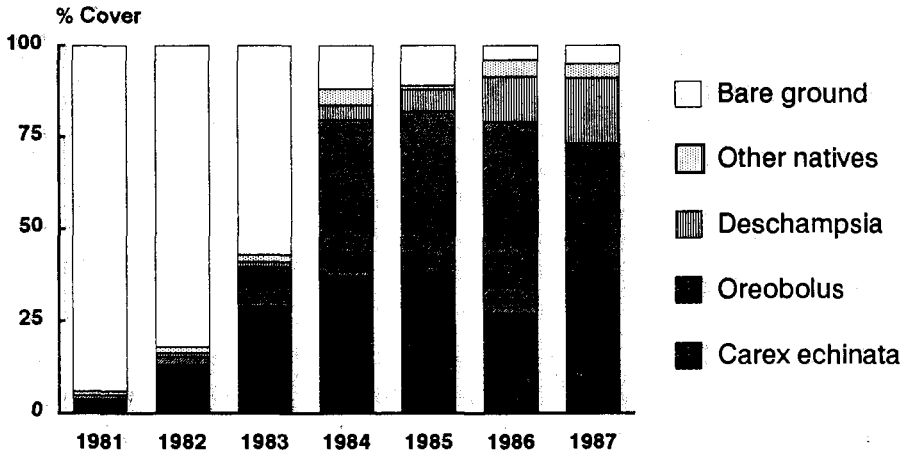


Figure 7: Mean cover for major cover categories in successive years for recovering pig-damaged vegetation in Greensword Bog. Based on 100 1 m^2 plots in five transects.

Table 1: Mean percent cover and frequency of vascular plant species in five transects in Greensword Bog from 1981 to 1987.

Species		1981	1982	1983	1984	1985	1986	1987	"Pristine" 1973
Carex echinata	%C	4	13	29	37	39	29	38	26
	%F	100	100	100	100	100	100	100	98
Oreobolus furcatus	%C	1	3	11	43	44	53	34	43
	%F	100	100	100	100	100	100	100	100
Deschampsia nubigena	%C	x	1	1	4	6	12	18	0
	%F	17	20	27	52	64	74	80	14
Dichanthelium cynodon	%C	1	2	2	4	1	1	1	4
	%F	91	82	85	85	88	84	79	14
Vaccinium reticulatum	%C	x	x	x	x	x	0.6	0.7	2
	%F	38	30	25	31	34	46	42	96
Plantago pachyphylla	%C	x	x	x	x	x	x	x	4
	%F	5	3	3	3	5	8	6	60
Styphelia tameiameiae	%C	x	x	x	x	x	x	x	1
	%F	1	5	3	23	26	31	29	56
Calamagrostis expansa	%C	-	x	x	x	x	x	-	0
	%F	-	3	1	6	5	2	-	20
Argyroxiphium grayanum	%C	-	-	x	x	x	1.6	x	8
	%F	-	-	5	5	6	19	18	76

Continued...

Metrosideros polymorpha	%C	-	-	-	x	x	x	x	0
	%F	-	-	-	13	8	32	15	6
Viola maviensis	%C	-	-	-	-	-	-	-	0
	%F	-	-	-	-	-	-	-	2
Carex thunbergii	%C	x	x	x	x	x	x	x	-
	%F	1	1	1	3	4	3	2	-
Carex montis-eeka	%C	-	-	-	x	-	-	-	0
	%F	-	-	-	1	-	-	-	6
Rhynchospora sp.	%C	-	-	-	x	-	x	-	-
	%F	-	-	-	1	-	1	-	-
Dryopteris hawaiiensis	%C	x	x	x	x	x	1	2	2
	%F	22	25	23	29	44	60	61	58
Athyrium microphyllum	%C	-	-	-	x	x	-	x	-
	%F	-	-	-	1	7	-	8	-
Sadleria pallida	%C	-	-	-	x	x	x	x	0
	%F	-	-	-	1	17	12	1	4
Cibotium glaucum	%C	-	-	-	-	-	x	x	-
	%F	-	-	-	-	-	1	7	-
Lycopodium venustulum	%C	-	-	-	x	x	x	-	-
	%F	-	-	-	1	2	1	-	-
Selaginella deflexa	%C	-	-	-	-	-	x	x	-
	%F	-	-	-	-	-	4	3	-
**Erechtites valerianifolia*	%C	x	-	-	x	-	-	-	
	%F	3	-	-	1	-	-	-	-
**Holcus lanatus*	%C	-	-	-	x	x	-	-	-
	%F	-	-	-	1	2	-	-	-
**Hypochoeris radicata*	%C	-	-	-	x	-	-	-	-
	%F	-	-	-	1	-	-	-	-
Bare ground and dead vegetation	%C	94	81	57	12	11	4	5	15

