Eradication of feral pigs (*Sus scrofa*) on Santa Catalina Island, California, USA

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Abstract Control efforts initially designed to reduce feral pig numbers, and subsequently altered to remove all feral pigs began on Santa Catalina Island, California, in 1990. The programme occurred in four phases, each with different management objectives and geographical emphases. Phase I involved reducing pig numbers on the western 20% of the island. Control efforts were expanded in Phase II to include reduction of pig numbers island-wide. Phase III involved eradication of pigs on the west end with continued control elsewhere. Phase IV involves the removal of all pigs from the island and has a scheduled completion date of 2004. To date, at least 11,855 pigs have been killed. Removal strategies include trapping (39%), systematic hunts with dogs (30%), systematic and opportunistic ground hunts (26%), aerial hunting (3%), and night spotlighting (2%). Catalina has a resident human population of 5000, and more than 1,000,000 visitors annually, requiring close integration of removal efforts with other island activities. At least 96,500 hours have been expended by staff, contractors, and volunteers. Total costs exceed USD3,175,000. Less than 300 pigs are estimated to remain in October 2001.

Keywords Santa Catalina Island; feral pigs, *Sus scrofa*; eradication strategies.

INTRODUCTION

Attempts to control or eradicate feral pig (*Sus scrofa*) populations on islands have been undertaken in different parts of the world for many years (Hone and Stone 1989; Katahira *et al*. 1992; Lombardo and Faulkner 2000). Since 1990, intensive efforts to remove pigs have occurred on Santa Catalina Island, the third largest of the eight California Channel islands. The programme has evolved through the last decade with several distinct phases, each with different objectives and on-island geographical emphases (Table 1). Current objectives call for the removal of all pigs from the island. This paper discusses all pig removal efforts since November 1990.

Pigs are not being removed from Catalina because they are non-native, but because of their impact on the island's ecosystem. Near the beginning of the programme a series of vegetation transects were placed on the west end of the island and baseline data collected (Laughrin *et al.* 1994). Results of this and subsequent monitoring indicated an increase in the percent of vegetative ground cover and an increase in species diversity from 1990 to 2000. While many of the species contributing to this increased diversity were exotic plants, the increase in ground cover was considered a positive step as it decreased the potential for continued topsoil erosion. More systematic and complete monitoring programmes for both vegetation and fauna are being established and will provide results in the coming years. However, since both pigs and goats were removed from this area at the same time, making an accurate assessment of recovery due solely to pig removal will be problematic (Gay 1999; Kraus 2000).

Table 1 Phases and objectives of pig removal efforts on Santa Catalina Island since 1990.

Phase	Date	Objective	Location
I	11/1990-4/1991	As many pigs as possible	West End
II	2/1992-6/1996	As many pigs as possible	Entire island
III	7/1996-12/1997	All pigs	West End
	7/1996-6/1998	As many pigs as possible	Eastern 80%
IV	7/1998-present	All pigs	Entire island

Study area

Santa Catalina Island (SCI), lies 32 kilometres (km) south of Point Vicentes, Los Angeles, California, U.S.A (Fig. 1). Ranging in width from <1 to13 km, the 194 km^2 island is approximately 35 km long with a highest elevation of 640 metres. The rugged, mountainous topography of SCI

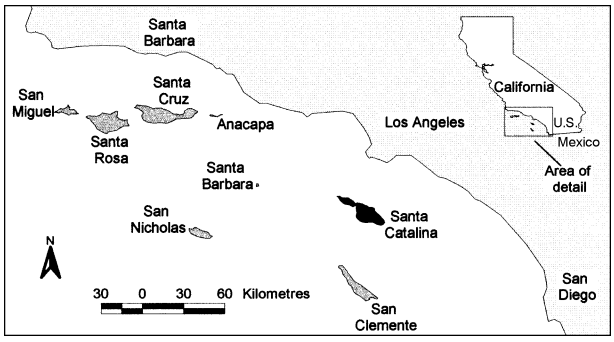

Fig. 1 Santa Catalina Island, the third largest and most populated of the eight California Channel Islands, lies south-west of the large Los Angeles metropolitan area.

Pages 274-286 In Veitch, C. R. and Clout, M. N. (eds.). *Turning the tide: the eradication of invasive species*. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.

is dominated by a north-west to south-east mountain range containing complex arrays of lateral canyons. Slopes normally range between 20° and 30° although they may be nearly twice as steep. The western 20% of the island (38 km^2) is isolated from the remaining portion by a narrow, low (<15 m elevation) isthmus providing a natural barrier for use in control programmes (Fig. 2). The climate is Mediterranean with wet winters, long dry summers, and relatively mild year-round temperatures. Rainfall varies both annually and spatially over the island but generally averages between 200 mm and 400 mm. At least 14 distinct plant communities have been documented on SCI (Thorne 1967; D. Knapp pers. comm.). Grassland accounts for nearly 30% of the total area, while chaparral and mixed-oak woodland comprises 44% of the vegetative cover. Twenty percent of the island is covered by low-growing coastal sage scrub, maritime desert scrub or *Opuntia* scrub and the remaining 6% is eroded badlands, cultivated areas, or developed sites (Minnich 1980). A depauperate native mammal fauna includes island fox *(Urocyon littoralis catalinae*), Beechey's ground squirrel (*Spermophilus beecheyi nesioticus*), deer mouse *(Peromyscus maniculatus catalinae*), harvest mouse *(Reithrodontymis megalotis catalinae*), ornate shrew (*Sorex ornatus willetii*), and at least five bat species (Von Bloker 1967). All terrestrial mammal species, excluding bats, are endemic to Catalina at the subspecies level. Introduced alien herbivores currently include feral goats (*Capra hircus*), American bison *(Bison bison*), mule deer *(Odocoileus hemionu*s), feral pigs, and a small herd of black buck (*Antelope cervicapra*). Numerous sheep *(Ovis arie*s) were removed from the island by the mid-1920s and the majority of cattle (*Bos taurus*) were gone by the late 1950s (O'Malley 1994). Thirty-nine bird species breed on the island and more than 225 species have been recorded (Schoenherr *et al*. 1999; R. Hansen pers. comm.). There are 11 species of reptiles and amphibians regularly recorded on the island. There are 472 native plant species and 235 introduced plant species. Of the native species, six are restricted to just Santa Catalina Island while at least another 22 are restricted to the California Channel islands and are not found on the mainland.

