A Trap Monitoring System to Enhance Efficiency of Feral Cat Eradication and Minimize Adverse Effects on Non-Target Endemic Species on San Nicolas Island

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ABSTRACT: Feral cats have significant negative impacts on island ecosystems and are a major threat to resident seabird populations. In an attempt to restore populations of Brandt's Cormorants, western gulls, and other native species on San Nicolas Island, California, feral cats were targeted for eradication. In over 83 successful feral cat eradications from islands, removal by padded leg-hold traps was the most commonly used eradication technique. However, the size of San Nicolas, 5,896 ha (14,562 acres) and the presence of >600 diminutive (average 1.7 kg) endemic island fox presented challenges. A telemetry-based trap monitoring system was developed to remotely check trap status, decrease staff time spent checking traps, and decrease response time to captured animals to limit fox injuries and mortalities due to exposure. This system enabled a team of 6 staff to maintain daily checks of approximately 250 traps and have a response time to captures of <60 minutes during daylight hours. Field staff were trained to assess fox health in the field, and a mobile veterinary hospital was established on island to treat any injuries. The trap monitoring system was composed of transmitter units connected to traps, an island-wide repeater system, a GIS database with field PDA data collection, and a user interface hosted on a local internet network. When activated, each transmitter sent a trap-specific ID code every 4 hours, indicating it was operational. When sprung, a modified ID code was transmitted every 30 minutes until the trap transmitter was reset. Repeaters relayed trap status data, both to a dedicated PC where a set of scripts filtered the raw data to find capture events, and simultaneously to the internet. A web-based software user interface was designed to combine capture events with location information from a GIS database, allowing field staff to quickly identify which traps were sprung and plan the most effective route between all sprung traps. Ultimately, this system was a powerful adaptive management tool that increased staff efficiency and minimized effects on non-target species.

KEY WORDS: data collection, eradication, *Felis sylvestris catus*, feral cats, island restoration, non-target species, San Nicholas Island, trap alarm, trap monitoring, trapping

INTRODUCTION

San Nicolas Island is located in the southern California Channel Islands, 60 miles (97 km) off the coast of Los Angeles, and is an arid and sparsely vegetated island owned by the U.S. Navy. The Trustee Council for the Montrose Settlements Restoration Program (MSRP) identified the removal of feral cats (*Felis sylvestris catus*) from San Nicolas Island as a priority to restoring seabird populations affected by past releases of DDT off the coast of southern California (USFWS 2008). Feral cats are one of the greatest threats to seabird populations on islands, including Brandt's cormorants (*Phalacrocorax penicillatus*) and western gulls (*Larus occidentalis*), the federally threatened island night lizard (*Xantusia riversiana*), and the endemic deer mouse (*Peromyscus maniculatus exterus*). The removal of introduced species, including feral cats, has become a widely accepted method for restoring the natural balance of island ecosystems (USFWS 2008). Therefore, the eradication of feral cats was proposed to offset the effects of DDT releases on native seabird populations.

Cats have been successfully eradicated from 83 islands world-wide; use of padded leg-hold live traps was

by far the most common and effective technique for capturing cats in successful campaigns (Campbell et al. 2011). However, due to the large presence, >600 individuals (Garcelon and Hudgens 2008), of the endemic island fox (*Urocyon littoralis*), their diminutive size (1.5 - 3 kg), and fox cohabitation with feral cats, a comprehensive injury mitigation plan was necessary before the project could begin. A trapping trial, eradication plan, and injury mitigation plan all focused on reducing adverse effects caused by trapping on island foxes. Key points to mitigate negative impacts of trapping on foxes included:

1) No trapping during critical months in the fox reproductive cycle, i.e., when young pups are dependent.
2) Use of customized Oneida Victor® #1 Soft Catch® leg-hold live traps, as opposed to the standard #1.5 and #2 traps used in most eradication campaigns (Hanson et al. 2010).
3) Standardized walk-through trail sets used to avoid vegetative entanglement and reduce the risk of injury from restraint (Hanson et al. 2010). Also, a trial conducted in 2006 showed that island foxes

had the capacity to learn to avoid walk-through sets (Island Conservation, unpubl. data).

4) Establishment of an on-site veterinary clinic with personnel that can respond to potential injuries in the field and care for short- and long-term patients (operated by the Institute for Wildlife Studies, Arcata, CA).

