COOPERATIVE NATIONAL PARK RESOURCES STUDIES UNIT

UNIVERSITY OF HAWAII AT MANOA

Department of Botany
Honolulu, Hawai'i 96822
(808) 956-8218

Technical Report 76-78

STUDIES IN MONTANE BOGS OF HALEAKALA NATIONAL PARK

August 1991

UNIVERSITY OF HAWAII AT MANOA

NATIONAL PARK SERVICE

STUDIES IN THE MONTANE BOGS OF HALEAKALĀ NATIONAL PARK

78. Degradation of Vegetation in Two Montane Bogs: 1982-1988

Arthur C. Medeiros, Lloyd L. Loope, and Betsy H. Gagné

Haleakalā National Park, P.O. Box 369, Makawao, Maui, Hawai'i 96768, U.S.A.

ABSTRACT

The increase of alien herbaceous plant species and decrease of native species in two montane bogs in Haleakalā National Park, Maui, Hawaiian Islands, were documented from 1982 through 1988. These two bogs, Big Bog (5.4 ha) and adjacent Mid-Camp Bog (3.0 ha) at 1650-1660 m (5400-5440 ft) elevation, comprise over half the total bog acreage of East Maui where they are also the two largest bogs. They contain relatively large populations of plant species that are otherwise rare and/or restricted in distribution, including the only known populations of the local endemic, *Geranium hanaense*. Feral pigs arrived into the area in the early 1970s and their heightened activity through the 1980s has caused the loss of native plant cover and invasion by alien plant species. The invasion of alien species into *Carex echinata*-dominated sites was much greater than at *Oreobolus* sites. During the six year study period, cover of alien species at *Carex echinata* sites increased from 6% to 30%. Meanwhile, the cover of alien species at six *Oreobolus* sites increased only modestly from 0.2% to 2.6%; however, *Oreobolus* declined by 50% (from 32% to 15% cover) with increases in bare ground and native species. Native bog species readily recolonize bare areas, but are replaced in *Carex echinata* communities by more aggressive alien species with repeated disturbance. Of alien species present at the study site, *Holcus lanatus*, *Juncus planifolius*, and *Sacciolepis indica* showed the greatest increases in cover and frequency. All major bogs within Haleakalā National Park are now protected from feral pigs by exclosure fences. Without management action, feral pig rooting and the spread of alien plant species would have continued until alien species would likely have dominated the vegetation of these montane bog areas. Feral pig control and/or construction of fences is required if native plant communities are to be maintained in Hawaiian bog communities.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Biological invasions by introduced species threaten nature reserves worldwide (Macdonald *et al.* 1989). They pose a particularly serious threat to the endemic biota of oceanic archipelagoes (Elton 1958, Brockie *et al.* 1988). In some oceanic island ecosystems, the complete conversion of native communities to those dominated by alien species has occurred. In the Hawaiian Islands, examples of pristine communities survive, primarily in high-elevation habitats, on recent lava flows, and in bogs. Nevertheless, even 1500 years after the arrival of Polynesian colonizers and more than 200 years after the first European contact, the disruption and replacement of native communities by alien species continues. This report documents the disruption of recently pristine Hawaiian montane bog habitat by feral pig rooting and subsequent alien plant invasion.

Hawaiian bogs occur in openings in high-elevation rain forest on the islands of Kaua'i, O'ahu, Moloka'i, Maui, and Hawai'i. Mid-Camp (3.0 ha) and Big Bogs (5.4 ha), the study area, are located at 1650-1660 m (5400-5440 ft) elevation in Haleakalā National Park on the island of Maui (Figure 1). These two bogs comprise over half the total bog acreage of East Maui where they are also the two largest bogs. They contain relatively large populations of plant species that are otherwise rare and/or restricted in distribution, including the only known populations of the local endemic, *Geranium hanaense*.

Montane bogs occur on Haleakalā volcano of East Maui along the northeast volcanic rift at 1450-2270 m elevation (Loope *et al.* 1991a). Most of these bogs occur in Haleakalā National Park, but two (State and Waiho'i Bogs) are on State-owned lands. Montane bogs on Haleakalā usually occur near cinder hills on a water-impervious substrate layer which combined with high annual rainfall (ca. 10,000 mm / 400 inches) creates standing water in low-lying areas.

Bog vegetation at Mid-Camp and Big Bogs is dominated by the native sedges *Carex echinata* and *Oreobolus furcatus*, with smaller monospecific stands of *Carex alligata*. Other characteristic species in the largely endemic flora include *Argyroxiphium grayanum*, *Plantago pachyphylla*, and *Geranium hanaense*; the sedges *Rhynchospora chinensis* subsp. *spiciformis*, *Carex montis-eeka*, and *Carex thunbergii*; and the grasses *Deschampsia nubigena* and *Dichanthelium cynodon*[1]. On the higher more elevated sites is a turf of compact dwarf sedges (mostly *Oreobolus* in driest sites, *Carex echinata* in wetter sites), grasses, mosses, lichens, and low herbs and usually sprawling woody shrubs. In low areas, the vegetation forms thicker mats or monospecific stands of *Carex alligata*; often with standing water beneath. A few deep sinkholes occur in the turf, apparently discontinuities or holes in the water-impervious layer. During torrential rains, these sinkholes either drain water or fill with water, often flooding adjacent areas.

The study area provides the sole known habitat for the rare local endemic *Geranium hanaense* discovered in the early 1970s and recently described. One of six endemic species of Hawaiian *Geranium*, the entire population of *Geranium hanaense* estimated at 500 to 700 plants is restricted to the two bogs in the study area, Mid-Camp and Big Bogs (Medeiros and St. John 1988). The species is a trailing, adventitiously rooting shrub with distinctive and attractive silvery foliage and large, often purple-streaked flowers. Bogs of the study area also are also the bulk of the population of *Argyroxiphium grayanum* (Maui greensword) with extensive stands of the species found nowhere else within its range.

Little literature is available regarding Hawaiian bogs, especially those of East Maui. Botanist C.N. Forbes of the B.P. Bishop Museum explored the windward slope of Haleakalā in 1919; he noted "extensive bogs" (Forbes 1920) and collected specimens in the uppermost bogs (Loope *et al.* 1991a).

[1] Nomenclature follows Wagner et al. (1990).

With the exception of reconnaissance by Forbes, the bogs of East Maui were unknown to early biological explorers of the Hawaiian islands and were not visited by scientists prior to the 1970s. The incorporation of this area into Haleakalā National Park in 1969 stimulated interest in its study and conservation.

This area was the site for a National Science Foundation-funded study by a team of university students named the Hāna Rain Forest Project in 1973. They found pigs present in the study area in 1973, but with minimal impacts. They recorded eleven species of alien plants occupying only a negligible area (B.H. Gagné, A.Y. Yoshinaga, pers. comm.).

Though located on a small island (1860 km^2), access to Mid-Camp and Big Bogs is nonetheless difficult, requiring either a helicopter or two days each way on foot, partly through dense montane rain forest. As a result of this remoteness and the lack of trails into this area, these bogs have until recently received little disturbance to native biota compared to most Hawaiian habitats. Feral pigs arrived into the area in the early 1970s and their heightened activity through the 1980s has caused the loss of native plant cover and subsequent invasion by of alien plant species.

Feral pigs damage vegetation in a wide variety of Hawaiian habitats (Spatz and Mueller-Dombois 1975, Jacobi 1981, Diong 1982). Pigs were brought to the Hawaiian Islands by Polynesian colonizers as early as the 4th century A.D., but apparently did not extensively penetrate high-elevation forests of Maui and other islands until recent decades (Diong 1982). Scarcity of available protein in the native forest may have deterred their spread (Stone and Loope 1987). The feral pigs currently in the uplands of Maui apparently descended from domestic stock released from piggeries along the coast, beginning in the early 1900s (Diong 1982); pigs were first observed in Haleakalā Crater in the 1930s (Diong 1982).

The seriousness of the impacts that feral pigs presented to the bogs of the Park first became apparent in the early 1980s in the smaller, higher elevation Greensword and New Bogs. The dramatic destruction of the bog turf at Greensword Bog, the resultant fencing, and subsequent rapid recovery of native species focused much Park attention on the threats and conservation of bog vegetation (Loope *et al.* 1991b).

As a result, the status of other larger, more remote bogs of the Park, Mid-Camp and Big Bogs, became the focus of a large-scale monitoring effort. In order to establish baseline information and assess floristic and vegetation change in the largest bogs of northeast Haleakalā, a network of sampling sites was established in Big Bog and Mid-Camp Bog. As a result of the early findings of this study and the recovery of the fenced area at Greensword Bog (Loope *et al.* 1991b), Big Bog was fenced in April 1987 and Mid-Camp Bog was fenced in August 1988 to provide protection from feral pigs.

