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Evaluation of New Telemetry Technologies For Research on Island Foxes

By

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Evaluation of New Telemetry Technologies For Research on Island Foxes

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EXECUTIVE SUMMARY

Island foxes (*Urocyon littoralis*) occur on the 6 largest Channel Islands off the coast of southern California. This insular situation results in inherently small and therefore highly vulnerable populations, as exemplified by recent catastrophic fox declines on 4 of the islands. Thus, information that contributes to effective management of populations and habitats will facilitate long-term conservation of island foxes.

Radio-telemetry has been used extensively to monitor and gather information on island foxes, and has been an invaluable tool. Almost all of this telemetry work has been conducted using traditional VHF (Very High Frequency) transmitters. New telemetry technologies have recently become available for potential use on island foxes. These include GPS (Global Positioning System) units and proximity logger units. GPS units use satellites to determine animal locations, and proximity loggers record information on contacts between individuals wearing the units. Both intensive and extensive field efforts would be required to collect such information using traditional VHF technology.

Little information is available on the efficacy of GPS units in collecting data on island foxes and none is available for proximity logger units. The goal of this project was to evaluate the use of these units to collect information on island foxes under actual field conditions. Specific objectives were to: (1) confirm that these units can be safely deployed on foxes, (2) assess the performance (e.g., endurance, data collection rates, data recovery) of the units under field conditions, (3) assess the quality of the data collected by the units, and (4) develop recommendations for using these new technologies to collect data that can contribute to island fox conservation.

During 2009-2010, 14 GPS units were deployed on foxes on Santa Rosa and 17 proximity logger units were deployed on foxes on San Miguel. Foxes wore GPS units for 274-432 days. The units were easy to fit on foxes and did not appear to cause any injuries or adverse effects to the foxes. Either by recapture of foxes or remote download, data sets were recovered from 12 GPS units, and the information collected appeared to be high in quality based on comparison to known points and known area use by foxes. However, numerous problems were experienced with the units, including improper factory programming, high failure rates of VHF transmitters, faulty mortality sensors, poor VHF signal strength, breakage of the unit housing or antenna, faulty data port covers, and GPS battery life that was much less than expected. Two foxes were not recaptured and therefore no data were recovered from these animals. The remote download function on the 6 units with this function worked successfully. Foxes wore proximity logger units for 205-323 days. The units were easy to fit on foxes and did not appear to cause any injuries or adverse effects to the foxes. Of the 17 foxes wearing these units, 16 were recaptured. All 16 units yielded an abundance of data that appear to have a high level of accuracy, based on concordance in contact rates and duration between pairs of units. The proximity logger units all performed as expected.

Both the GPS and proximity logger units can collect highly useful and valuable data that would be more difficult and expensive to collect using conventional VHF methods. Recommendations include: (1) using the GPS units with caution, given the problems experienced, (2) using GPS units with a remote download function, (3) attempting GPS unit data downloads from the air, (4) downloading data from both types of units as frequently as is practicable, (5) frequently monitoring foxes using the VHF transmitters to determine area use, and (6) rigorously pretesting all functions on both types of units prior to deployment on foxes.

INTRODUCTION

Island foxes (*Urocyon littoralis*) occur on the 6 largest Channel Islands off the coast of southern California. Pre-1994 population estimates on the islands ranged from 450 foxes on San Miguel to 1,780 foxes on Santa Rosa (Coonan et al. 2010). Due to these relatively small population sizes and restricted distributions, the island fox was listed as Threatened by the State of California in 1987. In the mid to late 1990s, fox populations on 4 of the 6 islands declined markedly due to golden eagle (*Aquila chrysaetos*) predation (San Miguel, Santa Rosa, and Santa Cruz) and disease, probably distemper (Santa Catalina). On all 4 islands, captive breeding colonies were established using surviving animals, and for several years there were no (San Miguel, Santa Rosa) or very small (Santa Cruz, Santa Catalina) wild populations. The foxes on these 4 islands were listed as Federally Endangered in 2004 (Coonan et al. 2010).

Beginning in 2004, releases of foxes from the captive colonies were initiated, and wild populations are again present on all 6 islands. The catastrophic declines on the 4 islands highlighted the vulnerability of island fox populations. These small, insular populations will always be at risk, and therefore, will be "conservation reliant" (Scott et al. 2005, U.S. Fish and Wildlife Service in press). Consequently, continual monitoring of populations and threats will be necessary. Also, gathering new ecological and demographic information will enhance understanding of island fox population dynamics and ecosystem interactions, which will facilitate the optimization of conservation efforts. In particular, habitat conditions on the islands are changing rapidly now that most non-native grazing animals have been removed and restoration efforts have been initiated, and fox densities are increasing on the 4 islands that experienced catastrophic declines a decade ago (Coonan et al. 2010). Fox responses to these changing habitat and demographic conditions should be assessed so that conservation strategies can be adjusted as warranted.

Radio-telemetry has been used extensively to monitor and gather information on island foxes, and has been an invaluable tool. Almost all of this telemetry work has been conducted using traditional VHF (Very High Frequency) transmitters (Rubin et al. 2007, Coonan et al. 2010). New telemetry technologies have recently become available for potential use on island foxes. These include GPS (Global Positioning System) units and proximity logger units. GPS units use satellites to determine animal locations, and then collect and store these locations at programmed intervals. This technology precludes the need to deploy field personnel to collect each location, and therefore can save considerably on staff time and effort. Proximity loggers record information on contacts between individuals wearing the units, and this information can be invaluable for assessing social interactions and the potential for disease transmission. Both intensive and extensive field efforts would be required to collect such information using traditional VHF technology.

Limited field testing of GPS units on foxes has been conducted on Santa Catalina Island (J. King, Catalina Island Conservancy, personal communication). Other than this effort, no information is available on the efficacy of GPS and proximity logger units in collecting data on island foxes. The goal of this project was to evaluate the use of these units to collect information on island foxes under actual field conditions. Specific objectives were to:

1. confirm that these units can be safely deployed on foxes,
2. assess the performance (e.g., endurance, data collection rates, data recovery) of the units under field conditions,

3. assess the quality of the data collected by the units, and
4. develop recommendations for using these new technologies to collect data that can contribute to island fox conservation.

STUDY AREA

Island foxes are restricted to the 6 largest Channel Islands located off the coast of southern California (Figure 1). More detailed descriptions of the biotic and abiotic attributes of each island can be found in Schoenherr et al. 1999.

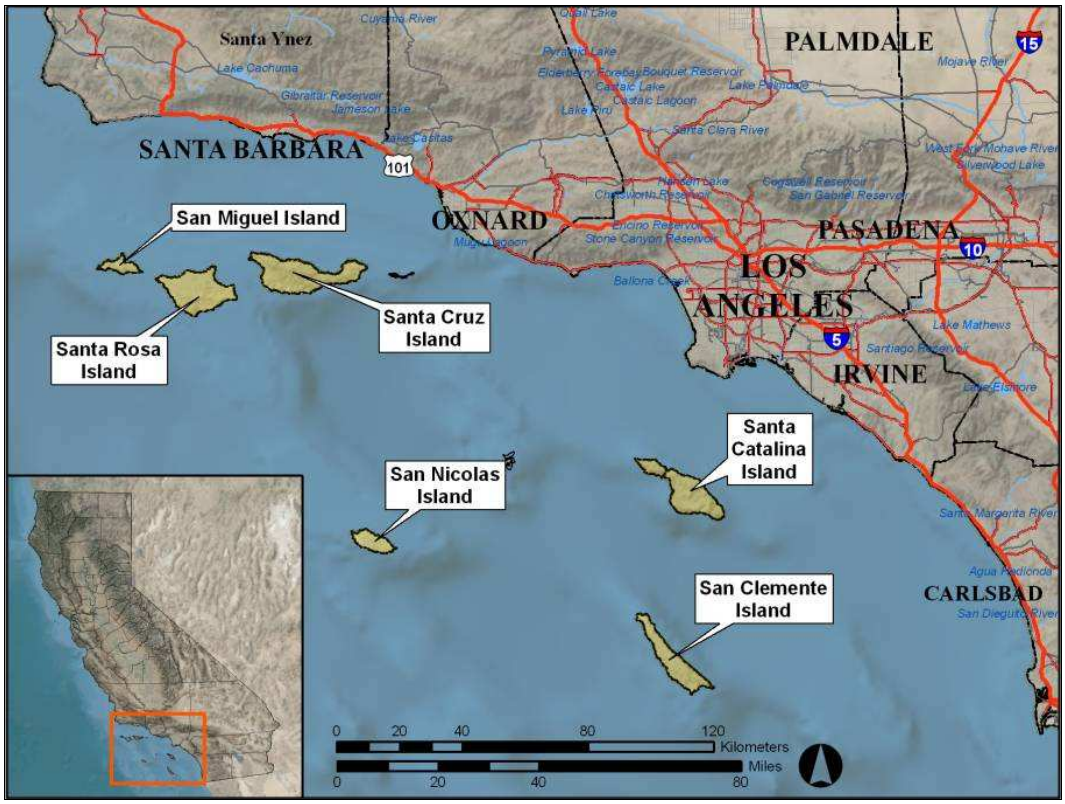


Figure 1. Channel Islands in Santa Barbara, Ventura, and Los Angeles counties, California.