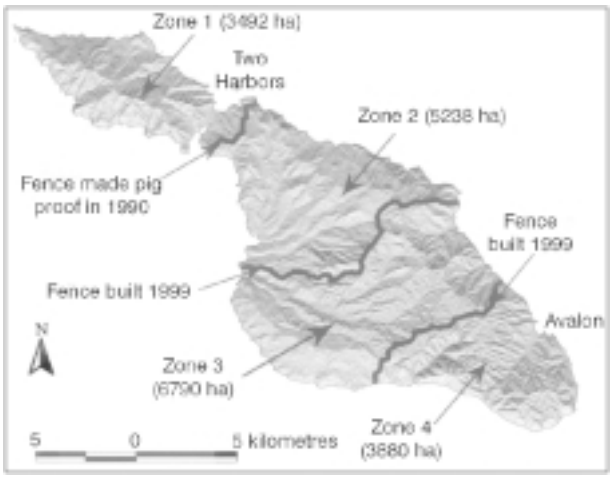

Fig. 2 Four pig management zones were created on Santa Catalina Island by constructing 29 km of fence.

In addition to native plant, vertebrate, and invertebrate species, Catalina also has a resident human population of approximately 5000 people and nearly 1,000,000 visitors per year. The town of Avalon has 4500 residents and receives the majority of the visitors. The remaining population is located in the small town of Two Harbors (pop. 200) or at various camps and facilities. The Santa Catalina Island Conservancy (Conservancy) owns and manages 88% of the island with a primary goal of natural resource protection while still allowing appropriate public access. Members of the William Wrigley Jr. family established the Conservancy as a private, non-profit organisation in 1972. The Santa Catalina Island Company, which operates most of the island's commercial ventures, owns 11% of the island and allows the Conservancy access to its land for a variety of conservation purposes. The remaining 1% is privately or publicly owned.

History and impacts of pigs

During the 1930s, pigs were first introduced to Santa Catalina Island, allegedly for either sport hunting or to help control Catalina's rattlesnake population (Overholt and Sargent 1971). The animals came from Santa Rosa Island where they were originally introduced from an unknown source, most likely in the mid-1800s (Collins 1981). During the 1990s, the National Park Service eliminated pigs from Santa Rosa Island (Lombardo and Faulkner 2000). A syndactyl breed of pig was introduced to Catalina prior to 1955, although only a very few pigs with this morphological characteristic are still sighted (K. Ryan pers. comm.). The number and distribution of Catalina's pigs vary dramatically year to year. In 1980, the pig population was estimated to be between 1260 and 2040 animals (Baber and Coblentz 1986). Although present over the entire island, densities of pigs are highest in moist canyon bottoms and lowest on exposed ridges. Condition of the pigs is closely tied to the availability of acorns and other food sources. During years with poor quality or quantity of forage, the pig population decreases and animals can be nearly too weak to stand. The presence of antibodies for pseudorabies virus, San Miguel Sea Lion Virus (a calicivirus of marine mammals similar to swine virus), and trichinosis has been documented for Catalina's pigs, indicating prior exposure to these diseases (Timm *et al*. 1994).

The ecological effects of feral pigs on island resources are known from numerous places around the world, although documentation is not always easy to obtain (Wood and Barrett 1979; Stone 1985; Coblentz and Baber 1987; Pavlov *et al.* 1992). Effects may vary depending upon the density of pigs and relative sensitivity of the ecosystems (Bratton 1975; Singer 1981). The impacts of feral pigs on the ecosystems of Catalina and the other California Channel Islands are documented (Thorne 1967; Hochberg *et al*. 1980; Baber 1985; Baber and Coblentz 1986; Sterner 1990; Peart *et al*. 1994; Lombardo and Faulkner 2000). Impacts on Catalina include extensive rooting of slopes, disturbance of soils around the base of native trees, including the endemic genus of Catalina Island ironwood

trees (*Lyonothamnus floribundus* spp. *floribundus*), uprooting and trampling of small seedlings and saplings, and direct consumption of small native vertebrates and invertebrates (Baber 1985; Garcelon 1995, 1998). The decline in range and population size of several native plant species is suspected to be associated with pig presence (Thorne 1967). Pig foraging on acorns is likely a major factor in the almost complete lack of regeneration of two endemic oak species (*Quercus pacifica* and *Q. tomentella*). As noted by Lombardo & Faulkner (2000), areas of pig rooting create optimum growing conditions for invasive exotic plants such as spiny clotbur (*Xanthium spinosum*), fennel (*Foeniculum vulgare*), and horehound (*Marrubium vulgare*). On other California Channel Islands, archaeological sites, especially those located in caves, have been heavily impacted by feral pig rooting and bedding behaviour (Lombardo and Faulkner 2000). Given the widespread evidence of Native American habitation on Catalina in comparable sites, we think it is reasonable to expect similar degradation to the island's cultural sites.

Previous control efforts

Since their introduction, island residents, land managers and visitors have hunted pigs for both sport and subsistence. Prior to 1990, the goals of feral pig management programs on Catalina were not well defined and involved intermittently reducing pig numbers, utilising on-island resources and available time. Although sport and subsistence hunting was widespread, and land managers shot pigs opportunistically, it is unlikely, given the reproductive capacity of pigs, that this level of hunting had significant island-wide effect on pig numbers. This finding is consistent with preliminary results of the effectiveness of sport hunting in reducing feral pig populations in Hawaii and New Zealand (Barrett and Stone 1983; Clarke 1988). Until 1990, pig numbers were more likely influenced by the amount of annual rainfall, the acorn mast crop and the availability of other food sources (D. Propst pers. comm.).

Current control programme

Although Catalina faces many natural resource challenges and issues, the removal of non-native animals, particularly pigs and goats, has long been identified as a top priority. Bruce Coblentz (pers. comm.) raised the possibility of goat eradication in 1973 and again in 1980. Finally, in the late 1980s, the administration and board of the Conservancy, with strong urging from Dr. Robert Thorne, director of the Rancho Santa Ana Botanic Garden, discussed increasing feral animal control efforts (D. Propst pers. comm.). Goats were the initial focus of removal efforts, however, the control of both species became top priorities by 1990.

Although almost the entire island is privately owned, pigs are considered the property of the State of California and, as such, all management programmes must be authorised by the California Department of Fish and Game (CDFG). In 1990, a Memorandum of Understanding (MOU) between the CDFG, the Conservancy, and the Institute for Wildlife Studies (IWS), was signed to allow the Conservancy to eradicate pigs on the west end of Catalina. In 1992, a new MOU was signed allowing the Conservancy to eradicate pigs over the entire island. The Institute for Wildlife Studies, a non-profit conservation group, was a signatory to the MOUs as they were contracted by the Conservancy to implement the control programmes. Both MOUs allowed pig carcasses to be left on site rather than utilising or burying them as is normally required in a depredation permit. This permission was crucial to the success of the programme due to Catalina's rugged, inaccessible terrain, the inability to follow government standards for preparing meat for human consumption, and the logistical constraints of obtaining approved butchering and transport facilities.

