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Remote Monitoring of Island Foxes

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Technical Report

Background

The U.S. Department of Defense (DoD) has recently designated the island fox as a species at risk candidate, and a focal point of conservation efforts for species at risk. The Navy currently manages fox populations on two islands- San Nicolas Island, San Clemente Island; and owns San Miguel Island which is managed by the National Park Service. Four of the six island fox subspecies, including the San Miguel Island fox, have been listed for protection under the Endangered Species Act due to rapid population declines. While the specific mechanisms causing these declines differ among islands, they are all associated with a sudden increase in mortality rates. For example, fox numbers on San Miguel Island declined from several hundred to less than

Figure 1. Collared fox.

twenty animals following invasion by a novel predator, the golden eagle (Coonan et al. 2005). Rapid detection of disease outbreaks, novel predators and other threats allows for management action to reduce the impact on fox populations (e.g., vaccination or predator removal programs). It may also reduce the need for intensive captive-rearing programs or for protection under the Endangered Species Act.

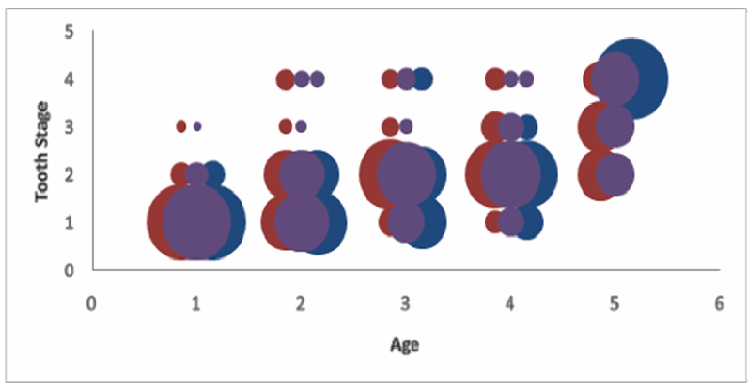
Ongoing yearly surveys on San Nicolas Island indicate that fox densities are unusually high (Schmidt et al. 2007), making this population particularly susceptible to the spread of virulent diseases. The key to rapidly detecting such a threat to the island fox is intensive monitoring. But many monitoring programs, including those called for in some endangered species recovery plans (Morris et al. 2002) do not specify any results that should trigger management actions. For monitoring to be effective, results must be tied to appropriate management actions. At one extreme, every observed death in a monitored population could trigger some sort of protective intervention. While this tactic has the greatest chance of preventing population decline, it is also extremely costly, both in terms of limited conservation funds and the good will of the people impacted by those interventions. One of the greatest challenges in managing island foxes is knowing what monitoring results warrant different management actions.

In this report we evaluate an innovative radio-telemetry system for monitoring San Nicolas Island foxes through a DoD Legacy funded research and demonstration project. We first describe our monitoring efforts and accomplishments using this system. We then summarize the results of the first year of intensively monitoring fox survival using this system and develop a preliminary set of monitoring-based criteria to trigger management actions based on these results. Finally, we discuss ways in which the system can be improved and new developments to be implemented in the second year of this project.

Methods

We collared 64 adult foxes representing all age-sex classes with radio-transmitters. An original set of 59 foxes were captured from two trapping grids during annual summer monitoring (Schmidt et al. 2007) and fitted with radio collars (figure 1). Adult foxes were assigned to one of four age classes (age class 1-4, increasing with age) based on patterns of tooth wear (Wood 1958, Collins 1993). The relationship between age classes and known-age foxes (i.e., those originally captured as pups in previous years) is presented in figure 2. As animals in the original sample group died, we maintained our desired sample size by placing collars on animals brought to Navy and IWS biologists for care after injuries suffered from human-fox interactions to maintain our desired sample size. All animals were released near to where they were captured.

Figure 2. Relationship between tooth stage and age for known-age foxes trapped from 2000-2005 on SNI. Each circle is proportional to the fraction of animals of a given age assigned to a particular age-class based on tooth wear ("Tooth-Stage"). Red circles represent females, blue circles males, violet circles the population as a whole.