Mean percent cover (%C) and frequency (%F) values in August 1981, June 1982, June 1983, October 1984, August 1985, December 1986, and September 1987. "*" denotes alien species, removed at the time of sampling. "x" denotes negligible cover (0-0.5%). "-" denotes not present. "Pristine" values obtained from data in Yoshinaga (1977 and field data --see text) are given for comparison.

In the first year of recovery, the percentage of bare ground declined from 94% to 81%. Cover of *Carex echinata* increased from 4 to 13%, apparently by expansion of surviving clumps. The small increase in cover (1% to 3%) made by *Oreobolus* during the first year was due to growth and recovery of surviving plants. At the second sampling (1982) however, numerous tiny seedlings of *Oreobolus*, *Carex echinata*, and *Dichanthelium cynodon* were noted, apparently having germinated from a substantial stored seed bank. We confirmed that these plants were seedlings, not vegetative sprouts, by pulling up a representative sampling.

In the second year of recovery, bare ground declined from 81% to 57%. Clumps of *Carex echinata* continued to expand, colonizing open ground and attaining a cover of 29%. Barely surviving *Oreobolus* clumps expanded; cover reached 11% as seedlings began to contribute.

Bare ground declined dramatically during the third year of recovery, from 57% to 12%. In 1984, the cover of *Oreobolus* in the highly disturbed area was comparable to that in 1973 (43% vs. 43%), prior to its disturbance by feral pigs. The dramatic increase (11% to 43%) of *Oreobolus* cover between 1983 and 1984 was largely due to growth of seedlings established the first year following disturbance. *Carex echinata* covered 37% of the area in 1984; the grasses *Dichanthelium cynodon* and *Deschampsia nubigena* each had 4% cover.

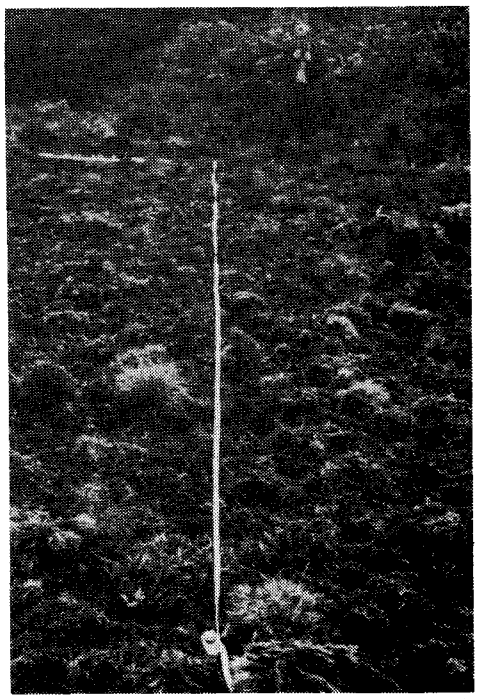
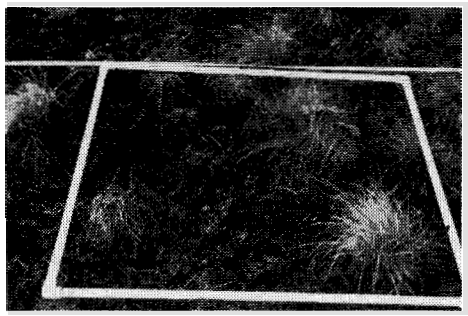
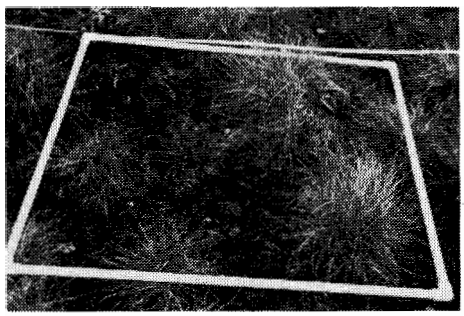


