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Short communication

Conservation action in the Galàpagos: feral pig (*Sus scrofa*) eradication from Santiago Island ☆

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Abstract

Introduced mammals are major drivers of extinction and ecosystem change. As omnivores, feral pigs (*Sus scrofa*) are responsible for wholesale adverse effects on islands. Here, we report on the eradication of feral pigs from Santiago Island in the Galápagos Archipelago, Ecuador, which is the largest insular pig removal to date. Using a combination of ground hunting and poisoning, over 18,000 pigs were removed during this 30-year eradication campaign. A sustained effort, an effective poisoning campaign concurrent with the hunting program, access to animals by cutting more trails, and an intensive monitoring program all proved critical to the successful eradication. While low and fluctuating control efforts may help protect select native species, current eradication methods, limited conservation funds, and the potential negative non-target impacts of sustained control efforts all favor an intense eradication effort, rather than a sustained control program. The successful removal of pigs from Santiago Island sets a new precedent, nearly doubling the current size of a successful eradication, and is leading to more ambitious projects. However, now we must turn toward increasing eradication efficiency. Given limited conservation funds, we can no longer afford to spend decades removing introduced mammals from islands.

Keywords: Control programs; Exotic species; Island restoration; Introduced mammals; Invasive

1. Introduction

Introduced mammals are major drivers of extinction and ecosystem change. Nowhere is this more apparent than on islands; a large percentage of vertebrate extinctions have been insular in nature (Groombridge, 1992). As omnivores, feral pigs (*Sus scrofa*) are responsible for wholesale adverse effects on islands, threatening native fauna and flora, and changing ecosystem dynamics (Challies, 1975; Cruz and Cruz, 1987; Drake and Pratt, 2001; Roemer et al., 2002; Vtorov, 1993).

In the mid 1900s, New Zealand conservation practitioners applied mainland hunting techniques to eradicate feral pig populations from small islands (<200 ha, Veitch and Bell, 1990). More recently, poisoning techniques have been developed to control or eradicate feral pig populations in efforts to minimize biodiversity and economic impacts (Choquenot et al., 1990; O'Brien and Lukins, 1990). Hunting and poisoning techniques, often used in combination, now facilitate pig eradication efforts on larger islands (Lombardo and Faulkner, 2000; Schuyler et al., 2002; Veitch and Bell, 1990). While the eradication of introduced mammals from islands is perhaps our most powerful tool in preventing extinctions, such efforts remain largely unpublished and thus

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knowledge generated by them unavailable to conservation practitioners (Donlan et al., 2003b).

Here, we report on the eradication of feral pigs from Santiago Island in the Galápagos Archipelago, Ecuador, which is the largest insular pig removal to date. Pigs were likely introduced onto Santiago Island shortly after Darwin visited in 1835, and were numerous by 1875 (Cookson, 1876). Since then, pigs have had a variety of adverse impacts on the native biodiversity of Santiago Island, preying on plants, invertebrates, the eggs and hatchlings of Galápagos tortoises (*Geochelone elephantopus*), lava lizards (*Microlophus albemarlensis*), green sea turtles (*Chelonia mydas*), and Galápagos petrels (*Pterodroma phaeopygia*), as well as other native vertebrates (Coblentz and Baber, 1987; Cruz and Cruz, 1987; Hoeck, 1984; Itow, 1995). Pigs, along with other introduced mammals, are thought to have played a substantial role in the majority of extinctions on the Galápagos islands (Loope et al., 1988; Steadman, 1986).

In response to this ecosystem degradation, the Galápagos National Park Service and the Charles Darwin Research Station initiated a pig control program on Santiago Island in 1968. After a decade of targeted control efforts in important breeding areas of Galápagos tortoises and sea turtles, revised techniques were implemented with the goal of eradication. As a result of these efforts and an intensive monitoring program, Santiago Island is now pig-free.