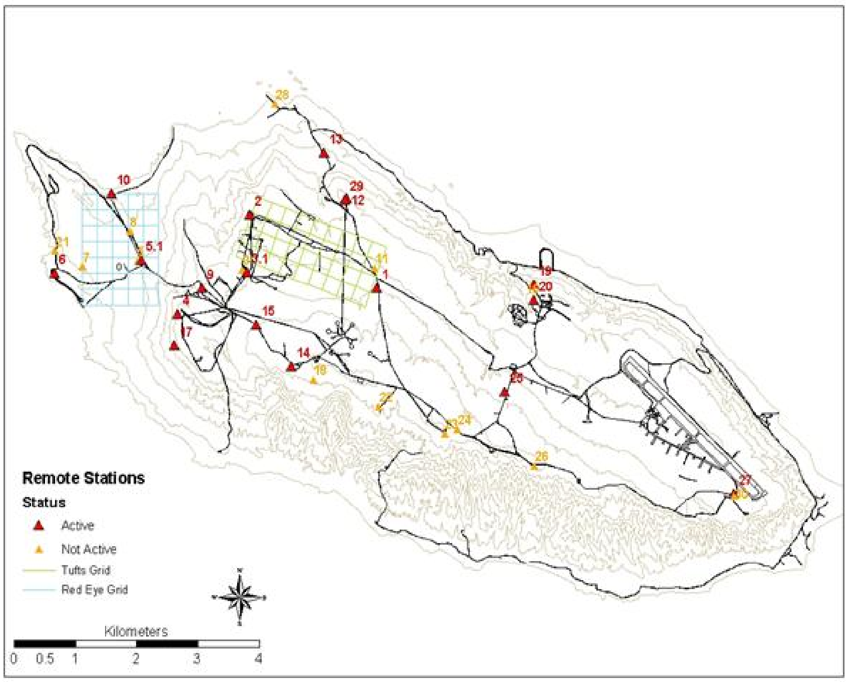
Radio-transmitters sent a unique ID in Morse code hourly, which were digitally recorded onto a digital voice recorder (DVR) at 34 receiving stations placed across island (figures 3,4). When an animal had not moved for a period of six hours, the transmitter went into mortality mode. A one or two character prefix to the unique ID indicated whether the animal wearing the transmitter was alive or dead. Collars also emitted a standard VHF telemetry signal to allow animals to be tracked when missing or dead. Collars in mortality mode emitted a standard telemetry signal on a different frequency than collars in normal operating mode. This allowed us to scan for dead foxes while driving around the island conducting other project duties. Transmitters were initially capable of transmitting ID signals to receiving stations up to three kilometers away under ideal conditions. However, in most cases topographical

Figure 3. Remote receiving station overlooking north shore, San Nicolas Island

limitations and compromised antennae restricted signal range. Nonetheless, most collared foxes were recorded from multiple stations every day.

We downloaded data recordings to at text file every one to three days and checked for mortality signals. We attempted to locate foxes with collars transmitting mortality signals or missing for over four consecutive days. All dead foxes were recovered and sent to Dr. Linda Munson at UC Davis for necropsy.

Figure 4.Map of receiving station locations showing grids where original set of foxes were captured. Stations in red were active as of 3/31/07.



Accomplishments

Over eight months, we tracked a total of 64 foxes, recorded 530,837 ID signals from hourly check-ins, and documented ten mortalities in 14,906 fox-days of monitoring. Of these mortalities, five were detected by the receiving stations. Four were not detected by the receiving stations but were detected by the biologist while monitoring via vehicle, and one, which died of vehicular trauma, was reported and picked up before enough time elapsed for the mortality sensor to be activated. The mortality signals not detected by the receiving stations involved either a collar with an antenna broken at the

Table 1. Collared fox mortalities.

Sex	Estimated Mortality Date	Date Retrieved	Method Detected	Age Class (Year) of First Capture	Age Class at Death	Minimum (Estimated) Age[1]	Pathology Results
M	8/5/2006	8/7/2006	stations	1 (2001)	4	6 (6)	punctures wounds in chest, abdomen; severe emaciation; extremely high Spirocerca count w/ perforations through colon and free in abdominal cavity
M	9/2/2006	9/3/2006	stations	0 (2005)	1	1 (known age)	automobile trauma
M	9/5/2006	9/8/2006	stations	2 (2000)	4	7 (8)	trauma (source unknown); severe emaciation; muscle atrophy; very low Spirocerca count
F	9/8/2006	9/10/2006	biologist	4 (2000)	4	7 (10)	trauma; puncture wounds with partial evisceration
F	9/15/2006	9/19/2006	stations	3 (2001)	4	6 (8)	decomposition advanced; trauma (possible); emaciation; very low Spirocerca count
F	10/18/2006	11/10/2006	biologist	2 (2002)	4	5 (6)	decomposition advanced (no soft tissues or organs left); no signs of trauma to skeleton
M	11/17/2006	11/18/2006	biologist	4 (2004)	4	3 (6)	trauma (possible); blood in abdomen; emaciation; high Spirocerca count with telescoping through intestines
F	12/6/2006	12/8/2006	stations	2 (2000)	4	7 (8)	emaciation; high Spirocerca count; gastric ulcers; septiciemia in liver
M	3/28/2007	3/28/2007	reported	1 (2004)	3	4 (4)	automobile trauma; excellent nutritional conditional; low Spirocerca count
F	3/29/2007	3/31/2007	biologist	1 (2003)	4	5 (5)	pending

1. Minimum age was calculated by assuming that each fox was born the year prior to first capture (unless the individual was captured as a pup and age was known). Estimated age takes into account the age class at first capture and allows one year per age class. Thus a fox captured as an AC 2 in 2000 is assumed to have been born in 1998.

base where it emerges from the collar (1 of 4), a carcass located in an area where the topographical features, such as hills or ravines, interfered with the transmission of the signal (2 of 4), or a combination of both (1 of 4).