We selected Santa Rosa and San Miguel for the deployment of GPS units and proximity logger units, respectively. These islands are both managed by the National Park Service (NPS). Active research and monitoring programs are on-going on both islands, and these programs include annual trapping and radio tracking of island foxes. This annual trapping and tracking provided an opportunity to deploy GPS and proximity logger units without requiring additional field efforts.

Santa Rosa is approximately 217 km^2 (84 mi^2) in size. The island is topographically complex with elevations ranging up to 484 m (1,589 ft), and with deep canyons interspersed among rolling hills. Habitat types include Coastal Grassland, Coastal Beach and Dune, Coastal Bluff Scrub, Coastal Sage Scrub, Island Chaparral, Oak Woodland, Island Woodland, Riparian Woodland, Bishop Pine Forest, and Torrey Pine Forest (Schoenherr et al. 1999). Thus, a diversity of habitat conditions is present. Historically, Santa Rosa probably supported over 1,700 foxes, but the current recovering population in 2009 was under 400 (Coonan et al. 2010). Because of this low population size, intra-

specific competition was relatively low providing an opportunity for foxes to select preferred habitat conditions. Thus, we chose to deploy GPS units on foxes on Santa Rosa in the hopes of gathering information on habitat preferences in addition to evaluating the performance of the units.

San Miguel is approximately 37 km^2 (14 mi^2) in size. The island is less complex topographically with elevations ranging up to 253 m (830 ft), and consisting primarily of a large plateau dissected by deep ravines. Habitat types include Coastal Sage Scrub, Coastal Grassland, Coastal Dune, Coastal Bluff Scrub, and Fresh Water Marsh (Schoenherr et al. 1999). Historically, San Miguel probably supported about 450 foxes and the current recovering population in 2009 was over 300 (Coonan et al. 2010). Thus, the population on this relatively small island is closer to its natural carrying capacity compared to Santa Rosa, and fox density is higher. Therefore, we chose to deploy proximity logger units on San Miguel in the hopes of gathering information on contact rates between individual foxes in addition to evaluating the performance of the units.

METHODS

GPS and proximity logger units were purchased and provided to NPS staff engaged in island fox monitoring and research on Santa Rosa and San Miguel islands. NPS biologists tested, deployed, and monitored the units in 2010. The GPS and proximity logger projects essentially were unique efforts conducted by separate field teams. Thus, separate methods, results, discussion, and conclusions are presented for the two units.

GPS UNITS

The GPS units were purchased from Telemetry Solutions (Concord, CA). Telemetry Solutions currently is the only manufacturer that produces GPS monitoring devices sufficiently small in size and mass to meet the 4% of body weight limit for telemetry devices placed on island foxes. Another company, Televilt, used to manufacture units of appropriate size and mass. Televilt was originally contacted regarding units for this project, but the company discontinued production of the units soon after the initiation of this project.

The units purchased were Quantum 4000E Mini Collars. Detailed specifications for these units are provided in Appendix A. These units consisted of a GPS receiver bundled with a VHF transmitter in an acrylic housing and mounted on a machine belting collar (Figure 2). The units also included a mortality sensor. The entire unit weighed 65 g. The GPS units use satellites to determine location, and the units can be programmed by the user to record locations at specified times or intervals. The locations along with associated information including time and date are stored within the unit. Basic units must be retrieved in order to download the stored data. However, some of the units included a remote download function. For these units, data could be downloaded by approaching within approximately 300 m of the fox and then downloading the data using a specialized “base station” connected to a PDA (personal digital assistant) or laptop computer. Either a manufacturer-supplied whip antenna or user-supplied yagi antenna could be used with the base station for communicating with GPS units. The base station and GPS unit must remain in communication for 30-60 sec to successfully complete the data download. The VHF transmitter (166-169 MHz) permitted instantaneous tracking of the unit. The estimated battery life expectancy for the GPS function was 144-435 days, depending upon the number of locations collected per day. The estimated battery life expectancy for the VHF

function was 200 days. Costs were $1,495 for each store-on-board unit and $1,795 for each remote-download unit, and $1,895 for 2 additional remote-download units ordered after the initial requisition.

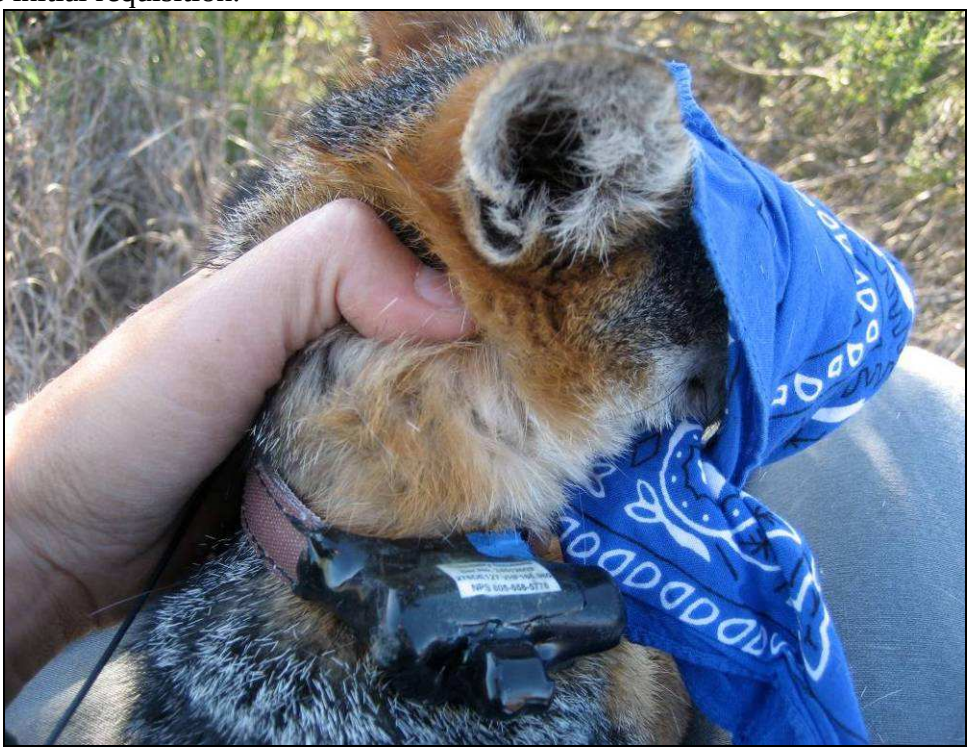


Figure 2. GPS unit on an island fox on Santa Rosa Island.

The GPS units could be programmed by the user using company supplied software and a USB cable connection. Programmable options allow the user to structure the collection of data (i.e., animal locations) both to address study objectives and to maximize battery life. Users can select options regarding time to acquire a fix (TTF), additional time if a fix is not acquired in the allotted time, and interval between fix attempts. A fix is equal to a location on the animal. For TTFs, 75% were set at 90 sec while 25% were set at 60 sec. Additional time was set at 45 sec, extending the time to acquire fixes to 105 or 135 sec. Fix interval was set at 7 hours to yield 3-4 locations per day, and to vary the time for fix attempts such that during the course of 7 days, locations would be collected throughout the 24-hour daily cycle. With these settings, expected battery life for the GPS function was approximately 210 days, and the potential number of locations that could be collected was approximately 670.

Prior to deployment on foxes, each GPS unit was tested to ensure that GPS locations were being recorded and the VHF transmitter was operating properly, and to determine the optimal VHF transmitter frequency (because frequencies can “drift”) and the approximate distance of detection for the VHF signal.

To deploy the GPS units, island foxes on Santa Rosa were captured in live-traps. Live-trapping was conducted by NPS field personnel (under permit TE086267-0) as part of annual monitoring and research efforts. Foxes were captured in single-door wire-mesh box traps (66 x 23 x 23 cm; Tomahawk Live Trap Co., Tomahawk, WI). Dry vegetation was placed on trap bottoms for bedding, and traps were covered with burlap to provide protection from sun and wind. Traps were baited with dry cat food, wet cat food, and a

loganberry lure (Knobb Mountain Fur Co., Berwick, PA). Traps were checked each morning. Captured foxes were physically restrained without immobilization drugs. Information collected from foxes included weight, sex, age (based on tooth wear), reproductive condition, and a general condition assessment. All new foxes (first capture) were marked with a passive integrated transponder tag (PIT tag; Biomark Inc., Boise, ID). Selected foxes were then fitted with a GPS unit, and released at the capture site.

