CONTROL OF FERAL UNGULATES AND SMALL MAMMALS IN HAWAII'S NATIONAL PARKS: RESEARCH AND MANAGEMENT STRATEGIES

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SUMMARY

Feral pig (Sus scrofa) and goat (Capra hircus) control has been successfully accomplished within fenced areas of Hawaii Volcanoes and Haleakala National Parks. Organised hunts with dogs conducted by Park Service personnel in the former have reduced pigs in 1 to 18 km^2 areas to low densities ($<1/km^2$) or zero. Organised drives and hunts, sometimes with the help of barrier fences, have reduced goats to low population levels and radio-collared 'Judas goats', released to find wild flocks, have enabled Park Service hunters to nearly eliminate goats over a large (260 km^2) area. Control of small Indian mongooses (Herpestes auropunctatus) and cats (Felis catus) in marginal predator habitat through live-trapping has successfully protected colonies of the endangered Hawaiian dark-rumped petrel (Pterodroma phaeopygia sandwichensis) at a reasonable cost. A programme to develop a chemical toxicant for temporarily reducing mongooses in habitat shared with endangered birds is under way and preliminary results are given. The initial results of studies of the behaviour and ecology of Rattus rattus and R. exulans and of preliminary attempts to reduce rodent populations in native forests are also described.

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INTRODUCTION

Hawaii's only native land-dwelling mammals are the Hawaiian hoary bat (Lasiurus cinereus semotus) and the Hawaiian monk seal (Monachus schauinslandi). At least 19 other species, currently present in wild or feral populations on eight major and 17 smaller islands and islets (Tomich, 1969), were introduced by a variety of immigrants over the last 2000 years. Three species of introduced rats (Rattus exulans, R. rattus and R. norvegicus) are agricultural (mainly affecting sugarcane and macadamia nut crops) or urban nuisances. A number of mammalian species have serious adverse effects on Hawaiian ecosystems and their flora and fauna (Stone and Scott, in press). The purpose of this paper is to present an overview of the most serious of the problems caused by alien mammals in areas managed to preserve native species and natural processes, Hawaii's national parks.

FERAL GOAT (CAPRA HIRCUS) PROGRAMMES

Goat control programmes in Hawaii's two national parks are at different stages. In Hawaii Volcanoes National Park on the island of Hawaii, there are perhaps 20 goats remaining in 260 km^2 of goat habitat (L. Katahira, personal communication). In Haleakala National Park on the island of Maui, an estimated 708-1298 animals remained in a 75 km^2 area in January 1985 (T.J. Ohashi and C.P. Stone, unpublished data). A brief history of management and research approaches in the two parks follows.

Hawaii Volcanoes National Park

Control efforts in the Park began in the 1920s and over 70,000 goats were eliminated between 1927 and 1970 by various methods, including drives and contracts to 'goat control companies' (Katahira and Stone, 1982). However, a helicopter census in 1970 suggested that about 15,000 goats remained (Baker and Reeser, 1972), as many as when control efforts began. Immigration from neighbouring ranches and the difficulty of hunting out remote areas and overcoming further recruitment (Rudge and Smit, 1970) prevented population reduction.

By late 1970, the completion of 64 km of boundary fences (at a replacement cost of US $6820/km) and internal drift fences made efficient removal of goats possible. Over 16,700 animals were removed from 260 km^2 during 1970-80, at first through organised drives and public hunting, but increasingly by Park staff through helicopter searches and horsemen using trained dogs.

In 1981, a 'Judas goat' programme was begun to eliminate the goats that remained. Radio-collared goats are released to seek out wild flocks, and are followed by Park Service hunters. When wild animals are sighted, a helicopter is summoned. The helicopter serves to flush out or corner hiding goats and the animals are then dispatched by hunters dropped from the helicopter or already on the ground. Statistics on this programme to date are presented in Table 1.

