THE USE OF SHOCK COLLARS TO PREVENT ISLAND FOX (*UROCYON LITTORALIS*) PREDATION ON THE ENDANGERED SAN CLEMENTE LOGGERHEAD SHRIKE (*LANIUS LUDOVICIANUS MEARNSI*)

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ABSTRACT—Conflicts between listed species challenge wildlife managers to develop innovative management techniques. The island fox (*Urocyon littoralis*) is a known predator of the critically endangered San Clemente loggerhead shrike (*Lanius ludovicianus mearnsi*). Due to the island fox's conservation status as a California state listed species, we developed a novel non-lethal system, similar to the "invisible fence" system for pet owners, to exclude foxes from shrike nests and thus deter predation. From 1998 through 2002, we trapped island foxes and fitted them with collars, which administer an electric shock when triggered. We placed antennae, which broadcast a short-range signal that activates the shock collars, around accessible shrike nest trees. During the five years we used this system, we fitted an average of 68 foxes per year with shock collars in an attempt to protect 78 nests in 33 shrike territories. During the use of this system, mid-sized predators likely preyed upon three of 78 protected nests, although we believe only one nest was likely depredated by a fox. This shock collar system has potential application for predator management in other endangered species recovery programs as well as in reducing the predation of livestock.

Keywords: island fox, Lanius ludovicianus mearnsi, loggerhead shrike, nest predation, non-lethal control, predator management, Urocyon littoralis clementae

INTRODUCTION

Wildlife biologists are challenged by the complexity of managing state and federally protected species. In recent years, North America has witnessed an increasing number of threatened and endangered species, particularly on public lands (Hoekstra et al. 2002). With increased listing, we see the potential for more conflicts between protected species, either indirectly through competition or directly through predation. These conflicts challenge managers to develop creative management practices that benefit both species, or at least minimize the harm to one or both species. Examples of conflicts between listed and protected species are becoming more common, particularly in California, where rapid habitat loss caused by development has resulted in a large number of listed species in a limited expanse of habitat. Western snowy plover (*Charadrius alexandrinus nivosus*) and California least tern (*Sterna antillarum browni*) colonies are being threatened by several species of conservation concern, including peregrine falcons (*Falco peregrinus*), loggerhead shrikes (*Lanius ludovicianus*) and western gull-billed terns (*Sterna nilotica vanrossemi*), throughout southern California (Keane 2000, Molina and Marschalek 2003). Mountain lions (*Puma concolor*), which are protected in California, are considered one of the greatest threats to desert bighorn sheep (*Ovis canadensis* ssp.) (Wehausen 1996). On the northern California Channel Islands, golden eagles (*Aquila chrysaetos*) have decimated island fox (*Urocyon littoralis*) populations (Roemer et al. 2002).

On San Clemente Island, the island fox (*U. l. clementae*) is a known predator of the San Clemente loggerhead shrike (SCLS; *L. l. mearnsi*). The SCLS is an island endemic that was listed as an endangered species in 1977 (USFWS 1977) and at one time was considered to be one of the most endangered animal populations in North America, with a population low of 12 adults remaining in the wild in 1998 (Garcelon and Sharpe 1998, Mader and Warnock 1999). In 1991, the initial predator management program to protect the SCLS included both lethal and non-lethal techniques to control native and non-native predators. However, the island fox is a species of conservation concern due to small population sizes, coupled with a lack of genetic variation (Gilbert et al. 1990, Wayne et al. 1991) and a high risk of exposure and susceptibility to virulent canine diseases (Garcelon et al. 1992). The California Department of Fish and Game listed the island fox as a threatened species in 1987 (CDFG 1987). In 1989, the U.S. Fish and Wildlife Service listed the island fox as a candidate for federal protection (USFWS 1989). The species has gained extensive attention in recent years with four of the six subspecies experiencing drastic declines over the last decade (Coonan et al. 2000, Timm et al. 2000, Roemer et al. 2001, 2002) and in 2004, these four subspecies of the island fox were listed as endangered (USFWS 2004).