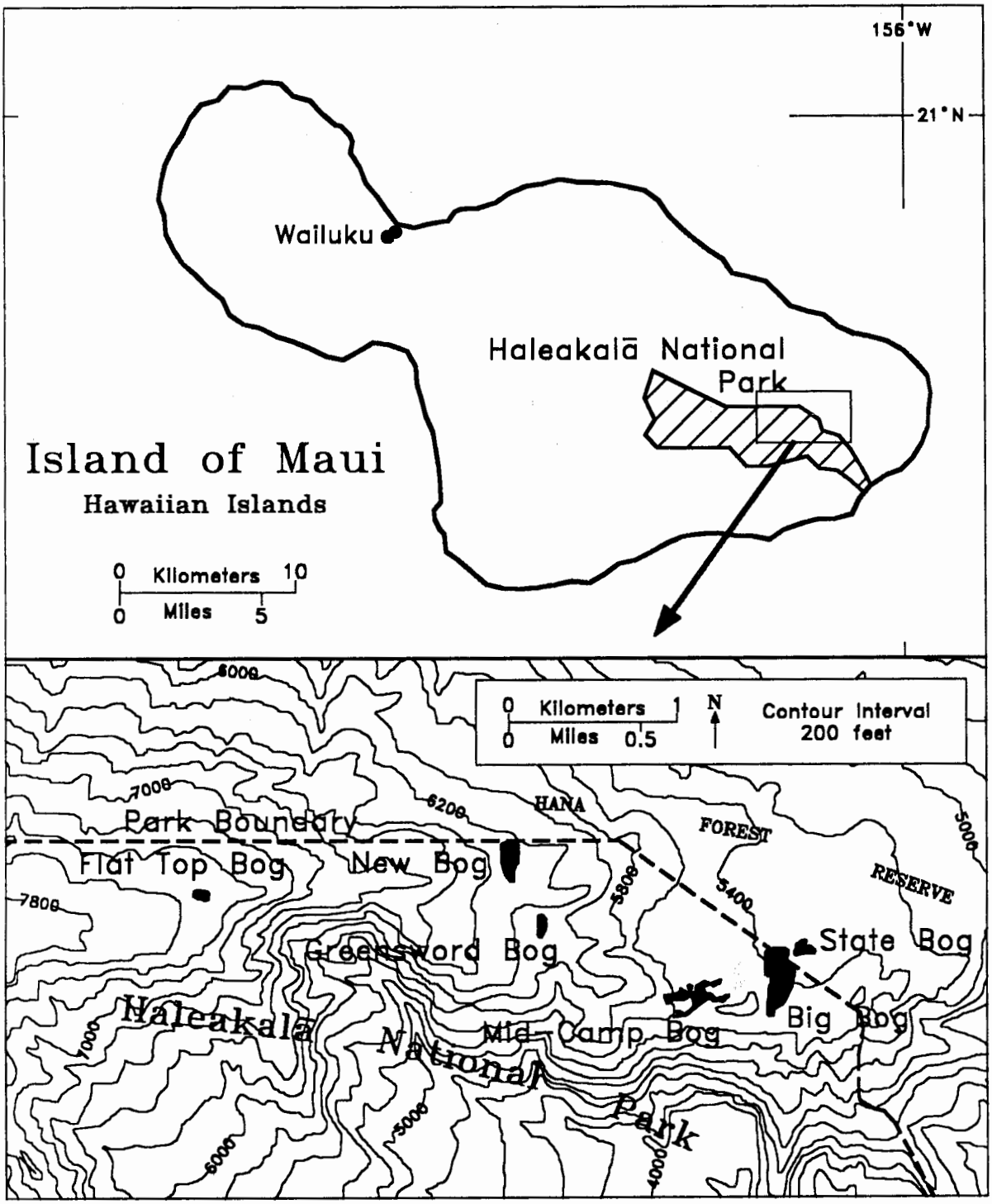

Figure 1: Location of the study area.

METHODS

Three primary vegetation types were identified in the study area, based on dominance of three native sedge species - *Oreobolus furcatus*, *Carex echinata*, and *Carex alligata*. Stands of the tall (to 1.5 m) native sedge *Carex alligata* were not sampled since these stands are virtually monospecific and lack diversity and are not subject to damage by pigs. At the start of the project in 1982, eleven 100 m^2 (10 m x 10 m) quadrats and two 10 m transects were established in sites chosen as representative of the other two communities, seven quadrats in *Carex echinata* and four quadrats and two transects in *Oreobolus* (Figure 3). All four corners of each quadrat were marked with PVC pipes; two corners were wired with stamped metal identification tags.

Twenty 1 m^2 plots were placed within each 100 m^2 quadrat, with ten plots along each of opposite sides; the 100 m^2 quadrats were also divided into four 25 m^2 subquadrats (Figure 2). For each species, presence/absence and an estimate of cover to the nearest 5% were recorded in the plots and subquadrats[2]. The twenty 1 m^2 plots were sampled using a meter-square PVC plot frame placed along a meter tape stretched between PVC poles, allowing accurate relocation of plots. To maximize continuity, one observer (the senior author) was present during each of the four sampling times over the six-year period. Observers estimated cover independently, then discussed and agreed on the final figure. The cover of uncommon species was estimated first, that of dominant species last. To increase standardization of estimates, methods were carefully reviewed prior to each sampling. Species with less than 2.5% or 2.5 dm^2 cover were recorded as "present" (1% for calculations), cited as "negligible" in text. Two sites (12 and 13), consisting of small areas of exceptionally intact *Oreobolus* turf, were sampled by a transect of ten 1 m^2 plots.

The sites were sampled four times at roughly two year intervals, in September 1982, October 1984, December 1986, and October 1988. Two sites in Big Bog (10 and 11) were enclosed by fencing in April 1987; the remainder of the sites, in Mid-Camp Bog, were enclosed by fencing in August 1988, two months prior to final sampling. Photographs of quadrats, transects, and plots were taken to supplement quantitative data.

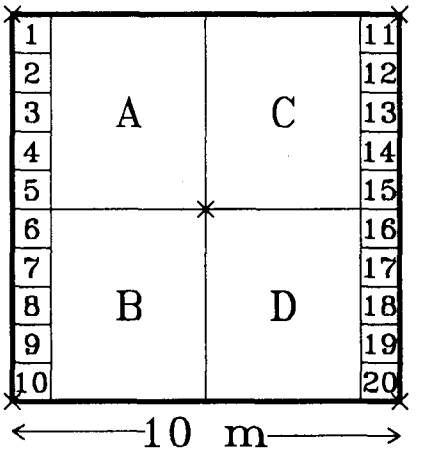

Figure 2: Diagram of 10 x 10 m quadrat, with nested subquadrats and plots, used in this study.

[2] Note: Results from quantitative cover estimates for plant species and bare ground were similar for both sampling methods (1 m^2 plots and 25 m^2 subquadrats). For simplicity, only data from 1 m^2 plots are cited in this report. The full data set is on file at the Research Office, Haleakala National Park.