Haleakala National Park

In Haleakala National Park, 51.5 km of fence, at a cost of about US $28,500/km, are nearly completed. Over 2400 goats were removed from this area in 1984, 1864 of them in six organised hunts conducted mostly by volunteers. Minimum costs were estimated to be US $3.55-6.48/goat on the last two hunts. Up to 625 animals have been removed in a five-day period by eight hunters in organised drives. Several more drives of one to two days each and live captures with a drift fence and corrals are planned for the last part of 1985. However, lasting population reduction depends upon fence closure and maintenance since animals from adjacent ranch and State lands still have numerous entry routes.

FERAL PIG (SUS SCROFA) PROGRAMMES

Feral pigs are the top big game mammals in Hawaii and have important economic, social and cultural values. They are currently also the most important vertebrate modifiers of native Hawaiian ecosystems, causing losses of native plants, reducing native bird and invertebrate habitats, enhancing conditions for alien plants and bird diseases, increasing erosion and altering nutrient cycles. As with the feral goat programmes, a separation of areas managed for native ecosystem preservation from those with feral animals is necessary.

TABLE 1. THE 'JUDAS GOAT' PROGRAMME IN HAWAII VOLCANOES NATIONAL PARK, 1980-84

	1980	1981	1982	1983	1984*
No. goats taken	168	149	49	53	42
No. helicopter hours	16	26	21	16	2
No. hunter-hours**	67	59	39	120	14
No. goats/hunter-hour	2.5	2.5	1.3	0.4	3.0
Cost per goat (US $)	28	49	159	156	45

*Earthquake damage in November 1983 allowed goat ingress through fences and probably increased hunt success in 1984.
**Park Service hunters only; citizen hunters took 23,9,0,0 and 28 animals. Park Service hunters took 28 of 42 goats in 1984 in their own time.

Over 55 km^2 of pig habitat in Hawaii Volcanoes National Park have been fenced into eight units of 1.4 to 18.9 km^2 with 81 cm woven wire at a cost of US $6800/km. Fencing for feral pig management in Haleakala National Park will begin once the goat fences are completed. Once the land is fenced, pig control within has been most effectively accomplished through systematic hunting by Park Service personnel using dogs. Overall hunting success at Hawaii Volcanoes has averaged 0.86 pigs/hunt (n = 172 hunts over two years). The cost of removal (largely accounted for by hunters' salaries and time) is estimated at US $74/pig ($n$ = 148).

Removal rates have been sufficient to overcome reproductive potential in five units, with over 50% of the estimated population removed in a six-month period. In one unit of mesic forest (18.9 km^2) and in two rain forest areas (4.6 and 1.4 km^2), all pigs have been removed. In another rain forest area, although the initial removal rate was adequate, elimination of the last few pigs has not been accomplished. Here, the initial density was estimated to be about 30 animals/km^2 and the current density is probably less than 2 animals/km^2. Research efforts to determine ways to remove the remaining pigs are in progress. The use of penned sows, pheromones and other scents, water attractants, baffles and wing fences with corral traps, and combinations of these with traditional methods, is being explored.

MONGOOSE (HERPESTES AUROPUNCTATUS) PROGRAMME

Predation by the small Indian mongoose on eggs and young is felt to restrict population recovery and productivity in eight species of endangered Hawaiian birds. Live-trapping of predators in natural breeding areas of one of these species has shown success and is discussed below. However, effective, safe and practical methods are needed to reduce mongoose predation when and where ground-nesting birds breed.

The US Fish and Wildlife Service has embarked upon a three-year project to develop methods for reducing predation on nesting endangered birds in Hawaii. The project was begun in June 1984 and emphasis to date has been placed on ways to assess mongoose abundance, on the use of aversive conditioning to prevent predation on eggs, on the establishment of long-term population studies and on the study of mongoose movements. Some results and tentative conclusions are presented below.

Mongooses have a keen ability to locate food and a strong tendency to carry off excess amounts to their dens. Bait take in a small area can therefore give a misleading indication of mongoose abundance, as baits tend to disappear quickly regardless of mongoose numbers. Although more labour-intensive, trapping probably provides a better index to populations than bait take. Bait removal has also made the evaluation of conditioned aversion more difficult. By using eggs to which lithium chloride had been added, it was hoped to teach mongooses that eating eggs would make them ill. However, although this additive did make the animals ill, they continued to take eggs. It has not yet been determined whether these eggs were eaten, just sampled (lithium chloride has a salty taste) or simply cached. Work is continuing in attempts to find out how to overcome this tendency to carry off eggs; removal of eggs from nests is destructive whether the eggs are eaten or not.