Although the SCLS recovery program has existed since 1991, we have documented very little direct evidence of SCLS predation, with <10 anecdotal observations (Cooper et al. 2003). On two occasions, we documented island foxes depredating SCLS nests (Garcelon 1996, Garcelon and Melody 1998). Due to the critical status of the shrike population, a working team of federal and contracted agencies and organizations managing SCLS considered options to reduce nest loss to predators, including foxes. While lethal control was initially employed by the agencies to mitigate potential fox impacts on nesting shrikes (Cooper and Garcelon 2002, Roemer and Wayne 2003), it soon became apparent that this type of management could not be sustained. In an attempt to prevent foxes from approaching SCLS nests, several methods including electrified fencing**,** sheet metal flashing to deter climbing, and a sonic deterrent device were investigated. However, each of these techniques had limited applicability due to cost, application constraints, or insufficient testing.

In 1997 and 1998, the Institute for Wildlife Studies began testing another deterrent, which involved using shock collars worn by the foxes to deter them from closely approaching SCLS nests (Garcelon and Melody 1998, Martin et al. 1998). Our goal was to reduce nest predation on SCLS using a low-cost, easily maintained system that relied on non-lethal management. We designed the system to repel foxes from shrike nesting substrates (trees or shrubs) using a commercially available shock collar and transmitter system working under the same premise as the “invisible fence” system used by pet owners.

STUDY AREA

San Clemente Island (SCI), located in Los Angeles County, is the southernmost of the California Channel Islands. SCI is administered by the U.S. Navy as a training range, but it is also managed for ecological and cultural resources (USDoN 2001). San Clemente Island is 109 km NW of San Diego, CA, and the nearest point on the mainland (Palos Verdes) is 92 km distant. The island is 44 km long, 2.4 to 6.4 km wide, and has an area of approximately 14,764 ha. Elevation ranges from sea level to 599 m. The island consists of a large plateau incised by canyons along both the western and eastern sides. The east side is a steep sloping escarpment descending from the plateau to the Pacific Ocean, while the west side consists of a series of step-like marine terraces, which gradually descend to the shore. On the north end of the island annual temperature extremes range from 10 to 22ºC and annual precipitation averages 15.7 cm. Vegetation is primarily of maritime desert scrub, with the canyon bottoms containing patches of canyon shrubland/woodland.

METHODS

In an attempt to increase productivity of nesting shrikes and ultimately increase the population to a size where intensive management is not warranted, we protected shrike nests from island foxes using a commercially available shock collar system for pets (Home Free Pet Containment System HF 200, Innotek Pet Products, Inc.; Fig. 1-2). This system was designed to administer an electric shock to a fox wearing a collar, if the animal approached within approximately one to two meters of the transmitting antenna. The shock collar gives an “all or nothing” response to the

Figure 1. Island fox with a shock collar. U.S. Navy photo by D.M. Cooper.

signal (i.e., if the collar has sufficient battery power to administer a shock, the shock will always be of the same magnitude). The collars weighed approximately 76 g, which represents 4.3% of an average fox's weight (1.78 kg).

The typical system configuration in the field was such that we placed an antennae wire around a nest tree. Because the system works at a very low frequency, we could place the antenna either on top of or under the ground. The limitation of the system was that the range of the transmitting antenna was short, and therefore it only functioned to provide a constant shock to the fox if the diameter of the antenna was 20 m or less. When the antenna diameter was greater than 20 m, the shock field only extended 1.5 m on either side of the antenna wire. We connected the ends of the antenna wire loop to a cable of twisted wire, which extended 100 to 250 m to the battery and transmitter. We used twisted wire because a shock field is not created when the transmitting wires are crossed. Separating the antenna from the transmitter allowed for changing the battery or checking on the operation of the transmitter without disturbing nesting shrikes. We placed each transmitter in a watertight container and supplied power with a single 12-volt deep-cycle marine battery that was connected to a solar panel to help maintain its charge. Battery voltage and integrity of the antenna was generally checked twice weekly and if a battery fell below 11.5 V it was replaced.