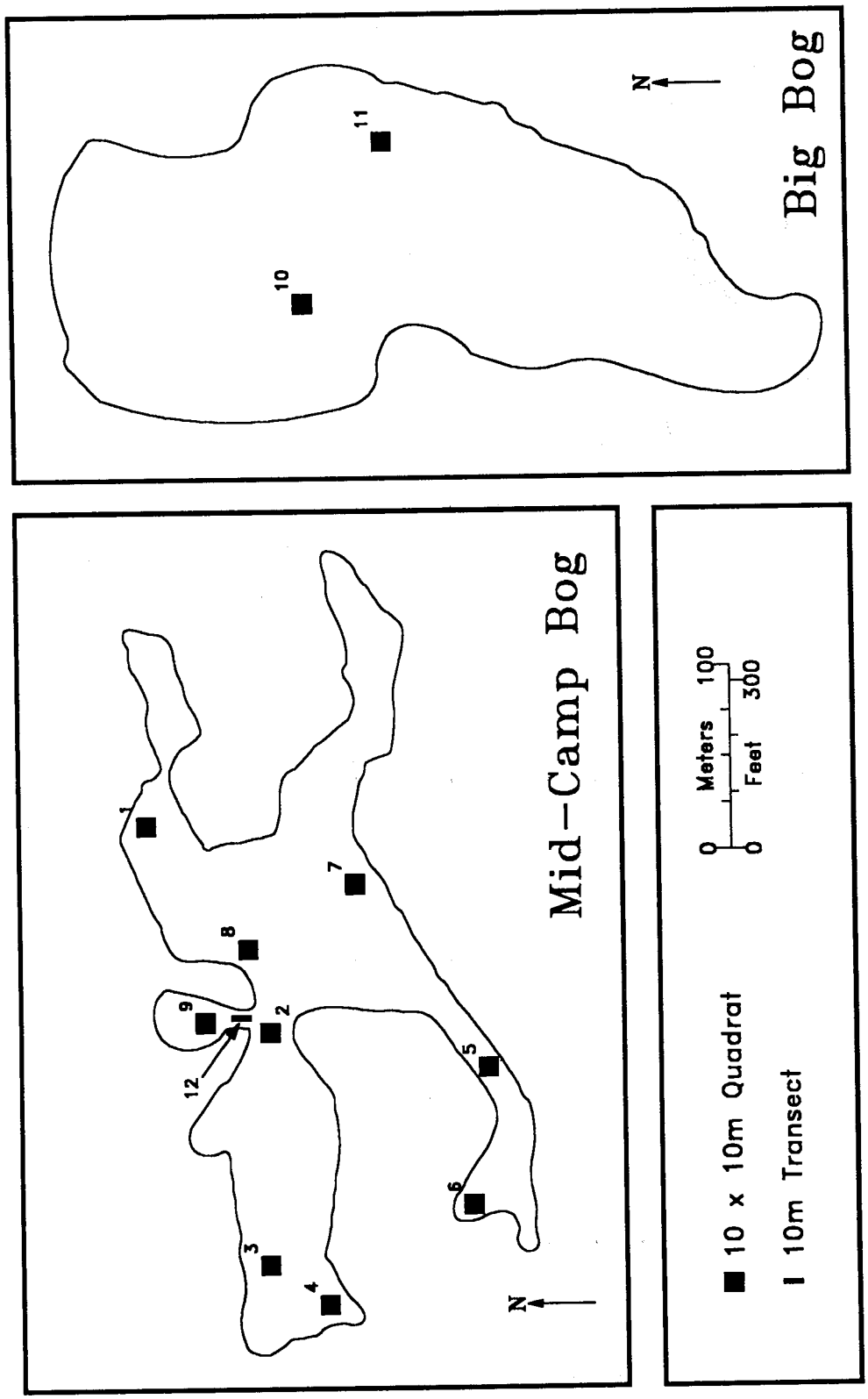

Figure 3: Location of sampling sites in Mid-Camp and Big Bog.

RESULTS

At the onset of the project in 1982, a total of 11 alien plant species and 29 native species were recorded in the 11 quadrats and 2 transects. By 1988, the total number of alien species at the 13 sites had increased from 11 to 12. Of native species, 27 of the original 29 species were still present and three new ones were recorded, giving a total of 30 species in 1988. The two native species that disappeared were *Dubautia plantaginea* and *Machaerina angustifolia*; the three that appeared were *Nertera granadensis*, *Sphenomeris chinensis*, and *Hypolepis punctata*. All five native species are of incidental occurrence in Maui bog vegetation so that the sparsity of their presence probably has little significance.

In 1982, no alien species were present at four (9, 11, 12, 13) of the six *Oreobolus* sites; of the remaining two, one (11) had two alien species and the other (8) had 3 aliens. All *Carex echinata* sites had alien species; six of the seven had at least 3% cover of alien species. Site 7 was the most pristine of the *Carex echinata* sites, with only two alien species with negligible cover. Sites 4 and 5 had the highest cover of alien species (12% and 15% respectively) of *Carex echinata* sites. The most frequent and abundant alien plants in 1982 were *Holcus lanatus* (velvetgrass), *Sacciolepis indica* (Glenwood grass), and *Cyperus halpan.*

In 1982, cover of bare ground and dead vegetation varied from 2% (site 11) to 53% (sites 4 and 12). A small percentage of bare ground (ca. 2-10%) in many Hawaiian bogs is natural; in this study, no attempt was made to differentiate bare ground resulting from pig damage from that which was natural.

By 1988, three of the four initially pristine *Oreobolus* sites (9, 11, and 13) still lacked alien plant species. Site 12 remained alien-free through 1986, but *Sacciolepis indica* was present in low cover by 1988. Though most native species maintained relatively stable during the six year period, mean cover of the endemic sedge *Oreobolus furcatus* declined by nearly 50% (from 32% to 15%) (Figure 4).

By 1988, *Carex echinata* sites suffered massive invasion of alien species with six of these seven sites having at least 19% cover of alien species (Figure 5); only site 7 remained nearly pristine. Sites 3, 4, and 5 were the most seriously impacted with the highest cover of alien species (41%, 52%, and 47%).

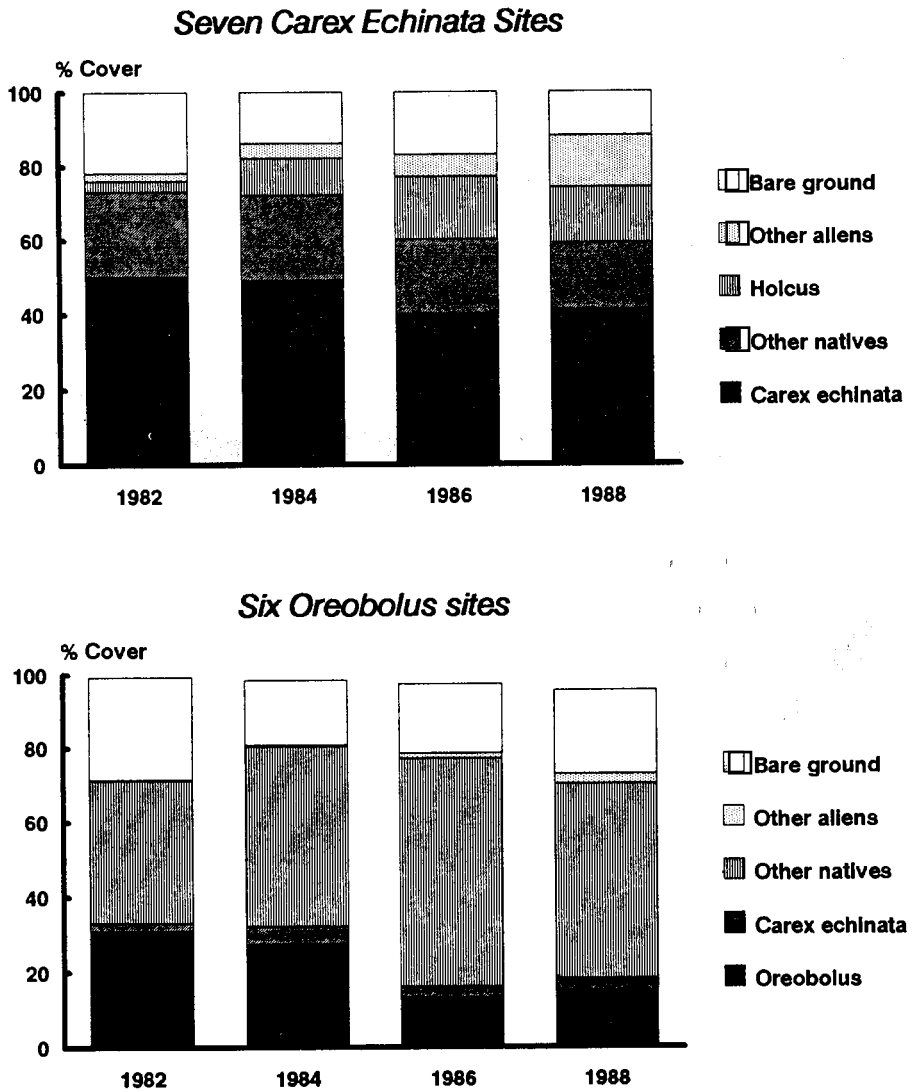

Figure 4: Mean cover for major categories in *Carex echinata* sites and *Oreobolus*-dominated sites. These data are based on cover estimates in 140 1 m^2 plots at seven sites for *Carex echinata* and 100 1 m^2 plots at six sites for *Oreobolus*.

Changes at sites dominated by *Carex echinata*

Carex echinata sites were much more susceptible to invasion by alien plant species than other East Maui bog plant communities. At the seven *C. echinata* sites (1-7), the average cover of alien species increased five-fold from 6% in 1982 to 30% in 1988 (Figure 5). The following is a discussion of vegetation changes at each of the *Carex echinata* sites.

Site 1 (Figure 6) initially had a high cover value for bare ground (36%) due to extensive recent pig digging; this value decreased below 10% on subsequent sampling dates. *Carex echinata* colonized some of the bare ground exposed by pig digging (36% to 43% increase). However, over the six year study period the greatest increases in cover for site 1 were made by alien grasses already present in small quantities in 1982. During those years, the combined cover of *Sacciolepis indica* and *Holcus lanatus* increased from 4% to 33%. On the other hand, another alien, *Cyperus halpan*, first recorded in this plot in 1984, has not spread extensively. The decline of native species has been subtle; natives other than *Carex echinata* have collectively declined by one-third. *Argyroxiphium* remained stable in cover while declining in frequency.

Site 2 has been substantially invaded by *Holcus* over six years (from 3% to 19% cover). The aggressive invader *Juncus planifolius* was recorded for the first time in 1988. The native species that declined most were *Carex echinata* and *Plantago pachyphylla. Plantago* decreased in cover from 10% to negligible (1%) and in frequency from 50% to 15% (disappearing from seven of 20 plots). The endemic sedge *Carex montis-eeka* increased from 10% to 18%. *Argyroxiphium* increased in cover (8% to 15%) and maintained its frequency (45 to 50%).

Site 3 (Figure 7) initially had 3% cover of *Holcus* and high cover values for bare ground (31%). *Holcus* reached 14% cover by 1988, and newly invading *Juncus planifolius* had 6% cover. Of native species, cover of *Carex echinata* and greensword increased slightly over the six years, but *Plantago pachyphylla*, with a 1982 frequency of 25% (present in five plots), was extirpated at the site by 1988.

