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EVALUATION OF NEW TELEMETRY TECHNOLOGIES FOR RESEARCH ON ISLAND FOXES

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ABSTRACT.—New telemetry technologies have recently become available for research on island foxes (*Urocyon littoralis*). These include GPS units, which collect location data, and proximity logger units, which record contacts between individuals. We evaluated these technologies on island foxes through 4 field studies. GPS collars were deployed on foxes on Santa Catalina during 2007–2008 ($n = 20$) and 2010–2011 ($n = 5$) and on Santa Rosa during 2009–2010 ($n = 14$). The GPS units had multiple issues including malfunctioning drop-off mechanisms, failure of some units to yield data, low location acquisition rates, improper factory programming, high rates of premature failure of VHF transmitters and GPS units, poor VHF signal strength, faulty mortality sensors, and breakage of the unit housing or antenna. Proximity loggers were deployed on foxes on San Miguel during 2009–2010 ($n = 17$). Performance was satisfactory and consistent with expectations. Both the GPS and proximity logger units yielded high-quality data when the units worked correctly. Some minor collar-related injuries were noted on 4 foxes with GPS units. We conclude that both technologies can potentially collect valuable data that would be more difficult and expensive to collect using conventional VHF methods and therefore could benefit island fox conservation. We recommend (1) using GPS units with a remote download function; (2) downloading data from both types of units as frequently as is practicable; (3) attempting GPS-unit data downloads from the air; (4) frequently monitoring foxes using the VHF transmitters to determine areas of use; and (5) rigorously pretesting all functions on both types of units prior to deployment on foxes.

RESUMEN.—Tecnologías telemétricas nuevas están recientemente disponibles para investigación del zorro gris de las islas (*Urocyon littoralis*). Esta tecnología incluye unidades GPS las cuales colectan información sobre localización y unidades de registro de datos de proximidad, que registran contactos entre individuos. Evaluamos estas tecnologías en el zorro de las islas a través de 4 estudios de campo. Colocamos collares con GPS en los zorros de Santa Catalina en 2007–2008 ($n = 20$) y 2010–2011 ($n = 5$), y en Santa Rosa en 2009–2010 ($n = 14$). Las unidades GPS tuvieron varios problemas incluyendo el mal funcionamiento del mecanismo, problemas para colectar información en algunas unidades, bajas tasas de adquisición local, programación errónea de fábrica, tasas altas de fallas prematuras en los transmisores de VHF y las unidades GPS, señal baja VHF, sensores de mortalidad defectuosos, y daños en la unidad central o en la antena. Las unidades de registro de datos de proximidad se utilizaron en zorros de San Miguel en 2009–2010 ($n = 17$). Los resultados fueron satisfactorios y de acuerdo con las expectativas. Ambos, GPS y las unidades de registro de proximidad obtuvieron datos de alta calidad cuando las unidades funcionaban correctamente. Algunos pequeños daños con respecto a los collares fueron identificados en 4 zorros con unidades GPS. Concluimos que ambas tecnologías son capaces de registrar información útil y valiosa que podría ser más difícil y costosa de reunir utilizando métodos VHF convencionales y, por lo tanto, pueden beneficiar a la zona de conservación del zorro de las islas. Recomendamos (1) utilizar unidades GPS con funciones de descarga a distancia; (2) descargar datos desde ambos tipos de unidades tan frecuentemente como sea posible; (3) intentar descargar información de las unidades GPS desde el aire; (4) monitorear frecuentemente a los zorros utilizando transmisores de VHF para determinar zonas de uso; y (5) examinar de manera rigurosa todas las funciones de ambos tipos de unidades antes de utilizarlas con los zorros.

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 342 foxes on San Miguel to 1465 foxes on Santa Rosa (Roemer et al. 1994, Coonan et al. 2000). 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; Roemer et al. 2001) and disease, probably

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canine distemper (Santa Catalina; Timm et al. 2009). On all 4 islands, captive breeding colonies were established using surviving animals; and for several years, wild populations were nonexistent (San Miguel, Santa Rosa) or very small (Santa Cruz, Santa Catalina). In 2004, the foxes on these 4 islands were listed as federally endangered (U.S. Fish and Wildlife Service 2004). Beginning in 2001 (Santa Catalina) and 2004 (Northern Channel Islands), 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 will therefore be "conservation reliant" (Scott et al. 2005, U.S. Fish and Wildlife Service 2012). 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, and this understanding will optimize conservation efforts. In particular, habitat conditions on the islands are changing rapidly now that most nonnative ungulates have been removed and restoration efforts have been initiated (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.

