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# Feral cat eradication in the presence of endemic San Nicolas Island foxes

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**Abstract** Projects to eradicate invasive species from islands are a high priority for conservation. Here we describe the process used to successfully eradicate an introduced carnivore on an island where a native carnivore of similar size was also present. We primarily used padded leg-hold live trapping to capture feral cats (*Felis silvestris catus*). Trapped feral cats were transported off-island and housed in a permanent enclosure on the continent. We used additional methods, such as tracking dogs and spotlight hunting, to detect and remove more-difficult individuals. Project implementation caused no

significant negative impacts to the endemic San Nicolas Island fox (*Urocyon littoralis dickey*) population. Mitigation measures included on-site veterinary resources, modified padded leg-hold live traps, conditioned trap aversion, a trap monitoring system and personnel training. To confirm eradication, we utilized camera traps and sign search data in a model to predict project success. A key part of the success of this project was the partnerships formed between NGOs, and government organizations. With support from the partnership, the use of innovative technology to improve traditional trapping methods allowed feral cats to be removed effectively in the presence of a native species occupying a similar niche. This project shows that strong partnerships, innovative methods, and use of technology can provide the conditions to eradicate invasive species when major barriers to success exist.

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## Introduction

Roughly 3 % of the earth's land mass is comprised of islands which together harbor a disproportionately large share of species biodiversity (Aguirre-Muñoz et al. 2008). Worldwide, biodiversity has declined due

to invasive species-induced extinctions, which is primarily an island based phenomenon (Atkinson 1989). As a generalist predator, feral cats (*Felis silvestris catus*) are considered one of the top invasive threats to island biodiversity. They have contributed to at least 14 % of the world's bird, mammal, and reptile extinctions and are the principle threat to a further 8 % of critically endangered vertebrates (Medina et al. 2011). As a result, eradication of introduced feral cats from islands has become a common objective for land managers that is practiced at an increasing frequency (Campbell et al. 2011; Nogales et al. 2004).

Removal methods for feral cats continue to evolve and practitioners utilize innovative techniques to implement projects of increasing complexity that once were considered unfeasible (Campbell et al. 2011). The eradication of feral cats from San Nicolas Island (SNI), approximately 105 km off the coast of California, USA, provided a challenging environment where fewer methods for removal were available than in other locations because of the presence of an endemic subspecies of the island fox (*Urocyon littoralis dickeyi*); an ecologically comparable predator to feral cats (Hanson et al. 2010; Will et al. 2010). The island fox was classified by the IUCN as critically endangered at the time of project planning and implementation, but has since been downgraded to near threatened (Coonan et al. 2013).

The goal of this project was to restore SNI's ecosystem for seabirds and to protect other native fauna by eradicating feral cats. Initial discussions to remove feral cats from SNI began in 2004 and led to the development of a diverse partnership and innovative methods that were critical to the success of the project. Here we report on the processes by which eradication of feral cats was achieved on SNI. Funding for the planning and implementation of this project was provided through the Montrose Settlements Restoration Program (MSRP).

## Materials and methods

### The Island

San Nicolas Island (5,896 ha) is located approximately 105 km off the coast of southern California, USA. The predominantly sandstone island is characterized by low coastal areas surrounding a large central

plateau (max elevation: 290 m) with transitions between the plateau and the coastal areas marked with steep terrain comprised of cliff faces and large canyons. The island is arid and sparsely vegetated, with a few natural springs supporting pockets of trees and thicker vegetation. SNI is owned and operated by the U.S. Navy who maintains an active runway, various radar and telemetry buildings, and infrastructure to support 100–200 personnel. Access to the island is restricted to active duty personnel, federal civil servants, and contractors; large portions of the island are regularly closed due to military operations and to protect sensitive environmental and cultural sites.

