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Fountain Grass Control in Hawai'i Volcanoes National Park 1985-1992

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ABSTRACT

Fountain grass (*Pennisetum setaceum*) is a perennial alien bunchgrass disruptive to native ecosystems in Hawai'i. Control of fountain grass began in Hawai'i Volcanoes National Park in the 1960's. Until 1985 the control program emphasized the core of the 8000 ha infestation in the park. Since 1985, fountain grass management has employed a two-step strategy, first controlling outlying populations and then the center of the infestation where fountain grass densities are higher. This report summarizes fountain grass population levels and workloads, 1985-1992, and thus addresses the effectiveness of a control strategy starting with satellite populations. There was a striking decline in number of fountain grass plants in satellite populations after 3-7 years of removing plants. Also, there appears to be little establishment of new populations in areas on the periphery of the main infestation and beyond. Workloads required to accomplish control of outliers decrease after intensive initial efforts. These trends indicate that the spread of fountain grass has been successfully checked, and that control efforts have been successful on the edge of the range. They also confirms the hypothesis of Moody and Mack (1988) that control is most successful when it focuses on satellite populations. Control of satellite populations should be maintained because of the capacity of fountain grass seeds to remain viable in the soil for at least 7 years. Management should also now emphasize the core of the infestation and employ the same intensive, systematic approach used with initial control of outliers. Successsful control in this area cannot be predicted at this time because fountain grass densities have increased with suspension of management in 1985. However, the use of a pre-emergent herbicide promises to reduce workloads.

INTRODUCTION

Impacts of Fountain Grass

Fountain grass (*Pennisetum setaceum*), a perennial bunchgrass introduced to Hawai'i around 1900, is one of the most disruptive alien plants in Hawai'i (Smith 1985). Similar to many other alien grasses in Hawai'i, it increases fuel loadings and thereby fire frequency and intensity (Smith and Tunison 1992). Fires carried by fountain grass have caused considerable damage to native lowland dry forest plants on the west side of Hawai'i Island in sites where it forms a continuous understory (Takeuchi 1992). Unlike other alien grasses, fountain grass can become established on mostly barren lava flows. This disrupts primary succession at early stages characteristically dominated by native vegetation.

The urgency of controlling fountain grass in Hawai'i Volcanoes National Park (HAVO) is indicated by its potential to become established in dry (<1,250 mm rain/yr) environments between sea level and 2,200 m (Jacobi and Warshauer 1992, Williams 1992). Knowing its potential range, we were concerned that fountain grass would spread throughout not only lowland dry habitats but also the montane seasonal and subalpine zones of Mauna Loa.

Control Programs, 1960-1984

Fountain grass was first detected and controlled along roadsides in Hawai'i Volcanoes National Park (Fig. 1) in the 1960's (National Park Service 1969). Management in the late 1970's and early 1980's emphasized the most conspicuous infestation at Kamo'oali'i in the southwestern part of HAVO (Figs. 1-3). Approximately $125,000 was spent from 1979-1983 on controlling this population, which was reduced 2-fold (Tunison, 1992).

An awareness of outlying populations prompted a systematic parkwide mapping project in 1984-1985. Fountain grass was found to occur in a total infestation comprising approximately 8,000 ha (Tunison 1992) (Fig. 2). Approximately 75% of the infested area had very low densities of fountain grass (<1 plant/ha) distributed in nearly 300 distinct small populations (a population was defined as a clustered group of individuals separated from others by at least 100m). Plant densities in the central core of the infestation were higher (>14 plants/ha). Fourteen small disjunct populations and more than 40 roadside populations were found. The workload required to systematically search infested areas for plants was also quantified. We found that each field worker, working in teams of 2-10 workers, could systematically search approximately 35-40 ha per day. Approximately $75,000 was spent on control efforts and distribution mapping in 1983 and 1984.

Distribution mapping and quantifying the workload stimulated consideration of 4 mangement strategies: 1) abandoning control altogether, 2) controlling only in Special Ecological Areas (SEAs), intensive alien plant control units, 3) confining fountain grass to the lowlands, and 4) controlling fountain grass parkwide.

Control Programs 1985-1992

The control strategy adopted in 1985 combined the second and third alternatives by emphasizing control of outlying populations (Tunison 1992). Roadside populations, populations disjunct from the main infestation, and populations on the periphery of the main infestation were targeted for control. Fountain grass was also managed in SEAs. Fountain grass is found in 3 of the 7 SEAs within the current range of fountain grass. Searching for fountain grass in these SEAs is conducted incidental to searching for other target alien plant species. Management of the core of the infestation was suspended until funding became available or control was completed on the periphery.

An approach emphasizing outlying populations was developed, in part, to permit funding of other management priorities such as feral ungulate control and alien plant control in SEAs. It was also guided by ecological considerations. Roadside populations, disjunct populations and populations on the periphery of

the main infestation tend to be small and scattered. Plant densities are much higher toward the center of the infestation. The outlying or satellite populations serve as important foci for further invasion, contributing to more rapid expansion of the infestation than interior populations because they spread seeds to new areas (Moody and Mack 1988). Seeds from plants in the interior fall mainly within the interior and therefore contribute little to expansion of the infestation. Moody and Mack (1988) mathematically simulated spread of an invading plant with a single main focus (population) and satellite foci, based on geometrical models of an expanding circle. They concluded that the overall effectiveness of control measures was greatly improved by controlling satellite foci, rather than the main focus. They also pointed out that the current practice of controlling alien plants usually emphasizes the main focus and ignores outliers. We did not want to make that mistake.

Management of fountain grass from 1985-1986 emphasized control in the sparsely populated areas east of Pepeiau and west of the Mauna Ulu flows below Poliokeawe Pali and Hilina Pali (Fig. 3). From 1987-1989, the control area was expanded to the west from Pepeiau to create a buffer zone on the northern edge of the infestation above 1500 ft elevation designed to prevent expansion of fountain grass. Beginning in 1990, the control area was expanded again toward the center of the infestation at Kamo'oali'i. By 1992, 85% of the range of fountain grass in HAVO was managed. The current objective of the fountain grass control program is to prevent the expansion of fountain grass from the infested area to other parts of the park and to eventually control it throughout its range in HAVO and immediate vicinity.