Field testing consisted of obtaining general locations on the foxes twice each week by tracking the VHF signal using a receiver (model R-1000, Communications Specialist, Inc., Orange, CA) and standard VHF antenna. For units with remote download functions, periodic attempts were made to locate foxes and download data in the field. Downloads were attempted both from the ground and from fixed-wing aircraft. A fixed-element yagi antenna was used for both approaches. At the end of the field testing period, live-traps were set in the areas used by each fox in an effort to recapture foxes and remove the GPS units. Data were then downloaded from the units to assess their success in collecting data under field conditions.

A variety of parameters was assessed to evaluate the performance of the GPS units and their potential utility in island fox monitoring and research (Table 1). Where possible, parameters were quantitatively measured (e.g., rate of successful GPS location, length of operational time). Otherwise, parameters were qualitatively evaluated (e.g., ease of placement on foxes, unit condition upon retrieval). We tried to collect as much information as possible to assist in evaluating unit performance and utility.

Table 1. Parameters evaluated to assess the performance and utility of GPS units for island fox monitoring and research.

General category	Parameter description
Pre-deployment issues	GPS functioning properly
	VHF functioning properly
	VHF transmission distance
	Ease of programming
Fox and collar issues	Ease of placement on fox
	Any injuries to fox from unit
	Any significant mass loss by fox
	Unit condition upon recovery • antenna condition • collar condition • transmitter housing condition
GPS performance	Length of operational time
	Successful data acquisition
	Data collected at appropriate times/rates
	General data accuracy
	Successful remote download of data
VHF performance	Length of operational time
	Average transmission distance
	Signal strength and pulse rate over time
	Any significant frequency drift

PROXIMITY LOGGER UNITS

The proximity logger units were purchased from Sirtrack Limited (Hawkes Bay, New Zealand). Sirtrack currently is the only manufacturer that produces proximity loggers sufficiently small in size and mass to meet the 4% of body weight limit for telemetry devices placed on island foxes.

The units purchased were model E2C 171 A proximity loggers. Detailed specifications for these units are provided in Appendix B. These units consisted of a UHF transceiver bundled with a VHF transmitter in an acrylic housing and mounted on a machine belting collar (Figure 3). The entire unit weighed 60 g. The proximity logger units use the UHF transceiver to communicate with other units. Specifically, when 2 units come within a specified distance of each other, both units detect and identify the other unit (this constitutes a "contact"), and each records the duration of the contact. The maximum distance for a contact and the separation time required to end a contact can be programmed by the user. All information regarding the contact is stored within the unit, and units must be retrieved in order to download the stored data. The VHF transmitter (148-151.999 MHz) permitted instantaneous tracking of the unit. Battery life for the units is estimated at 276 days. The cost per unit was $499.

Figure 3. Proximity logger unit on an island fox on San Miguel Island.

All of the units were programmed identically. NPS staff chose a 30-m proximity as indicating a contact between foxes. This distance is set by adjusting the "UHF coefficient", and the appropriate coefficient was determined based on tests with the units placed on a saline bag to simulate a fox body. Thus, a contact was recorded if 2 foxes wearing units came within approximately 30 m of each other. The contact duration terminated once the animals moved apart and the 2 units were not in contact for > 30 sec. A base station was also deployed to monitor fox presence at a specific location. This station was programmed to detect foxes within a distance of approximately 60 m, and

contact duration was terminated if the fox moved > 60 m from the station for > 30 sec. Data from the base station were downloaded and the station was moved approximately every 2 weeks. Prior to deployment on foxes, each proximity logger was tested to ensure that the units were detecting other units, and that the VHF transmitter was operating properly.

To deploy the proximity logger units, island foxes on San Miguel were captured in live-traps by NPS personnel using the same methods as described for the GPS unit deployment on Santa Rosa. Selected foxes then were fitted with a proximity logger unit, and released at the capture site.

Field testing consisted of obtaining general locations on the foxes approximately once every 2 weeks by tracking the VHF signals, as with the GPS units. At the end of the field testing period, live-traps were set in the areas used by each fox in an effort to recapture foxes and remove the proximity logger units. Data were then downloaded from the units to assess their success in collecting data under field conditions.

A variety of parameters was assessed to evaluate the performance of the proximity logger units and their potential utility in island fox monitoring and research (Table 2). These parameters were generally similar to those used to evaluate the GPS units. As with the GPS unit evaluations, some parameters were quantitatively measured and some were qualitatively evaluated, and we tried to collect as much information as possible to assist in evaluating unit performance and utility.

Table 2. Parameters evaluated to assess the performance and utility of proximity logger units for island fox monitoring and research.

General category	Parameter description
Pre-deployment issues	Proximity logger detecting other units
	Inter-logger detection distance
	VHF functioning properly
	VHF transmission distance
	Ease of programming
Fox and collar issues	Ease of placement on fox
	Any injuries to fox from unit
	Any significant mass loss by fox
	Unit condition upon recovery
	• antenna condition
	• collar condition
	• transmitter housing condition
Logger performance	Length of operational time
	Successful data acquisition
	Concordance of contact data from loggers involved in a given contact
VHF performance	Length of operational time
	Average transmission distance
	Signal strength and pulse rate over time
	Any significant frequency drift

Each of the proximity logger units records data independently. Therefore, two units should ideally record the same number of contacts with each other and the duration of these contacts should be similar. Data were compared between pairs of units to examine

concordance. Specifically, the number of contacts recorded and the total duration of contacts between unit dyads were examined to determine how closely they matched.

RESULTS

The purpose of this project was to evaluate the performance of 2 relatively new telemetry technologies on island foxes, and to assess the utility of using these technologies to collect field data on island foxes. Thus, the data collected by the units were only examined with respect to quality and quantity relative to expectations regarding the performance of the units. Presentation and discussion of the specific ecological results provided by the data (e.g., habitat selection, contact rates) were beyond the scope and budget of this project, and therefore are not included in this report.

GPS UNITS

In February 2009, 14 GPS units were ordered from Telemetry Solutions. These included 7 "store-on-board" (SOB) units and 7 "remote download" (RD) units. Two additional SOB units were ordered in April 2009 for a total of 16 units. The units were delivered in May 2009 to the Channel Islands National Park.

The software required for programming the units was continually being updated, and 4 updates of the software and associated users manuals were made available in July 2009, November 2009, December 2009, and January 2010. Once the proper software was obtained, the GPS units were relatively easy to program.

Several issues were encountered during pre-deployment testing of the GPS units. A significant problem was difficulty in deactivating the units after testing. Multiple communications with the company were required to resolve this issue. Also, 7 of the units initially produced an error message ("Error 76") when connected to a computer for programming. Among other problems, this error apparently prevented the downloading of data and also caused the software program to terminate. All 7 units were sent back to the company for repair and 6 were returned approximately 1 month later. However, 1 of these repaired units was missing a battery and again had to be sent back to the company.

Other issues were encountered during testing. For one unit (one of those with an "Error 76" issue), actual time intervals for collecting locations were inconsistent with those programmed. For example, although a 2-hour interval was programmed, the unit attempted to obtain locations randomly at 2, 3, or 4-hour intervals. The VHF transmitter on this unit also exhibited a rapid pulse rate that would have significantly reduced battery life. The VHF transmitter on another unit was not operating when the unit was delivered. Both of these units were returned to the company for repair or replacement, and neither was returned in time to be deployed on foxes. For another unit (another with an "Error 76" issue), the time on the internal clock was not stable and shifted, which then caused locations to be recorded at incorrect intervals. Finally, during testing of the remote download function, only one attempt to download data was successful. Apparently, the whip antenna supplied with the base station had an extremely short range (approximately 10 m). However, switching to a yagi antenna (3 or 6 elements) resolved this issue and subsequent download attempts were more successful.

During annual trapping efforts on Santa Rosa conducted by the NPS, 14 GPS units were deployed on foxes during 2 September-6 November 2009; 12 of the 14 were deployed in September 2009. In an effort to hopefully provide a larger safety margin in the event that the weight of the units proved to be a burden for foxes, all of the units were placed on adult

males because of their larger body size. Fox weights ranged from 1.75-2.6 kg (see Table) resulting in unit/fox mass ratios of 2.5-3.7%. The units all were deployed on foxes on the east side of the island to facilitate monitoring. No problems were experienced in placing the units on foxes and obtaining a proper fit. Of the 14 units deployed, 8 were SOB and 6 were RD.