The vast majority of mortalities involved animals in the oldest age class (table 1). Considered separately, animals in this age class had a significantly lower mean daily survivorship than the three younger age classes (table 2). Only the mortalities of the two youngest foxes were directly attributable to automobile trauma, with no other contributing factors revealed by necropsy. By contrast, while some of the necropsies of older animals showed evidence of trauma from unknown sources; many of them also revealed multiple instances of severe emaciation and severe infestations of *Spirocerca*, a parasitic worm endemic to the Channel Islands.

Table 2. Daily and annual survivorship of adult foxes.

Group	Daily Survivorship	95% CI	Yearly Survivorship	95% CI
Age Class 1-3 - young adults	0.9998	.9996-1.000	0.943	.869-1.00
Age Class 4 - old adults	0.9968	.9945-.9990	0.305	.134-.694
Age Class 1-4 - all adults	0.9993	.9993-.9989	0.783	.672-.911

Receiving stations varied widely in the number of ID signals received depending on their location (figures 4,5). Three “core” stations recorded an average of over 400 detections a day. Twelve “intermediate” stations recorded an average of 50-320 detections each day. These stations picked up many of the same foxes recorded by the core stations, but received signals from some animals more consistently than core stations due to their placement relative to the primary use areas of those individuals. Finally, twelve “specialty” stations recorded an average of 2-33 detections daily. These stations were typically used to cover small areas hidden to core and intermediate stations by topographical features (e.g., behind large sand dunes), to cover remote areas not typically used by collared foxes (e.g., on the southeast end of the island) or to target individuals which rarely checked into other stations.

Two notable events occurred while monitoring foxes during this study. First, a small fire burned 20 acres in the midst of our core study area in October 2006. While we cannot account for uncollared foxes, none of our study animals died during or immediately following the fire. Since a number of collared foxes resided in areas near the burn, we are confident that the fire did not have a dramatic impact on the population. Secondly, when three collared foxes died within six days, we expedited the necropsies to determine if there was reason for further concern. Since necropsy results indicated that different factors contributed to the death of each fox, and revealed no