5) Finally, a trap monitoring system would be developed to reduce extended exposure in traps, and allow staff to quickly attend to sprung locations, dramatically reducing the chance of injury (Larkin et al. 2003, Ó Néill et al. 2007).

The primary motivation for this monitoring system was to reduce potential fox injuries and casualties. However, with the amount of time and resources planned to be spent on developing such a system, we wanted to produce a system that would provide additional benefits; namely, reducing the total project cost by increasing staff efficiency and reducing the number of staff required to maintain the desired level of trapping effort.

METHODS
Design Goals

Before designing a trap monitoring system, we established several criteria to determine that the system would be both reliable and increase staff efficiency. Similar to previous trap monitoring systems, we wanted a system that updated regardless of trap status (Marks 1996). A system with a single state, which was activated by a sprung event, was not desirable because there was no failsafe for a monitor failure; the system did not provide a "heartbeat" verifying that it was operational (Larkin et al. 2003). Additionally, systems like those described in Hayes 1982, which used the absence of a signal to signify that a trap was sprung or required maintenance, were not desirable, because with a high number of anticipated traps sites it was critical to prioritize sprung locations over those that required maintenance. With two states, active and sprung, staff would be able to detect a trap in the field that had not reported after time elapsed for several update cycles, and respond to the location, thereby providing a failsafe for monitor failure (Powell and Proulx 2003). Furthermore, they would be able to differentiate between sprung events and traps that required maintenance.

Another consideration was that the monitor's design and attachment system must not interfere with trap function or pose a risk to a trapped animal, while still being easy to visually inspect and maintain. Monitors attached to the bottom of a trap were not preferred because they required un-bedding a trap to maintain or adjust system function (Halstead et al. 1995). Addition-ally, we required that the units be able to communicate when traps were placed in deep ravines. This made it necessary to have a separate, extendable reporting unit. As San Nicolas Island does not receive cellular phone signal systems, we were unable to utilize trap monitoring systems developed that utilize that infrastructure (Larkin et al. 2003, Ó Néill et al. 2007). Instead, we used a network of existing repeater stations already located on island. Finally, we wanted to design units that were watertight, lightweight, user-friendly, and had long battery life (>6 months) for extended use.

Regular visits to remotely monitored traps are still necessary to check on site conditions and conduct routine maintenance caused by weather or animals avoiding sets, but visits can occur less frequently than traps without a trap monitoring system (Powell and Proulx 2003). We hypothesized that a monitoring system meeting these criteria would greatly increase staff productivity and efficiency by reducing the frequency of visits to a trap site, allow managers to dedicate staff time to other activities, and reduce injury rates to trapped animals.

Monitor System Design

A network of 10 repeater stations located across the island provided adequate coverage to receive telemetry signals from monitors placed in the field. Repeater stations were developed by Communications Specialists, Inc. (Orange, CA) and installed on San Nicolas Island prior to this eradication project, as a means of deriving survival rates and determining age-specific causes of mortality in the island fox (Hudgens et al. 2007). The stations were designed to collect a variety of data including transmitter ID, data from movement sensors (to determine mortality), GPS location data, and receiving station battery voltage. Each station consisted of a receiving/transmitting antenna, receiver and transmitter, and solar-charged batteries.

A single station was also configured to transmit the data to Santa Catalina Island, which was then sent on to the mainland where it was received and put on the internet. Additionally, a direct receiving terminal was installed on San Nicolas Island, which allowed data to be printed to a text file where a web-based software program could interpret and present to staff, independent of the internet-based system. These two independent reporting systems allowed staff both on and off island to check the status of trap locations. The internet-based system was used during a trial period, but because of intermittent power issues and difficulty in accessing the internet, the project relied on the data receiver and used the internet-based system as a backup.