Purpose of Report

This report summarizes changes in workload and population levels of fountain grass, 1985-1992. It thus addresses the capacity of resource managers to control a widespread alien plant species. Control of localized alien plants in HAVO has been relatively successful (Tunison and Zimmer 1992). Eleven widespread alien plant species are controlled in localized areas or SEAs; they are not controlled throughout the park (Tunison and Stone 1992). Fountain grass is the only widespread alien plant to be managed throughout HAVO (Tunison 1992). The report also describes the effectiveness of a control strategy emphasizing outlying populations and thus tests the hypothesis of Moody and Mack (1988) that control is more effective if it emphasizes satellite populations.

CONTROL METHODS

Fountain grass is usually controlled physically by uprooting plants by hand. Picks are sometimes required to uproot plants >15 cm basal diameter. If inflorescences are present, they are collected in a plastic bag and later destroyed. Herbicides are used in areas with high densities of plants and high rates of seedling recruitment. Foliar applications of Roundup* (glyphosate) were tried but abandoned because of inconsistent effectiveness. Ten percent liquid Velpar* (at < 5 lb ai/A) is now used as a post-emergent and pre-emergent herbicide once a year. Post-emergent herbicides are used to kill established plants, and pre-emergent herbicides prevent establishment of seedlings. A pre-emergent is desirable in controlling areas with prolific seedling recruitment to reduce the frequency of manual control. Velpar at 9 lb ai/A was recommended by Park researchers, who found it was effective as a pre-emergent for 9-12 months (Greg Santos, pers. comm.). Ten percent liquid Velpar is now used in areas with high densities of plants, medium to shallow soils away from water courses and 'ohi'a (*Metrosideros polymorpha*) trees because of this species sensitivity to the herbicide.

* Reference to a product does not imply endorsement of that product by National Park Service.

Height and presence of flowers for each plant uprooted or treated with herbicide are recorded for plants treated in the 14 management blocks established for monitoring purposes (Fig. 4). In blocks where plant densites are low, data are managed by discrete, numbered and mapped populations. Worker-days required per block are also recorded.

All roadsides inside the Park and Highway 11 outside the park between the boundary and Punalu'u are searched semi-annually for fountain grass or from a vehicle. Away from roadsides, populations disjunct from the main infestation are searched on foot on an annual basis, with emphasis on the Ka'u Desert and Pu'u Loa areas (Fig. 3). Fountain grass control in the main infestation is largely conducted on foot or horseback by crews of 3-12 people based in temporary or Park Service back-country camps. There are approximately 5-9 camp trips per year. Searching on horseback is conducted in extensive grasslands near Keauhou, Kue'e, and Pepeiau. Helicopter searching is most effective on sparsely vegetated lava flows. When plants are located from helicopter, either they are mapped for control during follow-up groundsearches, or the helicopter lands and the plants are uprooted. Approximately 5-10 hours of helicopter reconnaissance is conducted each year as a follow-up in coastal areas between Kukalau'ula and the Mauna Ulu flows and bare lava flows near the Great Crack, and for new areas to be searched on the ground.

Each new management block is systematically surveyed on the ground for the first 1-3 years of management. After initial systematic searches, follow-up management emphasizes systematic ground searches of localized sites with mapped populations and helicopter surveillance between the known populations.

CHANGES IN FOUNTAIN GRASS POPULATIONS

Roadsides

Fountain grass is easily dispersed by automobiles, and has been found along roadsides in the park starting in the 1960's. The number of fountain grass plants found has declined considerably in the last six years with semi-annual control efforts (Table 1). Fountain grass was relatively abundant in the mid-1980's along Highway 11, mostly between Namakani Paio Campground and the Ka'u entrance. Two large populations between Footprints trailhead and the Ka'u boundary were reduced, 1985-1987. A large population was found just off the road near Namakani Paio Campground in 1988. This has also been controlled. Plants are now occasionally seen near Footprints trailhead following a shoulder widening project. Populations on Crater Rim Drive are now mostly found near Jaggar Museum. These undoubtedly were dispersed by automobiles used by park visitors or US Geological Survey staff. Chain of Craters Road has the largest and most persistent populations of fountain grass, particularly near Kealakomo, the Hairpin Turn, and along the coastal section of the road. There is a population near the Hairpin Turn that has escaped from the roadside into the adjacent grassland. Seedling recruitment continues to occur in this population. Two populations were found along Hilina Pali Road, one near Kipuka Nene and the other 1.5 miles below this. No plants have been seen since 1984.

Additional populations continue to be found in new locations along some roadsides or near parking lots, indicating low levels of continuing dispersal from vehicles.

Outlying Populations

Fountain grass populations distinctly disjunct from the main infestation and roadsides are described here as outlying populations (Fig. 2).

Most disjunct populations are small and located in the Ka'u Desert north of the main infestation. These are checked annually, along with much of the upper Ka'u Desert located within the Keamoku Special Ecological Area. Several small populations of 1-2 plants each were found in 1985 and 1986 along jeep tracks used by US Geological Survey employees to service instruments in the Upper Ka'u Desert. No plants have been found along these roads since 1987 (Table 2). Fountain grass is scattered on the lower walls and floors of the Pit Craters near Pu'u Koae. Accessible plants have been controlled by herbicide since 1988, and no plants have been found in the area surrounding the Pit Craters since that time. Population #20 is located in the upper Ka'u Desert between the Keamoku Flow and the Ka'u Desert Trail. Over 20 plants were uprooted when this populations was first discovered in 1982. Few plants have been seen since 1987. There are two small populations in the eastern coastal lowlands, east of Pu'u Loa and north of Holei Sea Arch. The latter probably escaped from roadside plants which have been found frequently in this area. Eleven plants were first found in 1990; none were seen in 1992. Population #353 is located west of Kipuka Kaena Bihopa. One plant was found in 1989; none has been seen since. Population #340 is in lower Ainahou near Kipuka Papalinamoku. Thirty plants were uprooted in 1988 after the Uila Fire; no plants have been seen since then.