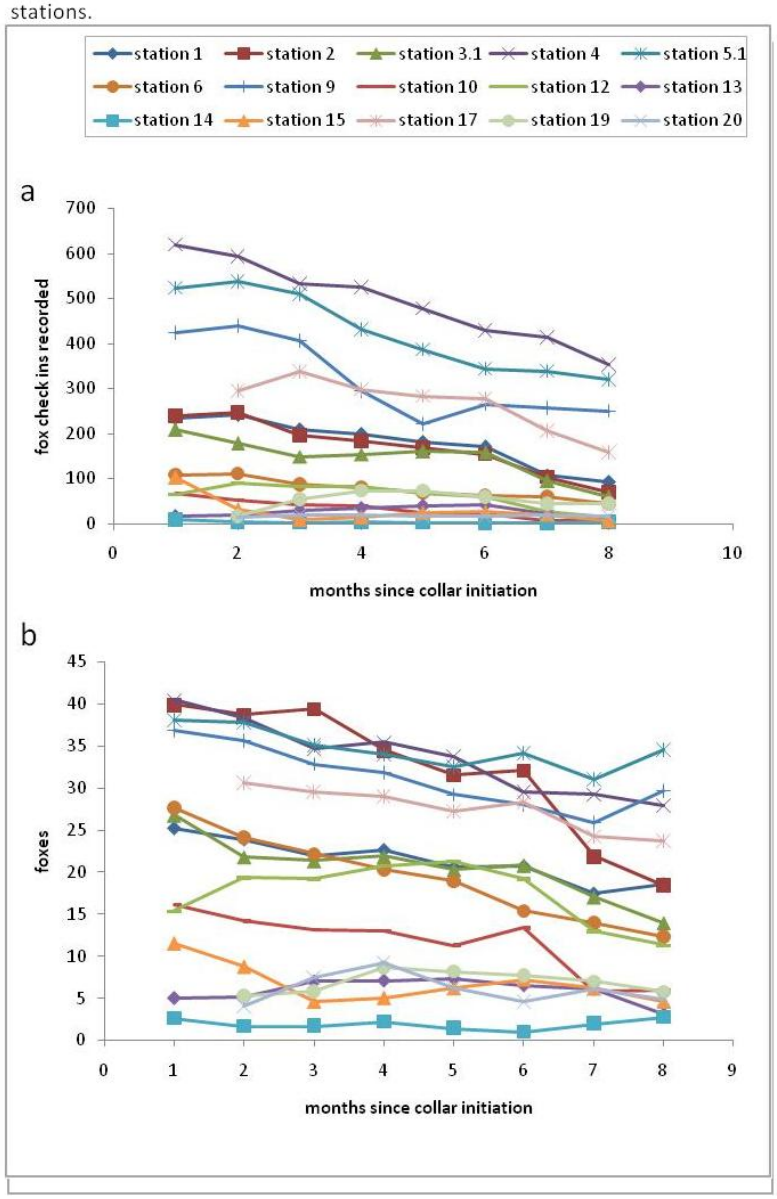


Figure 5. Decline in (a) ID signals recorded and (b) foxes detected by remote receiving stations.

evidence of virulent disease, no further action was necessary.

While the monitoring system used in this project was not designed to track the movements of collared animals, we were able to detect shifts in the areas some foxes regularly frequented based on which stations regularly received their signals. In order to determine movements, we examined the location of the three stations receiving the most ID signals from each animal. Most individuals were detected from same stations throughout year. However from one month to the next, a few foxes exhibited radical shifts in which stations they were detected by, indicating a shift in use area (figure 6). We considered an animal to have shifted its use area when there was a change in location of top three stations or a major shift (>90 degrees) in area encompassed by the top three stations.

Based on these criteria, eight foxes shifted areas of use (table 3). There was no clear spatial pattern to movement. Three animals moved from the area where they were originally collared to town, with one animal subsequently returning. The remaining five animals shifted to areas adjacent to where they were originally captured. Only two females were observed to shift use areas. Most movements involved young males; half of which were age class 1 males.

Figure 6: Movements and approximate locations of TKO (Age Class 1 male) as interpreted through the receiving station detections.

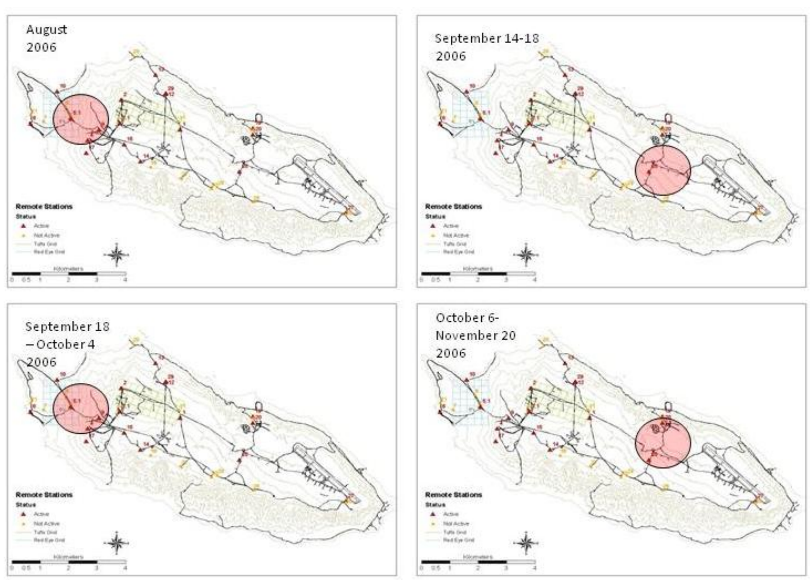


Table 3. Shifts in use area detected from radio-collared foxes.

Fox ID	Month Moved	Stations (before) --> (after)	Corresponding island areas
TAD	January '07	(4, 5, 19) --> (3, 1, 2)	Cliff to Tufts
TAS	October '06	(8, 2, 1) --> (25, 2, 20)	Cliff to Town
TDR	December '06	(2, 14, 1) --> (4, 5.1, 3.1)	Tufts to Cliff
TEO	February '07	(13, 12, 1) --> (12, 5, 4)	E. Tufts to W. Tufts
TER	November '06	(3, 2, 1) --> (9, 4, 5)	Tufts to Cliff SW of Tufts
TIM	March '07	(13, 19, 12) --> (13, 5, 4)	Northshore to Tufts/Cliff
TKO	October '06	(4, 5, 9) --> (20, 25, 26)	E. Redeye to Town
TKO	January '07	(20, 25, 26) --> (9, 5, 4)	Town to E. Redye
TMT	December '06	(8, 4, 9) --> (3, 15, 2)	Cliff SW of Tufts to Tufts

1. Month refers to the month in which move was completed.
2. Stations are the remote receiving stations recording the most IDs from each fox, listed in order (before)-->(after) each move.