Monitor units consisted of a magnet, sensor puck with a metal stake, and transmitter (Figure 1). The sensor puck was staked into the ground approximately 1 - 2 m away from the trap site and connected to the transmitter by lamp cord which could be cut to a desired length. The transmitter unit was placed to maximize signal coverage, which often required 10 - 20 m extensions to be placed out of ravine bottoms. A magnet was placed into the puck and attached to the metal stake by heavy monofilament line, while taut sewing thread connected the magnet to one jaw of the padded leg-hold trap. The puck contained an internal magnetic switch, similar to those on a radiotelemetry collar, which determines the state of the trap depending on the presence of the magnet (Halstead et al. 1995). When the magnet was in the puck, the trap was in the standby state, and when the trap went off and pulled the magnet out of the puck, it was in the active state. Placement of the puck and transmitter away from the trap circle was critical to ensure that a trapped animal could not damage or disable the transmitter unit, and so that the animal could not become entangled with the unit and cause injury. Additionally, sewing thread

was used so that animals could break it if entangled, further avoiding injuries. The thread selected was strong enough to pull the magnet from the puck, but would break at the knot on the trap when the animal moved with the trap attached.

Each monitor was assigned a unique ID code that was transmitted by repeater stations to the two redundant reporting systems. A unit in the active state would transmit the unique ID code at 4-hour intervals, while a unit that was in the sprung state would transmit at 30-minute intervals and add a symbol in front of the ID code to designate the change in state. A delay of 3 minutes between state changes was integrated into the system to allow staff to conduct maintenance at a trap location without overburdening the network with unnecessary transmissions.
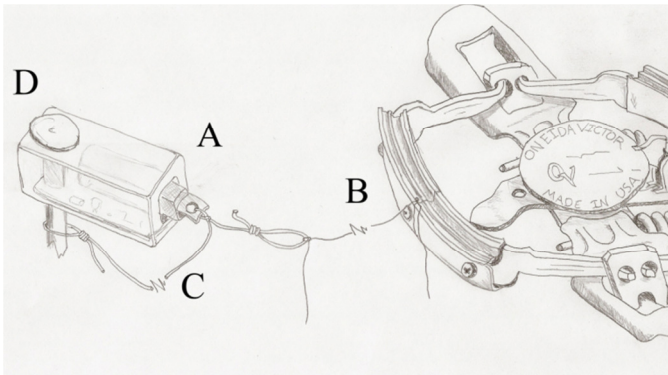

Figure 1. Leghold trap monitor attachment system.

A) Plastic puck that contains an internal magnetic switch and a free-moving magnet that determines the trap's state. B) Sewing thread that attaches the magnet to a jaw of the leghold trap, and removes the magnet from the puck when the trap is sprung. C) Heavy monofilament line attaches the magnet to a stake for easy retrieval after a trap is sprung. D) (not shown) **Lamp cord connects the puck and internal magnetic switch to the transmitting unit.**

GIS and Field Computer System

To maximize the efficiency of data collection, each staff member was equipped with a handheld ruggedized field computer with GPS (Archer PDA, Juniper Systems, Logan, UT) running a customized version of ESRI's ArcPad 7.1.1 (ESRI, Redlands, CA). Each GPS unit integrated with a Microsoft SQL Server Express 2005 ArcSDE geodatabase that captured information about trap checks, trap sets, trap deactivations, captures, location of cat sign, and an activity tracklog for each individual. Customized drop-down menus standardized data entry options and required field staff to choose from preset options. The database and ArcPad interface took the place of paper forms and streamlined the process of gathering information in the field and post-processing at the end of every day. All traps placed on island were managed using this system, and every time staff members visited a trap site they recorded information about its status and any action taken. By capturing information about trap checks and trap resets, we were able to use the database to create a regular maintenance schedule that included a visual inspection of each trap every 5 days. At the end of each field day, data from the Archers were checked in and synchronized with the database. Once all of that day's data had been incorporated, an updated version of the geodatabase was uploaded to each Archer, ready for the next day in the field.

One critical function of the Archer was to associate each trap's location with its unique monitor ID. This association merged geographic field data with transmission information from the trap monitors. It was imperative that the data collection system be designed so that a trap could only be registered with a single, unused, monitor ID. This eliminated potential monitoring failures by preventing multiple traps from being incorrectly registered to the same unique monitor ID.

PC User Interface

The open source server *WampServer 2* (http://www.wampserver.com) hosted a local server on the GIS computer providing a platform for a web-based software user interface. The HyperTerminal program *Termite* (http://www.compuphase.com) received incoming signals from the data receiver and recorded it to a text file stored on the computer. A set of scripts written in PHP were hosted on the web server and combed the monitor transmission information, tracking signal states and the time of state changes. Additionally, the Microsoft SQL Server Driver for PHP (Microsoft, Redmond, WA) allowed the webscripts to communicate with and query the ArcSDE geodatabase containing information collected by the Archer field computers. This final step created a relationship between the most recent transmission information and their corresponding geographic location.