Radiotelemetry has been used extensively to monitor and gather information on island foxes and is an invaluable tool. Almost all of this telemetry work has been conducted using traditional VHF (very high frequency) transmitters (summarized in Rubin et al. 2007 and Coonan et al. 2010). New telemetry technologies, specifically GPS (global positioning system) units and proximity logger units, have recently become available for potential use on island foxes. 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 can therefore save considerable 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.

No information is currently available on the efficacy or practicality of GPS and proximity logger units in collecting data on island foxes. This project evaluated the use of these units to collect information on island foxes under 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 AREAS

Field work was conducted on Santa Catalina (Catalina), Santa Rosa (Rosa), and San Miguel (Miguel) islands. GPS units were deployed on island foxes on Catalina and Rosa, and proximity logger units were deployed on foxes on Miguel. Detailed descriptions of the biotic and abiotic attributes of each island can be found in Schoenherr et al. 1999. Most (88%) of Catalina is owned and managed by the Catalina Island Conservancy (CIC). Miguel is owned by the U.S. Navy and Rosa is owned by the National Park Service (NPS), but both islands are managed by the NPS. Active island fox research and monitoring programs, including annual trapping and radio-tracking of foxes, are ongoing on all 3 islands. These programs provided an opportunity to deploy GPS and proximity logger units without requiring additional field efforts.

Catalina is approximately 194 km^2 (76 mi^2) in size. The island is topographically complex, with elevations ranging up to 648 m (2125 ft) and deep canyons interspersed among rolling hills. Primary habitat types include Coastal Sage Scrub, Coastal Bluff Scrub, Island Chaparral, Island Woodland, Riparian Woodland, and Coastal Grassland (Schoenherr et al. 1999). Historically, Catalina probably supported over 1300 foxes (Roemer et al. 1994), and the recovering population was estimated at 784 in 2008 (Duncan and King 2009). GPS units were deployed on foxes on Catalina in November 2007 to monitor fox response to a fire that occurred on 7 May 2007 and burned approximately 10% (1920 ha) of the island (Duncan and King 2009). GPS units were also deployed in 2010 to monitor fox response to the Catalina Grand Prix, a 3-day off-road motorcycle event.

Rosa is approximately 217 km^2 (84 mi^2) in size. Similar to Catalina, the island is topographically complex, with elevations ranging up to 484 m (1589 ft) and deep canyons interspersed among rolling hills. Primary 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). Historically, Rosa probably supported over 1700 foxes, but the recovering population in 2009 was under 400 (Coonan et al. 2010). Because of the lower population density, intraspecific competition was reduced and provided an opportunity for foxes to select preferred habitat conditions. Thus, GPS units were deployed on foxes on Rosa to gather information on habitat preferences, in addition to evaluating the performance of the units.

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. Primary habitat types include Coastal Sage Scrub, Coastal Grassland, Coastal Dune, Coastal Bluff Scrub, and Fresh Water Marsh (Schoenherr et al. 1999). Historically, Miguel probably supported about 450 foxes, and the recovering population in 2009 was over 300 (Coonan et al. 2010). Thus, the population on this relatively small island was recovering rapidly, and fox density was high compared to other islands. Proximity logger units were deployed on foxes on Miguel to quantify contact rates between individual foxes, in addition to evaluating the performance of the units.

METHODS

For the efforts on Catalina, GPS units were purchased by the CIC and deployed on foxes by CIC staff, who conducted all fieldwork. For the efforts on Rosa and Miguel, GPS and proximity logger units were purchased by California State Univeristy, Stanislaus and the Smithsonian Institution and were then provided to NPS staff, who deployed the units on foxes and conducted all fieldwork.

GPS UNITS

To monitor fox use of the burned and unburned areas on Catalina, GPS units were purchased from Televilt/TVP Positioning AB (Lindesberg, Sweden; now called Followit AB). At the time, Televilt was the only company that produced GPS units 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 Tellus Mini C3 collars. The units weighed about 72 g and consisted of a GPS receiver bundled with a UHF (ultra high frequency) transmitter in an acrylic housing and mounted on a thick rubber-tubing collar (Fig. 1a). The units were preprogrammed at the factory with user-supplied parameters to collect locations at specified times or intervals. For each location (or "fix"), data collected included latitude, longitude, and altitude coordinates; the fox identification number, date, time, and dilution of precision (DOP) due to satellite positions; and whether the fix was 2-dimensional or 3-dimensional. The data were stored within the unit, and therefore the unit had to be retrieved to download the data.