METHODS

Planning

Many methods of feral pig control have been tried and evaluated throughout the world (Hone and Atkinson 1983; Breuer 1987; Davis 1987; Hone and Stone 1989; Sterner 1991; Sterner and Barrett 1991; Barrett and Birmingham 1994; Jenkins *et al.* 1994; Choquenot *et al.* 1996; Lombardo and Faulkner 2000). Catalina's pig control programme should be viewed as an adaptive management program. Each phase of the 10 year programme provided new information which was incorporated into subsequent phases to improve results and efficiency. Methods were refined and adapted throughout the programme to meet new challenges and to help the program fit in with other activities occurring simultaneously on Catalina. With a resident human population and a million visitors per year, some methods could not be utilised on Catalina that might otherwise have proved more efficient in terms of efficiency, results, and cost. Both humaneness and the ability to accomplish programme goals were considered when deciding on appropriate methods.

Removal techniques

Phase I

The western end of the island was chosen as the first area to eliminate as many pigs as possible, due to its relative isolation provided by the isthmus barrier. In addition, an existing 5 kilometre bison fence on the east side of the isthmus was made pig-proof during the early stages of Phase I (Fig. 2). Phases I, II, and III utilised the two management areas created by this fence. Evaluating different techniques for potential use in reducing pig numbers island-wide was a second goal of Phase I.

The following combination of control techniques was used in Phase I: trapping, ground hunting without dogs, ground hunting with dogs, and aerial hunting by helicopter. Each method has advantages depending on season and localised pig density. In addition, limited sport hunting by archers and poaching took place during this period. Control of feral goats was conducted at the same time.

Two trap types were utilised. The majority were all medium-gauge chain link, 1 m x 3 m box traps with a drop door triggered by a line rigged over the bait located at the rear of the trap. The second type, also a box trap, had solid bottoms and a different drop-door trigger mechanism. Potential trap sites along roadsides were pre-baited up to one week prior to placing the trap. Bait trails from 0.1 to 1 km extended from the trap sites to attract pigs in from remote areas. Due to good availability and ease of handling (23 kg sacks), commercial pelleted pig finishing feed was chosen as bait. In addition, any seeds in the feed were sterile thus ensuring no new plants would be introduced to the island. Baited sites were monitored and replenished with bait as needed every other day. One or two traps were then placed at sites showing the highest bait consumption. Traps were set each evening for seven consecutive days and checked early each morning. Pigs found outside the traps were shot with rifles while those trapped inside were dispatched with a .357 magnum pistol. All animals were aged and sexed. Estimated weight and female reproductive status were also noted (Sterner 1991).

Opportunistic ground hunting occurred whenever pigs were sighted. Two ground-hunting trips with dogs, using three Catahoula and two Plott hounds, were conducted. Two to three hunters worked with three to four dogs. Dogs would locate, track, and detain a pig until a hunter came to dispatch it. Limited aerial hunting of pigs occurred during one of the goat removal aerial hunting trips. Phase I ended when island staff departed for other positions and were not replaced.

Phase II

Ten months passed before control efforts were resumed in Phase II. Financial constraints, the opinion of Conservancy administration and board members that pig numbers were sufficiently reduced on the west end to promote recovery, and the uncertainty on the part of some board members whether eradication could be achieved, were all reasons contributing to the delay in resuming the hunting efforts. When the decision was made to renew control efforts, the focus shifted to the entire island rather than just the west end. Financial constraints were again a factor in pursuing a control programme rather than an eradication project.

Phase II methods primarily followed those established in Phase I except trap design was changed to a 1 x 1 x 2 m box trap constructed from pipe, and a corral trap was added utilising 2.5 m panels that could be built in a variety of shapes. The size and design of the corral trap, coupled with adequate pre-baiting and good placement, allowed multiple captures of pigs in a single trap. Although the door was counter-weighted to allow additional pigs to enter, most multiple captures were a function of the larger trap size allowing several animals to enter before the door closed. The number of traps used was increased each year until a total of 23 corral traps and nine box traps were being utilised. In addition to daytime ground hunting without dogs, spotlighting was also instituted. Using a large spotlight, hunters would patrol roads after dark until an animal was seen, at which time rifles with laser sights were used to dispatch the pig. Staff from IWS acquired their own dogs, and used them more extensively than in Phase I. Dog breeds used in this programme included mostly Catahoula hounds, Plott hounds and crosses of the two breeds. All dogs were trained using shock collars to avoid non-target species. All dogs were vaccinated, and any injuries were immediately treated by project staff or a veterinarian. Aerial hunting by helicopter was again used, including missions flown at dawn or dusk using a Forward Looking Infrared (FLIR) device which has been tried elsewhere with varying success (Lombardo and Faulkner 2000). FLIR technology, which measures differences in temperature, detects warm-blooded organisms as they stand out from the surrounding cooler physical environment. Staffing during this phase normally consisted of one full-time hunter with occasional seasonal help, especially during the time when blood samples were being obtained for the disease study (see below).

In addition to recording standard age, sex and reproductive status of shot pigs, a subjective assessment of the pig's health condition was noted starting in 1992. In 1993, blood samples were collected during this phase which established the presence of pseudorabies virus and San Miguel Sea Lion Virus antibodies in the pig population (Timm *et al.* 1994). The likely exposure of island pigs to these diseases made the U.S. and California Departments of Agriculture, as well as CDFG, unwilling to consider live removal as a viable option (Gonzales 2000). This fact became more important as public awareness of the project increased and animal rights/welfare groups raised questions as to why live trapping and relocation were not tried.

Phase III

After three years of reducing pig numbers island-wide in Phase II, it became clear that control efforts, while effective in reducing numbers, were not resulting in any long-term population declines. Increased efforts were needed to eliminate pigs from the entire island. Before authorising an island-wide removal effort, the Conservancy's Board of Directors wanted to ensure it could be accomplished in a smaller area. In May 1995, IWS submitted a proposal outlining a programme to eradicate pigs from the west end (Zone 1) over a two-year period (Garcelon 1995). Control efforts would continue on the remaining eastern 80% of the island but at a reduced level. By utilising the isolated west end as a test area, IWS would be able to develop an estimate for the amount of effort and cost needed for an island-wide eradication programme.

Phase III methods generally followed those established in Phase II with the following additions. Full-time staff was increased to three; two for the west end eradication work and one for the control work on the rest of the island. The number of corral traps was increased to 32 and the design changed to improve portability with prefabricated chain link panels that could be easily assembled in the field. Helicopters were used opportunistically for aerial hunting

when brought to the island for other projects. They were also used to transport bait and traps to remote sites. Pigs that came to baited sites at night were dispatched using rifles equipped with night vision scopes.