After the units were deployed on foxes, the most prevalent and serious problem encountered during monitoring was the performance and reliability of the VHF transmitters. In essence, 100% of the VHF transmitters failed prematurely. Among the 14 units deployed, the average number of days that VHF transmitters operated was just 27 (Table). Five transmitters failed after only 1 day of operation while the longest any functioned was just 92 days. The VHF transmitters exhibited other problems as well. Signal strength was relatively weak on all of the units, and consequently, the signal detection distance was quite short. Typically, signals could only be heard from ≤ 100 m, and even this was commonly the line-of-sight distance (i.e., no topographic or other features between the transmitter and observer). Thus, even when the transmitters were operating, the weak signal strength and short distances made tracking the units challenging. Signal drift was not a problem with the maximum observed deviation being about 3 Hz (Table 3). Similarly, the pulse rate remained relatively stable. One problem associated with the VHF transmitters was malfunctioning mortality sensors. Three of the units emitted false mortality signals; in all 3 cases, live foxes were observed or recaptured thereby confirming the false signals.

Table 3. Performance of VHF transmitters in the GPS units placed on island foxes on Santa Rosa Island in 2009.

GPS unit	Initial frequency	Final frequency	Date deployed	Date last heard	No. days operated
24413309	167.370	167.368	2009-09-09	2010-02-09	24
24413409	168.080	168.079	2009-09-16	2009-10-18	33
24413509	168.281	168.278	2009-09-18	2009-10-17	30
24413609	168.496	168.495	2009-09-09	2009-09-17	9
24413709	168.646	168.643	2009-09-06	2009-10-05	30
24413809	168.703	168.702	2009-09-02	2009-10-03	32
24413909	168.996	168.995	2009-09-13	2009-10-19	37
24512609*	166.960	166.959	2009-09-18	2009-09-18	1
24512709*	167.001	166.999	2009-11-06	2010-01-30	87
24512809*	167.017	167.015	2009-10-18	2009-10-18	1
24513009*	167.171	167.170	2009-09-21	2009-09-21	1
24513109*	167.185	167.184	2009-09-20	2009-09-20	1
24513209*	167.249	167.248	2009-09-19	2009-09-19	1
44422909	168.971	168.971	2009-09-18	2009-12-16	92

* indicates remote download units.

While the units were deployed on foxes, attempts were made to remotely download data from the 6 RD units. Doing so was rendered significantly more difficult by the failures among the VHF transmitters, as described above. Downloads could only be performed at a maximum distance of approximately 300 m. Thus, getting within this distance was challenging without the aid of the VHF transmitters. Fortunately, most foxes remained in the general vicinity of the location where they were trapped and collared.

In December 2009, downloads were attempted on 3 units, only 1 of which had a functioning VHF transmitter. Downloads were conducted from the ground using a hand-held fixed-element yagi antenna. The downloads were successful, and the data from one unit indicated that the fox was likely dead because all of the most recent locations were from a single location. The coordinates for this location were used to conduct a ground search, and the carcass of the fox was located and collected. Cause of death could not be determined due to the advanced state of decomposition of the carcass, but there was no evidence to suggest that the GPS unit was responsible for the death. In February 2010, downloads were attempted on the remaining 3 RD units from the air using an antenna attached to a fixed-wing aircraft. None of these remaining units had functioning VHF transmitters, but because the foxes all were in the general area where they had been trapped, the download attempts were successful.

Live-trapping totaling 1,274 trap-nights was conducted from June 2010 to January 2011 in an effort to recapture foxes and recover the GPS units. Trapping was primarily associated with annual NPS monitoring efforts on Santa Rosa, but most of the trapping conducted during December 2010 and January 2011 specifically targeted foxes wearing GPS units. Eight of these foxes were recaptured (Table 4). Additionally, as described previously, 1 fox was recovered dead.

Table 4. Initial and final weights of island foxes receiving GPS units on Santa Rosa Island.

Fox ID	GPS unit	Collar date	Recapture date	Days unit worn by fox	Weight when collared (kg)	Weight when recaptured (kg)	Change in weight (kg)
M6	24413309	2009-09-09	- [a]	-	2.45	-	-
M15	24513209*	2009-09-19	- [a]	-	2.40	-	-
M33	24413409	2009-09-16	2010-09-01	348	2.30	2.35	+0.05
M48	24413809	2009-09-02	2010-08-07	339	2.00	2.20	+0.20
M51	24512609*	2009-09-18	2009-11-14	57	1.75	Mortality	-
M52	24512709*	2009-11-06	2010-08-07	274	2.30	2.30	0
M64	24413609	2009-09-09	2010-08-05	330	2.90	2.70	-0.20
M66	24513009*	2009-09-21	- [a]	-	2.50	-	-
M69	24413709	2009-09-06	2010-07-22	319	2.00	2.10	+0.10
M70	24413909	2009-09-13	- [a]	-	2.10	-	-
M71	24413509	2009-09-18	2010-08-23	339	2.30	2.00	-0.30
M72	44422909	2009-09-18	2010-09-01	348	2.25	2.20	-0.05
M73	24513109*	2009-09-20	2010-11-26	432	1.85	2.25	+0.40
M75	24512809*	2009-10-18	- [a]	-	2.20	-	-

[a] not recaptured.
* indicates remote download units.

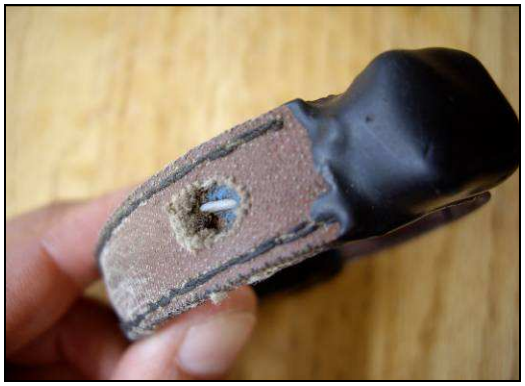
No injuries associated with collars were observed among the recaptured foxes that wore GPS units. Excluding the fox recovered dead, the other foxes recovered wore the units for 274-432 days (Table 4). Of the 8 foxes recaptured, 4 had gained weight, 3 had lost weight, and for 1 the weight was unchanged (Table 4). The weight losses were not considered excessive, particularly given the relatively long period that the foxes wore the units. The condition of the units upon recovery varied (Figure 4). Most exhibited excessive wear on the ends of the epoxy housing resulting in exposed wires. A piece of the housing was

missing from a unit that had malfunctioned, and this likely allowed moisture into the electronics of the unit causing the failure. The antenna on one unit was broken off where the antenna exited the housing. The antennas on most collars were frayed at the ends, and were bent or curled, as is commonly observed on conventional transmitter units recovered from foxes. Another pervasive issue involved the plugs used to protect the data port. These plugs consisted of small pieces of rubber that were secured in place with a layer of epoxy. Five of the 9 units recovered were missing the plugs. It is not clear whether the missing plugs affected performance. The only unit to exceed battery life expectations (see Table 5) also was missing the plug.

Unit 4442.2909 – Typical wear.

Unit 2441.3609 – Typical wear and antenna condition.

Unit 2451.3109 – Broken housing.



Unit 2441.3809 – Antenna broken at collar.

Figure 4. Examples of GPS unit condition after removal from island foxes.

GPS units were recovered from the 8 foxes recaptured and from the 1 fox found dead. Of the 5 foxes not recaptured, 3 had RD units and data were successfully downloaded from these resulting in GPS data sets for 12 of the 14 foxes that received GPS units (Table). All 12 data sets included apparently useable locations. Excluding the partial data sets from the 3 unrecovered units and the fox found dead, the average operational time for the remaining 8 units was 17.5 weeks (range 10-28 weeks). Of these 8, 2 malfunctioned and ceased operating due to damages (e.g., broken antenna or transmitter housing). The

expected operational life of the GPS battery varied from 23-30 weeks, depending on the frequency of location attempts programmed into each unit. Only one unit met or exceeded the expected operating time. The units were programmed to attempt to collect locations at prescribed times. On average, the units were successful in collecting a location in 81.7% (range 73.0-92.8%) of attempts (Table 5). The units collected an average of 357 (range 223-552) locations while they were deployed.

Table 5. Operation times and location success rates for GPS units deployed on island foxes on Santa Rosa Island.