The UHF transmitter permitted tracking of the unit but was programmed to transmit for only 3 h 1 day per week to conserve battery power. Each unit also included a mortality sensor set to activate if the collar was motionless for 12 h. The GPS unit was programmed to collect 9 locations every 24 h. At this rate, expected battery life was 214 days, and the potential number of locations was 1926. Each unit also included an automatic drop-off function programmed to activate 214 days after the unit was turned on. A 21-day beacon then would activate so that the unit and its stored data could be recovered. Each unit cost $1270.

The GPS units used on Rosa were purchased from Telemetry Solutions (Concord, CA). By 2009, when the project was conducted, Televilt had discontinued producing the units used on Catalina, and Telemetry Solutions was the only manufacturer producing a GPS monitoring device sufficiently small in size and mass to use on island foxes. The units purchased were Quantum 4000E Mini Collars. These units consisted of a GPS receiver bundled with a VHF transmitter in an acrylic housing and mounted on a machine belting collar (Fig. 1b). The units also included

Fig. 1. (a) Televilt GPS unit deployed on an island fox on Santa Catalina; (b) Telemetry Solutions GPS unit deployed on an island fox on Santa Rosa; (c) Sirtrack proximity logger unit deployed on an island fox on San Miguel.

a 6-h mortality sensor, and the entire unit weighed 65–70 g. Location data along with time, date, and various metrics on the quality of the GPS fix were stored within the unit. Basic units had to be retrieved in order to download the stored data. However, some of the units included an optional remote-download function. For these units, data could be downloaded by approaching within about 300 m of the fox and then downloading the data using a specialized "base station" connected to a 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 units had to remain in communication for approximately 30–60 s to successfully complete the data download.

These GPS units could be programmed using manufacturer-supplied software and a USB cable connection. Parameters that could be manipulated included options regarding time to acquire a fix (TTF), additional time if a fix was not acquired in the allotted time, and interval between fix attempts. For TTF, 75% of the units were set at 90 s and 25% were set at 60 s. Additional time was set at 45 s, extending the time to acquire fixes to 105 s or 135 s. Fix interval was set at 7 h, which yielded 3–4 locations per day and varied the time for fix attempts such that over 7 days, locations would be collected evenly throughout the 24-h diel period. 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. The VHF transmitter permitted instantaneous tracking of the unit, and the estimated battery life expectancy for the transmitter was 200 days. Costs were $1495 for each store-on-board unit, $1795 for each remote-download unit, and $1895 each for 2 additional remote-download units ordered after the initial requisition. The base station cost $2995.

GPS units from Telemetry Solutions also were used to examine fox response to a 3-day motorcycle event on Catalina in 2010. All of the units included the remote-download function. Fix interval was set at 1.25 h, potentially yielding an average of 19.2 locations per day over the 7-week study.

Prior to deployment on foxes, each Telemetry Solutions GPS unit was tested to ensure that GPS locations were being recorded and the VHF transmitter was operating properly, as well as 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, we captured island foxes on Catalina and Santa Rosa in live traps. Live-trapping was conducted by

CIC staff on Catalina and NPS staff on Rosa as part of annual population monitoring or target trapping efforts (e.g., to replace radio collars). Foxes were captured in single-door, wire-mesh box traps (66 × 23 × 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 or wet cat food and a loganberry lure (Knob Mountain Raw 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.

General locations were obtained on the foxes as often as was practicable, with most tracking being conducted from the ground using a handheld receiver and a standard VHF or UHF antenna. Attempts were made to locate each fox once per week on Catalina and twice per week on Rosa. Tracking occasionally was conducted from a fixed-wing aircraft, particularly on Catalina. For units with remote-download functions, periodic attempts were made to locate foxes and download data. 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 were 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).

Proximity Logger Units

The proximity logger units deployed on foxes on Miguel were purchased from Sirtrack Limited (Hawkes Bay, New Zealand). Sirtrack was the only manufacturer producing 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. These units consisted of a UHF transceiver bundled with a VHF transmitter in an acrylic housing and mounted on a machine belting collar (Fig. 1c). The entire unit weighed 60 g. The proximity logger units used the UHF transceiver to communicate with other units. Specifically, when 2 units came within a specified distance of each other, both units detected and identified the other unit (i.e., a "contact"), and each recorded the duration of the contact. The maximum distance for a contact and the separation time required to end a contact was programmed by the user. The contact information was stored within the unit, and units had to be retrieved in order to download the stored data. The VHF transmitter permitted instantaneous tracking of the unit. Battery life for the units was estimated at 276 days, and each unit cost $499.

The units were easy to program and all were programmed identically. NPS staff chose a 30-m proximity for indicating a contact between foxes. This distance was 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's 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 s. 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 about 60 m, and the contact was terminated if the fox moved >60 m from the station for >30 s. Approximately every 2 weeks, data from the base station were downloaded and the station was moved. Prior to deployment on foxes, each proximity logger was tested to ensure that it detected other units and that its VHF transmitter was operating properly.