Management Blocks Controlled Since 1985

Pepeiau

The Pepeiau management block is located above Hilina Pali from the Kamo'oali'i Lava Flows to Hilina Pali Shelter (Figs. 3-4). Much of this block was systematically searched on the ground on an annual basis between 1985-1990. Alternating portions of the unit were searched on the ground in 1991 and 1992, and from a helicopter in other areas. The number of plants found was relatively constant between 1985-1987 (Table 3). Prodigious seedling recruitment in Population #51 accounts for essentially all of the plants found in 1986. Most of the plants found in 1987 were seedlings in Population #73 and small plants in 12 new populations located in Kipuka Pepeiau. Population levels dropped from 1988-1990 and have remained at very low levels for the last 2 years.

Individual populations were monitored in the Pepeiau block, an area with low to medium densities of fountain grass, in order to determine patterns of seedling recruitment in known populations and establishment of new populations. Individuals found on subsequent searches were considered to belong to this population if within 100 m of the original individual(s). Forty-five populations were located in this 760 ha area over a 5 year period. Often 2-3 searches were required initially in the same area to find these populations.

Seventy-five percent of the populations consisted of 1-2 individuals when first located (Table 4). Eleven percent had 3-6 individuals. The largest populations consisted of 11, 19, and 33 individuals when first discovered. No seedling recruitment occurred in 44% of the populations with one original plant after removal of that individual, and no seedling recruitment occurred in 60% of those with 2-7 original individuals. Seedling recruitment continued in two of the three largest populations.

Seeds may persist for up to 7 years in the soil (Table 4). Delayed seedling recruitment occurred in 20 of the 45 populations. The mean period between control and subsequent relocation of plants was 3.7 years with a range of 2-7 years. This apparent delay may be partly due to overlooked plants or infrequent searching.

Hilina

The Hilina block lies south of Hilina Pali and east of the Ka'aha Trail on Kukalau'ula Pali (Figs. 3-4). There were declining numbers of plants found in the Hilina block after 1989 (Table 3). Most of the populations are located in drainages between Kukalau'ula Pali and Hilina Pali in relatively open terrain. Searching

from helicopter has been used extensively in the last 2 years, with scouting on the ground of areas with known populations in 1992. No plants have been located in the last 2 years.

Ka'aha

The Ka'aha block, located south of Hilina Pali and west of the Ka'aha Trail, includes a prominent alluvial fan below Hilina Pali and an adjacent 'a'a flow (Figs. 3-4). Most populations in the block are located on these features or in arroyos below them. The terrain is open and the block was searched systematically from the ground 1985-1989, with a 9-fold reduction in plants found during this period (Table 3). There are 4-5 persistent populations which are now annually controlled by landing the helicopter during an annual aerial reconnaissance of the coastal lowlands from the Mauna Ulu flows to the Ka'aha Trail.

Kaone

The Kaone block lies makai of Poliokeawe and Hilina Pali between Halape and Ka'aha (Figs. 3-4). Very few plants have been found in this block, and no plants have been found since 1987 when a small population was located at the base of Maka'ahanu Pali (Table 3).

Keauhou

The Keauhou block lies below Poliokeawe Pali and mauka of Keauhou Landing (Figs. 3-4). It was managed intermittently from the late 1970's to 1985. Intensive efforts began in 1986 with at least two ground searches per year. The number of plants found increased in 1988 following the 1987 Uila Fire. Population levels declined in 1989 and 1990, but increased slightly after the Mother's Day Fire in 1991. Fountain grass plants persist in a tall *Hyparrhenia rufa* grassland just north of Holei pali, in rocky sites below the pali, and around Halape.

Management Blocks Controlled Since 1987

Kamakaia Hills

This block surrounds the Kamakaia Hills on the northern edge of the main infestation in the Park (Figs. 3-4). Only four small populations are known. There has been no recruitment in the three northern ones since 1988 (Table 3). Seedlings were found in 1992 in one population in a sand dune area just north of Kipuka Pepeiau.

Pu'u Kou

The Pu'u Kou block lies along the Ka'u boundary west of Pepeiau above 1900 ft elevation (Figs. 3-4). Four populations with a total of 45 plants were found in ground reconnaissance 1987-1989 (Table 3). It has been searched by helicopter since then with only a single plant found in one population in 1992.

Red Cones

This block is located along the Ka'u boundary between 1500 ft elevation and 1900 ft elevation (Figs. 3-4). Twenty-six plants were found in 1985 during the fountain grass distribution mapping project. One population was found in 1987 along the park boundary while searching the Roger James unit outside the park. Systematic ground searches of the Red Cones unit began in 1988 with 33 plants found (Table 3). Similar numbers of plants were found 1989-1991. The number of plants found increased 5-fold in 1992 because new areas within the block in the Kue'e grassland were searched.

Plastered Cones

This block lies along the Great Crack below 1500 ft elevation (Figs. 3-4). Twenty-seven plants were found in 1985 during the fountain grass distribution mapping project. Systematic searches of the northern section of the block started in 1988 with 6 plants that year and 9 plants the next. The number of plants found increased nearly 10-fold in 1992 when the southern section of the block was searched for the first time.

Roger James

This block consists of state lease land west of the Great Crack and above 1500 ft elevation (Figs. 3-4). It was searched on the ground

during 1987-1990. Six populations, each with 1 plant, were found in 1987 and one additional small population was found in 1988 (Table 3). These populations have been searched subsequently with no new plants found. No systematic searches have been conducted since 1988.

Management Blocks Controlled Since 1990

Kukalau'ula

The Kukalau'ula block is centered on Kukalau'ula Pali south of Pepeiau below 1500 ft elevation (Figs. 3-4). The grassy area above the pali was occasionally searched prior to 1985 when fountain grass at Kamo'oali'i was regularly controlled. No searches were conducted between 1985-1989. Control efforts began again in the areas above Kukalau'ula Pali in 1990 with 162 plants found (Table 3). The number of plants found has decreased 4-fold during searches in each of the last 2 years.