A graphical user interface, also written in PHP, displayed several important signal categories, sorted by geographic zone: Sprung, No Signal >12 Hours, Inactive Trap Has Sprung, Unknown Monitor Has Sprung (Figure 2). The last three categories were important for identifying any potential monitor failures by reporting all sprung monitor states and the lack of a status update from a known active trap. If a monitor failed to report the active state after three expected updates, personnel would be notified that a potential failure had occurred and respond to check on the condition of the trap and monitor. In the event that a new trap was placed and was sprung before its information was recorded in the geodatabase, it would be displayed in the Unknown Monitor Has Sprung category. Also, when the internet was available, the user interface utilized Google Maps and Geo XML to overlay the locations of traps identified in signal categories on a basic map of SNI. Each signal category was color coded to assist managers in staff deployment and task coordination.

Because timestamps were associated with each monitor transmission, the user interface was able to track time between a monitor's change in state, which produced a capture length or response time to a sprung event at a specific location. By comparing timestamps for a specific location to timestamps recorded by field staff during a response, it was possible to associate capture duration and capture time to a specific animal and
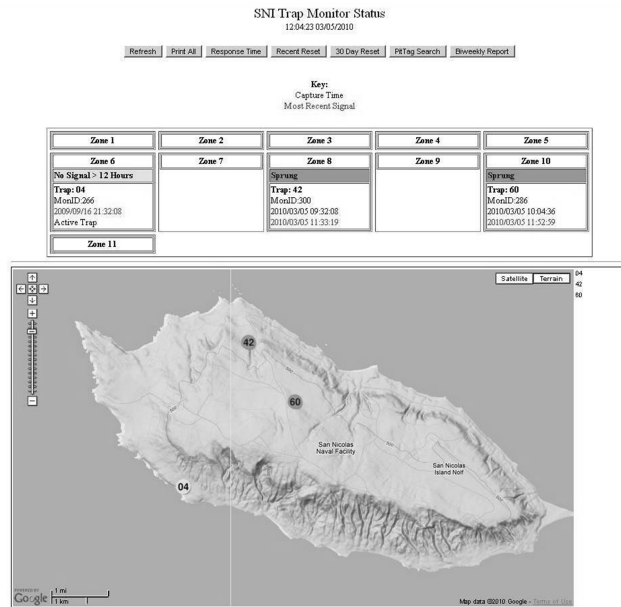
Figure 2. The PC User Interface was designed using web-based software and showed the most recent information about monitor signal states. This example shows two traps in the sprung state, and a monitor that requires checking because it has not updated its status in over 12 hours.

location. This was a particularly powerful association that allowed managers to gain insight into animal movement patterns and track response time to capture events. Additionally, using the high levels of detail collected by the field PDAs, field managers were able to monitor effort, area covered, and the progress of different eradication strategies over time.

Even though these software packages are all web-based, it is important to note that this system is independent of the internet because they create an internet-like environment on a single computer. This also means that this interface was not available remotely and was only accessible from the GIS computer on island. It is possible to configure this interface to be accessed remotely, but given the increased complexity and licensing fees, this was beyond the scope of our use. It took roughly 8 weeks to select the Archer field PDAs and program the

customized drop-down forms. Programming the customized user interface and related reports took approximately 4 weeks, with periodic modifications to both systems totaling another 2 weeks.

RESULTS

The average daytime response time for capture events was 43 minutes ± 31 minutes ($n = 162$), while the average overall response time was 5 hours ± 4 hours ($n = 853$). Foxes that were caught after working hours spent an average of 6 hours ± 3 hours ($n = 691$) in traps. While 4 foxes were in a trap for an unknown amount of time because of monitor failures, no animal was in a trap for more than 14 hours with a working monitor. There were 1,012 total non-target capture events with 74 injuries, for an injury rate of 7%. There were 9 monitor failures with 4 leading to injury or casualty. The majority of monitor failures occurred during our 3-week monitor trial period where traps were visually checked daily and adjustments to protocols occurred to correct reasons for failures (Table 1).