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

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

General category	Parameter description
Predeployment issues	Properly collecting locations (GPS)
	Properly detecting other units (logger)
	Interlogger detection distance (logger)
	VHF/UHF functioning properly
	VHF/UHF 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)
Unit performance	Length of operational time
	Successful data acquisition
	Locations collected at appropriate times/rates (GPS)
	General location accuracy (GPS)
	Successful remote download of data (GPS)
	Concordance of contact data between units (loggers)
VHF/UHF performance	Length of operational time
	Average transmission distance
	Signal strength and pulse rate over time
	Any significant frequency drift

Field testing consisted of obtaining general locations on the foxes approximately once every 2 weeks by tracking the VHF signals. 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 performance under field conditions.

A variety of parameters were assessed to evaluate the performance of the proximity logger units and their potential utility in island fox monitoring and research (Table 1). 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.

Each proximity logger unit recorded data independently. Therefore, 2 units ideally recorded the same number of contacts with each other and the duration of these contacts should have been similar. 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 examined with respect only 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., response to burn or motorcycle race, habitat selection, contact rates by social dyads) was beyond the scope of this paper.

GPS Units

In November 2007, 20 Televilt GPS units were deployed on foxes on Catalina: 5 males and 5 females in both burned and unburned areas. Unit-to-fox mass ratios ranged from 2.48% to 3.06% for females and 2.06% to 2.77% for males (Table 2). Tracking the foxes was difficult. The UHF transmitter activated only once a week for a relatively short (3-h) window; and due to a miscommunication with the manufacturer, that window was from 23:00 to 02:00. Although foxes tend to be active at this time and more easily detected, the window was not a convenient time to conduct fieldwork. Furthermore, darkness at this time complicated attempts to track the one collar that malfunctioned and automatically dropped off too early. Indeed, that collar was never recovered, and this issue led to the decision to attempt to recapture all collared foxes to recover the units prior to drop-off. A root

TABLE 2. Biological data and details on GPS and proximity logger units worn by island foxes during 4 projects to evaluate the efficacy of the units.

Fox ID	Sex	Days collar worn	Locations/contacts collected	Initial fox mass (kg)	Collar/fox mass ratio (%)	Fox mass change at recapture (kg)
Televilt GPS units, Santa Catalina, 2007–2008						
00747	M	210	42	2.60	2.77	–0.10
21019	F	195	117	2.45	2.94	–0.30
2266B	F	214	NA[a]	2.90	2.48	NA
2761A	M	209	91	3.40	2.12	–0.50
31B7B	F	207	32	2.65	2.72	–0.25
3270E	M	208	60	3.50	2.06	–0.50
43C4F	M	207	67	3.50	2.06	–1.00
52862	M	196	33	2.50	2.88	–0.10
53428	M	195	148	2.65	2.72	–0.52
54F5B	M	208	NA[b]	2.50	2.88	–0.20
A5C1B	F	210	81	2.60	2.77	–0.40
A760F	F	205	109	2.60	2.77	–0.60
B2B24	M	206	136	2.85	2.53	–0.35
B7325	M	207	64	3.00	2.40	–0.60
C4B3B	F	209	156	2.60	2.77	–0.60
E6918	F	196	NA[b]	2.65	2.72	–0.45
F1F00	F	195	123	2.35	3.06	–0.30
F3D42	M	196	123	2.70	2.67	–0.20
F4B03	F	194	146	2.35	3.06	–0.50
F5244	F	187	109	2.55	2.82	NA[c]
Telemetry Solutions GPS units, Santa Rosa, 2009–2010						
6	M	—[d]	—	2.45	2.65	NA
15	M	—[d]	441[e]	2.40	2.71	NA
33	M	348	452	2.30	2.83	+0.05
48	M	339	223	2.00	3.25	+0.20
51	M	57	236	1.75	3.71	NA
52	M	274	552	2.30	2.83	0
64	M	330	304	2.90	2.24	–0.20
66	M	—[d]	441[e]	2.50	2.60	NA
69	M	319	431	2.00	3.25	+0.10
70	M	—[d]	—	2.10	3.10	NA
71	M	339	482	2.30	2.83	–0.30
72	M	348	236	2.25	2.89	–0.05
73	M	432	225	1.85	3.51	+0.40
75	M	—[d]	266[e]	2.20	2.95	NA
Telemetry Solutions GPS units, Santa Catalina, 2010–2011						
4736E	F	51	323	2.50	2.80	–0.20
E6C5E	F	49	358	2.05	3.41	–0.35
96C03	F	48	517	2.30	3.04	–0.15
55169	M	—[d]	389[e]	2.20	3.18	—
24574	M	47	178	3.00	2.33	–0.25
Sirtrack proximity logger units, San Miguel, 2009–2010						
265	M	220	1241	2.20	2.73	+0.20
267	M	218	1290	2.10	2.86	+0.10
268	M	221	74	2.05	2.93	–0.05
264	M	217	4436	2.40	2.50	–0.20
351	F	219	1029	2.20	2.73	–0.05
353	F	229	4959	2.30	2.61	–0.20
352	F	233	2810	2.60	2.31	0
245	M	218	3530	2.50	2.40	0
266	M	—[d]	—	2.20	2.73	NA
214	M	217	4454	2.40	2.50	+0.15
313	F	217	3233	2.10	2.86	0
269	M	216	1736	2.10	2.86	+0.10
270	M	323	117	2.30	2.61	–0.20
271	M	216	1853	2.10	2.86	0
212	M	233	35	2.75	2.18	NA