To evaluate whether this system could work as a nest barrier, we conducted tests under controlled situations. We first established a feeding site to attract and habituate foxes to the test site. Foxes obtained food at a fixed location that we observed from a blind or with a closed-circuit video system. We used a floodlight at the feeding site to allow for observations and video monitoring at night. After foxes were observed feeding from the test site in the presence of the artificial light, we trapped six individuals using 70- x 23- x 23-cm box traps (Tomahawk model 106, Tomahawk Live Trap Company, Tomahawk, WI) baited with either wet cat food or dry cat food and a berry scented paste (On Target A.D.C., Cortland, IL). We shaved a small area (ca. 4 cm in diameter) on both sides of the fox's neck to provide better contact between the skin and the electrical contacts on the shock collar. We wrapped the collars with colored tape to

Figure 2. Close up view of the shock collar. U.S. Navy photo by D.M. Cooper.

allow individual fox identification from a distance. We released collared foxes on site.

We placed the transmitting antenna wire in an 8-m radius around the feeding site and placed pin flags at various locations along the wire to allow us to observe the relative position of the foxes and the antenna. After collaring the foxes, we waited one day to allow fox behavior to return to normal and resume feeding at the test site. After activating the shock system transmitter, we observed the behavior of the foxes as they approached the test site to determine the effectiveness of equipment in deterring the foxes.

Once the controlled experimental trials concluded, we applied this technique at all accessible SCLS sites. Because the SCLS remained at a critically endangered level throughout the five years of this program, we did not attempt to distribute protection at SCLS in a random design, but rather attempted to protect as many sites as possible. The only sites that did not receive protection from the shock antenna system were those sites that were logistically inaccessible or those sites that went undiscovered until late in the nesting cycle. Furthermore, in addition to the shock antenna system, we simultaneously provided protection to sites from predation by feral cats (*Felis catus*), black rats (*Rattus rattus*), and several other native predators, including common ravens (*Corvus corax*), red-tailed hawks (*Buteo jamaicensis*) and American kestrels (*Falco sparverius*). It should also be noted that sites that were not protected from fox predation by the shock antenna system generally did not receive protection from other predators as well.

In the field, we placed antenna wire around the nesting substrate (tree or shrub) containing SCLS nests. Our goal was to create the smallest possible perimeter around the tree or shrub that would still prevent foxes from accessing any portion of the nesting substrate. In 1998, we placed nest antennae after SCLS began incubating. There was one instance when the placement of the antenna may have caused the abandonment of a nest (Martin et al. 1998). Starting in 1999, we took precautions to avoid further occurrences of abandonment by installing antennae around all potential nest trees and shrubs before the breeding season began. Placement of the antennae around potential nest sites in advance greatly decreased the amount of time it was necessary to spend near the nest in order to activate the antenna. We waited to activate the antennae until SCLS had been incubating for at least three days. This three-day incubation period helped ensure that the birds had a sufficient investment in the nest attempt to discourage abandonment.

Activation of the nest antennae was coordinated with monitoring personnel, who observed SCLS to ensure that the pair remained in the area and did not abandon the nest. To activate an antenna, we carried the twisted wire from a distant site, typically a canyon rim, to the nest area. We then spliced the twisted wire together with the antenna wire, activating the antenna. A second person verified that the antenna system was active by checking an indicator light in the transmitter box. All personnel left the nest area as quickly as possible after activating the system, which typically took less than five minutes. Monitoring personnel observed the nest from a distance to confirm that SCLS adults returned to the nest following antenna activation. We turned off power to the transmitters after nests had failed or after fledglings had dispersed from the area, typically no later than the end of August.

We conducted regular trapping to capture and collar all foxes that overlapped SCLS territories as described above. We checked and reset traps at least once daily and re-baited when necessary. We individually marked each fox using alpha-numerically coded colored ear tags (Rototag, Nasco-West, Stockton, CA). We affixed the shock collars tightly enough to ensure contact between skin and electrodes, but loosely enough so that the electrodes did not abrade the skin. Because fox pups are provisioned by their parents and are unskilled foragers until reaching a weight of approximately 1.2 kg, we concluded that foxes weighing less than this did not present a threat to nesting shrikes and were left un-collared. We used shock collars only during the SCLS breeding season and re-trapped the foxes at the conclusion of SCLS nesting activity to remove collars. We typically initiated collaring during the first week of March and completed removal of collars by the end of August.