2. Background, methods and results

Santiago Island (58,465 ha), located in the center of the Galápagos archipelago, enjoys protected status and receives little visitation by scientists and tourists (Fig. 1). A major volcano (907 m), active in the 19th century, lies in the northwest part of the island; subsequently, a large portion of the island is basaltic lava (ca. 30%, Campbell and Cruz unpublished data). A number of endemic birds and five reptiles are present on the island, including the lava lizard and the giant Galápagos tortoise, two snakes (*Antillophis steindachneri*, *Alsophis biserialis dorsalis*), and a gecko (*Phyllodactylus galapagensis*). Land iguanas (*Conolophus* sp.) are thought to be extinct on Santiago. While Darwin recorded them abundant, only skeletal remains were found during a California Academy of Sciences expedition in 1905 (Slevin, 1935; VanDenburgh and Slevin, 1913). The endemic rice rat, *Nesoryzomys swarthi*, which was considered extinct since 1906, was rediscovered in 1997 (Dowler et al., 2000). Introduced goats (*Capra hircus*), donkeys (*Equus asinus*), rats (*Rattus rattus*), house mice (*Mus musculus*), and smooth-billed anis (*Crotophaga ani*) are present.

Limited pig control efforts began in 1968. Hunting was sporadic, and in general details on methods were not recorded. Traps and snares were used sporadically, which were generally ineffective. After 1974, hunting effort (number of hunters *x* days of hunting) was recorded. Ground-based hunters used 0.22 caliber rifles,

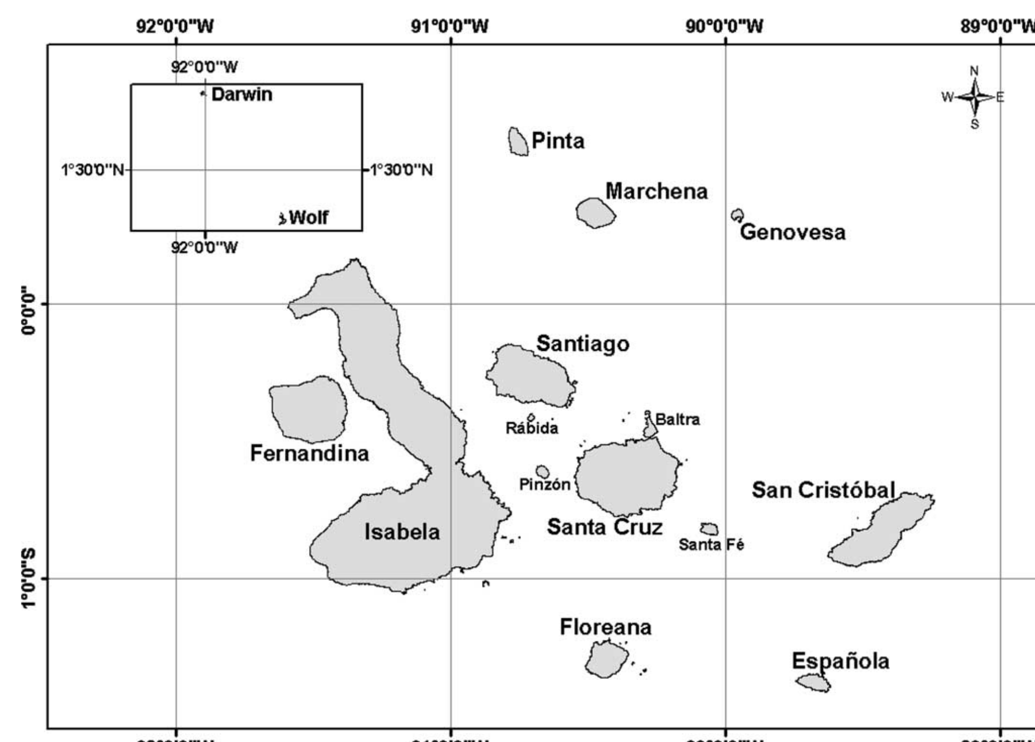

Fig. 1. The Galápagos Archipelago, Ecuador.