TABLE 2. Continued.

Fox ID	Sex	Days collar worn	Locations/contacts collected	Initial fox mass (kg)	Collar/fox mass ratio (%)	Fox mass change at recapture (kg)
354	F	205	911	2.10	2.86	0
273	M	215	1280	2.50	2.40	0

[a]Collar not recovered from fox.
[b]No data could be downloaded.
[c]Mortality.
[d]Fox not recaptured.
[e]Data from remote download.

cause of this issue was the fact that the units had to be programmed at the factory and not by the user. The UHF transmitter did emit a strong signal that could be heard up to distances of 1000 m. However, the gain on the signal could not be lowered, and therefore it was very difficult to obtain a signal direction when in close proximity to the unit. This effect contributed to the difficulty in locating the dropped collar.

The 20 foxes wore the units for 187–214 days (Table 2). One fox was found dead toward the end of the study, but the carcass was too decomposed to determine the cause of death and whether the GPS unit may have contributed to the death. Of the remaining 19 foxes, 18 were recaptured and the units were removed prior to the scheduled automatic drop-off date. The 19 units recovered were monitored, and the automatic drop-off mechanism activated properly on 14 of these. Data were recovered from 17 of the 19 units. The 2 units that could not be downloaded were sent back to the manufacturer, who also was unable to recover any data. It is unclear whether the 2 units failed to collect data or whether data were collected but could not be accessed. These 2 units also were among the 5 for which the automatic drop-off mechanism failed. Of the 17 units from which data were recovered, the maximum number of locations collected was 197 and the average number was 118 (Table 2). The number of locations obtained relative to the expected number was generally very low and averaged 6.1% (range 1.7%–10.2%). Recaptured foxes did not exhibit any injuries associated with the GPS units. All of the foxes lost weight (range 0.10–1.00 kg) while wearing the units.

For the Rosa project, 16 GPS units were purchased from Telemetry Solutions. These included 9 “store-on-board” (SOB) units and 7 “remote download” (RD) units. The software required for programming the units was continually being updated, which caused some problems. However, once the proper software was obtained, the units were relatively easy to program.

Several issues were encountered during predeployment testing of the GPS units. A significant problem was difficulty in deactivating the units after testing. Seven of the units experienced software errors that apparently prevented data download. For one of these units, actual time intervals for collecting locations were inconsistent with those programmed; and for another unit, the time on the internal clock was not stable and shifted causing locations to be recorded at incorrect intervals. The VHF transmitter on one of these units 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. All malfunctioning units were returned to the manufacturer for repair, but 2 units were not sent back in time for deployment on foxes. 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 Rosa conducted by the NPS, 14 GPS units were deployed on foxes during September–November 2009. In an effort to 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 to 2.9 kg, resulting in unit-to-fox mass ratios of 2.2%–3.7% (Table 2). All the units were deployed on foxes on the east side of the island to facilitate monitoring. 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, all of which failed prematurely. Among the 14 units deployed, the average number of days that VHF transmitters operated was just 27. Five transmitters failed after only 1 day of operation, and the longest any functioned was just 92 days. Signal strength was relatively weak on all of the units, and consequently, the signal detection distance was quite short. Typically, signals could be heard only from a distance of ≤100 m and often only when in 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. Another 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.

While the units were deployed on foxes, attempts were made to remotely download data from the 6 RD units. Such efforts were rendered significantly more difficult by the VHF transmitter failures described above. Downloads could be performed only 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 from the ground on 3 units, of which only one had a functioning VHF transmitter. 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 carcass decomposition, 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 by 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 was conducted from June 2010 to January 2011 in an effort to recapture foxes and recover the GPS units, and 8 foxes were recaptured. 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 2). Of the 8 foxes recaptured, 4 had gained weight, 3 had lost weight, and 1 was the same weight (Table 2). 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. Most exhibited excessive wear on the ends of the epoxy housing that resulted in exposed wires. The antenna on one unit was broken off where the antenna exited the housing.