The manufacturer's specifications indicated that the collar batteries should last a minimum of three months. However, Hawley et al. (2003) found that batteries for another Innotek collar might only last two to three weeks in the field. Although we did not formally test the field life of the collar batteries, we regularly checked the charge when handling foxes and observed the field life of at least one battery to exceed six months. During this study, we conservatively changed the shock collars every six weeks to prevent collar failure due to power loss. We did not observe any problems with dead batteries using this schedule. However, changing collars every six weeks required a nearly continuous trapping effort to cover all areas of the island inhabited by nesting SCLS. Normally we expected to capture and collar all foxes in an area within one week, although we conducted occasional trapping throughout the SCLS breeding season to ensure that no new foxes had moved into the area. One advantage of this frequent trapping was that we were able to regularly inspect foxes for detrimental impacts from the collars. We monitored the weight of all foxes and checked for lesions and other injuries or health problems resulting from wearing a collar.

Table 1. Number of SCLS sites and nests protected using the shock antenna system and number of individual foxes trapped and collared in these protected sites, 1998–2002.

Year	No. Sites	No. Nests	No. Foxes Collared
1998	6	8	50
1999	6	7	106
2000	9	10	64
2001	19	28	61
2002	19	25	59

RESULTS

During the baited field-testing, we observed four individual collared foxes attempting to approach the baited test site eight times. None of the attempts was successful. As a fox received a shock from the collar, it generally jumped into the air and then quickly departed the general area. In one case, a male fox made three separate attempts to approach the food over a short span of time and was repelled on each occasion. No foxes returned to the site on successive nights after being shocked. Based on the results of the field-testing we determined it was appropriate to implement the shock deterrent system at SCLS nest sites.

From 1998 to 2002, we established the shock antenna system at 78 SCLS nests sites (Table 1). During the first three years of this program, we protected 25 nests, while 53 nests were protected during the final two years. This difference was a result of an increasing SLCS population, due to a highly successful captive breeding and release program that was initiated in 1999 and fully implemented in 2000 (Brubaker et al. 2000, Turner et al. 2001). Fifty of the 78 protected nests (64%) were successful, producing at least one SCLS fledgling. During the same period, we left 36 nests unprotected due to logistic restrictions and only 11 (30.5%) of these nests were successful (Table 2).

Of the 28 protected nests that failed, we suspected 22 (78.5%) were depredated, whereas six failed due to unknown causes. It is generally difficult to identify predators based on sign remaining at the nest site (Lariviere 1999), and in most cases on SCI we have determined the most likely predator based on circumstantial evidence. We could find no evidence suggesting any particular predator for six of the depredated nests. We suspected that eight nests were depredated by rodents (primarily black rats), based on feces in the nest and bite marks on eggshell fragments. We

Table 2. SCLS nest success with and without protection using the shock antenna system. Nest success was defined as the number of nests that fledged at least one young.

	With Shock Antenna			Without Shock Antenna		
Year	No. Nests Protected	No. Successful Nests	Apparent Nest Success	No. Nests Unprotected	No. Successful Nests	Apparent Nest Success
1998	8	4	50.0%	1	1	100.0%
1999	7	2	28.6%	6	0	0.0%
2000	10	5	50.0%	2	0	0.0%
2001	28	20	71.4%	8	3	37.5%
2002	25	19	76.0%	19	7	36.8%
TOTAL	78	50	64.1%	36	11	30.6%

believe that five nests were depredated by avian predators (common raven, rock wren [*Salpinctes obsoletus*], or northern mockingbird [*Mimus polyglottos*]), based on the presence of ravens in the immediate vicinity of the nest or puncture marks on eggshell fragments. We observed evidence suggesting that an undetermined medium-sized carnivore (either a feral cat or an island fox) depredated three nests, although the suspicion was that a feral cat was responsible in two of three cases. In these three cases, evidence was variable. One nest monitored with a closed-circuit video camera, recorded an un-collared predator entering the nest. Based on previous telemetry work, we believe that we had collared all resident foxes in the area, meaning that the predator observed on the video was either an un-collared fox or a feral cat. We believe a feral cat was most likely responsible due to this evidence and the fact that cat scat was located approximately 50 m away from the nest. We discovered a second nest torn down and it appeared that a predator had jumped from an adjacent rock ledge, landing on the nest. No further evidence suggested fox or cat, but again all foxes trapped within 1 km were collared. Finally, we suspected that an island fox preyed upon one nest, based on fresh fox scat found under the nest.