Phase III was started in July 1996 and originally was estimated to take two years. After only 18 months, no pigs were known to remain and in April 1998, IWS submitted an island-wide pig eradication proposal (Garcelon 1998).

Phase IV

Phase IV started in July 1998 with an estimated completion time of 4-5 years. Prior to approving the initiation of Phase IV, the Conservancy board made sure adequate funding was either in place or at least committed to cover the duration of the removal programme. Phase IV methods continued to expand on those established in prior phases, with the exception of no aerial hunting. This decision was based on the negative reaction of the general public to use helicopters to shoot feral animals. Although effective, aerial hunting was only a small percentage of the total pig removal efforts. To meet the objective of removal of all pigs from the island, IWS staffing increased to seven full-time employees, and additional housing, vehicles, equipment, and dogs were obtained. An additional 125 corral traps were ordered. A permanent kennel, complete with a septic system, was constructed in the middle of the island with facilities for up to 36 dogs.

As outlined in Garcelon's 1998 proposal, building new fences to compartmentalise the pig population into six zones was part of the planned removal effort. Although technically and logistically feasible to work in larger zones, the need to allow safe and regular access to many parts of the island and to minimise impacts on existing resident and visitor activities required smaller areas. There was much discussion and debate regarding the size of management units and associated fence construction design and costs. Other pig eradication programmes have faced similar concerns and some, such as the programme on Santa Rosa Island, opted to do without fences (Lombardo and Faulkner 2000). However, to maintain other island activities, and to keep previously controlled areas free of pigs in case of an unforeseen slowdown or temporary stoppage of the programme, the Conservancy built 24 km of new fence, creating four rather than six management zones (Fig. 2). The fence cost USD825,000.

The fences are constructed out of 1 m tall hog mesh with a strand of predator barbed wire stretched tautly along the contours of the ground to discourage digging. Although not needed to prevent pig crossing, three strands of barbed wire were added above the hog mesh to make the fence more visible to the free-ranging non-native bison and deer herds. To be effective, the fence needed to be checked regularly to locate any breaks. A programme of regular fence monitoring and repair was designed and instituted using local community volunteers.

The plan for Phase IV called for a systematic removal effort in Zones 2, 3, and 4, as well as continued monitoring in Zone 1. Zones were to be cleared to a point where no or very few animals were known to be left before focusing on the next zone. Trapping along both sides of a zone fence was conducted to reduce pig pressure on the fence. This also created a buffer area and reduced the probability of immigration by pigs into a cleared area in the event of a break in the fence. Even as work in a new zone commenced, the old zone would be monitored regularly and any animal spotted would be immediately removed. Once Zone 2 was completed, a strategic decision was made to clear Zone 4 before Zone 3 in case of unforeseen contingencies requiring extra time due to the presence of the town of Avalon and its numerous human activities, and the potential for public relations problems. The plan for Zone 4 called for trapping the entire area outside of Avalon Canyon during the summer months and then moving into the canyon area immediately surrounding the town with traps and dogs during fall and winter months when visitor activities were at their minimum (Fig. 3). By starting at the outer edges of Zone 4, we hoped any pigs that normally moved in and out of Avalon canyon would be caught outside, thereby reducing the number of pigs needed to be taken near town. Zone 4 eradication efforts began in May 2000 and were slowing down by June 2001. Efforts then shifted to Zone 3, which is projected to be completed by spring 2002. A minimum of two years to find and remove the last few known pigs is then expected. Following that, regular and systematic monitoring will be conducted for another 2-3 years before declaring the island to be pig free.

Although the same methods were employed in Zone 4 as in the other zones, additional measures were taken to ad-

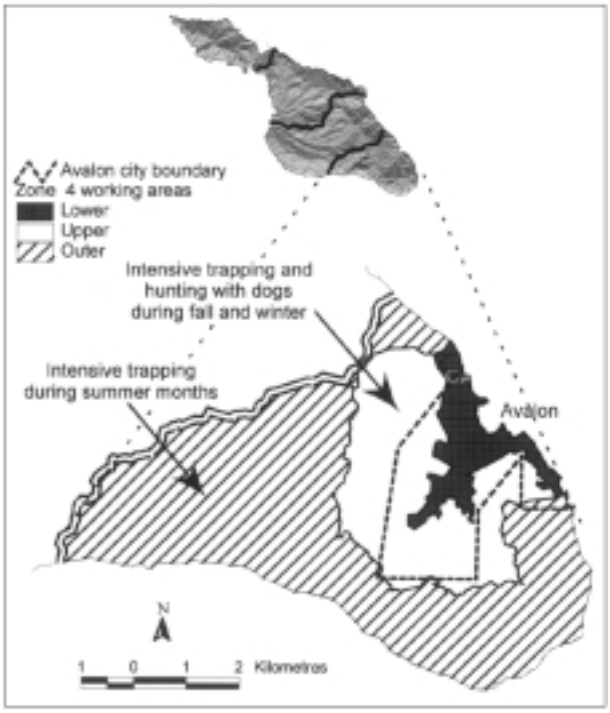

Fig. 3 Detailed map of Zone 4 pig management area, including the town of Avalon, Santa Catalina Island.

dress public safety and public relations concerns. These are addressed in the Public Relations/Education section below.

Monitoring and evaluation

During Phases I and II, when the goal was only to control pig numbers, monitoring of pig distribution and abundance was not considered a critical component of the programme. Staff were limited and the objective was to remove as many pigs as possible without a defined endpoint. However, during Phases III and IV, when eradication was the objective, monitoring changes in pig numbers in order to evaluate success became an important programme component. No systematic permanent transects were established, but staff regularly scouted for sign along game trails, at watering holes, stream crossings, and on dirt roads. In addition, dogs were repeatedly taken into areas when pig densities became low to see if they detected fresh scent. During the winter, disturbance of the new green vegetative groundcover was a good indicator of pig rooting. During summer months, dirt roads and trails were brushed to help detect new pig tracks or, on hard-pan soils, a covering of fine soil was laid down to help detect tracks.

To assist in increasing our understanding of the spatial relationship of animals removed, and to help relate habitat and topographic features with animal densities, the island was overlain with a 500 m^2 grid and each grid given a unique alphanumeric code. All trap sites and each pig removed were then located on the grid and entered into a geographic information system (GIS) database. As more pigs were removed, GIS analysis provided insight into where we might expect higher pig densities as we moved into new zones. As numbers of pigs diminished and animals were only found in groups of one or two, regular systematic monitoring was instituted. At this point, it was very important to receive sighting information from the general public and Conservancy staff, as locating animals became the critical time-consuming task.