Figure 8: Transect 6, Greensword Bog, August 1981. Soon after protection from pig rooting, vegetation covers only 5% of the area. (ACM photo)

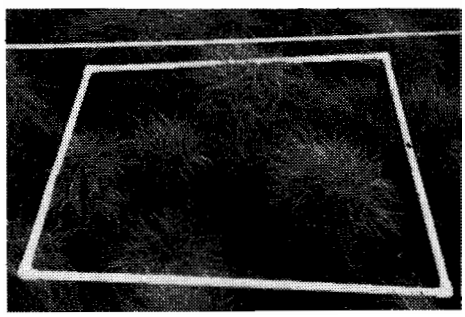
Figure 9: Transect 6, Greensword Bog, October 1984. After three years of protection from pig rooting, native vegetation covers 90% of the area. Dominant species are the sedges *Oreobolus furcatus* and *Carex echinata*. (ACM photo)

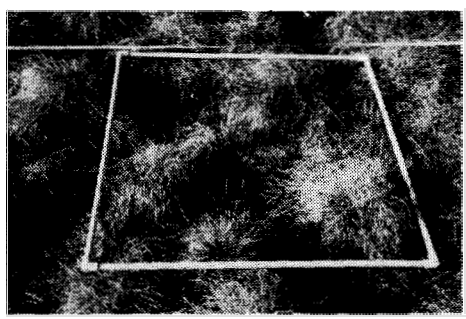


1981



1982

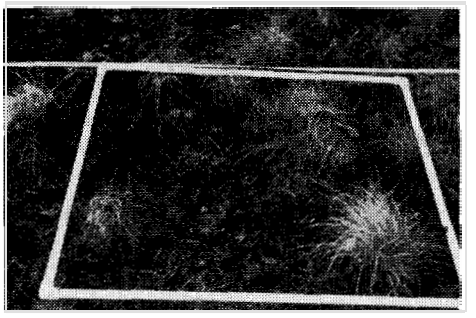




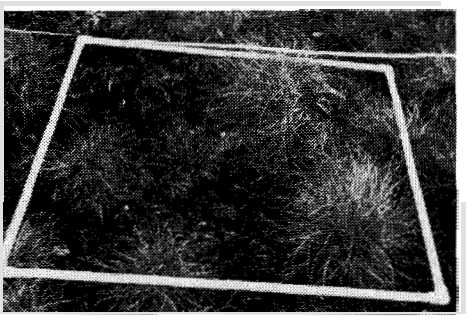
1984

Figure 10: The photo sequence on the facing page, shows the first three years of recovery of native vegetation in Transect 1, Plot 5 (1 m^2), Greensword Bog. (ACM photos) Cover values (%) for species present are given below.

	1981	1982	1983	1984
Oreobolus furcatus	1%	1%	5%	35%
Carex echinata	5%	35%	50%	55%
Deschampsia nubigena	1%	-	-	1%
Dichanthelium cynodon	1%	1%	1%	-
Styphelia tameiameiae	1%	1%	1%	-
Bare ground and dead vegetation	95%	65%	45%	10%



1981



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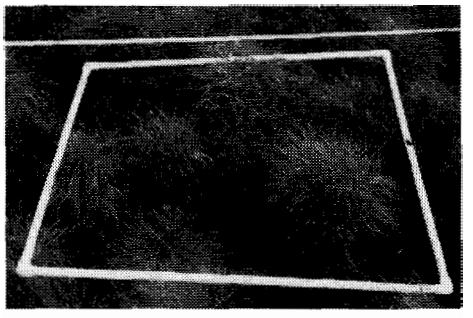