Kue'e

The Kue'e block is located below 1500 ft elevation north of Kue'e ruins (Figs. 3-4). Prior to 1985, plants along the four wheel drive road were occasionally uprooted during control sessions at Kamo'oali'i. Control efforts were resumed in 1991 with searches in the mauka portion of the block. Fifty-nine plants were located (Table 3). Over 1500 plants were uprooted or treated with herbicide in 1992 when the entire block was searched.

Kamo'oali'i

This block is located east of the Kamo'oali'i lava flows below 1500 ft elevation (Figs. 3-4). Fountain grass was controlled 2-3 times per year in portions of this block from 1979-1985. Control efforts resumed in 1990 with tests using Velpar near the backcountry shelter where fountain grass reaches its highest density in the park (Table 3). Northern portions of the block between the shelter and Kipuka Pepeiau were searched in 1991 and 1992. Southern areas have not been systematically searched.

Ka'u Boundary

This is a new management block established in 1992 to control fountain grass immediately outside the park boundary on state lands below 1500 ft elevation. Two hundred and five plants were located in scattered populations above Pu'u Ulaula and in one large population below Pu'u Ulaula.

CHANGES IN WORKLOAD

Workload patterns reflect successful control efforts in areas of low fountain grass density and reallocation of field time to new areas toward the interior of the infestation (Table 5). Total workloads were lowest in 1986 and 1987 as a fountain grass strategy emphasizing outliers started. The workoad was highest in 1988 and 1989 when areas west of Pepeiau above 1500 ft elevation were added without diminishing efforts between the Mauna Ulu flows and Pepeiau. Workloads in 1990 shifted from outlying areas to areas of high fountain grass density in Kue'e, Kukalau'ula, and Kamo'oali'i, after substantial control was achieved in the areas between Pepeiau and the Mauna Ulu flows. The average costs of the fountain grass program were approximately $20-$30,000/year in 1986-1987 and $45-50,000/year, from 1988-1992.

DISCUSSION

Fountain grass has been largely contained, as demonstrated by the paucity of new establishments outside the existing range and sharply declining population levels of outlying populations, including roadside populations, disjunct populations, and populations on the periphery of the main infestation. Reduction of disjunct populations and populations on the periphery of the main infestation demonstrates the efficacy of a control strategy emphasizing satellite populations and supports the hypothesis of Moody and Mack (1988) that control is most effective when it emphasizes satellite populations rather than the main infestation.

Control of the entire infestation has not yet been achieved (Fig. 3). Failure to control

fountain grass in the core may eventually negate efforts to eliminate satellite populations, if densities increase in the core and seed dispersal increases greatly. However, high wind events such as hurricanes, tropical storms, and severe winter storms could contribute to massive medium and long range dispersal of fountain grass from the core area. Management of a portion of the core began in 1990 but management of some of the areas with the densest fountain grass has not been started. Furthermore, fountain grass densities have increased in this area when control was curtailed in 1985 in favor of satellite populations (Tunison 1992). Prolific seedling recruitment in the core of the infestation required frequent manual control efforts.

It is difficult to predict the workload required for controlling the core area without beginning actual management. Three treatments per year were required at Kamo'oali'i prior to 1985 to minimze the incidence of flowering (Tunison 1992). Two treatments per year are still required at Keauhou which has a moderate density of fountain grass plants. Two to 3 treatments per year in the core may double the workload required by the fountain grass program. The use of Velpar may reduce this workload because of its pre-emergent action. However, Velpar cannot be used in all dense stands of fountain grass because of the absence of soil or presence of native trees.

RECOMMENDATIONS

The fountain grass control program should be continued. The strategy of emphasizing satellite populations first and then the interior populations has been effective and should continue to be pursued. Control of satellite populations should be maintained while more aggressively managing interior populations. Specifically, roadsides should be searched at 6 month intervals for the indefinite future because of the potential for continued reintroduction by seeds brought in by vehicles. Disjunct populations and outlying populations on the periphery of the infestation should be checked every 12 months for seedling recruitment. Areas between known populations should be searched periodically for new establishments. The apparent capacity of seeds to remain viable in the soil for up to 7 years indicates the need for long-term management of outlying populations.

Control efforts should be expanded to the remaining unmanaged 15% of the infestation as soon as possible because fountain grass densities are increasing there. Control should be expanded to state land outside the park near Pu'u Ulaula to prevent this population from becoming a significant source of dispersal back into the park.

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LITERATURE CITED

Moody, M. E. and R. N. Mack. 1988. Controlling the spread of plant invasions: the importance of nascent foci. Journal of Applied Ecology 25:1009-1021.

National Park Service. 1969. Natural Resources Management Plan, Hawai'i Volcanoes National Park. 247 pp.

Smith, C. W. 1985. Impact of alien plants on Hawai'i's native plants. *In* C.P. Stone and J.M. Scott (eds), pp. 180-250. Hawai'i's Terrestrial Ecosystems: Preservation and Management. University of Hawai'i Cooperative National Park Resources Studies Unit. Honolulu: University of Hawai'i Press.

Smith, C. W. and J. T. Tunison. 1992. Fire and alien plants in Hawai'i: research and management implications for native ecosystems. *In* C. P. Stone, C. W. Smith, and J. T. Tunison (eds.), pp. 394-408. Alien Plant Invasions in Native Ecosystems of Hawai'i: Management and Research. University of Hawai'i Cooperative National Park Resources Studies Unit, Honolulu: University of Hawai'i Press.

Takeuchi, W. 1992. Botanical survey of Pu'uwa'awa'a. Unpublished report for the Department of Land and Natural Resources. 62 pp.

Tunison, J. T. 1992. Fountain grass control in Hawai'i Volcanoes National Park: Management considerations and strategies. In C. P. Stone, C. W. Smith, and J. T. Tunison (eds.), pp. 376-393, Alien Plant Invasions in Native Ecosystems of Hawai'i: Management and Research. University of Hawai'i Cooperative National Park Resources Studies Unit, Honolulu: University of Hawai'i Press.

Tunison, J. T. and C. P. Stone. 1992. Special Ecological Areas: An approach to alien plant control in Hawai'i Volcanoes National Park. *In* C. P. Stone, C. W. Smith, and J. T. Tunison (eds.), pp. 781-798, Alien Plant Invasions in Native Ecosystems of Hawai'i: Management and Research. University of Hawai'i Cooperative National Park Resources Studies Unit, Honolulu: University of Hawai'i Press.