GPS unit	Dates of operation (begin / end)	Operating time (weeks)	Difference from expected operation[a] (weeks)	Successful locations	Percent successful locations	Comments
24413409	2009-09-22 / 2010-03-04	22	-5	452	82.5	
24413509	2009-09-22 / 2010-03-04	22	-5	482	85.6	
24413609	2009-09-22 / 2010-01-18	16	-11	304	76.8	
24413709	2009-09-22 / 2010-02-16	19	-8	431	87.3	
24512709*	2009-12-01 / 2010-06-30	28	+2	552	73.0	
44422909	2009-09-22 / 2009-12-14	11	-17	236	81.4	
24413809	2009-09-22 / 2009-12-07	10	-16	223	88.5	Broken antenna
24513109*	2009-09-22 / 2009-12-19	12	-18	225	73.1	Broken housing
24512609*	2009-09-22 / 2009-12-22	12	-16	236	74.0	Mortality
24512809*	2009-11-03 / 2010-02-12	13	-10	266	76.0	Not recovered, partial data from RD
24513009*	2009-09-27 / 2010-02-12	14	-10	441	92.8	Not recovered, partial data from RD
24513209*	2009-09-22 / 2010-02-12	15	-9	441	89.6	Not recovered, partial data from RD
24413309	N/A	N/A	N/A	N/A	N/A	No data, not recovered
24413909	N/A	N/A	N/A	N/A	N/A	No data, not recovered

[a] expected operation varied from 24-30 weeks, depending upon unit programming.

* indicates remote download units.

PROXIMITY LOGGER UNITS

In September 2009, 17 proximity loggers were ordered from Sirtrack. The units were delivered to the Channel Islands National Park. The units were relatively easy to program, and no issues were encountered during programming. All of the units were tested prior to deployment on foxes and all appeared to be functioning as expected.

During annual trapping efforts on San Miguel conducted by the NPS, 17 proximity logger units were deployed on foxes during December 2009-January 2010. All were deployed within an approximately 4-km^2 area to facilitate monitoring and to increase the potential for recording contacts between individuals. Units were placed on both males and females, and on foxes ranging in age from < 1 year to > 7 years (Table 6). Fox weights ranged from 2.05-2.75 kg (see Table 4) resulting in unit/fox mass ratios of 2.2-2.9%. No problems were experienced in placing the units on foxes and obtaining a proper fit.

The performance of the VHF transmitters on the units met expectations. None of the transmitters failed while deployed on foxes. Also, there were no observed deviations in signal strength, frequency, or pulse rate during the period of deployment.

One of the foxes with a proximity logger was found dead on 27 August 2010. The carcass was too decomposed to determine the cause of death, but the fox had worn the unit for a number of months and also had worn multiple conventional radio collars in the past, and

NPS staff felt that the logger unit was not likely to have contributed to the death. Live-trapping was conducted during summer and fall 2010 in an effort to recapture foxes and recover the proximity logger units. Trapping was primarily associated with annual NPS monitoring efforts on San Miguel. Of the 16 foxes still wearing units, 14 were recaptured during July-August 2010, 1 was recaptured in November 2010, and 1 eluded recapture (Table 6).

Table 6. Data on island foxes that wore proximity logger units on San Miguel Island during 2009-2010 and performance measures for the units.

Fox ID[1]	Age (yrs)	Date collared	Date recaptured	Days unit worn	Days UHF Active	Reliable Records >1 sec	Capture wt (kg)	Recap wt (kg)	Weight change (kg)
M265	1.5	2009-12-09	2010-07-17	220	211	1241	2.20	2.40	+0.20
M267	0.5	2009-12-09	2010-07-15	218	217	1290	2.10	2.20	+0.10
M268	0.5	2009-12-10	2010-07-19	221	212	74	2.05	2.00	-0.05
M264	1.5	2009-12-09	2010-07-14	217	204	4436	2.40	2.20	-0.20
F351	3.5	2009-12-09	2010-07-16	219	210	1029	2.20	2.15	-0.05
F353	1.5	2009-12-15	2010-08-01	229	222	4959	2.30	2.10	-0.20
F352	3.5	2009-12-09	2010-07-30	233	212	2810	2.60	2.60	0
M245	2.5	2009-12-09	2010-07-15	218	215	3530	2.50	2.50	0
M266	1.5	2009-12-09	- [2]				2.20	-	-
M214	6.5	2009-12-24	2010-07-29	217	209	4454	2.40	2.55	+0.15
F313	5.5	2009-12-24	2010-07-29	217	214	3233	2.10	2.10	0
M269	0.5	2009-12-24	2010-07-28	216	207	1736	2.10	2.20	+0.10
M270	1.5	2009-12-25	2010-11-13	323	114	117	2.30	2.10	-0.20
M271	0.5	2009-12-25	2010-07-29	216	213	1853	2.10	2.10	0
M212	7.5	2010-01-06	2010-08-27	233	174	35	2.75	-	-
F354	0.5	2010-01-08	2010-08-01	205	205	911	2.10	2.10	0
M273	1.5	2010-01-08	2010-08-11	215	214	1280	2.50	2.50	0

[1] M = male, F = female

[2] Not recaptured

Excluding the fox recovered dead, the recaptured foxes wore the proximity logger units for an average of 226 (range 205-323) days (Table 6). No injuries associated with collars were observed among the foxes. Of the 15 foxes recaptured, 4 had gained weight, 5 had lost weight, and 5 were the same weight (Table 6). The weight losses were not considered excessive, particularly given the relatively long period that the foxes wore the units. Generally, the units appeared to be in good condition upon recovery (Figure 5). They exhibited some wear, but none of the wear was considered excessive for collars deployed on wild foxes for multiple months. The housing and antenna were intact on all units. The antennas held up particularly well and did not exhibit the curling and fraying that was commonly observed among the GPS units and that also is commonly observed among conventional radio collars.

Figure 5. Typical wear observed on proximity logger units deployed on San Miguel island foxes in 2009-2010.

The proximity logger units all recorded contacts between foxes wearing the units. Twelve of the 16 recovered units recorded at least 1,000 contacts, and 3 units recorded over 4,000 contacts (Table 6). Difficulties were only detected for one unit; it malfunctioned after 177 days on the fox and afterward recorded 16,516 unusable records. Otherwise, all units performed as expected. Most of the foxes were recaptured prior to the estimated termination of battery life (276 days), but the last fox recaptured wore the unit for 323 days and the unit was still operating. After recovery, the units could not be deactivated by simply passing a magnet near the external activation site and magnets had to be taped to units in order to deactivate them, but this was a minor issue. Also, the base station failed within a few weeks of deployment, but a replacement sent by Sirtrack worked fine during the remainder of the project.

The number of contacts and the total duration of contacts between units within a dyad generally were very similar (Tables 7 and 8). For example, M265 recorded 63 contacts totaling 2,134 seconds with F352 while F352 recorded 58 contacts totaling 2,257 seconds with M 265. This general concordance was common among almost all the unit dyads. Thus, this indicates a relatively high level of accuracy among the data recorded by the units.

Table 7. Number of contacts between island foxes wearing proximity logger units on San Miguel Island during 2009-2010. Values are the number of times that foxes in each row recorded a contact with a fox in each column.

	M265	M267	M268	M264	F351	F353	F352	M245	M266	M214	F313	M269	M270	M271	M212	F354	M273
M265	-	112	8	3	33	7	63	189	56	0	4	0	4	0	0	160	2
M267	113	-	6	2	0	7	250	718	120	2	1	0	19	0	0	2	1
M268	7	4	-	3	50	3	2	0	6	0	0	0	0	0	0	0	0
M264	3	1	3	-	19	3872	26	18	12	7	115	0	5	8	0	0	8
F351	43	0	54	22	-	15	4	8	0	0	0	0	0	0	0	24	9
F353	5	8	3	3978	13	-	26	15	7	27	162	26	6	21	0	0	80
F352	58	306	2	25	2	26	-	1853	0	2	3	0	25	1	1	3	134
M245	188	625	1	19	7	13	1875	-	0	2	11	0	33	2	0	70	54
M266[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
M214	0	1	0	9	0	25	1	6	0	-	2142	969	2	1286	0	0	0
F313	1	1	0	114	0	143	3	10	1	2126	-	372	0	405	0	0	0
M269	0	0	0	0	0	22	0	0	0	1044	386	-	0	215	0	0	0
M270	4	18	0	4	0	4	22	32	0	2	0	0	-	12	0	0	6
M271	0	0	0	8	0	19	0	2	0	1146	391	208	4	-	0	0	0
M212	0	0	0	0	0	0	1	0	0	0	0	0	0	0	-	0	0
F354	154	1	0	0	22	0	4	69	0	0	0	0	0	0	0	-	654
M273	4	51	0	8	10	77	117	72	0	0	0	0	3	0	19	685	-

[1] M266 was not recaptured and therefore the number of times that it recorded contacts with other foxes is unknown.

Table 8. Duration of contacts between island foxes wearing proximity logger units on San Miguel Island during 2009-2010. Values are the number of seconds during which foxes in each row recorded a contact with a fox in each column.