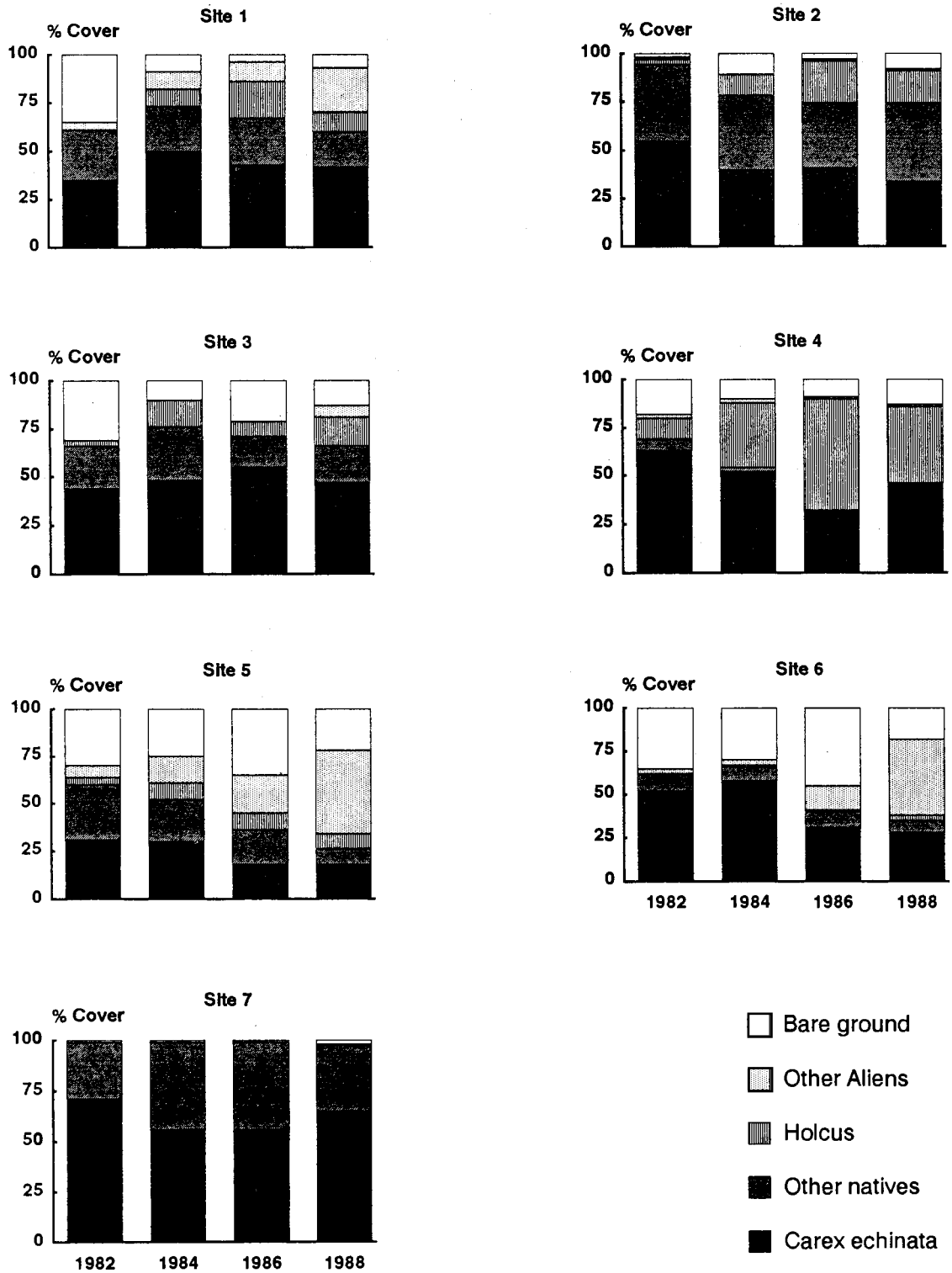

Figure 5: Mean cover by category at each *Carex echinata* sites based on cover estimates in twenty 1 m^2 plots at each of seven sites.

Figure 6: *Carex echinata*-dominated site 1, in Mid-Camp Bog, in 1982, with recent pig digging in the foreground; 36% of the cover was bare ground. Combined cover of alien grasses *Sacciolepis* and *Holcus* increased from 4% to 33% over the next six years. (ACM photo)

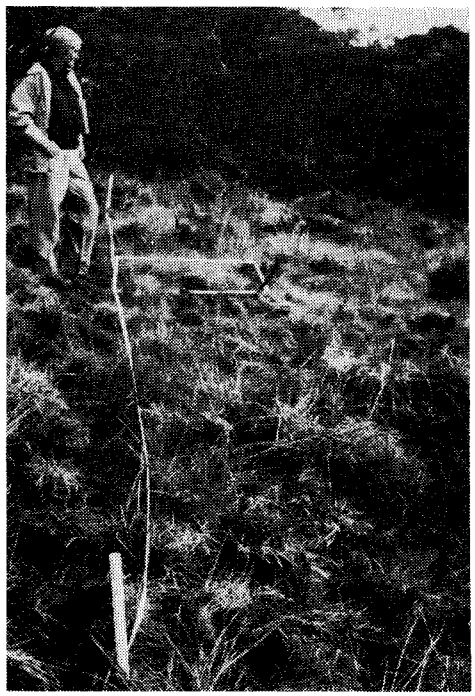

Figure 7: Another *Carex echinata* site, no. 3, in Mid-Camp Bog. Like site 1, this site initially had substantial bare ground (31%) exposed by recent pig digging. Alien plants (mainly *Holcus lanatus* and *Juncus planifolius*) increased from 3% to 20% cover by 1988. (ACM photo)

Sites 4 and 5 were, in 1982, the most disturbed sites studied. The cover of *Carex echinata* declined from 63% to 47%, while alien *Holcus lanatus* increased cover from 11% to 40% over six years. *Cyperus halpan* was present in 1982, but increased only slightly during the study. *Juncus planifolius* first appeared in the plot in 1986 and had attained only negligible cover by 1988. The endemic species *Plantago pachyphylla* and *Deschampsia nubigena* were extirpated at the site and *Carex montis-eeka* declined.

During the study period, sites 5 and 6 had the greatest increases of alien species of any plots in bog vegetation in the Park. The two plots are located on a narrow extension of bog in an area which has consistently been subjected to heavy pig activity. Cover values for bare ground for sites 5 and 6 were high throughout the four sampling periods. Native vegetation at site 5 (Figure 8) declined precipitously with *Carex echinata* decreasing by half in six years (cover from 28% to 14%). Eight alien species with 12% cover were present in 1982; by 1988, there were 10 species with 52% cover. The 1982 and 1988 cover of alien species were as follows: *Juncus planifolius* - 0% to 24%, *Sacciolepis indica* - 0% to 9%, *Holcus lanatus* - 5% to 8%, *Cyperus halpan* - 6% to 5%, *Centella asiatica* - 0% to 4%, and *Eragrostis brownei*, - 0% to 2%. *Senecio sylvaticus*, *Juncus bufonius*, *Hypochoeris radicata*, and *Erechtites valerianifolia* were also present but with negligible cover. The two *Juncus* species were first recorded in 1986. The rare native sedge *Carex thunbergii* declined from 19% to negligible cover concurrent with the increases in alien species.

In 1982, site 6 had only 3% cover of alien species (*Cyperus halpan* - 1% and *Hypochoeris radicata* - 2%), but by 1988, had increased to 47% (Figure 9). By 1988, cover values for alien species had increased as follows: *Juncus planifolius* - 28%, *Centella asiatica* - 10%, *Cyperus halpan* - 4%, *Holcus lanatus* - 3%, *Juncus bufonius* - 2%) As in plot 5, *Juncus planifolius* increased dramatically within two years after it was first detected in 1986. By 1988, *Carex echinata* had declined from 54% to 28%.

Site 7 (Figure 10) was the only *Carex echinata* site that remained stable throughout the study period. Cover of bare ground did not exceed 5% on any of the four sampling dates. *Hypochoeris* with negligible cover was recorded in 1984 and 1988, but not at other samplings; no other aliens were recorded. Cover of the rare endemic species *Argyroxiphium grayanum* and *Geranium hanaense* remained stable.