### Planning

Millions of kilograms of chemicals, including DDT and PCBs, were dumped into the southern California bight between the late 1940s and early 1970s. The MSRP was established in 2001 to restore the natural resources that have been affected by these chemicals, including seabirds such as Brandt's Cormorants (*Phalacrocorax penicillatus*) and Western Gulls (*Larus occidentalis*). In 2005, the Montrose Trustee Council identified the removal of feral cats from SNI as a priority in restoring seabird habitat along the California coast (Montrose Trustee Council 2005). In the same year, the Integrated Natural Resource Management Plan for SNI recommended the control/eradication of feral cats to protect native and endemic island species and seabirds (US Navy 2005). The initial partnership for the eradication campaign included the MSRP, U.S. Navy, U.S. Fish and Wildlife Service (USFWS), Island Conservation (IC), and the Institute for Wildlife Studies (IWS). The project was a joint U.S. Navy and USFWS effort with the USFWS managing the project on behalf of MSRP. IC and IWS were cooperators that implemented the eradication methods (IC) and provided fox mitigation and monitoring (IWS). IC operated under a Cooperative Agreement with USFWS and IWS through a contract with the National Fish and Wildlife Foundation. Initial methods were proposed by IC based upon a feasibility assessment developed after a site visit in 2005. Several complicating factors such as island size, available methods, and the abundance of island foxes were identified and assessed by project partners who determined the complete removal of feral cats from

SNI was possible. Specific methods were recommended for additional review, and in 2006 a trial of padded leg-hold live trapping methods was conducted to determine the feasibility of using padded leg-hold live traps to catch feral cats while having minimal impact on the endemic, similarly sized, island fox (Hanson et al. 2010; Island Conservation 2006). Major conclusions of the trial were: cats could be removed in the presence of foxes, foxes could be made averse to trap sites, trap modifications could reduce injuries to foxes, veterinary care would be required to mitigate major injuries to foxes, and a trap monitoring system (TMS) needed to be developed and deployed to facilitate monitoring and rapidly responding to a large number of traps.

Communication and outreach to various stakeholders occurred during the planning process. Outreach and communication plans were created, along with guides to address frequently asked questions. The goal was to ensure all involved parties communicated about the project in a consistent and appropriate manner.

A draft environmental assessment (EA) was completed in 2008, and identified padded leg-hold live trapping with humane dispatch of feral cats as the primary removal method. The Humane Society of the United States (HSUS) responded to the EA offering services and assistance in identifying alternative methods. A dialogue between HSUS and the project partners ensued regarding alternatives and in December of 2008 the U.S. Navy, USFWS, and HSUS finalized a Memorandum of Agreement. The purpose of the Memorandum of Agreement was to promote coordination and collaboration in the implementation of a Pilot Program to further test the use of cage traps on SNI and the feasibility and humaneness of transporting trapped feral cats off-island. The feral cats would then be held for the remainder of their lives in a secure, enclosed facility where they would not adversely impact birds and other native wildlife on the mainland.

The Pilot Program occurred from November 2008 to January 2009 and tested a variety of cage trap sizes, configurations, and lures. Shortly after the Pilot Program concluded, a brief padded leg-hold live trapping effort was conducted in January 2009. The results of both trapping methods were analyzed and padded leg-hold live trapping was deemed to be 12–15 times more effective than cage traps for catching feral cats on SNI (Garcelon 2009).

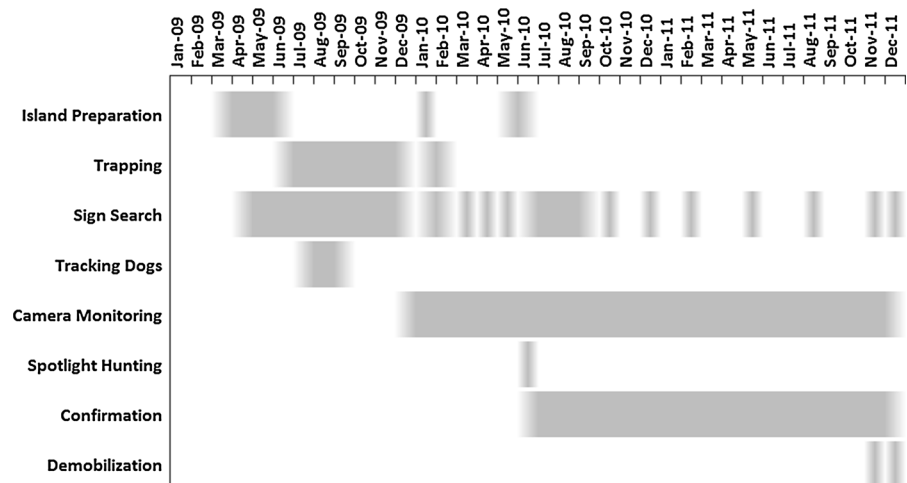
The Pilot Program also showed that it was feasible to transport feral cats from SNI to permanent enclosures on the mainland. Based on the results of the Pilot Program, the Final EA for the project was finalized in May 2009 and specified that healthy feral cats that could be safely removed from a trap site may be transferred to the custody of a USFWS-approved animal welfare organization, such as HSUS (USFWS 2009). Shortly after project initiation in June 2009, HSUS secured funding to have all trapped feral cats transported to an enclosed outdoor facility in Ramona, California.