Monitoring recommendations

Based on our first year's monitoring results we suggest establishing a set of action triggers based on mortalities of both collared and uncollared foxes. The criteria outlined below are designed to minimize the risk of catastrophic decline to the SNI fox population while at the same time reducing the need to expend valuable resources protecting against non-existent or minor threats.

The primary criteria determining action triggers should be based on daily monitoring of a relatively large population of radio-collared animals. We recommend monitoring 55-90 age class 1-3 ("younger") and five to ten age class 4 ("older") radio-collared animals. The expected mortality of radio-collared animals would be less than one death per month in each of the two groups (or 1-2 deaths of older animals if more than seven are collared; table 4). Foxes dying at significantly-higher rates would be cause for concern and would trigger management actions.

Table 4. Expected mortalities in a monitored fox populations including the upper 90%, 99% and 99.9% confidence limit.

Observed population	Expected mortalities in 30 days[1]	90% high[2]	99% high[3]	99.9% high[4]
minimum collared age class 1-3 (55)	0-1	2.0	2.6	3.4
maximum collared age class 1-3 (90)	0-1	3.2	4.3	5.6
minimum collared age class 4 (5)	0-1	1.1	1.4	1.7
maximum collared age class 4 (10)	1	2.2	2.7	3.3
island-wide age class 1-3 (475)[5]	2-3 (1)	17.0 (3.4)	22.7 (4.5)	29.4 (5.9)
island-wide age class 4 (75)[5]	7 (2)	16.7 (3.3)	20.5 (4.1)	25.0 (5.0)

1. The expected number of mortalities during 30 days in the observed population given its mean daily mortality rate (Table 2).
2. The upper 90% confidence limit of the expected number of mortalities in the observed population.
3. The upper 99% confidence limit of the expected number of mortalities in the observed population.
4. The upper 99.9% confidence limit of the expected number of mortalities in the observed population.
5. Numbers in parentheses represent the expected number of reported mortalities if there is a 20% chance of finding a dead uncollared fox.

Table 5 outlines a series of prudent actions to be triggered by relatively high numbers of unexplained deaths within a 30-day period. A critical component to the recommended protocols is that the triggering criteria refer to unexplained mortalities. Any mortality reasonably determined to be caused by a population-threatening disease (e.g. rabies, canine distemper virus) should immediately lead to vaccination efforts and the preparations to quarantine a healthy population of foxes in captivity, if necessary. Conversely, we may discount mortalities clearly due to causes unlikely to result in further deaths (e.g., vehicular trauma, starvation of older animals) if no suspicious contributing factors are detected at necropsy. For example, two younger radio-collared animals are hit by vehicles 15 days apart triggering a rush of both animals for necropsy as recommended in table 5. While the necropsy results reveal both animals were healthy at the time of their deaths, a third younger animal is found dead on the side of the road and an older animal dies in the following week. Because the first two animals

Table 5. Management responses and trigger points based on observed mortalities in an intensively monitored population.

Response[1]	Trigger point[2]	Actions
Category 1	90% high	*Rush carcasses for necropsy within 24 hours to determine cause of death
Category 2	99% high	*Initiate vaccination against most likely disease threats (canine distemper and rabies). *Set up trapping grids away from mortalities while getting vaccines onto island. *Begin trapping and innoculating animals until threat abated.
Category 3	99.9% high	*Initiate capture and seclusion of healthy foxes and captive breeding program. *Immediately prepare quarantined captive holding facility on island and trapping foxes away from mortality. *Captured foxes should be tested for disease and held in separated cages until determined to be disease free. *Continue capturing healthy animals until disease threat is abated or a total of N animals representative of the population are captured.

1. Response is triggered if the number of unexplained mortalities in a 30 day period exceeds the trigger point.
2. The number of mortalities observed within 30 days of collared foxes in different age classes or of collared and uncollared foxes in different age classes coresponding to these trigger points is presented in table 4.

were known to have been killed by vehicular trauma and without other suspicious contributing factors, the appropriate response would simply be to rush these other two animals for necropsy, rather than to initiate vaccination or capture efforts. However, if the third fox had died prior to receiving the necropsy reports on the first two, or if necropsies did not alleviate suspicions that disease contributed to their deaths, initiating vaccinations against likely disease threats would be warranted.

Even if the maximum recommended number of foxes is radio-collared, most foxes on the island will not be collared. Therefore, we also developed recommendations to include observations of mortalities of non-collared foxes. These recommendations assume an island-wide population of between 400-600 foxes. The estimated population size has fluctuated within this range over the last seven years.