	M265	M267	M268	M264	F351	F353	F352	M245	M266	M214	F313	M269	M270	M271	M212	F354	M273
M265	-	26556	773	101	1464	756	2134	16530	1613	0	0	0	296	0	0	10633	177
M267	28409	-	136	116	0	338	22960	95689	21939	44	72	0	972	0	0	70	29073
M268	605	294	-	17	1738	77	67	0	463	0	0	0	0	0	0	0	0
M264	87	51	20	-	2411	913861	2908	711	243	75	7915	0	145	396	0	0	452
F351	2084	0	1870	2427	-	213	114	942	0	0	0	0	0	0	0	1558	836
F353	923	322	70	953061	181	-	1325	349	332	1186	25789	2103	181	8987	0	0	30005
F352	2257	35605	58	3064	90	898	-	560695	0	21	113	0	715	115	18	260	7767
M245	15550	77725	4	689	986	303	535694	-	0	770	701	0	1961	92	0	62278	3412
M266[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
M214	0	42	0	101	0	894	4	176	0	-	741312	21245	36	159596	0	0	0
F313	0	73	0	8762	0	23951	104	704	20	743198	-	106077	0	95021	0	0	0
M269	0	0	0	0	0	2130	0	0	0	223833	119418	-	0	12189	0	0	0
M270	299	931	0	101	0	151	569	1864	0	54	0	0	-	441	0	0	38
M271	0	0	0	367	0	8846	0	87	0	164440	96936	12227	555	-	0	0	0
M212	0	0	0	0	0	0	15	0	0	0	0	0	0	0	-	0	3335
F354	9823	54	0	0	1183	0	272	62020	0	0	0	0	0	0	0	-	49180
M273	189	28171	0	743	743	29341	8085	5818	0	0	0	0	28	0	3357	57764	-

[1] M266 was not recaptured and therefore the total duration of the contacts that it recorded with other foxes is unknown.

DISCUSSION

GPS UNITS

The performance of the GPS units was mixed. Some aspects of these units were very successful while others fell well short of expectations or advertised performance. The

units were worn successfully by island foxes in that they did not cause any detectable injuries (e.g., lacerations, abrasions, hair loss, or breakage) to foxes that were recaptured and examined, and no adverse effects on survival, reproductive success, or condition were detected. One fox died while wearing a unit, but there was no evidence that the unit contributed to this death. The GPS units do appear to be a bit bulky, which is probably a function of bundling multiple functions (e.g., GPS receiver, VHF transmitter, mortality sensor, associated batteries, antenna) into a single package. Also, protrusions project from the top of the collar and from the bottom of the housing. However, observations of captive animals wearing the units would be necessary to determine whether the bulk or protrusions caused any noticeable discomfort to the foxes.

The weight of the units potentially could limit the foxes on which the units are deployed. A general recommendation when conducting research on animals using telemetry equipment is to limit the weight of the equipment to $\leq 5\%$ of body weight. For rare species, a more conservative approach commonly is recommended with the equipment/body weight ratio sometimes limited to $\leq 3\%$. The federal permit issued to NPS for handling island foxes includes a 4% limit, which would allow the 65-g GPS units to be placed on foxes weighing ≥ 1.625 kg. In an analysis of radiocollar effects on 542 endangered San Joaquin kit foxes (*Vulpes macrotis mutica*), possible detrimental effects were only detected when equipment exceeded 6% of body weight, and these effects were primarily detected among juveniles (Cypher 1997).

Once all of the proper software and instructions were in hand, the units generally were easy to program. A number of programming options were available such that the number of locations collected per day, the specific times or time intervals at which locations were recorded, and the amount of time allowed for a unit to obtain a location all could be programmed by the user to more effectively address study objectives and also to maximize battery life.

The GPS receivers generally worked well. Such receivers need to communicate with orbiting satellites in order to calculate and record locations. Obstacles such as dense vegetation or topographic features and behaviors such as den use can impede communications between the units and satellites resulting in failed attempts to obtain locations (e.g., Johnson et al. 2002). Island foxes do indeed use dens on occasion (Moore and Collins 1995) and also commonly use areas of rugged terrain, such as canyons. However, the proportions of attempts during which successful locations were secured were relatively high, demonstrating that the units were quite effective in collecting the desired data. It is unknown whether a particular factor or factors (e.g., topography, vegetation, den use) were consistently associated with failed location attempts. During pretesting, the units successfully collected locations in grassland, chaparral, and mixed woodland habitats, although the rates of successful locations were not determined.

The most significant issue with the GPS function was that the duration of operation fell well short of expectations for all but one unit. Almost all of the units operated for several weeks, and in some cases several months, less than expected. Consequently, the number of locations collected also fell short of expectations. The expected battery life and programmed parameters should have yielded approximately 670 locations. However, even accounting for failed location attempts, only one unit achieved the expected number of locations (which was the same unit that also exceeded expected battery life).

A remote download function was included in 6 of the GPS units and this function was very successful with the proper antenna. The short range on the whip antenna supplied with the base station rendered it essentially incapable of remotely downloading data from units, particularly under field conditions. However, switching to a yagi antenna resolved this issue. Data were successfully downloaded from all 6 units. Downloading from the ground did necessitate maneuvering to within about 300 m of the foxes, which could be challenging depending upon factors such as road access, topographic ruggedness, and vegetation density. However, downloading also was effective from the air. Aerial downloading may seem more expensive due to the costs of aircraft charter, but ground downloading could consume significantly more staff time, and this might reduce or even negate any differences in cost-efficacy between the 2 methods. Regardless of method, the immense value of the remote download function was sharply highlighted by the inability to recapture 3 of the foxes with RD units. Without this function, no data would have been recovered from these animals, and indeed, no data were recovered from 2 foxes with non-RD units that also were not recaptured.

The accuracy of the locations obtained by the GPS units was not precisely quantified. However, qualitative evidence suggests that the locations were reasonably accurate. The locations were effective in leading field biologists to the fox that had died. Because the foxes are small and the carcass was decomposed and not obvious, the locations had to lead to a relatively small area. After the fox died, the GPS unit collected 90 locations. On average, these locations were <10 m (range 0.4-81 m) from the coordinates provided by a hand-held GPS unit for the same location. Such precision would be sufficient for conducting detailed spatial analyses, such as examining use of habitats and landscape features by foxes. Also, in examining the preliminary data, the locations downloaded from the units (Figure 6) seem to make good sense, based on the field biologists' knowledge of the space use patterns of the foxes that wore the units. Occasionally, there were some obvious errors, such as locations out in the ocean or locations far outside of the area typically used be a given fox (these were generally single locations with the prior and subsequent locations being back in the fox's typical area of use). However, these aberrant locations were uncommon, and usually easily identified.

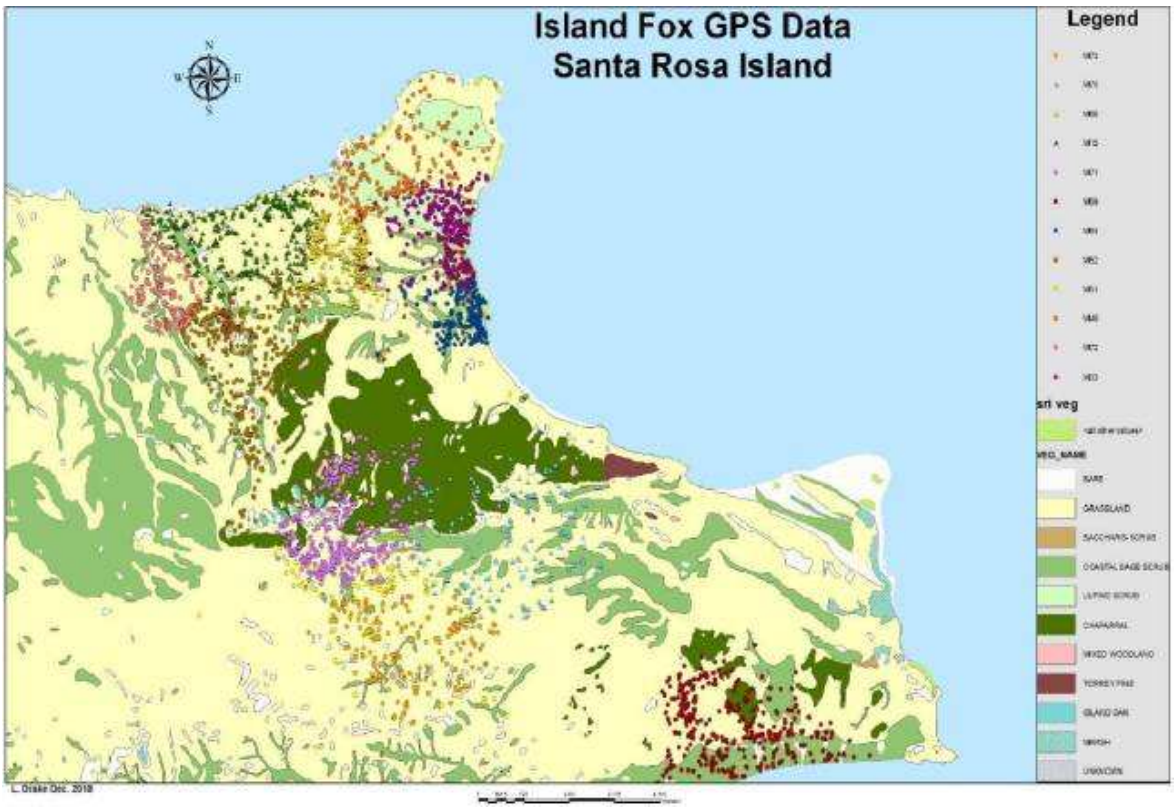


Figure 6. Locations of island foxes on Santa Rosa Island in 2009-2010, as recorded by GPS units worn by the foxes.