### Implementation

Cats were removed from SNI primarily through live trapping with #1 padded leg-hold live traps (Oneida Victor, Cleveland OH, USA) set at key points across the island (Hanson et al. 2010). Trapping began in June 2009 and ended in February 2010 (Fig. 1), culminating in 30,205 trap nights. Walk-through trap sets with scented lures (a mixture of cat urine, cat feces, catnip oil and glycerin) were based on Wood et al. (2002) and refined through additional trials on Isla de la Plata, Ecuador (Hanson et al. 2010). Traps were opened in a 'rolling front' starting on the northeast end of the island and working counter-clockwise around the perimeter and into the center of the island (Hanson et al. 2010). Trap locations were scouted in advance to allow for rapid deployment. Sixty traps were opened in the first week, then the rate of progress was slowed to accommodate for the initial high number of fox captures and access restrictions on the west end of the island. A specific trap density was not mandated; trained staff determined exact trap locations based on sign search, terrain, and knowledge of feral cat behavior. It took 69 days to activate traps over the entire island and up to 236 traps were active at once. In the event of a capture, project staff would approach animals quietly and cover them with burlap fabric to obscure their vision and create a calm environment while they were safely removed from the trap. Captured feral cats were cared for by IWS until they were transferred to HSUS's facility on the mainland.

Several mitigation measures were put in place to reduce the impact to the island fox, which is abundant on SNI. Trained staff assessed each captured fox for injury. Any foxes showing signs of injury (trap related

**Fig. 1** Time sequence of activities on SNI for feral cat eradication and monitoring 2009–2011



or not) were treated at a mobile veterinary hospital that was stationed on SNI for the duration of the trapping campaign through post-implementation monitoring. The traps used on SNI were smaller than those typically used to capture feral cats and incorporated further modifications such as lighter springs and additional swivels (Hanson et al. 2010; Jolley et al. 2012). Capture events acted as a negative stimulus to foxes and induced aversion to trap locations which reduced the overall number of fox captures during the project (Jolley et al. 2012). All trap sets included a custom radio-based trap monitoring system that increased efficiency and reduced the amount of time animals spent in traps (Will et al. 2010).

Three specialized tracking dogs were brought to SNI to assist in detecting and locating feral cats (Hanson et al. 2010). Dogs are normally banned on SNI due (in part) to the risk of passing infectious disease and parasites to the fox population. The dogs used on this project were subject to extensive medical checks and on-island quarantine designed to safeguard the fox population. Dogs were used primarily as a follow-up tool after live trapping had reduced the feral cat population in a particular zone. The dogs worked the island systematically, investigating canyons and ridges initially, before searching back and forth across flat topography. The dogs and handler were each equipped with GPS units to record coverage and help identify gaps. The use of dogs occurred from July to September 2009, after which the dogs were removed from the island.

Project data were recorded in ruggedized field computers equipped with GPS capabilities and customized software (Will et al. 2010). The simple touch-screen interface allowed for the rapid collection of spatial and non-spatial data related to trapping, captures, sign search and monitoring. Data were uploaded into a central database daily to allow for near real-time tracking of project progress (Will et al. in press).

Camera traps were used extensively from January 2010 to December 2011. Trials using two camera traps (Reconyx, Holmen, WI, USA) in late 2009 confirmed that at least one feral cat was still present on the island. In January 2010, an additional 24 camera traps were deployed along key travel routes across the island. Camera traps remained active from January to May 2010 in an effort to detect residual animals as well as track the movements of the previously detected feral cat. The trapping network had been deactivated during this time to eliminate risk to the foxes during their pupping/rearing season. Monitoring during this period required staff to periodically visit the island to recover and analyze photo data, and move or adjust cameras if necessary. In June 2010, camera traps detected an additional feral cat, and an additional 28 (for a total of 54) camera traps were deployed to improve the frequency of detections and reduce gaps in monitoring coverage.