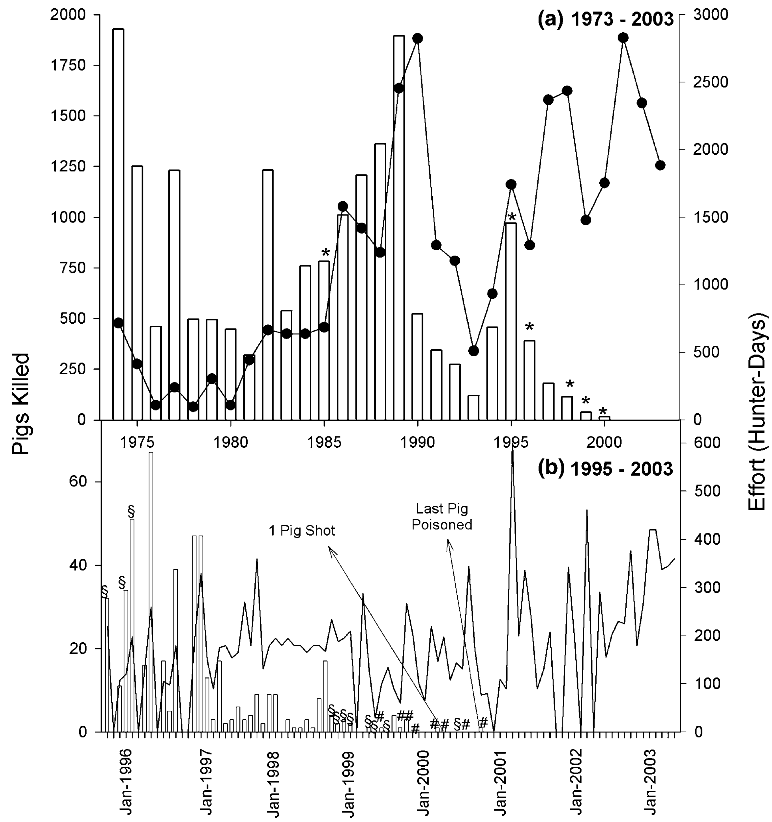

Fig. 2. Pig control/eradication effort on Santiago Island 1973–2003. Number of pigs killed (bar graph) and hunting effort (hunter-days: line graph) are shown. Annual data is shown in the top panel (a), while the bottom panels is broken down by month for the latter part of the campaign (b). Asterisks (∗) indicate that a concurrent poisoning program was used (§: 1080 and #: warfarin). Between 1972 and 1985 hunting effort was consistently low, indicative of control efforts. Between 1989 and 1995 effort was increased, however, fluctuated often with consecutive months with no effort. From 1997 to 2003 hunting effort was consistently high, despite very few pigs being killed.

with intermittent use of non-specialist dogs. Hunting effort varied between 250–500 hunter-days/year over a decade (1974–85; Fig. 2). In 1985, effort was increased and a poisoning campaign was initiated, using sodium monofluoroacetate (1080). Goat meat and sea turtle eggs were used as baits (50 mg/bait); 57% of the baits were consumed by pigs (Table 1). Effort remained ~1500 hunter-days/year until 1989, when effort was doubled under a revised hunting campaign. Hunters changed to 0.22 magnum caliber rifles. In 1989, 1896 pigs were removed; the following year 523 pigs were removed with a similar effort, after which effort was again reduced (Fig. 2).

In 1995, hunting effort was increased, along with an increased use of non-specialist hunting dogs and 1080 poisoning using goat carcasses as bait (700 mg 1080 injected in nine places in bait; Fig. 2; Table 1). Poisoned carcasses were placed out haphazardly along trails in October 1995, December 1995 and January 1996; 15% of the baits were consumed (Table 1). In 1998, the entire

Table 1
Pig poisoning campaigns used concurrently with hunting on Santiago Island

	1985	1995–1996[1]	1998	1999	2000
Sodium monofluoroacetate (1080) without anti-emetic	1199 (57)	746 (15)			
Sodium monofluoroacetate (1080) with anti-emetic			120 (5)	284 (3)	9 (0)
Warfarin				191 (3)	894 (0.6)

Two poisons were used (1080 and warfarin). Number of baits placed on the island are shown, with the percentage of baits taken by pigs in parenthesis.