Public relations and education

An often-overlooked, but increasingly-necessary component of animal removal programmes is working with or at least informing the general public of progress and plans (Sterner 1991; Barker 1995). For Phases I, II, and III there was very little public interaction or concern relating to the programme. Generally, any dialogue occurred on a one-to-one basis. As the programme scaled up, its visibility increased and the Conservancy felt the need to provide public information on the reasons and scope of the project. This was particularly true as we implemented trapping and hunting in and around the town of Avalon.

In 1999, the Conservancy held a series of public community forums to explain the scope of the eradication project and to answer questions. The forums brought forth numerous questions and concerns, although most of the concerns focused on the goat rather than the pig removal programme. However, realising the potential for impacts on both residents and visitors when control activities began in the Avalon area, the Conservancy began meeting with invited city and county agencies and affected business interests nearly a year and a half prior to actually starting work in Avalon Canyon. At these meetings, we outlined our approach and asked for input from all parties, particularly regarding safety and logistical issues. As a result the following measures were taken prior to or during work in Zone 4: (1) all trail heads in the area were posted with signs in both English and Spanish outlining the nature of the program and who to contact for additional information, (2) all traps in Avalon canyon were posted with bilingual signs describing their purpose, (3) all traps in Avalon canyon were locked open when not actually set to capture pigs, (4) all pigs caught in traps were chemically immobilised and removed rather than being shot in the trap, (5) all pig carcasses were removed from the Avalon Canyon area, (6) the sheriff's department was notified each and every day IWS was in the area with a potential to discharge firearms, (7) any affected businesses, such as the horse stable and trail riding operations, were notified before IWS worked in their areas, and (8) a mailing in both English and Spanish was sent to all island post office box holders (there is no home mail delivery on Catalina) outlining the programme and who to contact for additional information. The Conservancy also submitted a number of articles to the local newspapers, mentioned the removal programme at all regularly-scheduled Conservancy education and field activities, and made staff available to speak to any local organisations or homeowner groups requesting additional information.

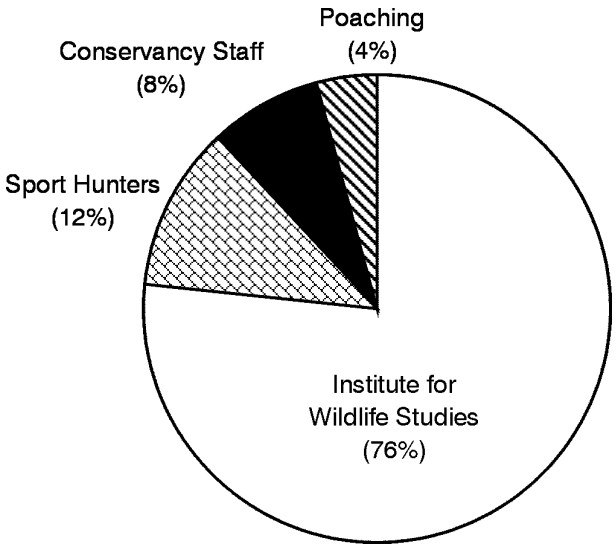

Fig. 4 Percentage of pigs removed by different personnel between 1990 and September 2001 on Santa Catalina Island (n = 11,855). Pig numbers estimated for staff and poaching percentages. Numbers for sport hunting calculated by dividing known number of sport hunter days per year by estimated take ratio. IWS numbers came from detailed records.

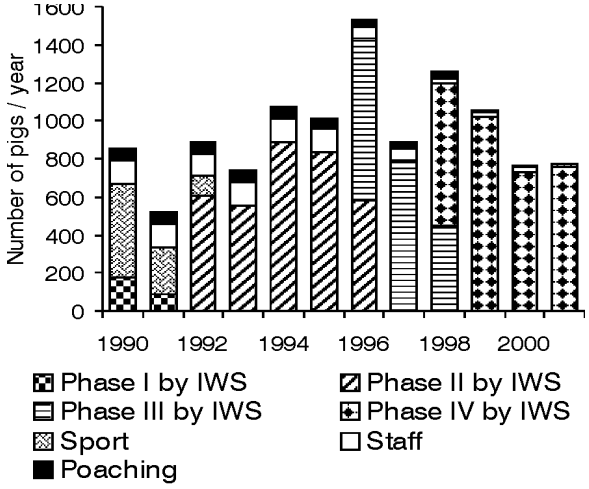

Fig. 5 Number of pigs taken annually on Santa Catalina Island between 1990 and September 2001 by different sources (n = 11,855).

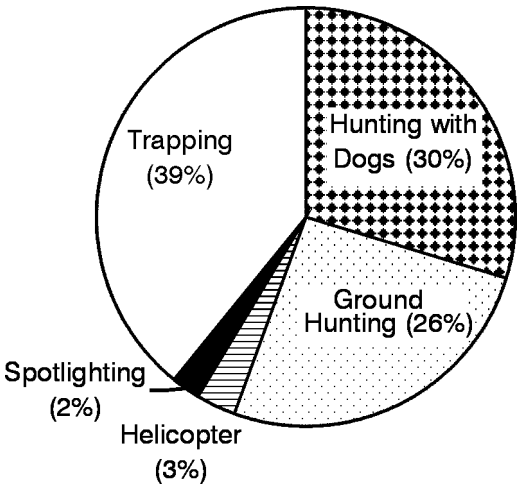

Fig. 7 Percentage of pigs removed by different methods between 1990 and September 2001 on Santa Catalina Island (n = 9123). This includes all kills by IWS as well as a few records by other island residents. The remaining 2732 animals were likely taken by ground hunting by sport hunters, staff or poachers.

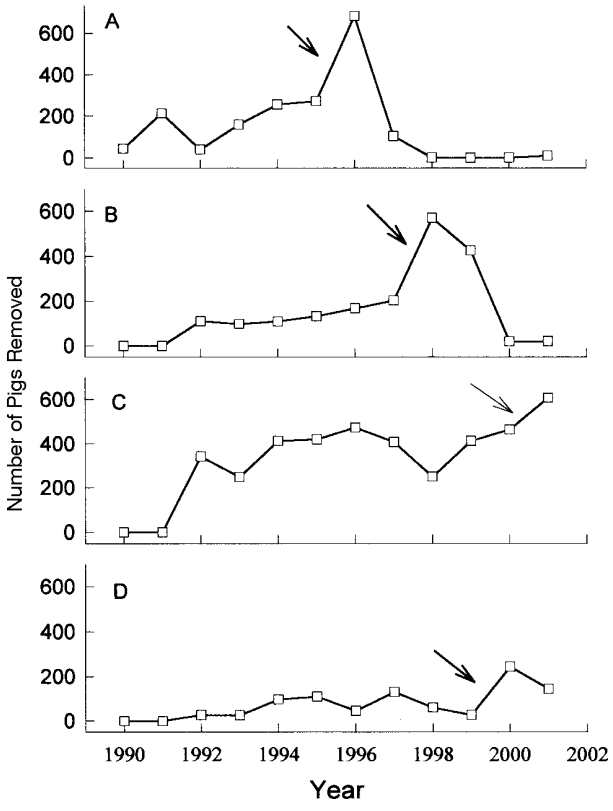

Fig. 6 Number of pigs annually taken from each zone on Santa Catalina Island between 1990 and September 2001; (A) Zone 1: total = 1774, (B) Zone 2: total = 1852, (C) Zone 3: total = 4043, and (D) Zone 4: total = 914. Arrows indicate when objective changed from control to eradication. Accurate locations for 3272 pigs removed before fence construction could not be determined and are not shown.