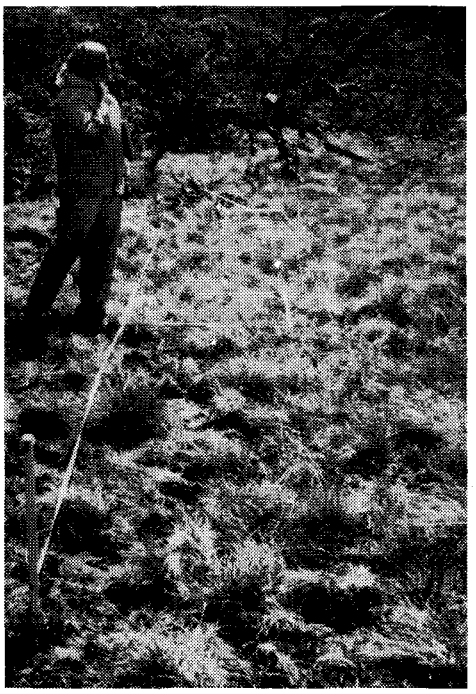

Figure 8: *Carex echinata* site 5 in Mid-Camp Bog, in 1982, was heavily rooted by pigs throughout our study. Here, alien plant species increased their cover from 12% to 52% over six years. *Juncus planifolius*, first discovered in 1986, had reached 24% cover in two years. (ACM photo)

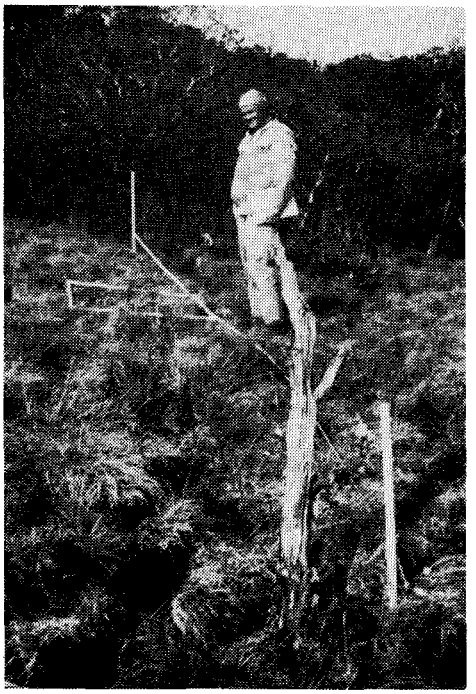

Figure 9: *Carex echinata* site 6, in Mid-Camp Bog, showed a response to severe pig rooting common to sites dominated by this species. Alien plant species in this site increased from 3% to 47% over six years. Photo taken in September 1982. (ACM photo)

Figure 10: Site 7 (Mid-Camp Bog) in 1982 dominated by *Carex echinata* (44% cover). This was the only *Carex echinata* site with little or no effect of feral pig damage over the six year study period. As of 1988, only one alien plant species (*Hypochoeris radicata*) had invaded (negligible cover) this site. Rosettes of greensword, *Argyroxiphium grayanum*, and flowering spikes of *Plantago pachyphylla* are conspicuous in foreground. The local endemic *Geranium hanaense*, with silver leaves, is in the center of photo under PVC plot frame. (ACM photo)

Changes at sites dominated by *Oreobolus furcatus*

Sites dominated by *Oreobolus* were much less susceptible to invasion than sites dominated by *Carex echinata*. At the six *Oreobolus*-dominated sites, the average cover of alien species was only 0.2% in 1982; it had increased to 2.6% by 1988 (Figure 4). However, *Oreobolus furcatus* declined substantially at four of the six *Oreobolus*-dominated sites over the six year study period (Figure 11). The following is a discussion of vegetation change at each of the *Oreobolus* sites

Site 8 was relatively stable compared to other *Oreobolus* sites. *Oreobolus* only slightly decreased from 16% to 15% cover over the six years. *Deschampsia nubigena* increased from 5% to 29%, occupying bare ground continually exposed by pig rooting. Native species *Carex montis-eeka* and *Dichanthelium cynodon* increased slightly while populations of other native species remained stable. Alien *Holcus* started with negligible cover and did not increase appreciably, but *Sacciolepis* went from negligible cover to 5%. Alien *Cyperus halpan*, *Eragrostis brownei*, and *Juncus planifolius* have become newly established (in 1984, 1986, and 1988 respectively).The greatest decrease in *Oreobolus* cover over six years took place at sites 9 and 11. At site 9 (Figure 12), *Oreobolus* decreased from 41% to 14% cover, with a low of 9% in 1986. Alien plants were not recorded in site 9 until 1988, when a small amount of *Juncus planifolius* was noted.

At site 10 (Figures 13, 15), *Oreobolus* initially (1982) shared dominance with *Rhynchospora chinensis* subsp. *spiciformis* and *Carex montis-eeka*. *Oreobolus* declined from 12% to 3% cover by 1988. *Carex montis-eeka* increased from 10% to 14% over six years; *Rhynchospora* increased from 19% to 26%. The native bunchgrass *Deschampsia nubigena* increased from 5% to 28%. In this case, *Rhynchospora* and *Deschampsia* apparently increased by occupying ground exposed by feral pigs. The only alien present, *Eragrostis brownei*, increased from 4% to 7% between 1986 and 1988 despite protection from pigs by fencing in 1987.

At site 11, *Oreobolus* decreased from 42% to 6% over six years. The only alien plant species present were *Hypochoeris radicata* and *Centella asiatica* in 1984; they were absent in subsequent years. The decline of *Oreobolus* was accompanied by increases in the cover of three native species - *Rhynchospora chinensis* subsp. *spiciformis* (17% to 36%), *Carex montis-eeka* (16% to 22%), and *Argyroxiphium* (8% to 15%) - as well as in bare ground (8% to 14%). *Plantago pachyphylla*, highly sensitive to pig disturbance at most sites, maintained 100% frequency through the six year period of the study. The only other site where *Plantago* remained stable was 10.

In 1982, site 12 had the highest cover value (53%) for bare ground recorded at any of the 13 sites on any of the four sampling dates. Yet excellent recovery of *Oreobolus* and other native species took place over the six years of the study. *Oreobolus* (35% to 49% cover), *Carex montis-eeka* (12% to 18%), and *Deschampsia nubigena* (2% to 9%) contributed most of the increase. By 1986, the alien *Sacciolepis* was present at this site, which initially was free of alien plant species. As of 1988, although bare ground still covered 22% of the transect, the cover of alien species was still negligible.

At site 13 (Figures 14, 16), cover of *Oreobolus* declined from 65% to 46%, reaching a low of 30% in 1986. The sharp decline from 1984 to 1986 was accounted for by a substantial increase (11% to 32%) in bare ground (caused by accelerated pig digging) and by increases in the native species *Carex montis-eeka* (9% to 26%) and *Deschampsia nubigena* (3% to 7%). No alien plant species have been recorded at site 13.

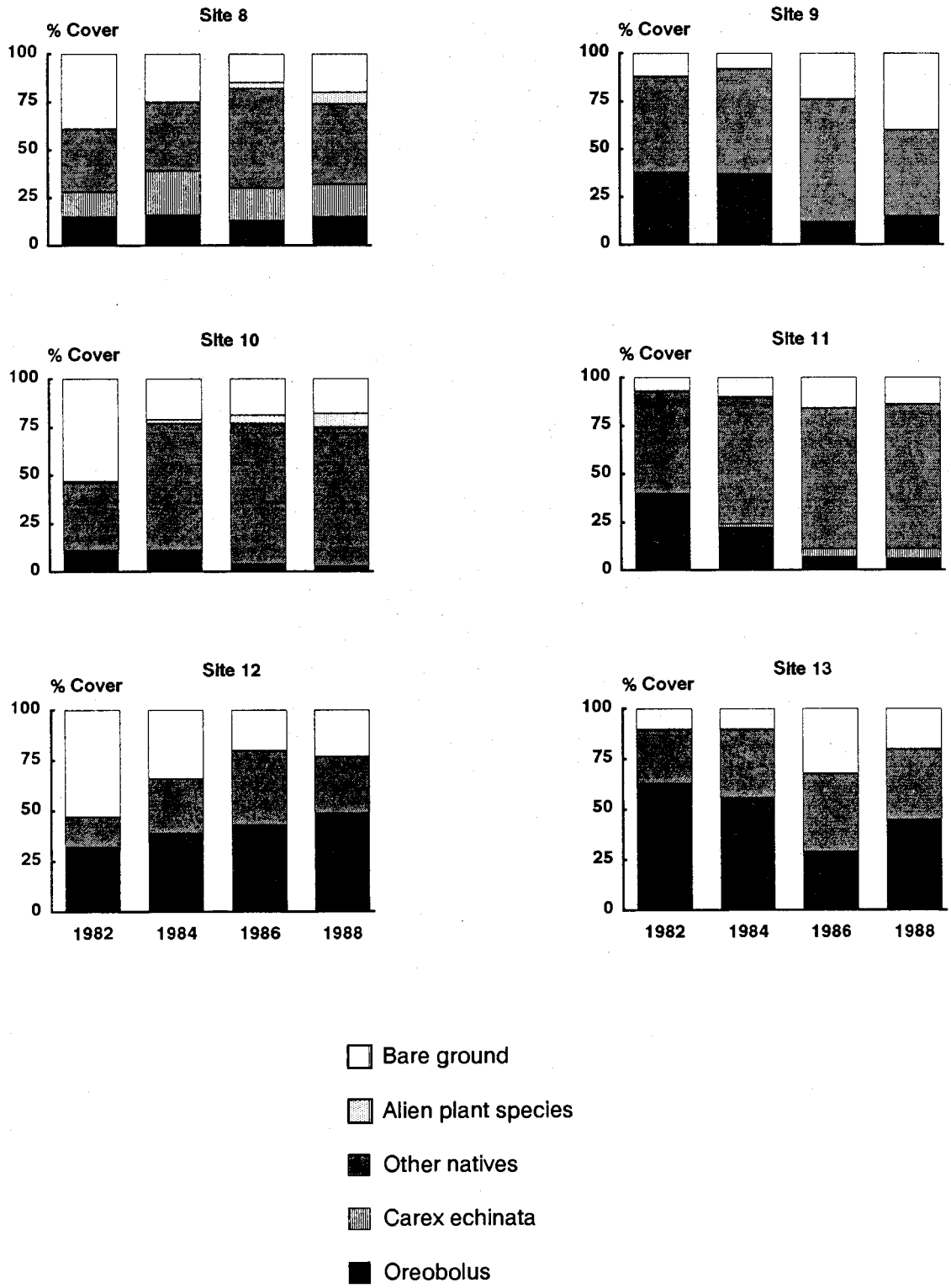

Figure 11: Mean cover by category at each *Oreobolus furcatus* site based on twenty 1 m² plots at each of four sites and ten 1 m² plots at two sites.