GPS units were recovered from the 8 foxes recaptured and from the one fox found dead. Of the 5 foxes not recaptured, 3 had RD units and data were successfully downloaded from these resulting in at least partial GPS data sets for 12 of the 14 foxes that received GPS units. All 12 data sets included usable 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, two 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 to 30 weeks, depending on the frequency of location attempts programmed into each unit. Only one unit met or exceeded the expected operating time. On average, the units successfully collected a location in 81.7% (range 73.0%–92.8%) of attempts. The units collected an average of 357 (range 223–552) locations while they were deployed (Table 2).

In the second GPS collar study on Catalina, 5 Telemetry Solution GPS units were deployed on foxes (3 males and 2 females) in November 2010. Fox weights ranged from 2.05 to 3.00 kg resulting in unit-to-fox mass ratios of 2.33%–3.41% (Table 2). The study for which the units were deployed was relatively short, and foxes were retrapped in January

2011 to remove collars. Four of the 5 foxes were recaptured, and these 4 had worn the collars for 47–58 days (Table 2). All 4 had hair loss and abrasions on their necks from the collars. Also, all of the foxes had lost weight (range 0.15–0.35 kg). One unit malfunctioned (both the VHF and GPS functions ceased working) just before the fox wearing that unit was recaptured. Data were successfully downloaded from all units during the study. The number of locations collected ranged from 178 to 517. The proportion of attempts in which the units successfully obtained a location ranged from 19.7% to 56.0%. The range on the VHF transmitter was relatively short and was estimated at 150–300 m. However, the transmitters were readily heard during aerial searches.

Proximity Logger Units

For annual trapping efforts conducted by the NPS on Miguel, 17 proximity logger units were deployed on foxes during December 2009–January 2010. All were deployed within an approximately 3.5-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. Fox weights ranged from 2.05 to 2.75 kg, resulting in unit-to-fox mass ratios of 2.2%–2.9% (Table 2).

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 several months and also had worn multiple conventional radio-collars in the past, and NPS staff felt that the logger unit likely did not contribute to the death. Live trapping was conducted during summer and fall 2010 in an effort to recapture foxes and recover the proximity logger units. Of the 16 foxes still wearing units, 14 were recaptured during July–August 2010, one was recaptured in November 2010, and one eluded recapture.

Excluding the fox recovered dead, the recaptured foxes wore the proximity logger units for an average of 226 (range 205–323) days (Table 2). 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 2). 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. 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 proximity logger units all recorded contacts between foxes wearing the units. Of the 16 recovered units, 12 recorded at least 1000 contacts, and 3 units recorded >4000 contacts (Table 3). Difficulties were detected for only 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 (Table 3). For example, M265 recorded 63 contacts with F352, totaling 2134 s; whereas F352 recorded 58 contacts with M265, totaling 2257 s. This general concordance was common among almost all the dyads, indicating a relatively high level of accuracy among the data recorded by the units.

DISCUSSION

GPS Units

The performance of the GPS units was mixed. Some aspects of these units were very successful, whereas others fell well short of expectations or advertised performance. The units were generally worn successfully by

TABLE 3. Contacts between island foxes wearing proximity loggers, San Miguel Island, 2009–2010. Values are the number of times that a fox in a row recorded contact with a fox in a 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[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	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	—

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

island foxes. Some minor injuries were noted on the 4 foxes recaptured on Catalina that wore Telemetry Solutions units. These injuries were likely due to the positioning and placement of the VHF and satellite antennae. Instead of running parallel along the animal's back, the antennae were mounted perpendicular to the ground for better satellite reception. The antenna extended approximately 10 cm above the fox's head and therefore struck vegetation as the fox navigated through dense brush. These impacts most likely caused the collar to rock front to back on the animal's neck, thus causing the noted abrasions. However, no injuries were noted on the 8 foxes recaptured on Rosa that also wore Telemetry Solutions units.

One fox with a Televilt unit on Catalina was found dead, but the fox was too decomposed to determine whether the unit contributed to the death. One fox died on Santa Rosa while wearing a Telemetry Solutions unit, but there was no evidence that the unit contributed to this death. Weight loss was commonly observed among foxes wearing GPS units, but again it is unclear whether the units contributed to this loss. On Catalina, the Televilt units were deployed in late fall when island foxes may be heavier, and they were removed in early summer when the foxes are commonly lighter. Winter to summer weight loss of similar magnitude also was observed among foxes that did not wear GPS units (J. King unpublished data). Thus, at least some of this weight loss may have been attributable to natural physiological patterns among the foxes. Kit foxes (*Vulpes macrotis*) exhibit similar seasonal variations in weight (Warrick and Cypher 1999).