1983

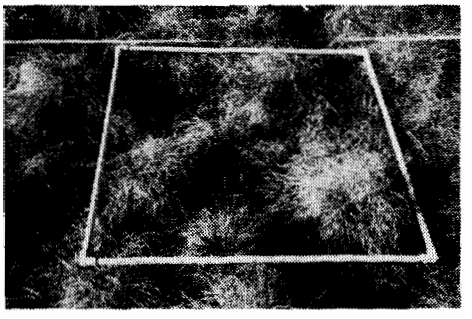
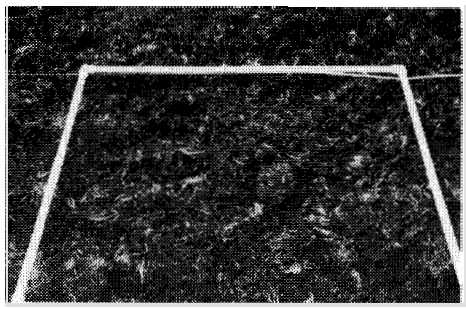
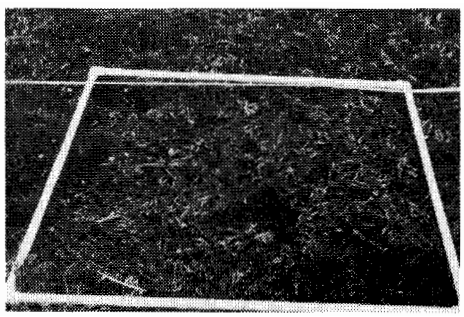


Figure 10: The photo sequence on the facing page, shows the first three years of recovery of native vegetation in Transect 1, Plot 5 (1 m^2), Greensword Bog. (ACM photos) Cover values (%) for species present are given below.

	1981	1982	1983	1984
Oreobolus furcatus	1%	1%	5%	35%
Carex echinata	5%	35%	50%	55%
Deschampsia nubigena	1%	-	-	1%
Dichanthelium cynodon	1%	1%	1%	-
Styphelia tameiameiae	1%	1%	1%	-
Bare ground and dead vegetation	95%	65%	45%	10%



1981



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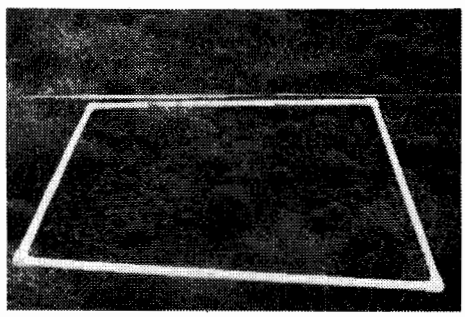

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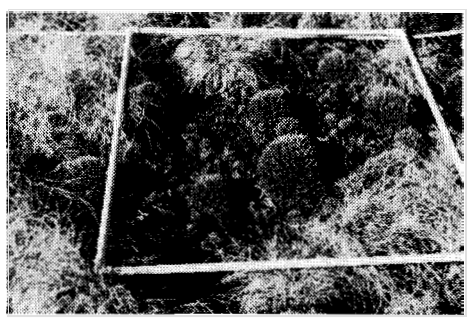
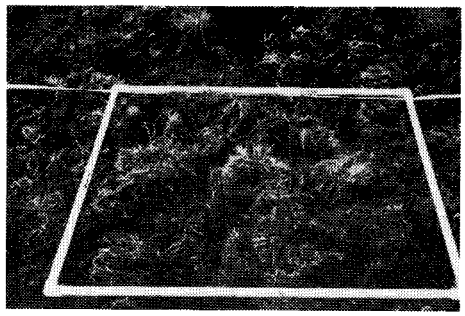


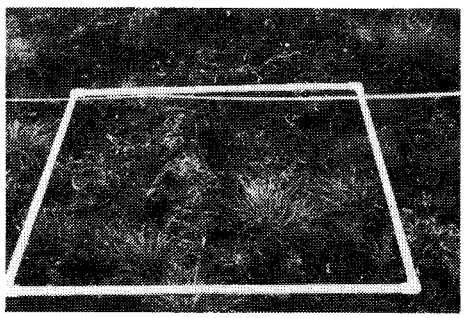
1984

Figure 11: The photo sequence on the facing page, shows the first three years of recovery of native vegetation in Transect 2, Plot 25 (1 m^2), Greensword Bog. (ACM photos) Cover values (%) for species present are given below.