Detection data informed spotlight hunting efforts in June 2010. Three staff including a designated shooter searched for animals while driving slowly and

sweeping spotlight beams across the landscape. Hunting efforts covered all roads and all-terrain vehicle trails while giving priority to areas where feral cat activity had most recently been detected. Protocol required all three staff members to identify detected animals to species before a shot could be considered.

Camera trap and sign search data satisfied the conditions of a model that was created to quantify the chances that a feral cat remained undetected on SNI (Ramsey et al. 2011). The model was created in early 2010 using removal and detection effort data collected earlier in the project to determine the amount and type of additional detection effort necessary to be 99 % confident that eradication was achieved while balancing the financial costs of unnecessary search effort with the cost of re-doing the eradication should success be declared prematurely. During this process it was noted that having baseline data is advantageous as it will improve the model's statistical significance if collected prior to implementation of the project.

Camera traps remained deployed on-island for an additional 15 months after the model's first parameter was satisfied. The primary reason for the additional effort was to meet the monitoring requirements laid out in the EA, but also to build confidence in the detection model. Staff made additional trips to SNI every 2–3 months to check and relocate camera traps. Demobilization of project equipment and supplies from SNI occurred in December 2011 once the partnership agreed that the eradication of feral cats was successful.

The project was broken into four phases for the purpose of analyzing costs: planning (including legal compliance), implementation, confirmation, and fox mitigation. The planning phase occurred from 2004 to June 2009 and included all costs associated with scoping, planning, eradication trials, and the compliance process. Implementation ran from June 2009 to June 2010 and included all costs associated with the actual removal of feral cats from SNI. Confirmation ran from June 2010 to December 2011 and included the costs of fulfilling the confirmation model and all additional camera monitoring. Veterinary care was provided to any fox encountered that was considered to be injured or sick to mitigate for project related injuries or casualties. Although some veterinary costs were accrued during early trials, mitigation occurred primarily during implementation from March 2009 to

November 2012 and included the costs of the fox veterinary facilities and pre- and post-project fox monitoring by IWS. Mitigation costs associated directly with the removal methods (e.g., the TMS) are included within the implementation phase.

## Results

### Partnership

The Draft EA received 5,788 comments. Of those, 1,465 were unique comments and 4,323 were identical form letter statements regarding the project. Many comments suggested various alternatives to remove or manage feral cats without euthanizing them, or that the proposed methods were illegal or inhumane. Comments were grouped by topic and responses were included as an appendix to the Final EA. The public comment process, along with other discussions, collaboration with HSUS, and trials, ultimately resulted in a change in the project plan from dispatching feral cats on-site to transferring alive them off-island. No lawsuits intending to stop or delay the project were filed.

The eradication of feral cats from SNI was a complex project so problems during the project were expected and an adaptive and collaborative management approach was taken to overcome issues. Important issues regarding impacts to wildlife, military operations, or changes to the operational plan were addressed by the partners throughout the project. For example, the original plan did not require special considerations during rain events; however the implementation occurred during an El Niño year, resulting in unusually high rainfall. In order to reduce exposure impacts to trapped foxes and ensure the safety of project staff, a specific protocol for rain events was developed. The protocol included reducing the overall number of activated traps, removing traps from the bottoms of drainages and difficult-to-access locations, and responding to triggered traps 24-h a day during rain events. Issues of lesser significance were dealt with by implementation staff on an as-necessary basis.

### Costs

The project cost approximately 2.9 million US dollars to complete. Of that, 5.5 % was spent on planning and

compliance, 54.5 % was spent on implementation, 16.7 % was spent on the confirmation phase of the project, and 23.3 % was spent on fox mitigation and on-island feral cat handling and care. The largest line-item expense was personnel costs, comprising 42 % of the implementation and confirmation phase. These costs do not include funds spent by HSUS to transfer feral cats off-island, or the costs associated with building and running the feral cat facility at The Fund for Animals Wildlife Care Center. Also not included are in-kind resources provided by the Navy, such as the use of a bunkhouse, a building utilized as a base-station and workshop, transportation to the island, and utilities.