The performance of the VHF transmitters was essentially unacceptable. This extremely poor performance was quite puzzling given that VHF technology has been used in wildlife telemetry equipment for decades, including equipment much more miniaturized than the systems in the GPS units. None of the transmitters even came close to operating for the advertised life expectancy of 200 days. The longest any operated was 92 days and 6 of the 14 deployed units failed after <10 days. This failure in performance is extremely problematic as it significantly reduces the probability of obtaining data, particularly from units lacking the remote download function. The absence of a VHF signal precludes tracking and locating animals for status checks, targeted trapping, or remote data downloads, and also precludes the detection of dead foxes as the mortality sensor operates by altering the pulse rate of the VHF signal. Only one of the RD units had a functioning VHF transmitter when remotely downloaded. The remaining 5 were located and downloaded after searching within the area assumed to be used by a given fox or by searching over broad areas from the air. Two foxes with non-RD units were not recaptured, and in the absence of a VHF signal, it is unknown whether the foxes were still present within the areas trapped or even if they were still alive. Consequently, no data were obtained from these foxes despite the effort and expense invested in deploying GPS units on them. Staff at Telemetry Solutions attributed the VHF failures to "a bad batch of batteries", but similar failures were experienced on another project on kit foxes in Arizona (E. Rubin, Arizona Game and Fish, personal communication) in which identical units were deployed.

GPS tracking technology that is sufficiently miniaturized for deployment on animals the size of island foxes is relatively new. Currently, Telemetry Solutions is the only company

manufacturing such technology, and only has been doing so for about 2 years. Another company previously manufactured similar technology, but discontinued production following unacceptably poor performance during several field studies (e.g., Clevenger et al. 2010). Thus, manufacturing such miniaturized technology clearly is challenging. Given that the technology is relatively new, issues and problems are not unexpected. In essence, this project served as somewhat of a "field test" for this technology. That said, some of the problems experienced during this project appear to fall in the category of "quality control" issues. Some of the examples include incorrect software supplied with the units, incorrect software loaded on the units, units not deactivating properly, one "refurbished" unit lacking a battery, units having malfunctions "right out of the box", improper attachment hardware supplied with the units, and the failure of the VHF transmitters, among other issues. Although staff at Telemetry Solutions were responsive and cordial in addressing problems, the issues encountered consumed considerable time, resulted in project delays, resulted in 2 units not being deployed because problems could not be resolved quickly enough, required extra field time, and also resulted in a much lower quantity of data than expected, or in some cases no data being obtained from some of the units. These issues all have significant costs associated with them, both in terms of time and actual monetary expense.

PROXIMITY LOGGER UNITS

In marked contrast to the GPS units, the performance of the proximity logger units was excellent. The units essentially functioned as expected. The small number of problems that did surface, almost all of which were relatively minor, fell within the bounds of expectations for a field study, particularly one in which relatively novel equipment and techniques are being tested.

Of greatest importance, the units were worn successfully by island foxes in that they did not cause any detectable injuries to foxes, and no adverse effects on survival, reproductive success, or condition were detected. One fox died while wearing a unit, but there was no evidence that the unit contributed to this death. At 60 g, the proximity logger units weighed just slightly less than the 65 g GPS units. To comply with the 4% equipment/body weight ratio limit in the federal handling permit, proximity loggers could be placed on foxes $\geq$ 1.5 kg.

The units were easy to program. Part of this programming ease was that there were not many parameters to program, and those that could be programmed had just a small number of options. Probably the most important parameter is the "UHF coefficient" that determines the distance at which a unit will detect another unit and record a contact. This parameter can be adjusted to alter the detection distance based on study objectives.

The units held up well under field conditions and did not exhibit any signs of damage or excessive wear. None of the units experienced premature battery failures and at least one unit exceeded estimated battery life. The VHF transmitters all functioned per expectations, and this greatly facilitated targeted trapping efforts to recapture foxes and recover the units. This was extremely important as the proximity logger units do not have a remote download function or automated drop-off system, thus necessitating recapture of the animals in order to recover the stored data. One fox was not recaptured, and therefore, no data were obtained from this animal.

Abundant data were collected using the proximity logger units. As important, the quality of those data appeared to be quite high, based on the examination of concordance within unit dyads. In most cases, the number and total duration of contacts did not match exactly between two units in a dyad. However, this could easily be attributable to several factors. First, the sensitivity of each unit in detecting another unit likely was not identical across units. This is due to inherent variations in the electronics of each unit. Second, the ability of a unit to detect another also is influenced by the orientation of each unit with respect to other units (e.g., height, position of fox, obstacles, etc.). Consequently, particularly when foxes were near the limits of their detection abilities, one unit may have detected a second unit whereas the second unit may not have detected the first. This would lead to the observed discrepancies within unit dyads. However, it should be emphasized that these discrepancies are not considered inordinately large, and that trends and patterns are easily detected in the data. Scientists using proximity loggers on other species have found similar occasional small discrepancies between the data recorded by 2 units in a dyad and developed ways to deal with them during data analysis (Prange et al. 2006, Hamade et al. 2008, Hauver et al. 2010).

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Clearly, both the GPS unit and proximity logger technologies have immense potential for obtaining valuable information on island fox ecology that would be more difficult or more costly to obtain using other approaches. An obvious caveat is that this potential can only be realized when the technology functions according to specifications. When this is the case, the quality and quantity of data obtained should easily outbalance the cost of the GPS units and proximity loggers, which is considerably higher than the conventional VHF units that are still the most commonly employed equipment in telemetry studies on animals. As with any research project, the most appropriate methods and equipment for achieving objectives should be selected. Thus, GPS and proximity logger units should only be employed when they constitute the most effective approach for collecting desired data. For example, neither GPS or proximity logger units would be cost-effective tools to investigate survival. However, for investigations of spatial ecology (e.g., home range characteristics, habitat selection, and dispersal), GPS units could be highly cost-effective. Likewise, for investigations of intraspecific interactions (e.g., social ecology and epidemiological risk), proximity logger units can provide unique and invaluable data.

The expense of the both units, particularly the GPS units, could be cost-prohibitive for limited research budgets. Another potential drawback is that even if the units work as expected, no data will be obtained from a given animal if that animal is not recaptured and the unit recovered. This occurred with both the GPS and proximity logger units deployed on island foxes. The failure to recapture animals was mitigated to a degree by the remote download function on the GPS units. An effective timed or remotely activated release system would also help mitigate recapture failures, and could even negate the need to recapture animals. However, such systems have been fraught with problems and currently are not consistently reliable.

RECOMMENDATIONS

Based on the results of this project, the following recommendations are offered:

1. GPS units should be used with caution

Currently, GPS units sufficiently miniaturized for safe deployment on island foxes are only manufactured by one company, Telemetry Solutions. For reasons that may include poor quality control, the reliability of these units must be considered low, based on the results of this project. However, although far less than expected, a considerable quantity of valuable data still were obtained in spite of the performance issues encountered. Thus, use of the units should not be ruled out completely, but users should be cognizant of the current limitations of the equipment and the potential issues that they may experience with these units. Hopefully, the manufacturer will continue to try to improve the units and other manufacturers soon may begin producing reliable GPS units that can be deployed on island foxes.

2. GPS units should include the remote-download function

The GPS units experienced a number of issues and problems that can result in loss of data. In particular, the frequent failure of the VHF transmitters on the currently available units makes tracking and target-trapping foxes difficult. Also, as previously discussed, recapture of animals wearing the units is never assured. The remote download function on the available GPS units seemed to be relatively reliable, and indeed, at least partial data sets were recovered from 3 animals that were never recaptured. Thus, for researchers choosing to use GPS units, the remote download function is highly recommended. This function does increase the cost of the units, but the increased cost is a worthwhile expense to increase the probability of obtaining data from the units.