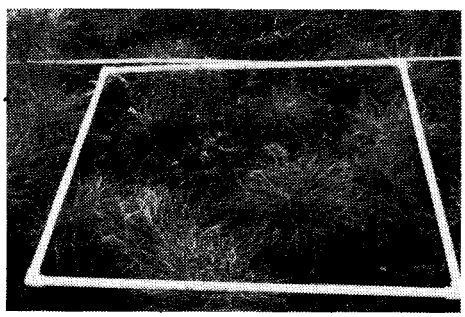
	1981	1982	1983	1984
Oreobolus furcatus	1%	5%	10%	45%
Carex echinata	1%	1%	10%	15%
Dichanthelium cynodon	1%	-	-	1%
Styphelia tameiameiae	1%	1%	1%	-
Bare ground and dead vegetation	95%	95%	80%	40%



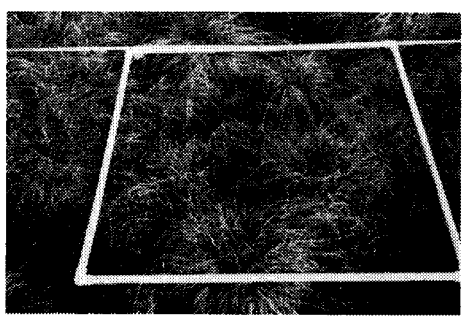
1981



1982



1983



1984

Figure 12: The photo sequence on the facing page, shows the first three years of recovery of native vegetation in Transect 5, Plot 85 (1 m^2), Greensword Bog. (ACM photos) Cover values (%) for species present are given below.

	1981	1982	1983	1984
Oreobolus furcatus	1%	5%	10%	45%
Carex echinata	5%	20%	55%	45%
Deschampsia nubigena	-	-	-	5%
Dichanthelium cynodon	1%	1%	5%	1%
Styphelia tameiameiae	1%	1%	1%	1%
Vaccinium spp.	-	1%	1%	1%
Bare ground and dead vegetation	99%	85%	55%	10%

In the fourth year, changes were minor; *Oreobolus* (44%) and *Carex* (39%) increased minimally. The most notable change was the decline of the tiny endemic mat-forming grass *Dichanthelium cynodon* from 4% to 1%. This apparent decline was due to overtopping of large *Dichanthelium* mats, which became established by seed in the first year, by other native grasses and sedges.

The cover of *Oreobolus* peaked at 53% in 1986 after five years, displacing *Carex echinata* (now reduced to 29% cover). By this time, *Deschampsia nubigena*, an endemic grass species present but without significant cover in 1973 data, continued to expand and reached 12% cover. Only 4% of the area was bare ground.

Oreobolus declined sharply in the 6th year (53% to 34%), with *Carex echinata* (38%) and *Deschampsia nubigena* (18%) overtopping it. The increasing *Deschampsia*, which had a 14% frequency in 1973, had attained a frequency of 80% by 1987.

Perhaps surprisingly, introduced species failed to become established in the initially bare ground within the fenced area. From 1981 through 1987, alien plant species were encountered only very rarely in the transects (three small *Erechtites valerianifolia* seedlings in 1981, one in 1984; one *Holcus lanatus* seedling in 1984, two in 1985; one *Hypochoeris radicata* seedling in 1984 - all removed). *Holcus lanatus* (velvetgrass), one of the more invasive alien species in native bog vegetation, is common in an adjacent *Carex alligata* bog outside the exclosure, but is absent within the fence. This apparent resistance of *Oreobolus*-dominated bogs to invasion by alien plant species is consistent with the findings of Medeiros *et al.* (1991) in nearby, unprotected bogs.

Both common endemic sedges, *Oreobolus furcatus* and *Carex echinata*, appear to recover well from disturbance. *Oreobolus* seedlings grow relatively rapidly in the first years after establishing but as bare ground decreases, growth slows and becomes confined to increases in tussock height. Photosynthetic tissue is apparently limited to the top few mm of the tussock surface. The center of large tussocks typically contains large amounts of dead material (Figure 15), which may tie up substantial amounts of nutrients. Tussocks tend to become drier as the mounds become taller, probably leading to water stress in periods of high solar radiation. Stands of *Oreobolus* become increasingly diverse over time, with invasion of old tussocks by other bog species, such as *Vaccinium*, *Metrosideros Styphelia*, and ferns.