In our attempts to protect SCLS, we trapped and collared between 50 and 106 foxes per year (Table 1). Data on trapping effort are not available for all years however this effort was extensive. We conducted trapping ~20–25 nights per month from March through August. During the period of 2000 through 2002, we averaged over 1,000 trap-nights per month. This trapping effort resulted in slightly more than 120 fox captures per month, with a high of 251 fox captures in August of 2000. Trapping efforts to maintain shock collars on foxes was certainly the most labor-intensive portion of this program.

This study was not designed to quantify the effects of trapping and collaring on foxes. However, from 2000 through 2002 we collected weight data on 100 foxes when the collar was attached and again when the collar was removed. These 100 foxes wore shock collars for an average of 73 ± 36 days (range 2–144). Over this time, we observed weight gain in 46%, weight loss in 42%, and no weight change in 12% of these foxes. The average weight gain was 175 g, with a range of 50–500 g, while the average weight loss was 167 g, with a range of 25–750 g. The four animals that exhibited a weight loss of 20% or more all had extenuating circumstances that were unrelated to shock collaring (e.g., females that were pregnant at the time of collaring). We assume that any weight gain was unrelated to the animal wearing a collar. We also regularly monitored the foxes for other detrimental effects caused by wearing a collar. In one instance, we observed a fox with small lesions from a collar that was too tight, however after we loosened the collar and treated the wounds the fox recovered within one week. No other injuries were observed during the five years we implemented the system.

DISCUSSION

Several programs have used electrical barriers to exclude predators from accessing species of conservation concern. For example, electric fencing can protect shorebird and waterfowl nests from terrestrial predators (LeGrange et al. 1995, Larson et al. 2002). Aguon et al. (2002) successfully used an electrical barrier to exclude brown treesnakes (*Boiga irregularis*) from the nests of the endangered Mariana crow (*Corvus kubaryi*). Electrical fences have also been an effective deterrent for other fox species (Poole and McKillop 2002). On San Clemente Island, shrikes typically select nest sites in deep, steep canyons. As a result, the topography is sufficiently rugged to make it logistically impractical to construct a standard electrical fence. Furthermore, as we can never be certain where the birds will nest, this method would require we build an electric fence over a substantial area to ensure protection to all potential nest sites.

Because the logistics of installing fencing on San Clemente Island were impractical, we explored other means of excluding foxes from SCLS nests. Linhart et al. (1976) used electric collars to train coyotes to avoid specific prey, but a human operator triggered these collars. By employing a commercially available method used for domestic pets, we could both circumvent the problems associated with construction of physical barriers and omit the necessity of having a human present to make the system operable.

The time and effort to install and maintain the shock antenna system to protect SCLS nests was minimal. By installing the antennae prior to the initiation of nesting activity, we minimized the amount of time necessary to activate an antenna around a nest, thereby decreasing the risk of abandonment by SCLS. Activating the nest shock transmitting system during the nest building stage, rather than during the early part of the incubation stage, would negate the risk of losing eggs to abandonment. However, activating a previously installed antenna typically requires less than five minutes time in the nest area, minimizing disturbance to the birds and limiting risk of abandonment, as female SCLS typically remained off the nest for an average of less than 15 minutes. Furthermore, even if a small number of SCLS pairs did abandon their nesting attempt after the placement of the shock system antenna, the effect on reproduction potential is likely small as SCLS typically build multiple nests during a breeding season.