[1] October 1995–January 1996.

island was broken into blocks, with teams of hunters covering select blocks. Hunters with dogs (12–15 hunters with 1–2 dogs each) had an almost continuous presence on the island, with more hunting at night occurring. Hunting dogs were not trained specifically for pigs; consequently, many pigs escaped when dogs would abandon a pig to pursue goats. Hunters carried VHF radios to coordinate hunting efforts and GPS units to document daily coverage of areas and location of pig sign. In the highlands where vegetation is dense, 260 km of additional trails were cut to provide hunters and dogs improved access to pigs, giving hunters a 580-km network of trails on the island.

Between 1998 and 2000, a revised poisoning campaign was implemented. Spot baiting was conducted at the end of hunting trips, using 1080 (230 mg/kg bait) with anti-emetic and later warfarin (960 mg/kg bait) injected into baits where fresh pig sign had been found and pigs not killed. Dosages were based on LD_{99} of 2.3 mg/kg body weight for 1080 (100 kg pig, McIlroy, 1983), and LD_{90} of 12.0 mg/kg body weight for warfarin (80 kg pig, single dose; B. Simmons, personal communication 1999). 1080 induces vomiting in pigs (O'Brien, 1988); anti-emetics were used in an attempt to reduce bait shyness and thus increase pig kills. While the anti-emetic does not prevent vomiting, it does increase kill rate possibly through allowing more 1080 to be ingested by delaying vomiting (Hone and Kleba, 1984). The anti-emetics used were metoclopramide (20 mg/kg bait) and atropine sulfate (8 mg/kg bait). Bait types used were primarily meat chunks or entire goat carcasses hidden under brush and vegetation to decrease the possibility of non-target poisoning to Galápagos hawks (*Buteo galapagoensis*). Additional goat carcasses were hung out of the reach of pigs above toxic baits as an attractant. Pigs became bait shy to 1080 poisoned baits (but not non-toxic baits), possibly smelling the anti-emetic. On several occasions, pigs would investigate but not consume toxic baits, or feed on the head of a poisoned carcass, leaving all poisoned bait portions. In 1999, warfarin was adopted for poisoning in an effort to: (1) eliminate non-target kills of hunting dogs, who are highly susceptible to 1080; (2) put at risk pigs with an aversion to 1080 baits with anti-emetics; (3) increase personnel safety (unlike 1080, an antidote is available for warfarin), and; (4) reduce the likelihood of secondary effects to birds of prey.

All pigs that consumed warfarin baits are thought to have died as a result, as judged by carcasses found or sign of those individuals never re-appearing. Pigs rarely take multiple baits, thus lethal single dosages were used, although multiple baits/doses were made available. The majority of pigs killed were smaller (20–50 kg live weight) than the weight used to calculate dosage. A two-dose LD_{90} of 6.1 mg/kg and an estimated single-dose LD_{90} of over 20 mg/kg has been reported for warfarin (O'Brien and Lukins, 1990). Pigs that took baits with warfarin on Santiago would have been exposed to these dosages. In addition, captive feral pigs on the Galapagos exposed to the warfarin dosage and baiting strategy used on Santiago died within 8–9 days; baits were highly effective for eight days, while kill rate decreased after 12 days of bait decomposition (Harwood and Campbell, unpublished data).

By mid 1999, the hunters were keenly aware of the few remaining pigs and could identify each individual's sign. The last pig was believed to have been shot in April 2000. In July 2000 an extensive monitoring program was initiated. Non-toxic goat carcasses where placed at equidistant points (initially at 500 m spacing, and later at 1 km spacing) over the entire island. Carcasses were monitored for disturbance by pigs 10–40 days later. This method was repeated up to four times in hunting blocks of preferred pig habitat. Further, hunters checked for pig sign at equidistant points (500 m spacing) in all marginal pig habitats. The last pig was detected using equidistant carcasses and poisoned using spot-baiting in October 2000 on the seventh monitoring trip, six months after the last shot pig and four months into intensive monitoring (2414 hunter/monitoring hours, 1128 toxic and non-toxic monitoring baits, and 1298 dog-hours).