The continual increase in *Deschampsia nubigena* (Figure 7, Table 1) to 18% cover and 80% frequency after six years is striking, considering its much less common occurrence in 1973 (0% cover and 14% frequency). This native grass is the dominant species in extensive grasslands on the north rim of Haleakalā Crater (Kalapawili Ridge). Those grasslands are higher in elevation (2135-2440 m) and drier (less rainfall, better soil drainage) than the montane bogs. *Deschampsia* occurs in nearby bogs 210 m lower in elevation, under a regime of chronic pig disturbance (Medeiros *et al* 1991), as well as in the natural disturbance of windward stream sources to much lower elevations.

While the two dominant bog species (*Carex echinata* and *Oreobolus furcatus*) recovered rapidly following protection from pig digging, and *Deschampsia* has increased sharply, some less common species have not recovered.

In 1973, the greensword (*Argyroxiphium grayanum*) had 8% cover and 76% frequency. However, by 1981 it had been eliminated from the central bog by pig digging, and persisted only at the bog margins. The species is slowly recovering by seedling establishment in the central bog, however, present in 18% of the plots after six years of recovery, but with cover still less than 1%. After five years (1986) greensword cover had reached 2%, but recovery by seedlings was set back by frost and wind desiccation damage in February 1987.

In the bogs of Haleakalā, the endemic *Plantago pachyphylla* is a large (vegetative parts to 35 cm tall), thick, fleshy herb characteristic of open bog turf vegetation. In the undamaged bog in 1973, the cover of *Plantago* was low (6%), but the species was quite common (60% frequency) (Yoshinaga 1977).

Plants and inflorescences of this species, easily apparent in the photographs taken that year, verify its abundance (Figure 1). The subsequent decline of *Plantago* due to feral pigs is evident, to less than 1% cover and 3-5% frequency in 1981-1985. Recovery has been slow, with seedlings accounting for nearly all recovery. By 1986, *Plantago* had increased to 8% frequency, but declined slightly in 1987, apparently due to seedling mortality in the February freeze.

Calamagrostis expansa is a tall, endemic grass, found only in cloud forests and bogs at high elevations on Maui. In photographs of Greensword Bog taken in 1973, the inflorescences of this grass were conspicuous; its frequency that year was 20% (Yoshinaga 1977). However, the frequency of *Calamagrostis* has not exceeded 6% during the course of this study (1981-1987).

The endemic *Dichanthelium cynodon* is a low, mat-forming bog grass (Figure 14) that had low frequency (14%) and rather low cover (4%) in the pristine bog in 1973. After pig damage and apparently in response to the availability of bare ground, seedlings of the grass appeared throughout the bog; while its frequency increased markedly (79-91%), total cover had dropped. By 1984, the species had regained its original cover level (4%) but then died back, failing to exceed 1% cover although its frequency remained high.

On the other hand, the rare native clubmoss *Selaginella deflexa* (Figure 16) was recorded in 4% of the plots in the highly disturbed area after the fifth year of recovery. Although this species was not recorded (probably overlooked) in Yoshinaga's 1973 work, it was present (B.H. Gagné, unpublished field notes).

Through six years of recovery (Table 1), *Styphelia* has increased consistently (from 1% frequency at initial sampling) but still has a frequency of only 29%, compared to 56% in the pristine bog. While the frequency of *Metrosideros* was 6% in the pristine bog, it was not present during the first two years of recovery. After five years of recovery, its frequency was 32%, but it then dropped to 15% frequency during the sixth year, due to seedling mortality caused by frost damage in February 1987.