Figure 12: At site 9 in Mid-Camp Bog, *Oreobolus* declined from 41% cover (pristine condition shown here in 1982) to 14% in 1988, as a result of pig damage. No alien species were present until *Juncus planifolius* appeared (with < 1% cover) in 1988. (ACM photo)

Figure 13: Heavily-damaged site 10, in Big Bog, in 1982, with *Rhynchospora chinensis* (19% cover), *Oreobolus furcatus* (12%), and *Carex montis-eeka* (10%). Bare ground accounted for 53% cover, due to the recent feral pig rootings. (ACM photo)

Figure 14: Initially,*Oreobolus* site 13, Mid-Camp Bog, had little disturbance as shown here in 1982. Pigs rooted the area (32% bare ground cover) by 1986. *Oreobolus* declined sharply, but no alien species invaded. (ACM photo)

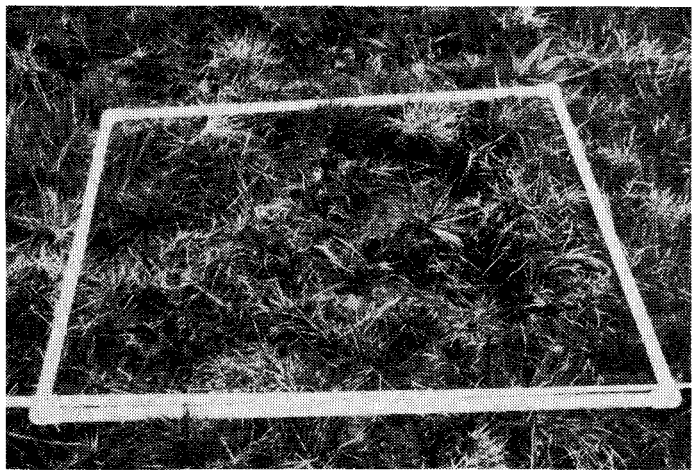

Figure 15: An example of pig-rooted vegetation at an *Oreobolus*-dominated site. Detail of pig-rooted 1 m² plot at site 10 (shown in Figure 13) in Big Bog in 1982. Principal cover values: *Rhynchospora* 30%, *Oreobolus* 5%, bare ground and dead vegetation 65%. (ACM photo)

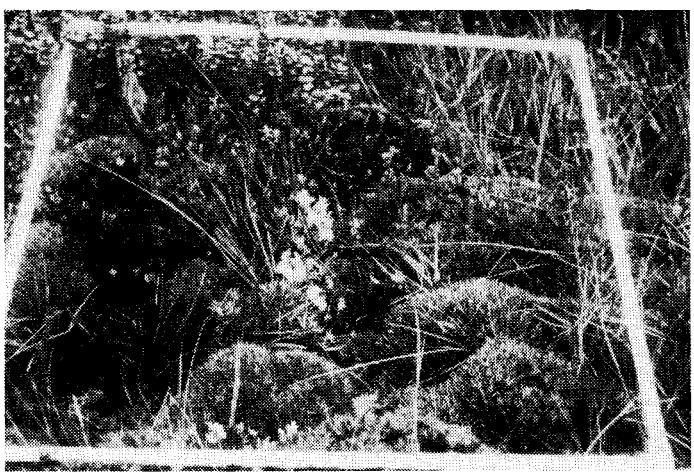

Figure 16: An example of pristine vegetation at an *Oreobolus*-dominated site. Detail of undisturbed 1 m² plot at site 13 in Mid-Camp Bog in 1982. Principal cover values: *Oreobolus* 75%, *Styphelia* 5%, *Metrosideros* 5%, *Carex montis-eeka* 5%, bare ground and dead vegetation 10%. (ACM photo)

DISCUSSION

Stability and decline of native plant species

The native species in this study that clearly declined (Figure 17, Table1) as a result of pig damage were the dwarf tussock-forming sedge *Oreobolus furcatus*, *Argyroxiphium grayanum* (Figure 18), *Carex thunbergii, Plantago pachyphylla* (Figure 19), *Selaginella deflexa* and *Trisetum glomeratum.* Other native species appeared to remain relatively stable in mean cover value over the six-year period. For example, the combined cover of three dominant native species, *Carex echinata, Carex montis-eeka,* and *Deschampsia nubigena,* when averaged over all sites, consistently totaled about 45% cover throughout the study.

The damage to *Oreobolus furcatus*, the dominant species of a distinct and unique plant community within the Park Service is particularly alarming; its cover at our sites declined by 50% during the six year study. The recoverability of an *Oreobolus* community has been demonstrated (Loope *et al.* 1991b). However, chronic disturbance of *Oreobolus* communities in the presence of abundant seed sources of alien species may result in substantial invasion by alien species.

The mechanism by which *Oreobolus*-dominated communities remain free from invasion by alien species remains undetermined. Though the climate of the region is very wet, *Oreobolus* sites are less inundated, drier, and located slightly higher topographically than those dominated by *Carex echinata* or *C. alligata*. Reasons for differential invasibility of Hawaiian montane bog communities are beyond the scope of this study, but may comprise a fruitful topic for future investigation. Possibilities include soil toxicity or low nutrient availability, allelopathy of *Oreobolus* peat, and greater moisture stress in *Oreobolus* turf due to extreme fluctuations between wet and dry conditions.

Most of the damage caused by pigs to native bog species seemed to be incidental to feeding and movement, often involving trampling or uprooting during plowing. The troughing caused by feral pig plows was occasionally extensive and seemed to result from search for vegetable material or invertebrates. Direct feeding by feral pigs on both *Argyroxiphium grayanum* and *Plantago pachyphylla* has been observed. Biting and removal of the apical meristem and young leaves are typical of pig damage for both species.

Increase of alien plant species

During the period of study, many alien species spread progressively into additional plots (Figure 20, Table 2). Two weeds were consistently invasive and capable of establishing high cover - *Holcus lanatus* and *Juncus planifolius*. *Holcus* remained the most abundant alien species throughout the study, but *Juncus*, which first appeared in 1986, is spreading very rapidly.

Holcus lanatus (velvetgrass or Yorkshire fog) is a sprawling perennial grass with pubescent foliage. It is a temperate species, native to northern Europe, is invasive in many areas worldwide and is common in upper elevation pastures and disturbed natural areas on East Maui and Hawai'i. In 1982, *Holcus* was present in six *C. echinata* sites with 4% mean cover and one *Oreobolus* site with negligible cover. By 1988, *Holcus* was present at the same sites but had increased its cover substantially to 16% of the area of all *C. echinata* plots; it was still present at only one *Oreobolus* site, with negligible cover.

Juncus planifolius is a perennial herb with rosettes of leaves, often characteristically reddened at the base, native to South America, Australia and New Zealand. By 1988, *J. planifolius* was present at six of seven *C. echinata* sites and covered 8% of the plot area; it was present at one of six *Oreobolus* sites, with negligible cover. It is a highly invasive species especially of montane bogs, and is often associated

with areas of high disturbance, e.g. trails, stream courses and bare ground. This species is spreading in wet upland areas on the islands of Kaua'i, Maui, Moloka'i, and Hawai'i.

In 1982, *Sacciolepis indica* (Glenwood grass) native to the paleotropics, was present at two *C. echinata* sites with 2.5% mean cover and one *Oreobolus* site with negligible cover. By 1988, *Sacciolepis* had increased modestly, present in three *C. echinata* sites (11% mean cover) and two *Oreobolus* sites (3% mean cover). All plots with this species present were in Mid-Camp Bog.

Eragrostis brownei (sheepgrass) was in 1982 confined to a single *Oreobolus* site in Big Bog with 1% mean cover. By 1988 it had spread into plots at Mid-Camp Bog apparently from other nearby populations, totaling one *C. echinata* site with 2% mean cover and three *Oreobolus* sites with 3% mean cover.