We further assume that approximately 15% of adult foxes are age class four, corresponding to the age distribution observed during the last five years. Based on these assumptions we would expect three to six younger and seven to twelve older adult mortalities each month.

Most of these mortalities would go undectected unless the animal is collared. In order to get a rough estimate of the detection probability for uncollared fox mortalities we looked at mortalities of foxes marked during annual summer monitoring efforts from 2000 through 2005 (Schmidt et al. 2007). Annual mortality estimated from mark-recapture data from this period was similar to annual mortality estimated from daily survivorship estimated from this study, and remained relatively constant from year to year (Schmidt et al. 2007). If we assume that age-specific mortality rates from 2000 to 2005 were similar to those observed during this study, we can calculate the number of marked foxes expected to die each year. The number of dead marked foxes reported to Navy biologists was approximately 20% of the number expected to die during this period.

If we apply both the monthly mortality and detection probabilities estimated above to the island-wide fox population, we would expect one or two younger and two to three older adults to be reported in a month’s time span (table 4). If the number of reported mortalities of uncollared foxes exceeds these expectations appropriate conservation actions should be triggered in accordance with tables 4 and 5.

In the next year of this project we anticipate three refinements to the action triggers put forth in this report. First, we will have better information on daily survivorship rates with an increased sample size and monitoring period. Second, we will be able to incorporate information on seasonal and annual variation in mortality risks as we collect multiple years of monitoring data. Finally, by extending the area in which we trap and collar foxes we will be able to look for spatial patterns of mortality risk that should be incorporated into trigger points and management actions.

System Issues

While the telemetry monitoring system demonstrated in year one of this project was an effective tool to efficiently monitor a large number of foxes, we discovered aspects of the system and its implementation that can be improved. These considerations fall into three categories. The first relates to station placement relative to landscape features. The second relates to the capability of remote receiving stations to receive, translate and record ID signals sent by radio-collars. The third category corresponds to the collars themselves. We provide an example data file in Appendix 1 to facilitate discussion of the first two categories.

Landscape issues

Interference

Receiving stations on or near buildings often experienced recording interference. This interference typically was in the form of nonsensical information and long strings of the Morse code letters ‘E’ and ‘T, sometimes filling over 7 ½ hours of data recordings. Relocating stations slightly away from buildings usually resolved this issue. Stations placed on buildings did not always experience interference; one station on top of an unused building normally provided excellent data. While recording interference was likely associated with electronics equipment operating inside the buildings, even receiving stations located well away from buildings experienced similar interference from time to time. It was not feasible to maintain records of the number of lines of nonsensical data deleted during the reporting period. However, during a sample period of four recording sessions spanning 16-24 July 2006, the number of lines deleted was documented in order to assess the amount processing effort required. The average percentage of lines deleted for all stations was 36.28%; for individual stations the percentage deleted ranged between 19.73 -71.88 %.

Because it is not always obvious which locations will be susceptible to signal interference, we recommend that station locations are tested in order to determine if a potential problem exists. Even if initial recordings prove satisfactory, interference may still be experienced from time to time.

Signal Reception and Interpretation Issues

Problematic Letter Combinations and Processing Effort

After raw data is downloaded from the DVR it must be processed prior to its analysis. Ideally, each recording would consist of strings of 2-letter ID collar codes preceded by either a 'T' or '??' a collar in normal or mortality mode, respectively. In addition to these normal code combinations, data files typically contained the following combinations that do not reflect a current fox ID: 1) 2-letter codes in which the 'T' had been dropped, 2) single letters (typically 'E',' I',' T'), 3) 3-letter codes starting with 'E' or 'I', and 4) other nonsensical combinations.

When an 'E' or 'I' (rather than a 'T') occurred at the beginning of a 3-letter sequence in which the last two letters identified a fox, they were considered to be 'T' whose signal was not fully recorded due to the delay in activation of the recorder. For example, an "ECG" would be considered animals "TCG" where the "T" was not decoded correctly. In Morse code, 'T' is represented by a dash, while 'E' and 'I' are represented by one and two dots, respectively (see Appendix 2 for Morse code alphabet). On average, 5.84% of IDs recorded were edited.

Manually editing the data required a significant investment of time. Converting from collars that emit a VHF signal to collars that emit a digital signal should produce less stray interference. Processing time could be further reduced by using software designed to screen data for IDs and automatically convert proper two letter codes or three letter codes beginning with ‘E’ or ‘I’.