Medeiros *et al.* (1991) have measured the spread of alien herbaceous plant species in two large montane bogs (elevation 1650-1660 m) in Haleakalā National Park between 1982 and 1988. The 10 x 10 m quadrats (with smaller nested plots) used in the study were placed in areas of bog vegetation, some with and some without alien plant species present. *Holcus lanatus*, *Juncus planifolius*, *Sacciolepis indica*, and *Cyperus halpan* are the aliens that increased most in cover and frequency in the series of 100 m^2 quadrats. Although native species still dominate the vegetation of the bogs, the mean cover of alien species at seven sites dominated by *Carex echinata* increased from 6% to 30% during the six-year period. During the same period, the mean cover of alien species at six sites dominated by *Oreobolus furcatus* increased from 0.2% to 3%; the mean cover of *Oreobolus furcatus* declined by 50%; and *Argyroxiphium grayanum*, *Plantago pachyphylla*, *Selaginella deflexa*, and *Trisetum glomeratum* were much reduced in frequency.

Results of this study and that of Medeiros *et al.* (1991) show that *Oreobolus* sites are relatively resistant to invasion by alien species. *Oreobolus* is capable of recovering from catastrophic disturbance, primarily by seed and requiring about three years without disturbance. With repeated disturbance by pigs, *Oreobolus* is replaced by other native species and, to a much lesser extent, by alien species.

In conclusion, feral pig damage in *Oreobolus* bogs of Haleakalā volcano may be at least partly reversible through exclusion of pigs by fencing. Though native dominants can recover rapidly, the recovery of uncommon species is slower and perhaps will not occur at all for some rare species. However, with continued protection, species composition in Greensword Bog may eventually closely resemble its pristine condition.

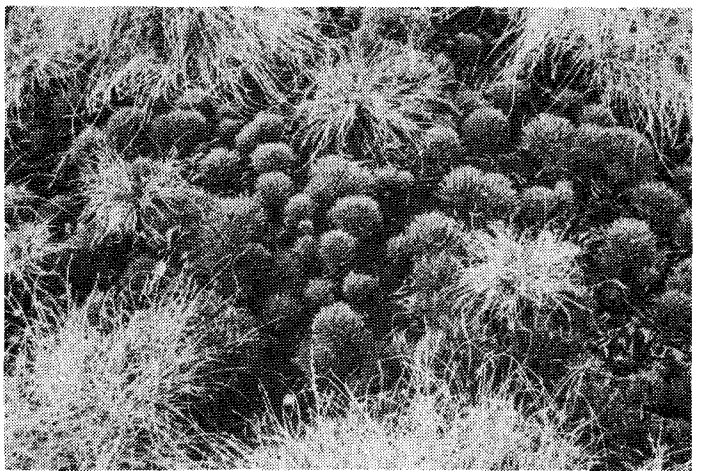


Figure 13: *Oreobolus* tussocks, established from seed, colonizing bare ground rooted by feral pigs. Greensword Bog, 1984. (ACM photo)

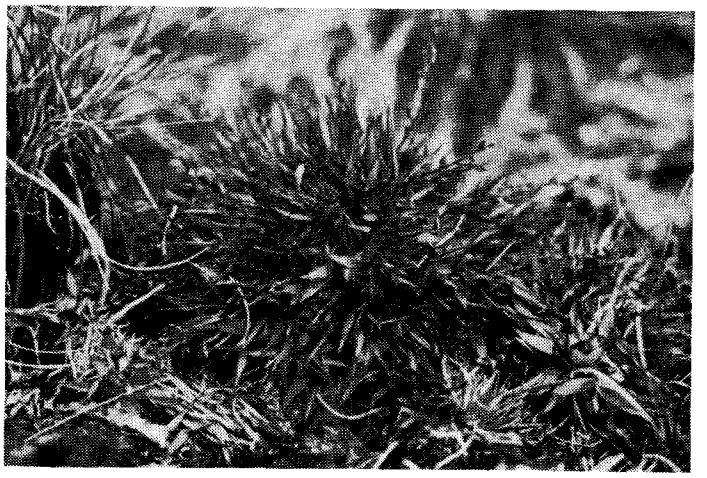


Figure 14: The tiny, mat-forming grass *Dichanthelium cynodon*, a characteristic species of East Maui bogs, especially growing with *Oreobolus*. Clump in center of photo is about 5 cm in diameter. (ACM photo)

Figure 15: *Oreobolus* tussock uprooted by feral pigs. New Bog, 1983. (ACM photo)

Figure 16: The rare native club moss, *Selaginella deflexa*, is vulnerable to damage by feral pig digging, and is recovering slowly. (ACM photo)

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