### Implementation

A total of 66 feral cats were removed from SNI during the eradication campaign, not counting 10 kittens that were born in captivity while awaiting transfer to the mainland. Seven feral cats (10.6 %) were removed during the Pilot Program and the padded leg-hold live trapping efforts between November 2008 and January 2009, four by cage trap and three by padded leg-hold live trap. Fifty-one feral cats (77.2 %) were removed via padded leg-hold live trapping between June 2009 and February 2010, one feral cat (1.5 %) was shot prior to initiating live transfer off-island, one (1.5 %) was captured by hand, and four (6.1 %) were detected by dogs and dispatched. The final two feral cats (3 %) were removed via spotlight hunting in June 2010.

A total of 1,011 fox capture events occurred involving 459 individual foxes [identified via passive integrated transponder (PIT) tags] between June 2009 and February 2010. Fox captures were highest when initially beginning to trap in an area and reduced over time. 95.3 % of captured foxes received no or only very minor injuries. Four foxes are known to have died as a direct result of the eradication efforts; three died as a result of trapping (one from hyperthermia and two from hypothermia) and one was killed by a tracking dog. The rigor of project monitoring data, including examination of recaptured foxes, provides confidence that few, if any, significant injuries or mortalities went undetected.

Camera traps photographed a large, light-colored feral cat in late December 2009. Padded leg-hold live traps were not successful at removing this animal before trapping stopped at the end of January 2010 to

accommodate the fox pupping season. The feral cat was detected an additional 10 times between February and May 2010 (Fig. 2); coloration, stature and a distinctive kink in the tail provided confidence that all photos were of the same individual. Detections occurred over a large portion of the island indicating the animal was ranging over one-third to one-half of the island, though no core area of activity could be identified.

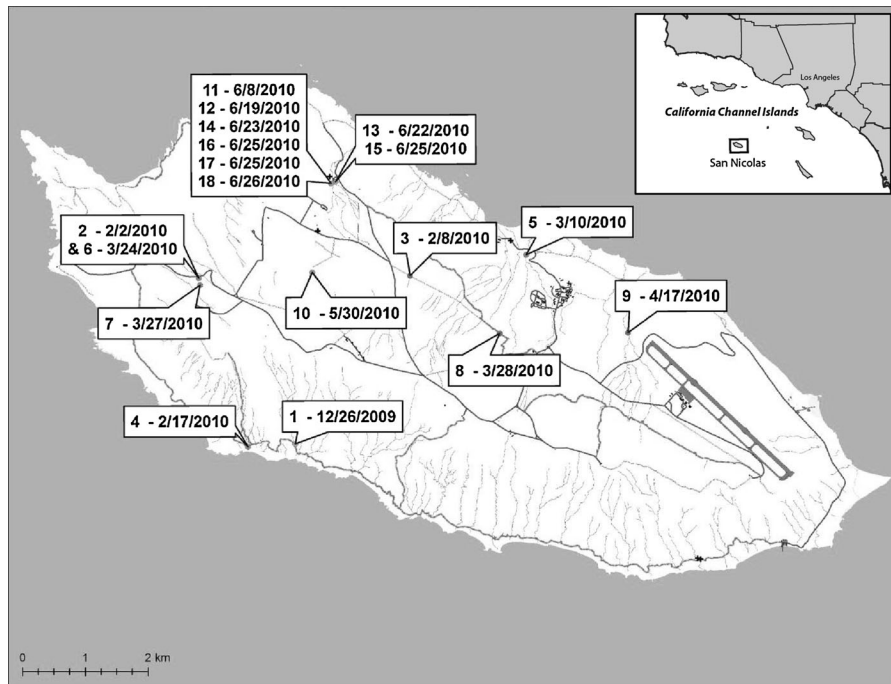
Camera traps detected an additional individual near a small ravine on June 22, 2010; the feral cat was small in stature, dark in color with a distinct pelage pattern, and was believed to be female. The ravine contains a fresh-water spring and is heavily vegetated. Sign search within dense vegetation located large latrines, indicating feral cats were frequenting the area. Additional camera traps were placed in the surrounding area and captured images of the previously detected feral cat interacting with the newly detected individual.