Tunison, J. T. and N. G. Zimmer. 1992. Success in controlling localized alien plants in Hawai'i Volcanoes National Park. *In* C. P. Stone, C. W. Smith, and J. T. Tunison (eds.), pp. 506-524, Alien Plant Invasions in Native Ecosystems of Hawai'i: Management and Research. University of Hawai'i Cooperative National Park Resources Studies Unit, Honolulu: University of Hawai'i Press.

Tunison, J. T., L. D. Whiteaker, L. W. Cuddihy, A. M. LaRosa, D. W. Kageler, M. R. Gates, N. G. Zimmer, and R. L. Stemmermann. 1992. The distribution of selected localized alien plants species in Hawai'i Volcanoes National Park. Cooperative Park Resources Studies Unit, Technical Report No. 84. University of Hawai'i, Honolulu. 40 pp.

Williams, D. G. 1992. Physiological Ecology of the Invasive Grass *Pennisetum setacum* in Hawai'i. Dissertation, Washington State University, Pullman, WA.

Table 1. Number of fountain grass plants found along roadsides in Hawai'i Volcanoes National Park.

ROAD	1985	1986	1987	1988	1989	1990	1991	1992
Crater Rim Drive	13	1	0	3	8	4	1	1
Chain of Craters Road	21	20	138	112	71	30	44	12
Highway 11	206	3	7	31	0	4	0	4
Mauna Loa Road	0	0	0	0	0	0	0	1
Hilina Pali Road	0	0	0	0	0	0	0	0

Table 2. Number of fountain grass plants found in populations outlying main infestation in southwestern part of park.

POPULATION	1985	1986	1987	1988	1989	1990	1991	1992
Upper Ka'u Desert Jeep Roads	12	16	0	0	0	0	ns	0
Pit Craters	10	34	4	2	8	10	ns	7
Population #20 (upper Ka'u Desert)	6	3	1	0	0	2	ns	0
Pu'u Loa/Holei Sea Arch	ns	ns	0	ns	0	11	ns	0
Population #353 (near Kipuka Kaena Bihopa)	ns	ns	ns	0	1	0	ns	0
Population #340 (lower Ainahou)	ns	ns	ns	30	0[g]	0[g]	0[h]	0[h]

ns = not searched
[h] = helicopter search only
[g] = searched on ground

Table 3. Changes in total number of fountain grass plants found in buffer zone units.

BLOCK	1985	1986	1987	1988	1989	1990	1991	1992
BLOCKS MANAGED SYSTEMATICALLY SINCE 1985								
Pepeiau	77[g]	64[g]	**79**[g]	44[g]	27[g]	20[g]	1[g]	5[g]
Hilina	40[g]	0[n]	25[g]	14[g]	52[g]	23[g]	**0**[h]	0[h]
Ka'aha	57[g]	7[n]	7[g]	1[g]	1[g]	**13**[h]	**0**[h]	**15**[h]
Kaone	0[g]	0[g]	2[g]	0[g]	0[g]	0[n]	**0**[h]	**0**[h]
Keauhou	0[g]	210[g]	85[g]	104[g]	62[g]	16[g]	24[g]	33[g]
BLOCKS MANAGED SYSTEMATICALLY SINCE 1987-1988								
Kamakaia Hills	0[n]	0[n]	7[g]	1[g]	0[g]	0[g]	0[h]	6[h]
Pu'u Kou	0[n]	0[n]	1[g]	26[g]	18[g]	0[s]	0[h]	1[h]
Red Cones	26[g]	0[n]	3[g]	**33**[g]	56[g]	24[g]	36[g]	159[g]
Plastered Cones	27[g]	0[n]	0[g]	6[g]	9[g]	0[n]	3[g]	**61**[g]
Roger James	0[n]	0[n]	6[g]	1[g]	0[g]	0[g]	0[g]	0[n]
BLOCKS MANAGED SYSTEMATICALLY SINCE 1990								
Kukalau'ula	0[n]	0[n]	0[n]	0[n]	0[n]	162[g]	135[g]	43[g]
Kue'e	0[n]	0[n]	0[n]	0[n]	0[n]	0[n]	59[g]	167[g]
Kamo'oali'i	3039[g]	0[n]	0[n]	0[n]	0[n]	144[g]	1135[g]	655[g]
Ka'u Boundary	0[n]	0[n]	0[n]	0[n]	0[n]	0[n]	0[n]	205[g]

[g] = searched on ground
[h] = helicopter search only
[n] = not searched
Bold denotes systematic search of entire block

Table 4. Changes in number of plants found in 45 populations in Pepeiau management block, 1983-1992.

Zeros may represent no plants found or the area not searched that year.