Trapping data and information obtained by tracking animals equipped with radio-collars during the breeding season showed that male mongooses travel long distances, especially in response to unusual food supplies. Four males were followed up to 1.6 km as they travelled either to food left by a hunter for his lost dog or to a dead pig. Females did not respond to these foods, but most were either pregnant or lactating at the time. Males ranged over about 1.0 km^2 (n = 13), whereas females used areas of only about

0.25 km^2 (n = 8). Again, these ranges were measured during the reproductive season when males may be moving widely in search of females in oestrus and females caring for young may be more sedentary.

To develop control methods, information is needed on the abundance, population dynamics, movements, behaviour and food preferences of mongooses. The approximate number of mongooses in an area must be known in order to determine the intensity of control measures required to protect birds. It is also necessary to know the mortality pattern during the year and the months when mongooses reproduce, as control should be undertaken after the period of greatest natural mortality and before reproduction. The frequency of control needed will be dictated by how rapidly mongooses reinvade controlled areas. Knowledge of movements is also needed to find out how far animals will travel to scents and baits. Food and bait preferences must be determined to ensure the selection of bait that is not only acceptable to mongooses, but is preferred over natural foods.

Considerable care must be taken in selecting a poison for mongoose control. It must consistently kill following the consumption of bait, but its action should be slow enough to allow mongooses to return to resting sites before they die. The poison cannot be one that persists, moves or accumulates in the environment. Either it should not be highly toxic to other organisms, or it must be used in ways that preclude other organisms from contacting it.

RAT (*RATTUS RATTUS* AND *R. EXULANS*) PROGRAMMES

Rattus rattus is thought to have arrived in Hawaii about 100 years ago (Atkinson, 1977), and occurs from sea level to the subalpine zone (van Riper and van Riper III, 1982). *Rattus exulans* arrived earlier, in Polynesian canoes sometime between A.D. 4 and 1778. The adverse effects of both species on a native biota unadapted to mammalian predation has undoubtedly been tremendous. The most severe impact today is probably caused by the more arboreal *R. rattus*.

Preliminary studies in Hawaiian montane rain forests show densities of 8-18 rats/ha for *R. rattus* and 8-20 for *R. exulans*; the two species often occur together. Movements exceeding 200 m are common for both species (C.P. Stone and C.A. Russell, unpublished data). *R. rattus* appears to have a more diverse diet but consumes more plant material than *R.*

exulans in rain forests. One study showed that R. exulans foraged largely in leaf litter and detritus, taking considerable quantities of small invertebrates (C.P. Stone and F.W. Howarth, unpublished data). The effects of rats on native rain forest insects in Haleakala are being analysed at present.

Rattus rattus activity was two to 15 times higher on the ground than in trees, as measured by snap traps in three rain forest habitats in Haleakala National Park (n = 220-360 trap nights/area), whereas R. exulans catches were 22-33 times higher on the ground than in the trees in the same three areas (Stone, unpublished data). Predation by rats (species unknown) on eggs in artificial tree nests over nine- to ten-day periods in important native bird rain forest habitat was 50-53% in three rain forest locations (n = 30 nests/area). Scent (coconut chunks) in artificial nests resulted in predation rates of 43, 70 and 87% in three areas (n = 30 nests/area). The predation studies were conducted in different areas from the arboreal activity studies.