To visit all traps once per day, without the monitoring system, it would have taken approximately 16 person-hours to complete. Additional time would have been required for handling animals and deactivating traps in the morning, and another 16 person-hours would be required to reactivate all traps in the evening. Without the monitoring system, traps would need to be deactivated during the day, as foxes were found to quickly overheat during the day (Island Conservation, unpubl. data). Using this protocol, an estimated total of >40 person-hours would have been required to maintain an average of 230 trap sites. With the monitoring system in place, the need to visit all 230 trap sites daily no longer existed. On average, staff responded to 5 captures per day, requiring approximately 3 person-hours. An additional 4 person-hours were spent performing routine maintenance of traps. We estimate a 10-fold increase in efficiency in staff time when employing the monitoring system. During the course of the project, we operated for 7 months, resulting in 30,171 trap-nights. With the same allocation of staff, we would have had significantly fewer traps set and less trap-nights, if all locations had to be checked manually.

Table 1. Trap monitor failures and mitigation measures to prevent future occurrences. Once these mitigation measure were in place, monitor failure rates were dramatically reduced.

| Failure	Mitigation	Number of Occurrences
String Failure String broke before pulling magnet out of puck.	Original string in trial replaced with sewing thread. String physically checked during routine maintenance.	2
Chewed Cables Animal in trap chewed on cable connecting puck and monitor.	Puck unit placed outside of trap circle, far enough away that with a rear-leg capture the animal could not reach the unit.	3
Magnet Back on Stake After trap sprung magnet flipped back onto stake close enough to puck to deactivate switch.	Rocks placed below an elevated puck and longer fishing line used to tether magnet.	2
Magnet Jammed in Puck Due to angle of puck or sand collected in puck string unable to move magnet before breaking.	Angles of puck adjusted, sand regularly cleaned from puck, string and magnet 'freedom' physically checked during routine maintenance.	2
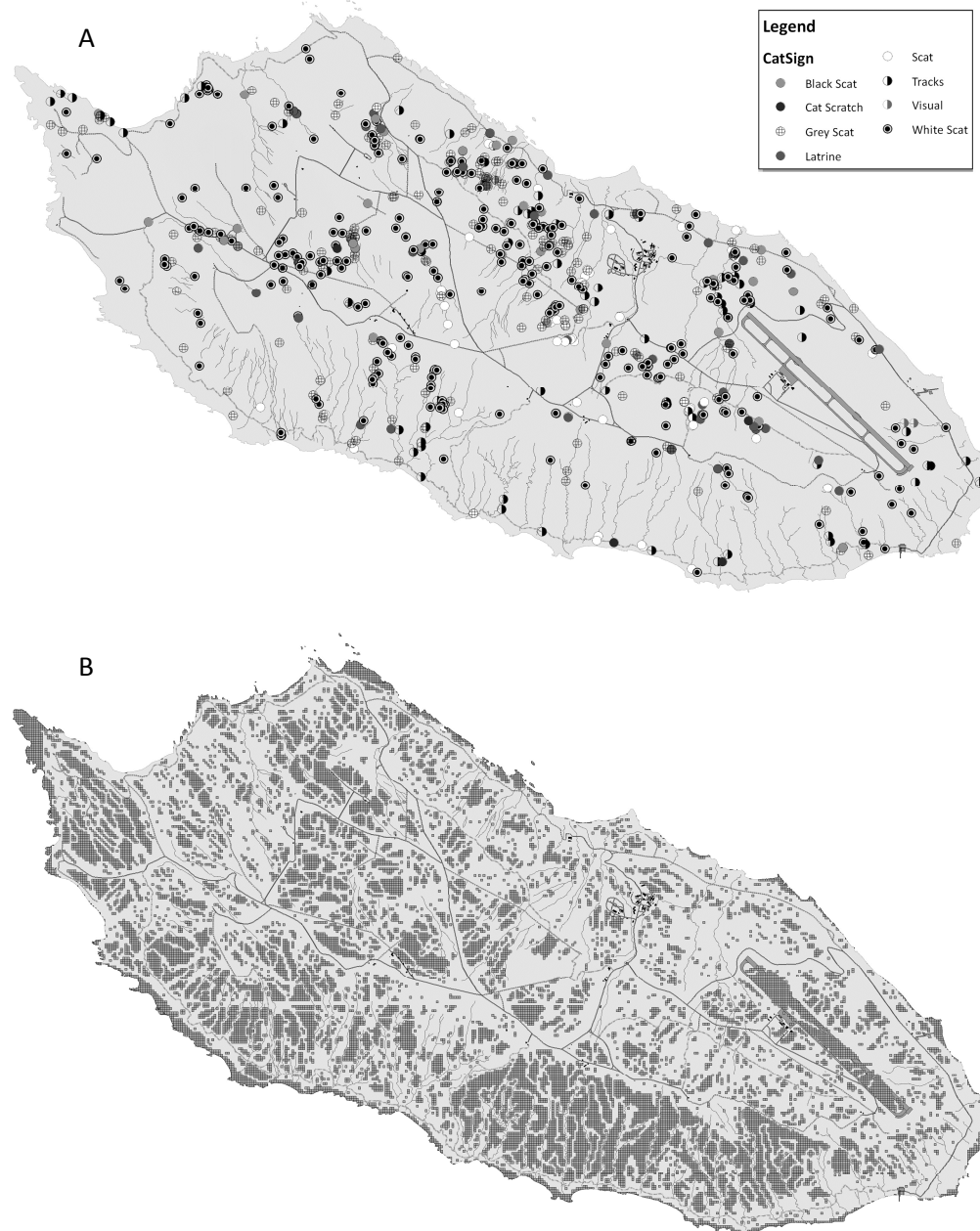
Figure 3. Data collection using the field PDAs allowed for instant access to maps from information collected in the field. A) Map shows cat sign that was observed by field staff over the course of the project, broken down into different categories. B) The island was broken into 30-m-square grids. Any time a GPS track from staff activity intersected a square, it was removed. The resulting map shows areas that were uncovered by staff; these are predominately extremely steep ravines or unvegetated areas.