POPULATION #	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
32	1	0	0	0	0	0	0	0	0	0
33	1	0	0	0	0	0	0	0	0	0
51	11	4	3	63	8	1	1	2	0	1
73	0	4	0	0	37	6	0	2	0	2
84	0	1	0	0	0	0	0	1	0	0
130	0	1	0	0	1	0	0	0	0	0
131	0	1	0	0	0	0	0	1	0	0
132	0	2	0	0	0	0	0	0	0	0
133	0	1	0	0	0	0	0	0	0	0
136	0	1	0	0	0	0	3	3	0	0
153	0	2	0	0	0	1	0	5	0	0
242	0	0	3	0	0	0	0	0	1	0
255	0	0	1	0	1	0	0	1	0	0
256	0	0	1	0	0	0	0	0	0	1
263	0	0	4	0	0	0	0	0	0	1
264	0	0	2	0	1	0	0	0	0	0
265	0	0	1	0	0	0	0	0	0	0
266	0	0	1	0	0	0	0	0	0	0
267	0	1	0	1	0	0	0	0	0	0
268	0	0	2	0	0	0	0	0	0	0
269	0	0	1	0	0	0	0	0	0	0
270	0	0	1	0	0	0	0	0	0	0
271	0	0	19	0	0	0	0	0	0	0
272	0	0	1	0	0	0	0	0	0	0
274	0	0	1	0	0	0	0	0	0	0
275	0	0	33	0	0	0	3	3	0	0
296	0	0	1	0	1	0	0	0	0	0
297	0	0	1	0	1	0	0	0	0	0
298	0	0	1	0	3	0	0	0	0	0
299	0	0	0	0	1	0	0	0	0	0
300	0	0	0	0	1	0	1	0	0	0
301	0	0	0	0	1	0	0	1	0	0
302	0	0	0	0	1	0	0	0	0	0
303	0	0	0	0	1	2	0	0	0	0
304	0	0	0	0	3	0	0	0	0	0
305	0	0	0	0	1	0	0	0	0	0
306	0	0	0	0	5	0	0	0	0	0
307	0	0	0	0	2	0	0	0	0	0
308	0	0	0	0	2	24	9	1	0	0
309	0	0	0	0	2	0	0	0	0	0
311	0	0	0	0	6	0	8	0	0	0
334	0	0	0	0	0	3	0	0	0	0
339	0	0	0	0	0	7	0	0	0	0
352	0	0	0	0	0	0	1	0	0	0
354	0	0	0	0	0	0	1	0	0	0
TOTAL	13	18	77	64	79	44	27	20	1	5

Table 5. Number of field worker-days expended on fountain grass program, 1986-1992.
No data are available for 1985 or roadside populations for any year.

AREA	1986	1987	1988	1989	1990	1991	1992
MANAGEMENT BLOCKS							
Pepeiau	41	3	20	30	32	15	5
Hilina	0	6	16	13	8	1	1
Ka'aha	11	9	18	12	9	1	1
Kaone	0	12	2	9	0	1	1
Keauhou	27	36	57	42	16	24	5
Kamakaia Hills	0	2	2	7	1	1	3
Pu'u Kou	0	0	5	22	1	1	1
Red Cones	0	12	35	42	24	12	19
Plastered Cones	0	0	14	12	0	0	19
Roger James	0	32	19	19	7	0	0
Kukalau'ula	0	0	0	0	11	15	15
Kue'e	0	0	0	0	0	24	44
Kamo'oali'i	0	0	0	0	16	32	12
Ka'u Buffer	0	0	0	0	0	0	19
Subtotal	79	103	186	208	125	133	135
OUTLYING POPULATIONS							
	44	8	18	18	57	0	17

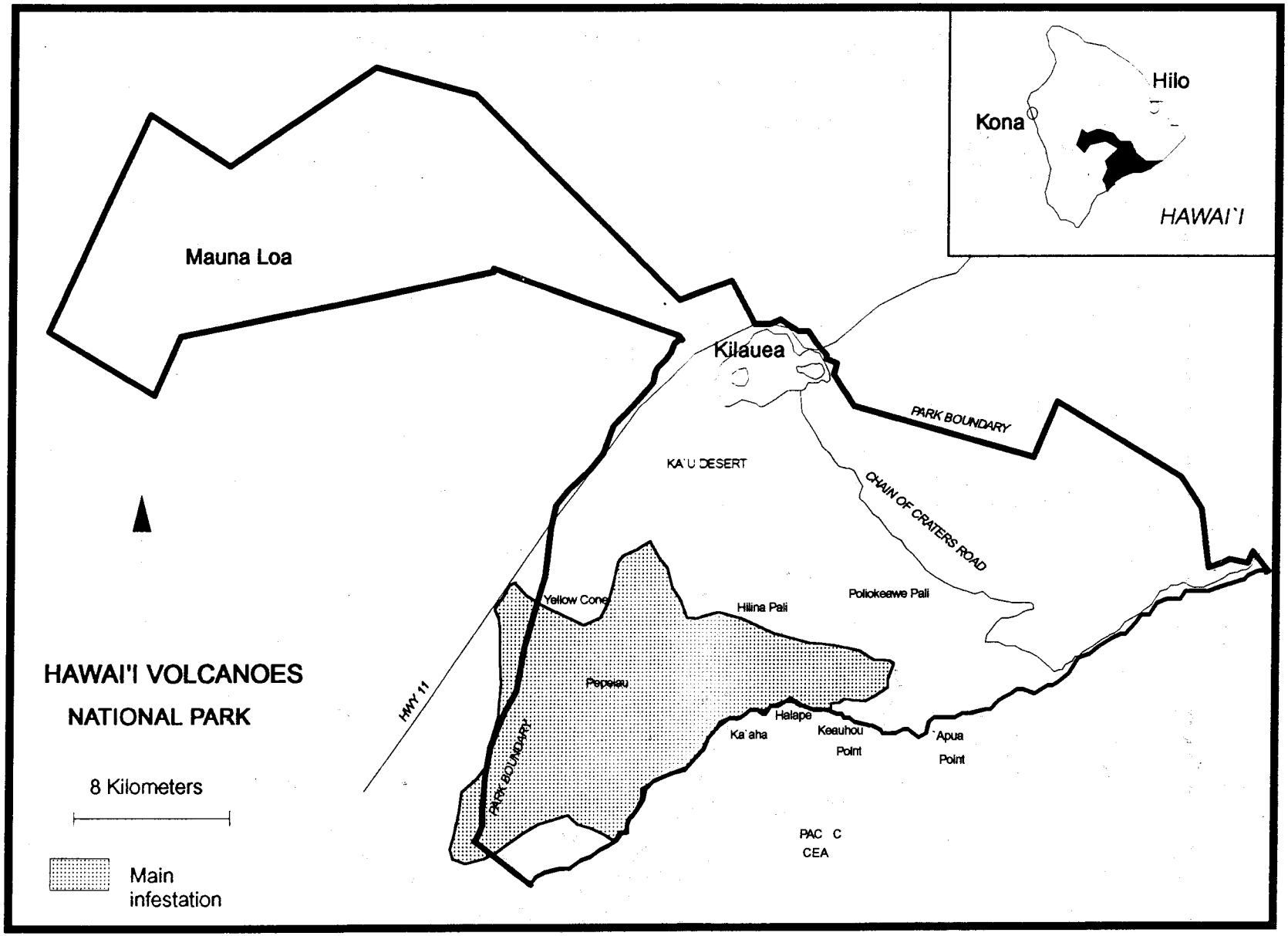

Figure 1. Map of Hawai`i Volcanoes National Park showing the main infestation.