Camera trap data informed the spotlight hunting strategy which allowed for the successful removal of the last two feral cats. Spotlight hunting was conducted by the team for 69.4 h and covered 403.2 km of roadway over 12 nights. The larger, light-colored feral cat (male) was removed on June 25, 2010 and the smaller feral cat (female) was detected and removed the following night. The feral cats' pelage patterns were compared to photos and confirmed the animals were the two that had been previously detected. A necropsy determined that the female was pregnant. Tissue samples of both adult feral cats and fetuses were sent for genetic analysis which suggested with high certainty that the male was the father. However, it was noted that a high level of inbreeding in the island's feral cat population is likely which increases the chance of misidentification of parentage without testing a greater portion of the population.

The model described in Ramsey et al. (2011) was satisfied at the end of August 2010 with zero feral cat detections after 3,294 camera trap nights and approximately 270 km of sign search, resulting in a posterior probability of a feral cat remaining of <0.0003. Cameras remained active on-island until December 2011, ultimately resulting in 27,224 camera trap nights.

### Discussion

As of this writing, SNI is the fifth largest island in the world to have had feral cats eradicated, and the largest



**Fig. 2** Map of feral cat photo captures listed in order December 2009–June 2010

feral cat eradication completed without the use of toxicants (Campbell et al. 2011; Island Conservation 2014a). Innovative measures allowed feral cat removal to occur without negatively impacting the population of island fox, a similar and more abundant non-target species, while strong organizational partnerships allowed complex socio-political factors to be navigated efficiently. Partnerships between diverse organizations, such as governments and NGOs, must feature partners with strong organizational identities working to maximize the benefit to their respective goals (Brinkerhoff 2002). Invasive species eradications may align with the primary goals of different organizations in different ways, so identifying roles and responsibilities is important. A solid conservation need can be the basis of a good partnership (Trauger et al. 1995); a criterion that is easily met on-islands.

The decisions and partnership with HSUS that allowed feral cats to be removed alive from SNI benefitted the project by garnering widespread support and demonstrates the value of collaboration with concerned parties. Live-removal can demonstrate a commitment to high animal welfare standards and potentially reduce delays and project costs by avoiding litigation. On SNI, the agreement to remove as many

feral cats as possible alive from the island was a direct result of public comment and a desire by the partners to be responsive to this public sentiment. Live-removal was a suitable option on SNI though this concept has increased risks and may not be applicable to projects elsewhere. Consideration must be given to the welfare of captive wild animals when being held in, and transferred from, a remote location. It may be more humane to utilize lethal methods on-site if the appropriate resources for long-term care and transport are not available. HSUS took on significant costs and efforts to coordinate flights off the island and provide long-term care for the feral cats. The project incurred additional expenses in processing and holding animals until transport off-island was arranged. When deciding on whether or not to incorporate live-removal in future eradication projects, managers will have to take into account issues relating to the real and perceived aspects of humaneness, logistics, economics, and socio-political implications.

This project would not have been feasible without multiple mitigation measures to reduce the impact on-island foxes. Without modified trapping techniques, avoidance of breeding season, the TMS, and an on-island veterinary service, the impact to the fox

population would have been unacceptable. Capture events acted as a negative stimulus for aversive conditioning reducing the total amount of fox captures; otherwise fox captures would have overwhelmed staff and precluded feral cats from being captured (Jolley et al. 2012).

It is recommended that small-scale trials be considered to inform complex and innovative projects. The 2006 trapping trials on SNI assisted with project budgeting, particularly the implementation phase, and provided foresight on fox injury rates, leading to further trapping modifications and the decision to have veterinary facilities present during the eradication campaign.

Eradication confirmation monitoring was an important component of the project. This phase was significantly greater than recommended by the model; however, continuing monitoring for over a year more than indicated by the model provided a valuable and relatively low-cost opportunity to test and confirm the model's accuracy. Site-specific modelling will continue to be of value on complex projects. If used, modelling should play a larger role in the overall project and begin early in the project process. The SNI model could have been improved by gathering additional island-specific data such as feral cat home range size and behavior (through GPS collars), having marked cats within the population and by more aggressively testing the probabilities of detecting feral cats through various methods such as sign search, camera trapping, and spotlighting. To aid in declaring eradication success, it is recommended that a probability of detection model be considered when implementing large or complex eradication projects.