DISCUSSION

The use of the trap monitoring system dramatically reduced the time animals were restrained in traps, and it increased the efficiency of staff and their availability to focus efforts on additional tasks. During the initial trapping trial, traps were checked manually in the morning, deactivated, and then reactivated later in the evening (Island Conservation, unpubl. data). With a total of 48 trap locations and 3 staff, this strategy was barely manageable, demonstrating that island-wide coverage using this approach was untenable. The trap monitoring system allowed a few staff to manage an island-wide trapping effort and reduced response times to sprung traps.

The trap monitoring system was a valuable tool for managers looking to assess the effectiveness of different eradication techniques. By combining GIS toolsets with time-sensitive capture information, managers were able to more effectively allocate staff time. For example, managers could overlay cat captures with cat sign and

deploy staff to revisit an area with cat sign that could not easily be attributed to a particular cat capture. Being able to filter GIS information by time allowed for informed management decisions; for example, the last month's search effort and cat sign could be viewed independent of all other data (Figure 3). Peak fox and cat capture times provided important insight into animal movement patterns, helping managers choose the best times to use detection dogs. Tracking captures for specific locations over time showed that foxes were learning to avoid trap sets, which was key to reducing adverse affects on foxes (Island Conservation, unpubl. data). Additionally, the system provided justification for leaving traps open for long periods of time, as traps over 100 days old remained successful in capturing target animals.

The efficiency of the trap monitoring system could be significantly increased by reducing the number of "no signals" and false sprung trap events. "No signal" events were caused by poor monitor placement or by monitor signal collision. The signal collision "walk-over" issue became noticeable later in the campaign when 200 - 250 units were in place. An average of 4 monitors a day would be categorized as having "no signal", because the system did not log a "trap active" signal for more than 12 hours, even though the units were in fact transmitting. The repeaters used did not contain the option to poll other repeaters if they were repeating a signal, and consequently signal collision could occur if the traffic was high enough. Another possibility is that changing environmental conditions might have attenuated marginal signals from some receiving stations, causing them to skip one report. It is important to note, however, that no "sprung" signals were missed due to any potential signal collision, because they were prioritized on the repeater network and occurred at more frequent time intervals than the "trap active" signals.

Additionally, the monitor system's efficiency could be improved by reducing the number of false sprung events. We experienced false events from wind, rain, birds, or animals navigating around traps when the string attached to the magnet was pulled out enough to remove the magnet, activating the "trap sprung" state. For example, during a single day with sustained winds of 80 - 100 kph, there were 74 false sprung events. These events could have been prevented by protecting the string with sticks and rocks that still allowed the string to move freely, but did not cause it to break prematurely.