The GPS units were bulkier than standard VHF units, which probably resulted from bundling multiple functions (e.g., GPS receiver, VHF transmitter, mortality sensor, associated batteries, antenna) into a single package. However, the additional bulk did not appear to produce any deleterious effects. The units also were a bit heavier than standard VHF units (typically <45 g). A general recommendation when using telemetry equipment to conduct research on animals is to limit the weight of the equipment to $\leq 5\%$ of body weight. Federal and state permits for handling island foxes included a 3% or 4% limit, and the collar-to-body mass ratios for all foxes receiving GPS units was $<4\%$ and in most case $<3\%$.

At this limit, the Televilt units could have been placed on foxes weighing ≥1.8 kg and the Telemetry Solutions units could have been placed on foxes weighing ≥1.625 kg. In an analysis of radio-collar effects on 542 endangered San Joaquin kit foxes (*V. m. mutica*), possible detrimental effects were detected only when equipment exceeded 6% of body weight, and these effects were primarily detected among juveniles (Cypher 1997).

The Televilt units were factory-programmed thereby reducing the chance of user error. However, due to a miscommunication, the units were programmed improperly with regards to the UHF transmitter time. This error made tracking the units significantly more difficult. For the Telemetry Systems units, once all of the proper software and instructions were in hand, the units generally were easy to program. Also, the variety of programming options allowed the user to more effectively address study objectives and also to maximize battery life.

GPS 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 and thus result in failed attempts to obtain locations (e.g., Johnson et al. 2002). Island foxes occasionally use dens (Moore and Collins 1995) and commonly use areas of rugged terrain, such as canyons. The numbers of locations collected by the Televilt units were considerably lower than expected, although all of the units that did not malfunction did produce data. For the Telemetry Solutions units, the proportions of attempts for which successful locations were secured were relatively high, at least on Rosa, 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 on the Telemetry Solutions units deployed on Rosa 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).

Six of the GPS units on Rosa included a remote-download function, which was very successful when used 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 positioning could be challenging depending on 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 thus reduce or even negate any differences in cost efficiency between the 2 methods. Regardless of method, the immense value of the remote-download function was highlighted by the inability to recapture 5 of the Rosa foxes. Data were obtained from 3 of these foxes that had collars with remote-download functions, whereas no data were collected from the 2 without this function.

The accuracy of the locations obtained by all models of 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 on Rosa. Because the foxes are small and the carcass was decomposed and not obvious, the locations had to lead to a relatively small area for the carcass to be found. 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 for the carcass provided by a hand-held GPS unit. Such precision is sufficient for conducting detailed spatial analyses, such as examining use of habitats and landscape features by foxes. Also, the locations from the collar GPS units were consistent with field biologists' knowledge of the space-use patterns of the foxes that wore the units.

The performance of the VHF transmitters associated with the Telemetry Solutions units deployed on Rosa was unacceptable. None of the transmitters 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. The failure of VHF transmitters precluded tracking and locating animals for status checks, targeted trapping, or remote download of data, and also precluded the detection of dead foxes, as the mortality sensor was an altered pulse rate of the VHF signal. Fortunately, data were obtained from 5 units with malfunctioning VHF transmitters by activating the download function and searching over broad areas from the air.

Proximity Logger Units

The performance of the proximity logger units was excellent. The units functioned as expected. The small number of problems that did surface, almost all of which were relatively minor, were to be expected 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 without causing any detectable injuries to foxes, and no adverse effects on survival 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, proximity loggers could be placed on foxes ≥1.5 kg.

The units were easy to program. Part of this programming ease was due to the limited parameters to program, and each parameter had just a few options. Probably the most important parameters are the "UHF coefficient," which determines the distance at which a unit will detect another unit and record a contact, and the time with no contact recorded required to terminate a contact. The first parameter can be adjusted to alter the detection distance based on study objectives, whereas setting the second for too short a time is likely to result in an extended interaction between 2 foxes being recorded as a series of short contacts.