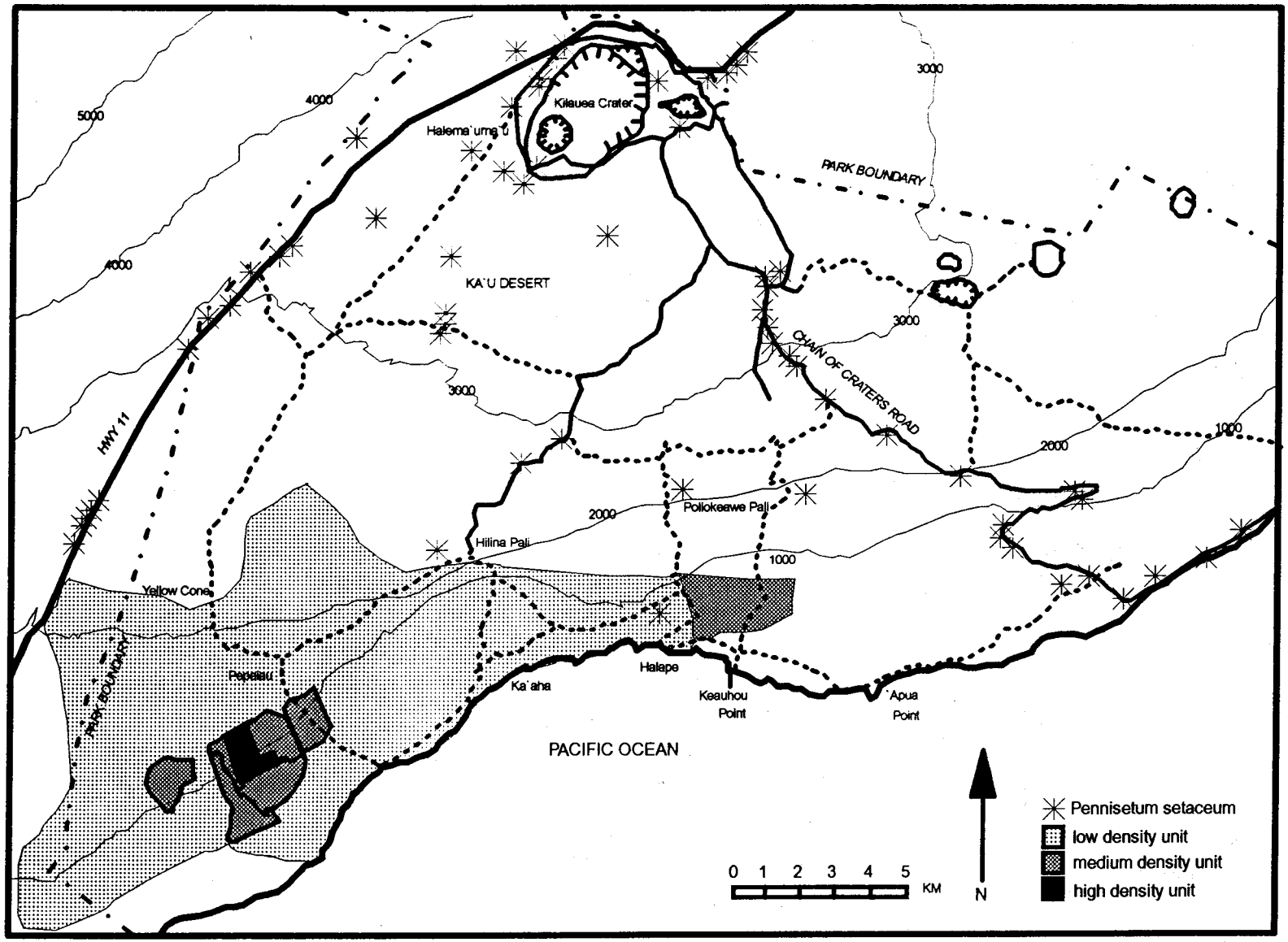

Figure 2. Distribution of fountain grass in Hawaii Volcanoes National Park and vicinity, 1992.