3. Attempt GPS unit downloads from the air

Animals wearing GPS units may move considerable distances or move into inaccessible terrain or vegetation, which could make it difficult to approach within a sufficiently close proximity to remotely download data from the units. Also, animals could be distributed over a large area significantly increasing the time required to get into close proximity. Finally, as discussed, the VHF transmitters incorporated within the GPS units can fail, making it impossible to track animals. For these reasons, it may be cost-effective to attempt remote downloads of data from aircraft. Larger areas can be searched more quickly from the air, and aerial searches are not limited by terrain, vegetation, or lack of roads.

4. Frequently download data from GPS and proximity logger units

Data should be downloaded from both the GPS and proximity logger units whenever the opportunity presents itself. As discussed in this report, data could be lost or not recovered from either type of unit for a variety of reasons, not the least of which is the inability to recapture animals wearing the units. For GPS units with the remote download function, animals do not need to be recaptured and therefore data potentially can be more easily downloaded, assuming that foxes can be located in the field. For these units, it may be prudent to attempt data downloads at least monthly, and even semi-monthly or weekly, if

possible. For the GPS units without the remote download function and for the proximity loggers, data downloads can only be conducted if animals are recaptured. Frequent trapping of animals may not be desirable due to the risk of injury or disruption to natural behavior. However, if animals are opportunistically recaptured prior to the conclusion of the data collection period, the units can be temporarily removed, the data downloaded, and the unit placed back on the animals, or the units could even be downloaded while still on the animals. However, both of these recapture scenarios necessitate having a portable computer in the field, which is not always practical.

5. Frequently monitor animals using the VHF transmitters

For both the GPS and proximity logger units, frequent monitoring of animals is recommended to determine areas being used by animals. Given that data from the proximity logger units and the GPS units without the remote download function can only be recovered upon recapture of the animals, it would be prudent to monitor animals and define areas of use. This will facilitate efforts to recapture the animals and recover data. Monitoring at least weekly is recommended. Such monitoring also is recommended for the GPS units with remote download function. The failure rates of the VHF transmitters obviously could inhibit monitoring, but these rates also are a reason to obtain as much information on space use as is practicable soon after the units are deployed.

6. Rigorously pretest all units

For many reasons, newly delivered equipment may not work properly. Thus, any equipment, telemetry units and otherwise, should be tested prior to deployment in the field. This is a particularly prudent measure given the problems experienced with the GPS units upon delivery. Pretesting should be conducted on all units and should include:

- VHF transmitter operation
- VHF frequency under field conditions
- VHF signal strength (i.e., distance signal can be heard)
- Mortality sensor operation (if equipped)
- GPS receiver operation (does it collect locations)
- GPS location accuracy (determine by letting unit collect locations at a known location)
- GPS data acquisition (are the proper associated data being collected with each location)
- GPS base station operation (does it work)
- GPS remote download function (does it work and what is the maximum distance)
- Proximity logger operation (does it work and what is the distance for contacts)
- Proximity logger accuracy (are contacts and associated data being recorded properly)
- Proximity logger base station operation (does it work)

LITERATURE CITED

Clevenger, A. P., Kociolek, A. V., and B. L. Cypher. 2010. Effects of four-lane highways on desert kit fox and swift fox: inferences for the San Joaquin kit fox population. Western Transportation Institute, Montana State University, Bozeman.

Coonan, T. J. 2003. Recovery strategy for island foxes (*Urocyon littoralis*) on the northern Channel Islands. National Park Service, Ventura, California.

Coonan, T. J., C. A. Schwemm, and D. K. Garcelon. 2010. Decline and recovery of the island fox: a case study for population recovery. Cambridge University Press, New York, New York.

Cypher, B. L. 1997. Effects of radiocollars on San Joaquin kit foxes. Journal of Wildlife Management 61:1412-1423.

Hamede, R. K., J. Bashford, H. McCallum, and M. Jones. 2009. Contact networks in a wild Tasmanian devil (*Sarcophilus harrisii*) population: using social network analysis to reveal seasonal variability in social behaviour and its implications for transmission of devil facial tumour disease. Ecology Letters 12:1-11.

Hauver, S. A., S. D. Gehrt, S. Prange, and J. Dubach. 2010. Behavioral and genetic aspects of the raccoon mating system. Journal of Mammalogy 91:749-757.

Johnson, C. J., D. C. Heard, and K. L. Parker. 2002. Expectations and realities of GPS animal location collars: results of three years in the field. Wildlife Biology 8:153-159.

Moore, C. M., and P. W. Collins. 1995. Urocyon littoralis. Mammalian Species 489:1-7.

Prange, S., T. Jordan, C. Hunter, and S. D. Gehrt. 2006. New Radiocollars for the Detection of Proximity among Individuals. Wildlife Society Bulletin 34:1333-1344.

Roemer, G. W. 1999. The ecology and conservation of the island fox. Dissertation, University of California, Los Angeles, California.

Rubin, E. S., V. J. Bakker, M. G. Efford, B. S. Cohen, J. A. Stallcup, W. D. Spencer, and S. A. Morrison. 2007. A population monitoring framework for five subspecies of island fox (*Urocyon littoralis*). Prepared by the Conservation Biology Institute and The Nature Conservancy for the Recovery Coordination Group of the Island Fox Integrated Recovery Team. U.S. Fish and Wildlife Service, Ventura, CA.

Schoenherr, A. A., C. R. Feldmeth, and M. J. Emerson. 1999. Natural history of the islands of California. University of California Press, Berkeley.

Scott, J. M., D. D. Goble, J. A. Wiens, D. S. Wilcove, M. Bean, and T. Male. 2005. Recovery of imperiled species under the Endangered Species Act: the need for a new approach. Frontiers in Ecology and the Environment 3:383-389.

U.S. Fish and Wildlife Service. In press. Recovery strategy for four subspecies of island fox (*Urocyon littoralis*). U.S. Fish and Wildlife Service, Sacramento, California.

APPENDIX A: SPECIFICATIONS FOR GLOBAL POSITIONING SYSTEM (GPS) UNITS FROM TELEMETRY SOLUTIONS

Telemetry Solutions
5051 Commercial Circle, Suite A
Concord, CA 94520
www.telemetrysolutions.com

Model: Quantum 4000 Enhanced GPS collar

Weight: 65 g

Collar material: belting

Antenna: external whip

Capabilities: GPS locations (store-on-board standard), VHF transmitter, mortality sensor (optional), remote-download of stored GPS data (optional)

VHF pulse rate: 55 ppm

Frequency range: 166-168.999 MHz

Separate batteries for GPS and VHF functions:

- Estimated battery life expectancy for GPS function: 144-435 days, depending upon the number of fixes per day

- Estimated battery life expectancy for VHF function: 200 days

Total number of locations: 259-1,783, depending upon programming

Programmable functions: Date, time, schedule for collecting fixes (numerous options provide wide range of flexibility in choosing dates and times), time to acquire a fix (TTF), additional time if a fix is not acquired in the allotted time, and interval between fix attempts.

Data recorded: Date, time, TTF, location coordinates, maximum signal-to-noise ratio, dilution of precision, number of satellites, type of fix (2D or 3D), voltage, and temperature.

Software versions used: 0.137, 0.146, 0.150, 0.160, and 0.161

User manual versions used: 1.0, 1.12, 1.3, 1.31, and 1.32

Costs (as of spring 2009):

- Store-on-board unit: $1,695

- Remote download unit: $1,795/$1,895

- Quantum remote download base station: $2,995

APPENDIX B. SPECIFICATIONS FOR PROXIMITY LOGGER UNITS FROM SIRTRACK.

Sirtrack LTD
Private Bag 1403
Goddard Lane
Havelock North 4157
New Zealand
www.sirtrack.com

Model: E2C 171 A

Weight: 60 g

Collar material: belting

Antenna: external whip

Capabilities: UHF transceiver (detects other units, data stored-on-board), VHF transmitter

VHF pulse rate: 40 ppm

VHF pulse width: 18 msec

Frequency range: 148-151.999 MHz

Estimated battery life: (one battery for UHF and VHF functions): 276 days

Programmable functions: ID #, separation time, UHF range coefficient, LED on/off, VHF transmit on/off, VHF pulse rate, UHF receiver mode on/off, UHF transmit mode on/off

Data recorded: Record ID, Encounter ID, Date, Encounter start time, Encounter length

Software versions used: 1.0.0.7

User manual versions used: 1.0.0.7

Costs (as of fall 2009):

- proximity logger units: $499
- base station: $439
- software and interface unit: $250