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. The VHF transmitters all functioned per expectations, and this greatly facilitated targeted trapping efforts to recapture foxes and recover the units. This ability 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, and 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 2 units in a dyad. However, this difference could easily be attributable to several factors. First, the sensitivity of each unit in detecting another unit likely was not identical across units 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 the other unit (e.g., height, position of fox, obstacles, etc.). Consequently, one unit may have detected a second unit whereas the second unit may not have detected the first, particularly when foxes were near the limits of unit detection abilities. This would lead to the observed discrepancies within unit dyads. In particular, an extended contact may be recorded as a series of shorter contacts and the number and length of these contacts may differ between the 2 collars (Prange et al. 2006). However, these discrepancies are relatively small, and trends and patterns were 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 have developed ways to deal with them during data analysis (Prange et al. 2006, Hamede et al. 2009, Hauver et al. 2010).

CONCLUSIONS AND RECOMMENDATIONS

GPS tracking technology that is sufficiently miniaturized for deployment on animals the size of island foxes is relatively new. As of spring 2013, Telemetry Solutions and Advanced Telemetry Systems are the only companies manufacturing such technology. Televilt discontinued production of fox-sized units following unacceptably poor performance during this and other field studies (e.g., Clevenger et al. 2010). Thus, manufacturing such miniaturized technology is challenging. Given that the technology is relatively new, issues and problems are to be expected. Indeed, very similar issues have been reported previously for both larger and similar-sized GPS units (Johnson et al. 2002, Gau et al. 2004, Matthews et al. 2013). Five GPS units were deployed on kit foxes in the Mojave Desert in 2007 (Clevenger et al. 2010). However, the animals could not be relocated due to poor performance by the UHF transmitters, and none of the animals were recaptured. Thus, no GPS locations were obtained. Matthews et al. (2013) summarize issues encountered during studies in which GPS collars were used on 13 species in Australia, including red foxes (*Vulpes vulpes*) and other similar-sized species such as cats (*Felis catus*), koalas (*Phascolarctos cinereus*), possums (*Trichosurus cunninghami*), quolls (*Dasyurus geoffroii* and *Dasyurus maculatus*), and wombats (*Vombatus ursinus*). These issues included premature failure of VHF transmitters or GPS receivers, programming problems, low fix rates, and minor injuries from the collars. Similar issues were experienced with GPS collars placed on fishers (*Martes pennanti*) in California (C. Thompson, U.S. Forest Service, unpublished data). Products will likely continue to improve. Indeed, GPS units from Telemetry Solutions currently (March 2013) are being used in 2 kit fox studies, and many of the issues experienced in the island fox studies have already been corrected (B. Cypher, personal observation).

Clearly, both the GPS unit and proximity logger technologies have immense potential for obtaining valuable information on island fox ecology. Despite the issues encountered, the GPS units provided very useful data on the effects of a fire and motorcycle race on Catalina (J. King unpublished data) and on habitat selection by foxes on Rosa (Drake 2013). The proximity loggers provided excellent data on social interactions on Miguel (Ralls et al. 2013) and were also used in a subsequent study to examine disease transmission potential among foxes on San Clemente Island (Sanchez 2012). Thus, these technologies are excellent tools for gathering information that would be more difficult or more costly, possibly prohibitively so, 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 outweigh 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 be employed only when they constitute the most effective approach for collecting desired data. For example, neither GPS nor 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 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 issue occurred with both the GPS and proximity logger units deployed on island foxes. The failure to recapture animals was mitigated somewhat by the remote-download function on the GPS units. Alternatively, an effective timed or remotely activated release system would also help mitigate recapture failures and could even eliminate the need to recapture animals.

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

1. Use GPS units with a remote-download function

The GPS telemetry units can experience a number of issues that can result in loss of data. In particular, failure of the VHF transmitters makes tracking and target trapping foxes extremely difficult. Even when the VHF functions properly, recapture of animals wearing the units is never assured. The remote-download function increases the cost of the units, but this is a worthwhile expense to increase the probability of obtaining data from the units.

2. Attempt GPS unit downloads from the air

Animals wearing GPS units may move considerable distances or move into inaccessible terrain or vegetation, which movement could make them 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 can malfunction and thus make 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.

3. 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. Data could be lost or not recovered from either type of unit for a variety of reasons, including 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 more frequently if possible. For the GPS units without the remote-download function and for the proximity loggers, data downloads can be conducted only 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 if the units have an appropriate computer cable port. However, both of these recapture scenarios necessitate having a portable computer in the field, which is not always practical.

4. Frequently monitor animals using the VHF transmitters

For both the GPS and proximity logger units, frequent monitoring of animals via conventional radio tracking is recommended to determine the general location of the collared animals. This monitoring will facilitate remote download or recapture attempts. Monitoring at least weekly is recommended. Monitoring at this frequency also facilitates the timely recovery and examination of dead foxes.

5. Rigorously pretest all units

For many reasons, newly delivered equipment may not work properly or as expected. Thus, all equipment should be tested prior to deployment in the field. 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)

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