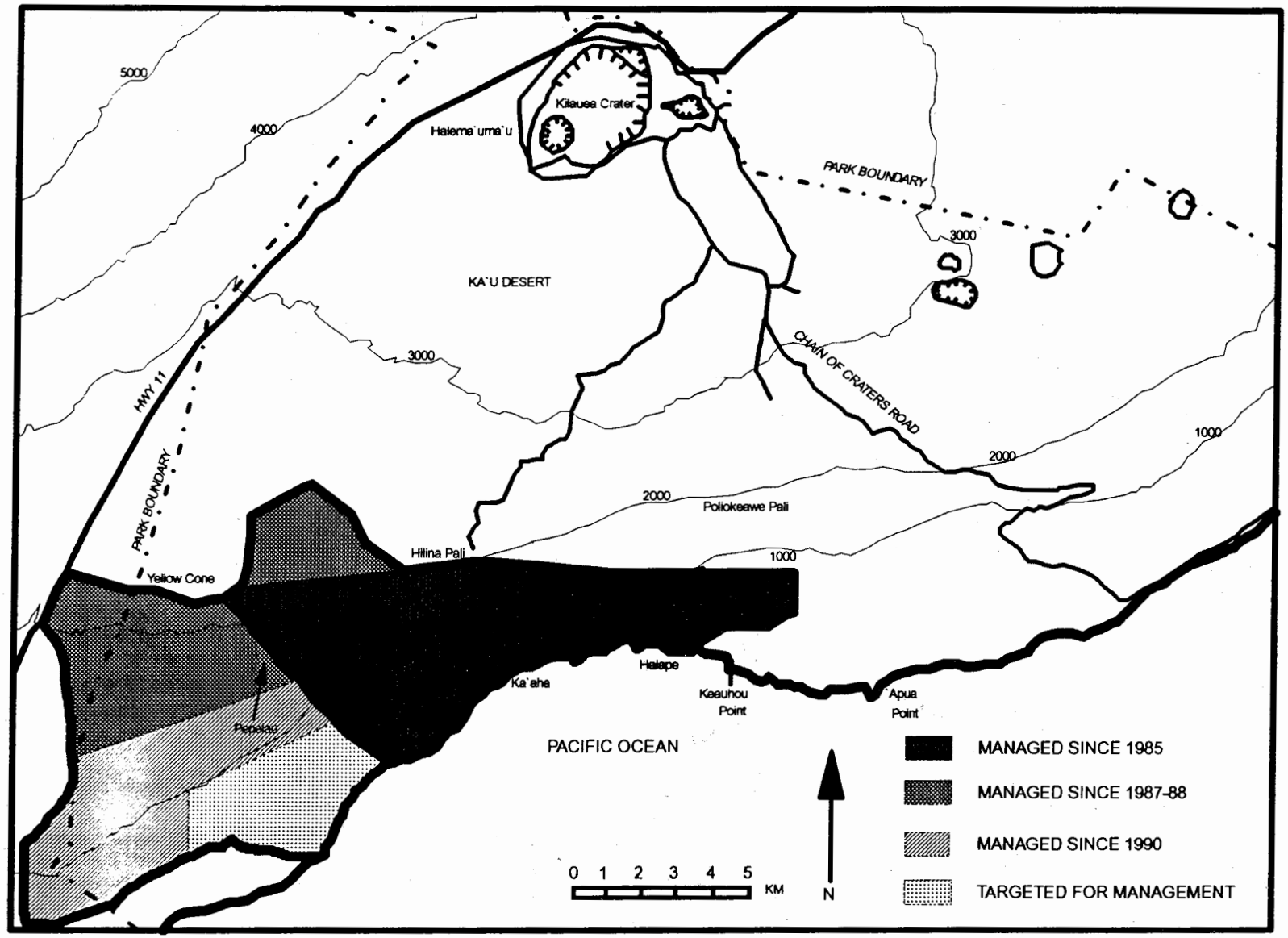

Figure 3. Management history in fountain grass infestation, 1985-1992.

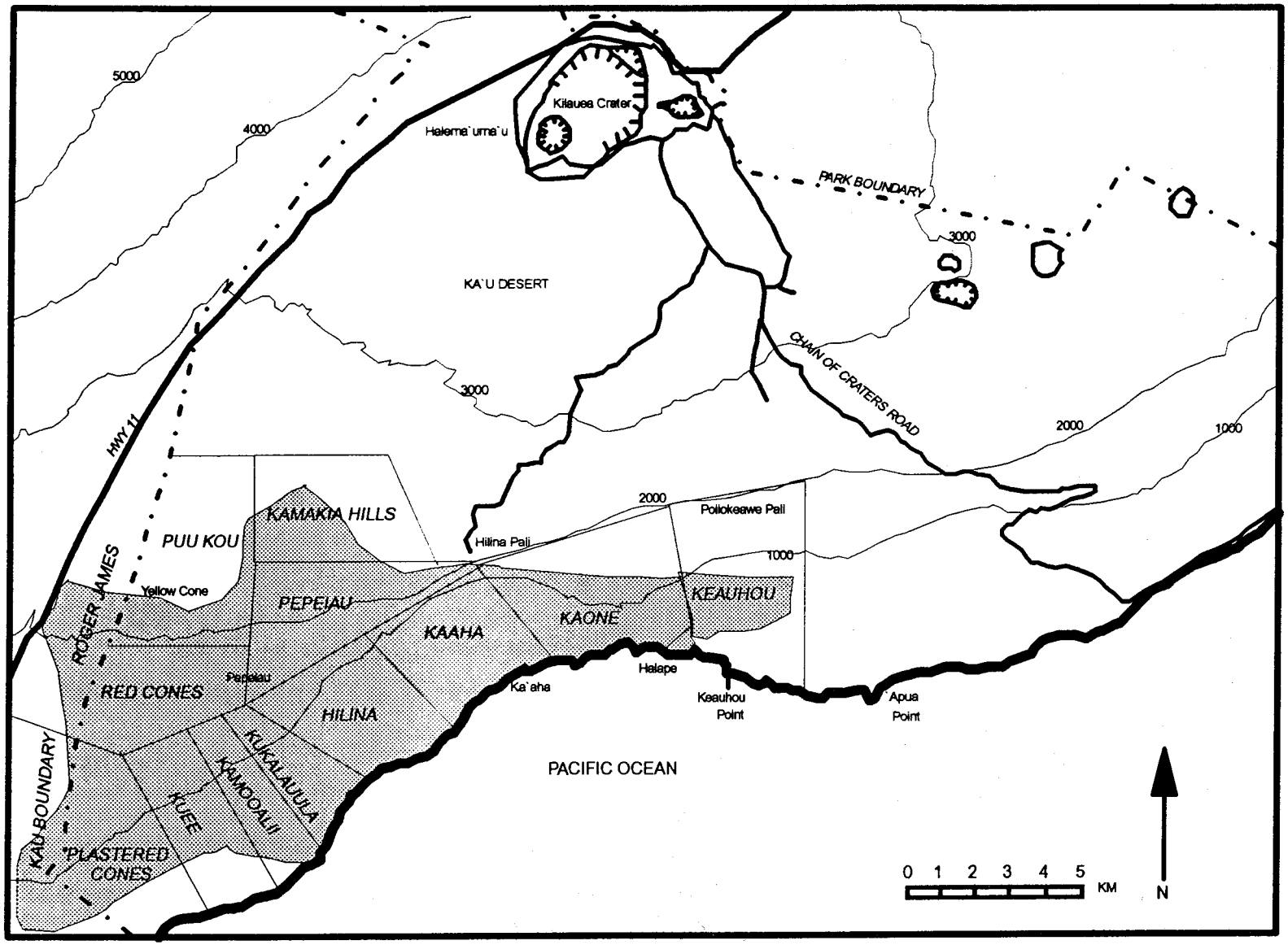

Figure 4. Management blocks in Fountain grass infestation.