3. Discussion

For the first time in over 150 years, Santiago Island is now free of pigs. Such action sets the stage for future proactive restoration such as additional introduced mammal eradications, invasive plant programs, and the reintroduction of extirpated species with populations from nearby islands (Steadman and Martin, 2003; Tye, 2000). Goats and donkeys are currently being removed from Santiago. Introduced rodents and plants will prove more challenging; however, the recent rat (*Rattus norvegicus*) eradication on Campbell Island, New Zealand (11,300 ha) is encouraging (P. McClelland, personal communication; McClelland, 2002). While feral pigs have now been eradicated from at least 25 islands worldwide (Campbell and Donlan, 2004), the pig eradication on Santiago Island (58,465 ha) is by far the largest accomplishment to date, demonstrating the ability to remove introduced mammals from large islands. Over 18,800 pigs were removed from the island, compared to ~12,000 removed from Santa Catalina Island, California (19,400 ha), the second largest removal (Schuyler et al., 2002).

A sustained effort, an effective poisoning campaign concurrent with the hunting program, access to animals by cutting more trails, and an intensive monitoring program all proved critical to the successful eradication. Throughout the 1970s and 1980s, hunting effort was low (<500 hunter-days/year), while in the early 1990s effort increased but fluctuated (Fig. 2). In contrast, the revised campaign in the mid-1990s resulted in a continuous, minimum annual effort of 1500 hunter-days/year. Such dedicated efforts are a requisite for success. While low and fluctuating efforts (i.e., control programs) may help protect select native species, current eradication methods, limited conservation funds, and the potential negative non-target impacts of sustained control efforts all favor an intense eradication effort, rather than a sustained control program.

Hunter access to pigs was critical. Extra trails were cut and goats were not hunted in order to keep vegetation suppressed, allowing hunters and dogs access to all areas of the island. It is likely that pig-specific dogs would have improved the efficiency of the hunting program. Motivating hunters was a continual challenge, especially when pigs were at low densities. Social, moral boosting events and financial incentives for pigs killed, including a USD $12,000 donation to be divided amongst hunters following 18 months of monitoring after the last pig was believed killed, proved valuable in maintaining hunter motivation.

While the poisoning campaign actually killed relatively few pigs compared to hunting, the low cost of the poisoning makes such efforts especially cost-effective. The only non-target or secondary impacts observed from the poisoning campaign were several non-native rats (*R. rattus*) from 1080. Endemic rice rats have a limited distribution on the coast (Dowler et al., 2000), and this area was never baited with toxic baits. The compounds used are toxic to most species, and thus the decision to incorporate a poisoning campaign into an eradication effort must be balanced with the potential for non-target poisoning (Donlan et al., 2003a). The effectiveness of the poisoning campaign is best demonstrated during the monitoring program. In 2000, the last pig killed on Santiago was by poisoning, after an intensive monitoring effort and six months after the last pig was shot (Fig. 2). A sustained monitoring effort is critical to successful eradication. The lack of such an effort is responsible for many eradication failures, or often results in unnecessarily long removal campaigns, and thus an inefficient use of precious conservation dollars (Campbell et al., 2004).

Introduced mammals, such as feral pigs, are now being removed from larger and more biologically complex islands (Donlan et al., 2003b; Veitch and Clout, 2002). Current techniques and technology, coupled with persistence and determination, are resulting in major island conservation gains: the Aleutian Islands, Northwest Mexico, New Zealand, the sub-Antarctic and the Galápagos to name a few (Veitch and Clout, 2002). Now, we must turn toward increasing our eradication efficiency. Given limited conservation funds, we can no longer afford to spend decades removing introduced mammals from islands, as was the case for Santiago and other islands (Bester et al., 2000; Campbell et al., 2004). The successful removal of pigs from Santiago Island sets a new precedent, nearly doubling the current size of a successful eradication, and is leading to more ambitious projects. Feral goats and donkeys are currently being removed from Isabela Island, Galapagos (458,812 ha) – a project of unprecedented scale. Such accomplishments and aspirations are a slight hint that we are beginning to aim high enough in the fight against biotic homogenization.

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