RESULTS

Eradication techniques

At least 11,855 pigs were killed from 1990 to September 2001. The majority of these (9076) were removed by IWS staff, while the rest were taken by sport hunters, staff hunting, and poaching (Fig. 4). The estimated figures for both staff hunting and poaching probably under-represent the actual take (B. Boyd, D. Gardner, H. Saldaña pers. comm.). Numbers of animals taken during each phase of the programme are shown in Fig. 5. Numbers of animals taken from each zone are shown in Fig. 6.

Removal techniques had differing rates of success and were used in different proportions depending on the season (Fig. 7). Trapping was conducted primarily June through October. Using data collected for the 1998 and 1999 seasons in Zone 2, trapping success (No. traps capturing pigs/ total No. traps set (n = 606)), ranged from 1% to 90% with a mean of 43%. Although pig densities were much higher in 1998, as indicated by the fact that less than 20 pigs were estimated to remain in Zone 2 by late 1999, the seasonal difference in the means were not statistically significant (ANOVA; $p > 0.1$). However, in 1998, 65% of the nights with trapping had >40% success while only 38% of the 1999 nights had >40% success. Numbers of pigs caught in an individual trap at one time ranged from one to 22 during the course of the entire programme, with more than one pig being caught 45% of the time during the two seasons with recorded data (Fig. 8). There were no significant differences in frequency of multiple captures between the two seasons (ANOVA; $p > 0.1$). Dogs were used almost exclusively during the cooler winter and spring months of November through April. Ground hunting occurred year round on an opportunistic basis as animals were

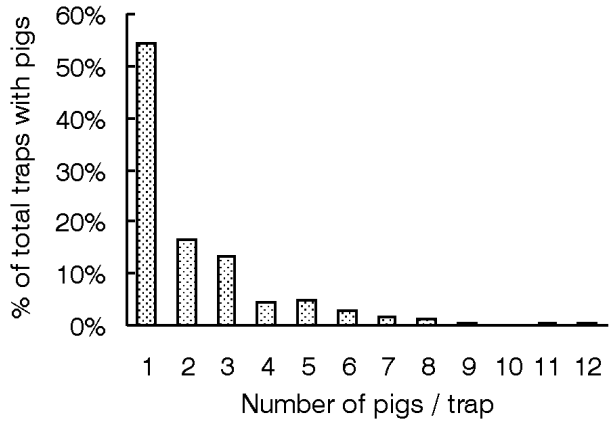

Fig. 8 Percentage of traps with single or multiple captures during the 1998 and 1999 trapping seasons in Zone 2, Santa Catalina Island (n = 268).

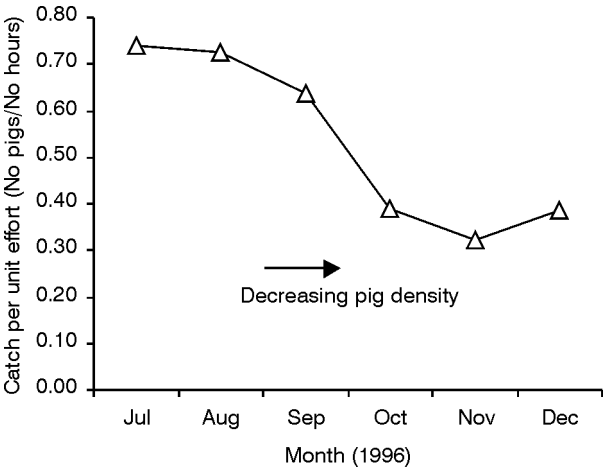

Fig. 9 Monthly catch per unit effort for July-December 1996 during initial Zone 1, Santa Catalina Island pig eradication efforts (n = 655 pigs, 1153 hours). Over 85% of all pigs eventually removed from the zone were taken during this period. Several removal techniques were used.

encountered. Helicopters were used infrequently, usually during the winter months when on the island for goat control efforts.

Catch per unit effort (CPUE) in Zone 1 decreased as the pig population went from high density to low density (Fig. 9). Monthly CPUE for several combined zones over a three year period also shows a steady decrease ranging from a high of 1.05 pigs/hour to a low of 0.03 pigs/hour. Total time efforts expended in Phases I - IV were tracked by different people in varying ways over the course of the programme. Table 2 summarises estimated totals for the programme period. Total annual effort in relation to annual take has not been calculated.

Ensuring the integrity of the fences has been adequately met using 15 volunteers who each assumed responsibility for a section of fence and checked it at least once a month.

Table 2 Total estimated effort expended on Santa Catalina Island from 1990 to September 2001 to remove feral pigs. Only Conservancy and IWS staff time shown. Time spent hunting by sport hunters, Conservancy staff or poachers is not included.

Activity	No. of person-hours expended
IWS field work	64,580
IWS administration	5265
Fence building	
- 1990 Isthmus fence upgrade	250
- 1999 fence construction	12,000
- fence monitoring (1998-Sep 2001)	1260
- fence repair (1998-Sep 2001)	775
Conservancy administration (planning and management)	6380
Education/Public relations	515
Conservancy general support: includes road repair, vehicle maintenance, material transport, fence volunteer management	5475
Total hours	96,500

Although fences suffered only minor damage due to natural or pig-related causes, vandalism of the fences occurred on a number of occasions, particularly just after their construction. Gates were left open and sections of fence, up to 15 m, were cut and removed. Fortunately, the combination of buffer zones along the fences coupled with regular monitoring and immediate repair of vandalised sections prevented any significant movement of pigs between zones.

Current status

Since this is an ongoing programme with an expected completion date no earlier than 2004, there are still pigs remaining on Catalina. Estimated pig numbers as of 1 October 2001 are no more than two in Zone 1, 15 in Zone 2, 200-250 in Zone 3, and 30 in Zone 4.