Other alien species which appear to be invasive in the study sites include: *Cyperus halpan* (present at four *C. echinata* sites and one *Oreobolus* site, all with negligible cover), *Centella asiatica*(Asiatic pennywort) (present at two *C. echinata* sites with 2% mean cover)

Based on our data, *Hypochoeris radicata* (gosmore or hairy cats ear), *Poa annua* (annual bluegrass), and *Senecio sylvaticus* (wood groundsel) appear to be less aggressive the above mentioned species in East Maui montane bogs. *Hypochoeris* is an important weed in many high-elevation ecosystems of East Maui but at these bogs remained negligible in cover and stable or even diminished somewhat in distribution. *Poa* remained localized at two adjacent sites in Mid-Camp Bog and negligible in cover. *Senecio* is more common that its occurrence at a single site would indicate. It is a common and conspicuous weed in the water-saturated area of eastern Mid-Camp Bog.

Other aliens recorded in the study sites but not important ecologically include *Conyza bonariensis* (hairy horseweed), *Epilobium billardierianum* and *Juncus bufonius* (common rush). *Erechtites valerianifolia* was not important at our sites, although large (up to 0.7 m diameter) rosettes of this species with dense dark green foliage were established, especially at Big Bog, in late 1988.

Other alien species occurring in Mid-Camp and Big Bogs, but not in our study sites include *Agrostis avenacea* (he'upueo), *Andropogon virginicus* (broomsedge), *Emilia fosbergii*, *Emilia sonchifolia* (Flora's paintbrush), *Prunella vulgaris* (self-heal), *Rumex acetosella* (sheep sorrel), and *Sonchus oleraceus* (pualele). Because of the extensive colonization of landslide slips in wet areas by *Andropogon virginicus* in nearby Kīpahulu Valley, a mechanical removal program was instituted in the late 1980s for this species in Mid-Camp and Big Bogs.

Effects of freezing temperatures and wind desiccation

In February 1987, there was a severe cold period with frost and ice in early morning followed at midday by full solar radiation and high winds. Effects of this event were most severe at higher elevations but extended to the study area at 1650-1660 m elevation, where much vegetation was killed within bogs and at bog margins (A.C. Medeiros, pers. obs.; Loope *et al.* 1991a). Mortality of seedlings of certain woody species (*Metrosideros polymorpha*, *Argyroxiphium grayanum*, and *Dubautia plantaginea*) and ferns (*Dryopteris wallichiana* and *Cibotium glaucum*) colonizing open bog turf was evident. Other species appeared to be resistant to this frost damage (native sedges, grasses, *Geranium hanaense*, *Styphelia tameiameiae*, *Vaccinium reticulatum*). Infrequent freezes may help to maintain the open condition of some Hawaiian bogs; effects of the February 1987 freeze are reflected in data of this study. The frost and subsequent winds may explain the loss of seedlings and saplings of woody plant species during the course of this study.

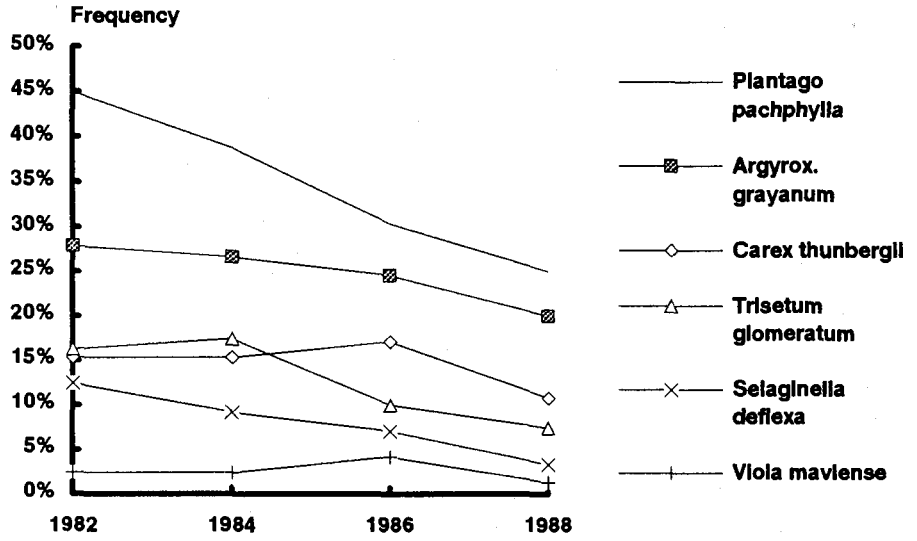

Figure 17: Frequency on the four sampling dates of native bog species that appear to have declined during the 1982-1988 period. Based on presence or absence in 240 1 m^2 plots at the 13 sites.

Table 1: Frequency of all native plant species at study sites in *Carex echinata*-dominated communities and *Oreobolus*-dominated communities in 1982 and 1988.

	Frequency in *Carex echinata* communities		Frequency in *Oreobolus* communities	
	1982	1988	1982	1988
Carex montis-eeka	80%	68%	100%	100%
Deschampsia nubigena	64%	49%	95%	91%
Carex echinata	99%	100%	16%	17%
Dichanthelium cynodon	7%	5%	94%	86%
Oreobolus furcatus	3%	3%	86%	78%
Plantago pachyphylla	24%	10%	80%	47%
Dryopteris hawaiiensis	10%	11%	56%	55%
Vaccinium reticulatum	2%	-	66%	49%
Styphelia tameiameiae	-	-	63%	41%
Argyroxiphium grayanum	43%	31%	7%	4%
Metrosideros polymorpha	1%	1%	40%	31%
Rhynchospora chinensis subsp. *spiciformis*	-	-	33%	36%
Sadleria pallida	4%	6%	33%	26%
Trisetum glomeratum	3%	2%	35%	15%
Carex thunbergii	29%	19%	-	-
Selaginella deflexa	0%	0%	30%	8%
Cibotium glaucum	1%	0%	13%	11%
Athyrium microphyllum	5%	5%	1%	4%
Geranium hanaense	4%	5%	3%	1%
Coprosma ochracea	4%	5%	2%	1%
Luzula hawaiiensis	7%	1%	2%	1%
Carex alligata	6%	3%	-	-
Viola maviensis	-	-	6%	3%
Dryopteris fusco-atra	-	2%	-	-
Dryopteris wallichiana	1%	1%	-	-
Calamagrostis expansa	-	-	0%	1%
Dicranopteris linearis	-	0%	-	1%
Hypolepis punctata	-	1%	-	-
Sphenomeris chinensis	-	-	-	1%
Dichanthelium hillebrandianum	-	-	1%	-
Pneumatopteris sandwichensis	0%	0%	-	-
Dubautia plantaginea	0%	-	-	-
Machaerina angustifolia	0%	-	-	-
Nertera grenadensis	-	0%	-	-

Frequency in Carex echinata-dominated communities is based on presence in 140 1 m^2 plots in 7 sites. Frequency in Oreobolus-dominated communities is based on presence in 100 1 m^2 plots in 6 sites. Dash (-) indicates absence of species at all sites (in 10 m x 10 m quadrats) for sampling date. Frequency of 0% indicates presence of species in at least one 10 m x 10 m quadrat.

Figure 18: View of montane bog with many greenswords (*Argyroxiphium grayanum*) in flower. This is one endemic species which is declining due to both direct and indirect damage caused by feral pigs. (ACM photo)

Figure 19: Rosettes of *Plantago pachyphylla* in a bog community dominated by *Carex echinata*. *Plantago pachyphylla* declined in frequency by about 50% in study plots over six years because of damage by feral pigs, mostly direct damage by biting and eating the new central growth. (ACM photo)

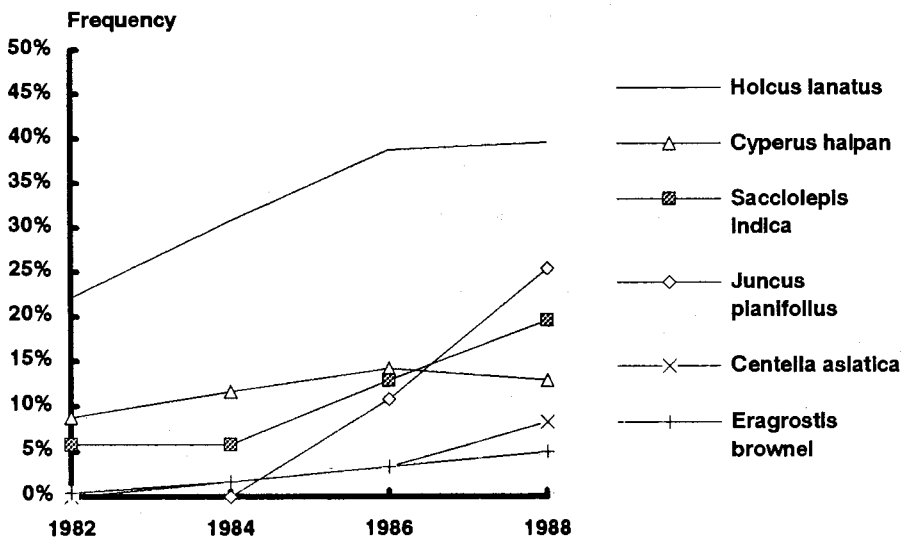

Figure 20: Frequency on the four sampling dates of aggressive alien plant species that are present in at least 5% of the plots. Based on presence or absence in 240 1 m² plots at the 13 sites.