ID Mistranslation

There were occasions in which a proper ID appeared on recordings when there was no collar with that code, the collar with the code was not deployed, or the associated fox was not known to frequent the area in which the receiving station was situated and was still being detected at its known home receiving stations. For instance, TAT was occasionally detected by the receiving stations, but the collar with this the letter combination was never deployed. Similarly, apparent detections of TGT and TDM continued to be recorded after these collars were taken out of service. A count of mistranslations was calculated for data collected 19-21 September 2006 and 20-22 March 2007. Of all three letter codes starting with ‘T’ that were counted as fox detections; 3%-4% were known to be false. Of codes in which the ‘T’ was missing or an ‘E’ or ‘I’ was present instead of a ‘T’, 26.1% - 31.4% were false. Because some false codes may have been recorded which represent animals still in the population, the actual rate of apparent detections may be higher than estimated here.

One possible mechanism generating these false codes may be degradation of signals from collars at some point in the recording or translation process. For instance, a signal from collar TDO may have been degraded by loss of the final dash, resulting in signal translation to TDM. If both collars were active and the foxes lived in similar areas, it would have been impossible to differentiate between the actual real signal of TDM and the degraded signal of TDO masquerading as TDM.

This is particularly problematic if we consider a single detection as evidence that a fox is alive and accounted for. A few detections might be from a degraded signal, leading to the conclusion that the fox is accounted for, when in fact it is missing. To minimize the chance that monitored foxes were inappropriately considered alive and accounted for by a false code, we treated any animal with less than five IDs recorded within a 24 hour period as missing during that period. Assuming that false codes are random, independent events, this greatly reduced the chance that any given fox was assumed alive and accounted for when it should not have been.

Another way to reduce the probability of false codes being recorded for active foxes would be to increase the ID to a unique three letter code rather than a unique two letter code. This solution would not necessarily reduce the chance of a signal being degraded into a different code, but significantly reduces the chance that a false code represents another monitored animal. Finally, conversion of the telemetry signal sent from each collar to a digital signal should virtually eliminate the risk of a monitored animal being inappropriately accounted for by a false ID.

Radio Collar Issues

Reduced Signal Strength.

The number of ID signals and number of foxes recorded by most stations decreased steadily throughout the period of this study (figure 5). During the final two-day recording session in this reporting period (29-31 March 2007), 9.4% of the foxes (n

= 64) were not detected at all, and 28.1% had less than 10 detections by all stations in the approximately 48-hour session. Of these missing or rare foxes (n = 24), the approximate locations of 29.2% were known; these individuals lived in areas in which their signals were detectable by one or two receiving stations and were confirmed via vehicle mounted receivers.

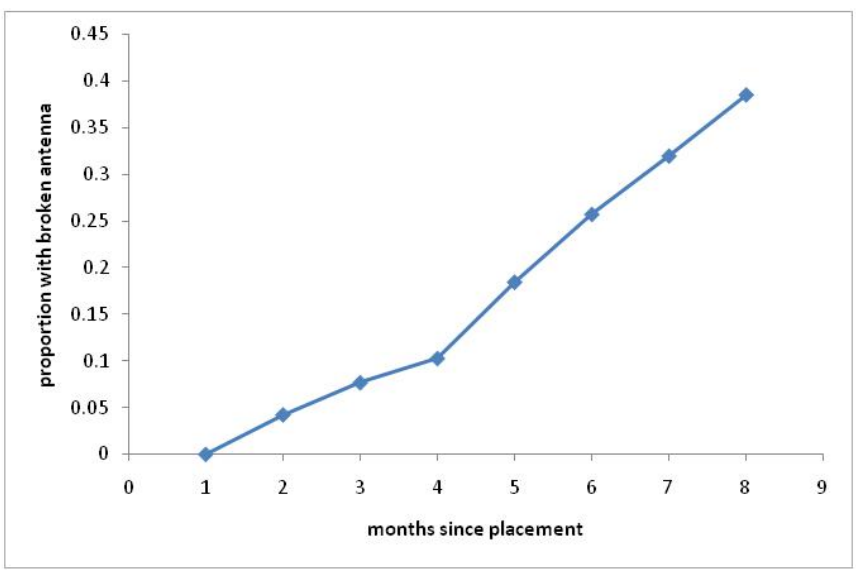
There are several possible mechanisms that could explain this pattern of signal loss. In some cases, reduced data recorded at receiving stations corresponded to animals being removed from their area of coverage. But this can only account for some of the observed reduction in IDs and foxes recorded at all stations. Collars from animals that died were generally replaced, and signals from animals dispersing from the reception area of one receiving station should have been recorded by receiving station(s) covering their new use area.

A second possibility is that collar batteries died before their projected life. Battery loss could account for increases in missing foxes at the end of the study, but does not explain the constant signal loss throughout the study. The batteries used in the collars typically maintain signal strength, with a rapid drop in signal strength at the end of their life.