Monitoring and evaluation

Methods established for monitoring and detection have so far proven effective. Continual scouting of suspected refuges or known areas of high density generally produced the last few pigs. Regular running of dogs through an area during winter months is also effective in finding pigs when numbers are extremely low. Regular systematic hunting in Zone 1 concluded in late 1998 because no animals were known to remain and no additional sign could be found. For the next 18 months, periodic monitoring continued even in the absence of any pig sign. In late summer 2000, pig sign was observed which, while not fresh, was still less than a year old. Scouting efforts were intensified and in November 2000 a solitary sow weighing 80 kg was removed. The sow was not pregnant and did not appear to have given birth in the previous season.

Table 3 Estimated costs (USD) for feral pig removal efforts on Santa Catalina Island from 1990-September 2001. * = combined personnel and operating costs, ** = estimated cost, * = value of volunteer labour. Costs reflect only animals removed by IWS. Dollar figures not adjusted for inflation.**

Activity	Cost/Value in U.S dollars
IWS Field staff costs	
- 1990*	10,000
- 1991*	15,000
- 1992*	66,000
- 1993*	72,200
- 1994	51,958
- 1995	47,760
- 1996	76,756
- 1997	91,597
- 1998	113,753
- 1999	151,161
- 2000	162,996
- 2001 (Jan.-Sep.)	159,863
Control methods	
- helicopter	14,725
- traps - construction	60,283
- traps - bait	17,937
- dogs (maintenance costs 1990- Sep. 2001)	138,982
Fence building	
- Isthmus fence upgrade and repair**	10,000
- 1999 fence construction	
- contract labour	520,000
- materials	325,000
- Conservancy preparatory fence work	18,326
- Conservancy administration**	10,000
- volunteer help (81.5 hours)***	1208
- fence monitoring (1252 hours)***	18,900
- fence repair (1999 - Sep 2001)**	38,238
Other	
- kennels (site preparation, construction)	34,412
- vehicles	
- Four-wheel-drive trucks	169,433
- All terrain vehicles (ATV)	15,900
- value of housing and office (1-3 houses/yr)	182,690
- general supplies and operating	71,863
- overhead (IWS contract)	283,926
- Conservancy administration**	191,000
- education/public relations (time, materials)**	13,000
- Conservancy general support**	99,093
- gasoline	57,194
- utilities	25,566
- miscellaneous volunteer (38 hours)***	570
Total	3,175,517

Table 4 Age class, sex, and average weight from feral pigs killed on Santa Catalina Island from 1990-September 2001. Sample size (n) for age class = 5777 pigs, n for average weight = 5697, n for sex ratio = 5509. Piglets were defined as <2 months, juveniles were 2-7 months, and adults were >7 months old.

Age class	% of population	Average wt (kg)	Male	Female	Sex Ratio (M:F)
Piglet	18%	0.5	496	482	1:0.97
Juvenile	38%	15.7	1105	1015	1:0.92
Adult	44%	32.1	1244	1167	1:0.94
Totals	100%	20.8	2845	2664	1:0.94

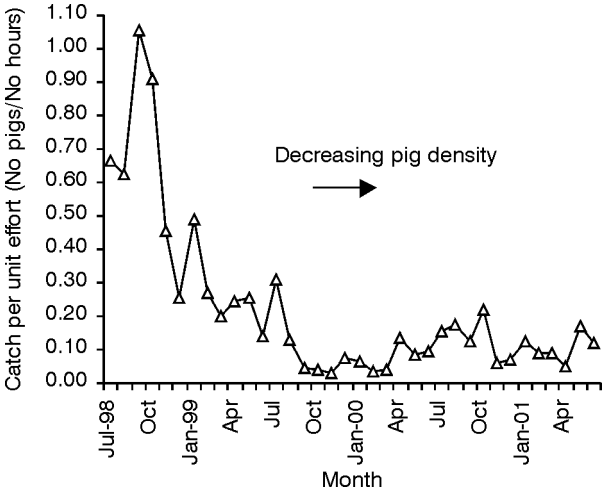

Fig. 10 Monthly catch per unit effort (CPUE) by IWS staff on Santa Catalina Island from July 1998 to June 2001 (n = 3029 pigs, 20 130 hours). Although overall pig densities decreased throughout the time period, making long-term CPUE comparisons is difficult because removal efforts annually shifted locations and seasonally changed removal methods.

Costs

There is a high cost associated with operating a removal programme of this magnitude and length. Known and estimated costs are shown in Table 3 and reflect only costs associated with pig removal efforts conducted by IWS. Current cost per animal averages out to approximately USD350/pig. If the programme stays on schedule, an estimated additional USD825,000 will be needed, bringing a final estimate for cost/pig to USD425.

Population parameters

Age, average weight and sex were noted for killed pigs whenever possible (Table 4). Data were not collected from pigs shot from helicopters nor those removed through sport hunting and poaching. Of the pigs sampled, 87% were estimated to be in average to good condition (Fig. 11; Table 5).

DISCUSSION

Removal efforts

We believe one key to the success of the removal programme to date has been the application of several different techniques. As Fig. 10 shows, trapping is successful and efficient in removing large numbers of pigs during the dry months when food resources are low; the lower the natural food supply, the better the trapping success. We recommend this technique as the starting point for managers facing a high number of pigs in a habitat with seasonal fluctuations in the food supply. For those countries or situations where poisoning is legal and feasible, poisoning could be even more effective than trapping as the initial removal method, as the poison could easily be placed in the bait and no traps would be needed. However, poisoning raises new issues, such as legality, effects on non-target species, and the humaneness of the technique. Since field poisoning of pigs is not a legal option in the United States, we did not consider it.

Dogs are less effective during the dry period and run the risk of becoming severely affected or incapacitated by barbed seeds or foxtails (the flowering heads of a number of grasses) working their way into the eyes, ears, foot pads or other open parts of the dog. During winter months, when pigs are less likely to enter traps if adequate natural food sources are available, dogs are more effective. The scent of the pig is held better on damp soil and vegetation allowing easier tracking. Hunting with dogs is useful not only during winter months when traps are less effective, but also when pig densities are low. It requires knowledgeable dog handlers and at least some "lead" dogs. An experienced "lead" dog with a sensitive nose will relentlessly search for pigs and engage the animal when located. Non "lead" dogs are still beneficial as they will follow and assist in holding the pig at bay until the hunter arrives.

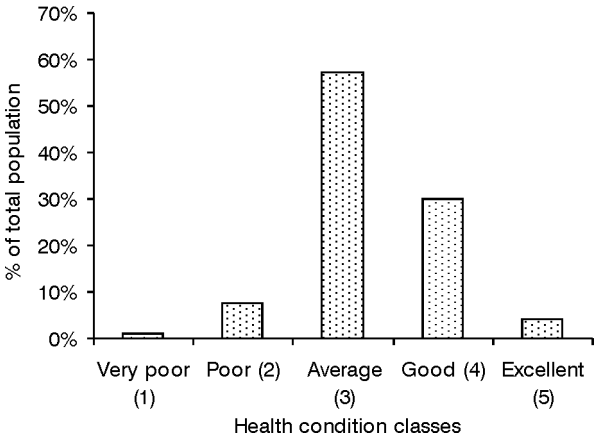

Fig. 11 Percentage of pigs on Santa Catalina Island in different health condition classes between 1994 and September 2001 (n= 5207). Class ratings based on subjective scale of very poor (1) to excellent (5) (See Table 5).