Prior to the use of the shock antenna system in 1998, we documented foxes depredating SCLS nests in both of the previous seasons (Garcelon 1996, Garcelon and Melody 1998). During the five years that the shock deterrent system was in use, there were only three cases of nests failing where we considered fox predation as the possible cause of failure, and in two of those cases, it appeared more likely that a feral cat was responsible. The third nest was located in a newly discovered site, where we had conducted minimal fox trapping before the nest was depredated. We suspect that a fox that we had not yet trapped and collared depredated this nest. Nests protected by shock antennae had a greater probability of being successful than those not protected. We observed a success rate of 64% for protected nests compared to 31% for unprotected nests. However, these results must be viewed cautiously. The shock antenna system was only one component of a comprehensive adaptive predator management program. The nests where the shock deterrent system was employed also generally received additional measures of protection from feral cats, black rats and avian predators. Nests not protected by shock system did not typically receive these other protective measures. Thus, the higher level of success for nests protected by the shock system cannot be attributed entirely to the fox deterrence.

Due to the nature of an adaptive management program to protect a critically endangered species, it was not possible to evaluate the field application of this system from a purely experimental manner. We conducted an experimental test of the system to provide a more stringent evaluation prior to the field application. This experimental evaluation indicated that foxes were unable to access a known food source while the antenna was active. Thus, we believe that the shock antenna system is a valuable tool for preventing SCLS nest predation by foxes.

Trapping foxes to maintain shock collar batteries was the most labor-intensive portion of this program. Between five and eight biologists operated an average of 6,000 trap-nights of effort during each shrike breeding season from 2000 to 2002. Not only was this effort costly from a personnel perspective, but it also was potentially detrimental to the foxes. Island foxes are easily trapped and often exhibit “trap happy” behavior (Garcelon 1999). This tendency resulted in several foxes being captured repeatedly, often spending 10 or more hours in a trap on consecutive nights. While it is difficult to quantify the impact of this extensive trapping on foxes, based on the weight change data, more foxes exhibited a weight gain than a weight loss and the weight change for the majority of foxes was within the expected range typical of seasonal weight fluctuations. We believe a greater impact on foxes may have resulted from the disruption of normal breeding behavior. We are concerned that spending extensive time in traps over a prolonged period may have negatively affected normal breeding behaviors, including pair bond maintenance and territorial defense. We also documented lactating females repeatedly entering traps, which may have resulted in health concerns for young dependent pups.

While the shock collar system likely had impacts on the island fox population, the alternative management option considered, lethal control, was far more detrimental to foxes (USDA APHIS-WS 1998). The conservation status of the island fox makes the use of lethal measures inappropriate for managing predation pressure on nesting SCLS. Given the alternatives, the shock collar system was an appropriate alternative to institute protective measures for SCLS as required by the U.S. Fish and Wildlife Service. Through the success of the SCLS recovery program, including predator management, a captive breeding and release program and habitat restoration, the SCLS population steadily increased during the five years of this program. By 2002, the SCLS population had increased from a low of 12 individuals in 1998 to a high of 103 individuals following the 2002 breeding season. With this population increase, the working group of agencies involved in the SCLS recovery program decided to eliminate the management of native predators, including the island fox, starting in 2003.

Given the adaptive nature of endangered species protection, we implemented this deterrent program to as many shrike nests as possible, only after field trails indicated that shock collars could deter foxes from accessing a known food source. We continued the use of the shock collar system for five years, despite a substantial labor cost, until the SCLS population had sufficiently increased to minimize our concern over nest predation by foxes. Although we acknowledge that the shock collar system might have negatively affected SCI's fox population, we believe it was a better alternative, with less impact, than the alternative option, lethal control. We recommend that wildlife managers facing a similar conflict involving mammalian predators consider this technique, especially as a short-term solution to mitigate conservation conflicts between two sensitive species.

Wildlife managers have used similar approaches to protecting livestock from predators. Andelt et al. (1999) controlled coyote predation on domestic sheep with aversive training using electronic dog-training collars. Schultz et al. (in press) conducted preliminary tests of shock collars on two wild wolves in Wisconsin and are currently evaluating shock collars as a method to reduce livestock predation by wolves. We believe this technique could be useful in other endangered species programs to reduce predation by terrestrial predators and as an alternative to lethal methods.

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