Further Applications

Invasive mammal eradication projects that often incorporate GPS-collared animals and traps could benefit from the infrastructure necessary to support a trap monitoring system (Parkes et al. 2010). GPS telemetry collars can be integrated to work with this system and provide a cheaper alternative to ARGOS or other tracking systems. This system would also be appropriate for other types of traps including, cage traps, and kill traps, because the attachment system can be easily modified. The attachment system used in this project was designed to reduce potential injuries; a more robust system could be designed for cage or kill traps. With the end result of increased efficiency, this system facilitates fewer staff accomplishing more by removing the necessity to perform routine daily checks, thus prioritizing activity to sprung locations.

While a network of 10 remote stations was used during the campaign on San Nicolas Island due to the complex topography of the island, other applications many not need as many stations; needs should be determined on an individual basis, based on target site size and topography. If a significantly high point were present, and the topography appropriate, a single receiving station would be sufficient to collect and repeat all transmitter signals. A similar system could be reproduced for a fraction of the cost at a small study site and be configured to report to a dedicated PC or directly to the internet (Table 2).

Table 2. Trap monitoring system component costs.

Component	Cost (U.S.)
Remote Station	$5,000
TNC/Receiver	$1,000
Dedicated Laptop PC	$1,000
Archer PDA	$1,600
ESRI ArcEditor License	$2,500
ESRI ArcPad License	$500
User Interface Software	Open Source

LITERATURE CITED

CAMPBELL, K. J., G. HARPER, C. C. HANSON, D. ALGAR, B. S. KEITT, and S. ROBINSON. 2011. Review of feral cat eradications on islands. *In*: C. R. Veitch, M. N. Clout, and D. R. Towns (Eds.), Island Invasives: Eradication and Management. IUCN, Gland, Switzerland. *In Press*.

GARCELON, D. K., and B. R. HUDGENS. 2008. Island fox monitoring and demography on San Nicolas Island 2007. Unpubl. report prepared by the Institute for Wildlife Studies, Arcata, CA. 28 pp.

HALSTEAD, T. D., K. S. GRUVER, R. L. PHILLIPS, and R. E. JOHNSON. 1995. Using telemetry equipment for monitoring traps and snares. Proc. Gt. Plains Wild. Damage Cont. Workshop 12:121-123.

HANSON, C. C., J. E. BONHAM, K. J. CAMPBELL, B. S. KEITT, A. E. LITTLE, and G. SMITH. 2010. The removal of feral cats from San Nicolas Island: Methodology. Proc. Vertebr. Pest Conf. 24:72-78.

HAYES, R. W. 1982. A telemetry device to monitor big game traps. J. Wildl. Manage. 46:551-553.

HUDGENS, B. R., F. FERRARA, and D. K. GARCELON. 2007. Remote monitoring of island foxes. Report to DoD Legacy Program, Instit. for Wildlife Studies, Arcata, CA. 13 pp.

LARKIN, R. P., T. R. VAN DEELEN, R. M. SABICK, T. E. GOSSELINK, and R. E. WARNER. 2003. Electronic signaling for prompt removal of an animal from a trap. Wildl. Soc. Bull. 31:392-398.

MARKS, C. A. 1996. A radiotelemetry system for monitoring the treadle snare in programs for control of wild canids. Wildl. Res. 23:381-386.

Ó NÉILL, L., A. DE JONGH, J. OZOLIŅŠ, T. DE JONG, and J. ROCHFORD. 2007. Minimizing leg-hold trapping trauma for otters with mobile phone technology. J. Wildl. Manage. 71:2776-2780.

PARKES, J. P., D. S. L. RAMSEY, N. MACDONALD, K. WALKER, S. MCKNIGHT, B. S. COHEN, and S. A. MORRISON. 2010. Rapid eradication of feral pigs (*Sus scrofa*) from Santa Cruz Island, California. Biol. Conserv. 143:634-641.

POWELL, R. A., and G. PROULX. 2003. Trapping and marking terrestrial mammals for research: Integrating ethics, performance criteria, techniques, and common sense. ILAR J. 44:259-276.

USFWS. 2008. Environmental assessment for the restoration of San Nicolas Island's seabirds and protection of other native fauna by eradicating feral cats. U.S. Fish and Wildlife Service, Dept. of the Interior. Report on behalf of the Montrose Natural Resources Trustee Council. Carlsbad, CA. 81 pp.