Each of the other methods used (spotlighting, ground hunting, aerial hunting, night vision hunting) provided a contribution to the programme, but each had constraints on their effectiveness depending on time of year, density of pigs, and/or physiographic features in the areas they were being employed.

Spotlighting is an effective technique at all pig densities providing a good road system is present, and tall vegetation near the roads does not obscure the shooter's line of vision. In habitats with low-growing ground cover, pigs can be shot at more than 200 m from the roads using this method. Ground hunting, which includes opportunistic shooting of pigs when conducting other activities, is likewise effective at all pig densities. However, due to safety concerns, shots could often not be taken when pigs were encountered. Aerial hunting from a helicopter can be effective in areas lacking dense woody vegetation during

Table 5 Criteria for assigning condition class for feral pigs killed on Santa Catalina Island. Criteria and averages based on Timm *et al*. (1994). Assessing the condition of these animals is subjective, particularly if animals exhibited traits in more than one condition.

Condition Class	Parasite Burden	Coat Condition	Fat Reserves	Average size for age and sex	Other physical and visual signs
Very poor (1)	very high	thin, sparse	emaciated; no fat reserves	stunted	obvious lesions and medical problems
Poor (2)	high	patchy	thin; visible bony points	<average	often disease processes evident
Average (3)	present	normal	normal muscling; lean with some fat reserves	average	no major medical problems
Good (4)	few	good	well muscled, points felt but not seen	>average	only minor visual signs of any disease
Excellent (5)	none/few	thick	very well muscled; abundant fat reserves; bony points not felt	large	no evidence of any problems

the cooler months of the year when pigs are more likely to be active during daylight hours. FLIR technology was not very successful on Catalina, probably due to heavy vegetation. Although effective, aerial hunting repeatedly caused more public concern than any other method.

Since the data collected and recorded was not designed to allow for direct comparisons of the catch per unit effort between each method, the results presented should be treated as estimates of the relative value of each technique. Due to multiple captures in a single trap, trapping accounts for large numbers of pigs early in a programme when densities are high and maintains effectiveness even during a lower-density second trapping season**.** Although the CPUE drops when using dogs, managers must remember several important factors: (1) pig densities are generally already low when dogs are used since work in all zones started with summer trapping, (2) use of traps during wet months would likely produce results with an even lower CPUE since most pigs are not interested in bait during the wet months, and (3) some pigs are "trap shy" and may not enter regardless of the bait or design used. We found the use of dogs after initial trapping to be a critical component of our success and generally increased the CPUE for a given area when first used.

Programme commitment

Even more important than any particular removal technique is the need to have organisational consensus on programme goals and full commitment and support to ensure the project is completed. It was not until the programme goal changed from control efforts to eradication that significant declines in pig numbers could be noted for any zone. Reviewing the numbers in Fig. 6, annual take remained relatively constant by zone until the goal shifted to eradication. Efforts in Phase I were effective in reducing pig numbers to less than 50 pigs in Zone 1. However, the 10 month break that occurred negated all Phase I efforts, and it was not until Phase III in 1996 that a sustained decline was again observed in this zone. Once the attempt to eradicate a pig population in an area has started, it is important to maintain or even increase efforts in order to reach the goal of zero animals. The alternative is to waste financial resources, jeopardise the natural resources we are seeking to protect, kill many animals with no lasting benefit to the resource, and possibly lose the momentum required to make the programme a success.

All programmes of this magnitude and duration will experience delays or setbacks during implementation. We experienced delays due to: (1) changing objectives on the part of some board members, (2) occasional financial constraints, (3) reduced access to areas after the 1997 El Niño winter produced near 100 cm of rain, (4) vandalism to traps and fences, and (5) occasional high turnover in staff. Without long-term commitment to the project, these types of natural and anthropogenic factors could have serious implications to the success and continuation of the programme.

Monitoring and search effort

The need for continual monitoring long after all animals are suspected to be removed is vital to success. Shutting down a large programme only to find a need to gear back up after several years could prove to be impossible if the commitment has waned or staff has moved on in the intervening years. A programme should be maintained until it is certain all pigs have been eradicated. In Zone 1, for two years we thought no animals remained, yet a 80 kg sow then appeared. Such a large animal escaping detection for an extended period of time indicates the need for monitoring to continue for a significant period after the last known sighting of any animal or sign.

Public relations and education

The need to have public relations and educational components of a control programme cannot be overemphasised. We found it is easier to be forthcoming with all aspects of a programme prior to implementation, rather than trying to defend past policies and practices. By implementing the programme in phases we had the opportunity to experience both situations in this programme. Phases I, II, and III were not actively brought to the public's attention whereas most of Phase IV had extensive prior exposure. There will always be a segment of the population who take issue with the need for such projects. We had unknown persons either capturing piglets on one part of the island or bringing them from the mainland and then releasing them in controlled areas. As long as animals remain anywhere on the island, this remains a possibility and dictates that both education and monitoring efforts need to continue long after the end of intensive field efforts. We think working with a well-researched and articulated set of goals and objectives with an informed public is better than allowing rumours and misinformation to shape the public's awareness.

Management implications

The methods used to eradicate feral pigs from Catalina are proving successful and we expect to complete the project in the next few years. The methods and results have application for eradication programmes elsewhere, although site-specific conditions will obviously play a large role in their timing, duration, and intensity. If eradication is the goal, a committed, high-intensity, well-funded effort is essential, and in the long run will be more labour efficient and cost-effective than long-term or sporadic control. We have found that all the results from even relatively-intense control efforts can be quickly lost if continual and increased pressure is not applied to achieving complete removal. An intensive, shorter programme will also lower the total number of animals needing removal. Managers who do not have the option of complete removal must seriously evaluate methods, costs, and expected results to find a programme that can be efficiently and humanely continued year in and year out.

If the Conservancy had to do this programme over, three key changes would be made. First, the programme would have been clearly defined as an eradication effort from the start. This would have reduced the overall length of the programme, reduced the amount of time subject to public relations issues, and reduced the cost of the programme to perhaps USD375/pig rather than the projected USD425/pig. Second, data collection protocols would be modified to gather more accurate figures for total costs, and total time expended as well, determining capture per unit efforts and percentage success for different methods and differing pig densities. Third, a public education programme would have been implemented prior to any control efforts and would have been continued for the duration of the entire project.

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