Park managers in Hawaii Volcanoes National Park have successfully protected a few unnaturally rare trees from rat damage through the use of permanent poison stations baited with the anticoagulant fumarin near tree bases. However, this method is costly for remote locations and results have been inconsistent, especially in closed canopy forests where rats use arboreal pathways. Preliminary experiments with fumarin in T-shaped poison stations showed a 32% reduction of R. rattus population indexes (based on percentages of coconut pieces removed before and after treatment) in three areas, compared with a 69% increase in three untreated control areas (probably largely the result of prebaiting with coconut pieces to determine rat activity levels). Post-treatment percentages of R. exulans and R. rattus taken in snap traps were 44 and 56 respectively in the areas treated with fumarin, and 25 and 75 respectively in control areas. Fumarin thus appeared to reduce R. rattus disproportionately more than R. exulans, despite the influx of R. rattus in response to prebaiting. The long-term effect of prebaiting and differential removal of R. rattus on ratios of rat species could not be determined in the Hawaii Volcanoes study. However, trapping of rats in six areas in Haleakala National Park at three intervals over a year suggested a pronounced effect on rat ratios, with increasing percentages of R. exulans as trapping continued (Stone et al., 1984).

PROTECTING DARK-RUMPED PETRELS FROM PREDATION

In 1979, a small mammal live-trapping programme was begun in Haleakala National Park to protect breeding colonies of dark-rumped petrels or 'ua'u (Pterodroma phaeopygia sandwichensis) from mongooses, cats (Felis catus) and rats. The dark-rumped petrel is an endangered species and most of the extant breeding population nests in and near Haleakala at elevations of 1800-3000 m. The results of the programme to date are summarised in Table 2.

The cost of the protection programme (including mammal and bird work combined) is about US $24,000/year, largely accounted for by salaries. About 340 'Havahart' traps are checked weekly in midsummer (petrel breeding season) and midwinter (Hawaiian goose (Nesochen sandvicensis) breeding season), and twice a month during the rest of the year. Although rats were the most abundant mammals in the catches, mongooses are judged to be the most serious predators. Feral cats have also taken birds, and both carnivore species continually invade marginal high altitude habitat from larger populations at lower elevations (Simons, 1983), perhaps attracted partly by rats. The effective management strategy is to remove transient predators before or shortly after colony entry, to remove shelter around buildings that attracts both rats and predators and to educate the public about the problem of predation upon the dark-rumped petrel.

DISCUSSION

Research and management programmes on introduced mammals in Hawaii's national parks are currently emphasising the removal of feral ungulates from within fenced areas. In the process, important information on ecology and population characteristics and control methods is being obtained. The programmes have been costly and long-lasting but effective in removing or reducing ungulates over large areas. The role of research is now largely to discover more effective ways to remove animals from some fenced areas when densities are low, to continue to document ecosystem recovery and the role of invading alien plants in some low ungulate density and ungulate-free areas, to determine alien plant control strategies, and to help managers to understand and choose important ecosystems to manage for ungulate removal and subsequent management.

TABLE 2. REPRODUCTIVE SUCCESS OF DARK-RUMPED PETREL IN HALEAKALA NATIONAL PARK IN RELATION TO SMALL MAMMAL REMOVAL

	1979	1980	1981	1982	1983	1984
Reproductive success *	38.7	71.4	61.3	64.0	67.8	88.4
Predation on active nests (%)	34.0	0.0	6.4	0.0	2.3	0.0
Rattus rattus removed (no.)	79	23	15	41	31	46
Rattus exulans removed (no.)	5	0	1	7	0	2
Felis catus removed (no.)	2	0	0	0	0	0
Herpestes auropunctatus removed (no.)	3	0	0	0	0	0

*Percentage of eggs laid in accessible burrows which produced fledglings (*n* = 41, 40, 47, 44, 44 and 42 for 1979-84).

A great deal of research effort is still needed to clarify the importance of small mammals as bird, invertebrate and plant predators, and as modifiers of Hawaii's native ecosystems. The potential for alleviating adverse effects, at least in some areas in some seasons, is largely unexplored. Although mongooses, rats and cats are widespread and numerous, manipulations of their populations in key areas to determine control feasibility and efficacy may be readily accomplished once emphasis is placed on small mammals in native ecosystems. This sort of approach successfully began with the dark-rumped petrel programme and is continuing with studies of the small Indian mongoose. If control of small mammals in Hawaiian ecosystems is to be effective, the potential and hazards of a wider range of currently used toxicants should be explored experimentally and efficacy determined in different situations.

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