The length of time required before we were able to detect the final cat, combined with the fact that this individual was a pregnant female, highlight the need for efficient and effective detection and removal methods throughout the life cycle of the project. Equally important are the tools used to confirm project success. The cost of removing individuals recruited into the population via reproduction at a late phase of the project could be very high. Even worse, declaring success and stopping work too early could invalidate years of work. Proper planning is necessary, and resources should be in place to ensure the project is followed through to completion.

High fox density resulted in an abundance of fox tracks, obscuring feral cat prints and inducing fatigue in

staff performing sign search. Foxes were observed defecating on top of feral cat scat and we found indirect evidence that foxes may have consumed feral cat scat in some situations, reducing our ability to detect feral cats. The sheer amount of fox sign encountered and a lack of positive reinforcement through locating feral cats hampered the effectiveness of tracking dogs. Before camera traps were available, a padded leg-hold live trap capture was our most effective way of detecting feral cats at low populations. Camera traps allowed us to consistently detect feral cats when trapping wasn't allowed during the fox pupping season. The effectiveness of camera traps gave the eradication team confidence in their ability to monitor for feral cats and confirm eradication success. Future projects should utilize camera traps throughout the project; if possible, gathering data before removal begins. This will help guide eradication strategies and will provide more robust data to inform an adaptive management plan and a probability of detection model.

At \$500/ha, removing feral cats from SNI was more expensive per hectare than any other feral cat eradication (Campbell et al. 2011). Of particular interest for comparison is Faure Island, which is effectively the same area (5,800 ha) yet was completed at \$4/ha. The primary method on Faure Island was the aerial broadcast of toxic bait (Algar et al. 2010); an option that would have posed a serious threat to the SNI fox as well as the island endemic subspecies of deer mouse (*Peromyscus maniculatus exterus*). These two examples demonstrate that when developing a project, particularly an accurate budget, the location and at-risk non-target species can result in significant changes including alternative methodology, compliance and mitigation components.

Cost efficiency is a common concern on all eradication projects, regardless of the project scale or budget. The SNI cat eradication wouldn't have been possible within the existing constraints and budget without the innovative use of technology. Centralized and automated data management increased efficiency, facilitated adaptive management responses, and allowed frequent and accurate updates to be provided to management and partners (Will et al. 2010, Will et al. in review). The use of a TMS allowed fewer staff to respond to traps more quickly reducing staffing costs; the largest project expense.

The strategies employed on SNI can be applied directly to other islands with invasive cats in the

presence of a similarly sized native predator. For example, feral cats live on-islands with two other subspecies of the island fox (Brand Phillips 2007; Guttilla and Stapp 2010; Island Conservation 2014a). On Cozumel Island in Mexico, feral cats exist alongside four other native and endemic carnivores of similar size (Island Conservation 2014b). Eradication of feral cats on a large island like Cozumel is unlikely in the near future, but the methods from SNI could be used in control programs to great effect. Eradicating or controlling feral cat population may reduce direct competition with native predators, direct predation of native predators, compounding effects on native prey species or some combination thereof.

The tools developed and used on SNI, as well as the lessons learned help set the stage for larger and more complex eradications. Strong partnerships will facilitate the navigation of complex planning, compliance and project management processes. Trap monitoring systems will allow staff to manage a greater number of traps in a larger area, and reduce response time. Modelling will be used to track project progress and inform a cost effective confirmation strategy. Greater refinement of current techniques along with future innovations will allow invasive species to be removed from islands where eradication projects would not currently be possible or cost effective.