Table 2. Frequency of all alien plant species at study sites in *Carex echinata* communities and *Oreobolus* communities in 1982 and 1988.

	Frequency in *Carex echinata* communities		Frequency in *Oreobolus* communities	
	1982	1988	1982	1988
Holcus lanatus	37%	65%	1%	4%
Sacciolepis indica	9%	30%	1%	6%
Cyperus halpan	15%	30%	-	1%
Juncus planifolius	-	19%	-	4%
Centella asiatica	0%	14%	-	-
Hypochoeris radicata	27%	13%	-	-
Eragrostis brownei	-	2%	1%	8%
Senecio sylvaticus	2%	4%	-	-
Juncus bufonius	-	3%	-	-
Erechtites valerianifolia	1%	1%	0%	-
Poa annua	1%	0%	-	-
Conyza bonariensis	0%	-	-	-
Epilobium billardierianum	0%	-	-	-

Frequency in Carex echinata communities is based on presence in 140 1 m² plots in 7 sites. Frequency in Oreobolus communities is based on presence in 100 1 m² plots in 6 sites. Dash (-) indicates absence of species at all sites (in 10 m x 10 m quadrats) for sampling date. Frequency of 0% indicates presence of species in at least one 10 m x 10 m quadrat.

CONCLUSIONS

The East Maui bogs were threatened beginning in the early 1970s with the arrival of feral pigs that rooted the native bog vegetation and promoted the spread of alien plants. Haleakalā National Park initiated a program to protect bog vegetation by exclosure fencing and to monitor vegetation changes in protected and unprotected areas. Results have shown that many native bog species readily recolonize bare areas, but in *Carex echinata* communities are replaced by more aggressive alien species with repeated disturbance. Though some native species may be resistant to limited levels of pig damage, others such as *Oreobolus furcatus*, *Plantago pachyphylla*, *Argyroxiphium grayanum*, *Carex thunbergii*, *Trisetum glomeratum*, and *Selaginella deflexa* decline rapidly.

The invasion of *Carex echinata*-dominated sites by alien species was much greater than at *Oreobolus*-dominated sites. The increase of alien species in *Carex echinata* plots from 6% to 30% cover is dramatic in that it occurred within only six years. Of alien species present at the study site, *Holcus lanatus*, *Juncus planifolius*, and *Sacciolepis indica* showed the greatest increase in cover and frequency. *Juncus planifolius* first appeared at four sites in 1986, but by 1988 was present in eight sites and was the second most abundant alien species.

All major bogs within Haleakalā National Park are now protected from feral pigs by exclosure fences. The question now is to what extent will the deterioration be reversed with protection from pig digging Now that pigs have been excluded, the cover of bare ground will diminish relatively quickly. Based on the data presented here, three native species and three alien species will largely fill this gap. The natives are the high-elevation bunchgrass *Deschampsia nubigena* and two characteristic bog sedge species, *Oreobolus furcatus* and *Carex echinata*. The alien species are the three most dominant species to this point -- two grasses, *Holcus lanatus* and *Sacciolepis indica*, and a rush, *Juncus planifolius*.

The recovery potential of *Oreobolus*-dominated communities following protection from pigs by fencing has been demonstrated (Loope *et al.* 1991b). This study suggests that a crucial component of the recovery potential of *Oreobolus* communities involves their long-term resistance to invasion by alien species.

After protection from feral pigs, the degree of eventual recovery of native species in *Carex echinata*-dominated communities once they have been substantially invaded by alien species is unknown. Future sampling of these sites may provide an answer to this question. Many of the invasive plants in this area appear to be pioneer species and may have thrived thus far because of the disturbance caused by pigs. Without pigs, it is possible that native species such as *Carex echinata* and *Deschampsia nubigena* may outcompete alien species and eventually regain dominance. In some areas of the Park where feral ungulates have been removed, native species have begun to outcompete alien species.

If problems in the bogs with selected alien species persist after removal of pigs, management through carefully targeted herbicide use or in some cases simple mechanical control, as is being currently attempted by Park resource managers at Mid-Camp and Big Bogs with *Andropogon virginicus*, may be feasible for restoration of bog communities.

Without management action, feral pig rooting and the spread of alien plant species would very likely have continued until alien species would have dominated the vegetation of the montane bog areas of Haleakalā National Park.

Montane bogs occur on the islands of Kaua'i, Moloka'i, East and West Maui and Hawai'i island. Five of seven of the major montane bogs on the northeast rift of Haleakalā (East Maui) are under protection by the National Park Service; the remaining two are owned by the State and are as yet unmanaged. The complex of 'Eke and adjacent bogs on northern West Maui is now under protection with fencing and pig control programs by the State-managed Natural Area Reserve Program. The

summit bogs of Pu'u Kukui on West Maui have always been pig free; pig control programs at lower elevations are underway to ensure protection of the bogs and adjacent, lower forests by a private company, Maui Land and Pineapple, with guidance from Nature Conservancy personnel. The Pepe'opae bog on Moloka'i is protected as part of the Kamakou Preserve by The Nature Conservancy.

On Kaua'i, the bogs of Wai'ale'ale and the upper Alaka'i plateau are some of the finest and most extensive in the State. They are of mixed State and private ownership and lack protection from feral pigs. The bogs in the Kohala mountains of Hawai'i island have been heavily degraded over the past 20 years by feral pigs (J. Jacobi, pers. comm.). Because of the widespread occurrence of pigs in the islands, feral pig control and/or construction of fences appears required if native plant communities are to be maintained in Hawaiian bog communities.

ACKNOWLEDGMENTS

We thank Catherine Davenport, who assisted in sampling in 1988. Ron Nagata and other personnel of Haleakalā National Park assisted frequently in providing for the logistics of helicopter access to the study area. Helicopter pilot Tom Hauptman demonstrated unusual dedication and competence in getting us in or out of this remote area in often adverse weather. Alvin Yoshinaga, Jim Jacobi, and Ron Nagata provided valuable insights into the status of the area prior to 1981. Joan Canfield helped immensely with editorial suggestions. Lars Mohr formatted this report for publication.

LITERATURE CITED

Brockie, R., L.L. Loope, M.B. Usher, and O. Hamann. 1988. Biological invasions of island nature reserves. *Biological Conservation* 44: 9-36.

Diong, C.H. 1982. *Population Biology and Management of the Feral Pig (Sus scrofa L.) in Kīpahulu Valley, Maui.* Ph.D. dissertation, Department of Zoology, University of Hawai'i, Honolulu.

Elton, C.S. 1958. *The Ecology of Invasions by Animals and Plants*. Methuen Co., London.

Forbes, C.N. 1920. New Hawaiian plants. VII. *Occasional Papers B.P. Bishop Museum* 7(3): 33-39.

Jacobi, J.D. 1981. *Vegetation Changes in a Subalpine Grassland in Hawai'i following Disturbance by Feral Pigs*. Coop. Natl. Park Resources Studies Unit, Dept. of Botany, Univ. of Hawai'i, Honolulu. Tech. Rept. 41.

Loope, L.L., A.C. Medeiros, and B.H. Gagné. 1991a. *Aspects of the History and Biology of the Montane Bogs of Haleakalā National Park*. Coop. Natl. Park Resources Studies Unit, Dept. of Botany, Univ. of Hawai'i, Honolulu. Tech. Rept.

Loope, L.L., A.C. Medeiros, and B.H. Gagné. 1991b. *Recovery of Vegetation of a Montane Bog in Haleakalā National Park Following Protection from Pig Rooting.* Coop. Natl. Park Resources Studies Unit, Dept. of Botany, Univ. of Hawai'i, Honolulu. Tech. Rept.

Medeiros, A.C. and H. St. John. 1988. *Geranium hanaense* (Geraniaceae), a new species from Maui, Hawaiian Islands. *Brittonia* 40(2):214-220.

Macdonald, I.A.W., L.L. Loope, M.B. Usher, and O. Hamann. 1989. Wildlife conservation and the invasion of nature reserves by introduced species: a global perspective. *In* J. Drake, F. di Castri, R. Groves, F. Kruger, H. Mooney, M. Rejmanek, and M. Williamson (eds.), *Ecology of Biological Invasions: a Global Synthesis*. John Wiley & Sons, Chichester, U.K.

Spatz, G., and D. Mueller-Dombois. 1975. Succession pattern after pig digging in grassland communities on Mauna Loa, Hawai'i. *Phytocoenologia* 3: 346-373.

Stone, C.P., and L.L. Loope. 1987. Reducing impacts of introduced animals on native biota in Hawai'i: what is being done, what needs doing, and the role of national parks. *Environmental Conservation* 14: 245-258.

Vogl, R.J., and J. Henrickson. 1971. Vegetation of an alpine bog on East Maui, Hawai'i. *Pacific Science* 25(4): 475-483.

Wagner, W.L., D.R. Herbst, and S.H. Sohmer. 1990. *Manual of the Flowering Plants of Hawai'i.* University of Hawai'i Press and Bishop Museum Press, Honolulu.