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## References

- Aguirre-Muñoz A et al (2008) High-impact conservation action: invasive mammal eradication from the islands of western México. *Ambio* 37:101–107. doi:10.1579/0044-7447(2008)37[101:HCIMEF]2.0.CO;2
- Algar D, Angus GJ, Brazell RI, Gilbert C, Withnell GB (2010) Eradication of feral cats on Faure Island, Western Australia. *J R Soc West Aust* 93:133–140
- Atkinson I (1989) Introduced animals and extinctions. In: Western D, Pearl MC (eds) *Conservation for the twenty-first century*. Oxford University Press, New York, pp 54–75
- Brand Phillips R, Winchell CS, Schmidt RH (2007) Dietary overlap of an alien and native carnivore on San Clemente Island. *Calif J Mammal* 88:173–180. doi:10.1644/06-mamm-a-015r2.1
- Brinkerhoff JM (2002) Government-nonprofit partnership: a defining framework. *Public Adm Dev* 22:19–30. doi:10.1002/pad.203
- Campbell KJ, Harper G, Hanson CC, Algar D, Keitt BS, Robinson S (2011) Review of feral cat eradications on-islands. In: Veitch CR, Clout MN, Towns DR (eds) *Island invasives: eradication and management*. IUCN, (International Union for Conservation of Nature), Gland, pp 37–46
- Coonan T, Ralls K, Hudgens B, Cypher B, Boser C (2013) *Urocyon littoralis*. The IUCN red list of threatened species. Version 2014.1. <http://iucnredlist.org/details/22781/0/>. Accessed July 22, 2014
- Garcelon D (2009) Report on testing of methods to remove feral cats from padded leg-hold traps, San Nicolas Island, California. Institute for Wildlife Studies, Arcata
- Guttilla DA, Stapp P (2010) Effects of sterilization on movements of feral cats at a wildland–urban interface. *J Mammal* 91:482–489. doi:10.1644/09-mamm-a-111.1
- Hanson CC, Bonham JE, Campbell KJ, Keitt BS, Little AE, Smith G (2010) The removal of feral cats from San Nicolas Island: methodology. Paper presented at the 24th vertebrate pest conference, Sacramento, CA, pp 72–78
- Island Conservation (2006) Restoring seabird populations on San Nicolas Island: testing techniques to remove feral cats. Santa Cruz, CA
- Island Conservation (2014a) Database of island invasive species eradications. Hosted by Island Conservation. <http://diise.islandconservation.org/>. Accessed May 16, 2014
- Island Conservation (2014b) Threatened island biodiversity database. Hosted by Island Conservation. <http://tib.islandconservation.org/>. Accessed May 16, 2014
- Jolley WJ et al (2012) Reducing the impacts of leg hold trapping on critically endangered foxes by modified traps and conditioned trap aversion on San Nicolas Island, CA, USA. *Conserv Evid* 9:43–49
- Medina FM et al (2011) A global review of the impacts of invasive cats on-island endangered vertebrates. *Glob Change Biol* 17:3503–3510. doi:10.1111/j.1365-2486.2011.02464.x
- Montrose Trustee Council (2005) MSRP restoration plan and programmatic EIS/EIR. Report of the Montrose Natural Resources Trustee Council, National Oceanic and Atmospheric Administration, U.S. Fish and Wildlife Service, National Park Service, California Department of Fish and Game, California Department of Parks and Recreation, and California State Land Commission
- Nogales M et al (2004) A review of feral cat eradication on-islands. *Conserv Biol* 18:310–319. doi:10.1111/j.1523-1739.2004.00442.x
- Ramsey DSL, Parkes JP, Will D, Hanson CC, Campbell KJ (2011) Quantifying the success of feral cat eradication, San Nicolas Island, California. *N Z J Ecol* 35:163–173
- Trauger DL, Tilt WC, Hatcher CB (1995) Partnerships: innovative strategies for wildlife conservation. *Wildl Soc Bull* 23:114–119

- US Navy (2005) Integrated natural resources management plan San Nicolas Island, CA, 2006–2010
- U.S. Fish & Wildlife Service (2009) Final environmental assessment for the restoration of San Nicolas Island's seabirds and protection of other native fauna by eradicating feral cats. Report on behalf of the Montrose Settlements Trustee Council and U.S. Navy
- Will D, Campbell K, Holmes N (in review) Using digital data collection tools to improve overall cost-efficiency and provide timely analysis for decision making during invasive species eradication campaigns. *Wildl Res*
- Will D, Hanson CC, Campbell KJ (2010) A trap monitoring system to enhance efficiency of feral cat eradication and minimize adverse effects on non-target endemic species on San Nicolas Island. Paper presented at the 24th vertebrate pest conference, Sacramento, CA, pp 79–85
- Wood B et al (2002) Removing cats from islands in northwest Mexico. In: Veitch CR, Clout MN (eds) *Turning the tide: the eradication of invasive species*. IUCN SSC Invasive Species Specialist Group, IUCN, Switzerland, pp 374–380