We believe that the primary driver is reduced transmission capability from collars with broken antennas. While trapping in March 2007, a missing fox was captured in the same area where he had originally been collared. The antenna was broken and the collar did not appear to be transmitting a signal. Several other foxes captured during this trapping session also had broken antennas and several foxes observed opportunistically have also been noted with broken antennas. Collars with compromised antennae would not be capable of transmitting as efficiently. Consequently signals from these collars might only be received when it is in an ideal transmission location (e.g. top of a dune) or is near to a receiving station. This mechanism is most consistent with the observation that specialty stations, which because of topographical limitation only receive signals from nearby animals, recorded relatively stable numbers of ID's throughout the monitoring period (figure 5).

We estimated the number and timing of broken antennae by examining the number of IDs recorded from each fox each month from August 2006 through March 2007. We considered a permanent 50% reduction in the number of IDs recorded for an animal over the course of a month not associated with a change in use area as evidence of antennae breakage. Antenna breaks occurred at a rate of approximately 3% per month for the first three months, and twice that for the last five months of this study (figure 7). In total, we estimate that 38% of collars had a broken antenna by the end of the study. We will attempt to confirm these estimates by trapping collared animals during the summer of 2007.

Figure 7. Cumulative proportion of collars with evidence of broken antenna.



Collars used in the next phase of the project will utilize thicker antennas that are reinforced at the base in order to reduce breakage. Reducing breakage will allow the collars to maintain their ability to transmit a strong signal. Any faulty collars that are retrieved will be analyzed to determine the nature of the failure so that future products provide more consistent and reliable results. Additionally, the next phase of receiving stations will be located at higher elevations, such on the top of towers that already exist on San Nicolas. One station moved from ground level to a height of approximately 25 feet experienced a ten-fold increase in detections. Since stations at higher elevations consistently had more detections and are more likely to detect weak signals, we anticipate that placing stations on towers will reduce the number of mortalities that are not detected as well as the number of missing or rare foxes.

Mortality Algorithm

Each collar is programmed with a mortality function which broadcasts an altered ID code after 6 hours have elapsed with no movement. The transmitter requires relatively intense shaking to revert to normal mode. This function was designed to prevent mortality mode from being easily deactivated and therefore delaying detection of mortalities. Scavengers feeding on the carcasses and inadvertently resetting the collars are a common concern when tracking individuals via radio telemetry and the settings employed were reflective of others used for this species.

During the reporting period, multiple incidences of false mortality signals occurred in which the collar broadcast in mortality mode but the fox was alive. Over half (30/59) of the collars went into false mortality mode, several on more than one occasion. During one recording session in December, eight collars broadcast false mortalities nearly simultaneously and required various amounts of time to revert back to normal mode. Since the receiving stations have no way of indicating if a fox was actually dead or in false mortality, resources had to be used to track the signals in order to confirm by signal modulation or visual that a fox was alive. Some collars remained in mortality mode for extended lengths of time despite clear activity by the foxes.

While false mortalities are a potential issue for any telemetry system including a mortality signal, they were more common in this study for three reasons. First, as mentioned above, we deliberately set the collars to require a large amount of movement to reset after entering mortality mode. Second, due to the use of receiving stations and special collars broadcasting ID signals, the monitoring coverage provides hourly data which is more complete than intermittent information provided by traditional telemetry. Finally, island foxes may be more sedentary than previously believed, especially during the pupping season. Two instances of false mortality mode documented this spring appeared to be triggered by the reduction of movement by females while giving birth to or nursing very young pups. Lack of predators may have reduced vigilance to such a degree that the foxes spend a large portion of their day sleeping without rousing themselves to occasionally assess the safety of their surroundings. Such behavior could lead to the excessive triggering of mortality mode.

There are two options available to reduce the incidence of false mortalities, increasing the length of the motionless period required to trigger mortality mode, or decreasing amount of movement required to reset a collar in mortality mode. Because we have found no evidence of large scavengers feeding on fox carcasses, we will deploy collars in the next phase of this project that will come out of mortality mode more quickly when the fox begins movement again.

We have opted to maintain a six-hour motionless period to trigger mortality mode to maximize the chance of early recovery for dead foxes. While this decision may allow for some false mortalities to be recorded, false mortalities should be easily distinguishable by subsequent “live” signals once foxes resume activity. Balancing the amount of time required to trigger mortality mode and the amount of activity required to reset a collar in mortality mode is a necessary consideration for any telemetry monitoring program, and the proper balance will depend on the behavior of the monitored populations as well as the tolerances of the people conducting the work.

Conclusions

The telemetry system demonstrated in this project proved to be an effective and efficient way to monitor daily survivorship of a large number of foxes. Receiving stations collected copious quantities of data daily, which could be scanned by a single technician to identify missing or dead animals while allowing time for follow up on those animals. Based on these data, we were able to estimate background mortality rates for two distinct classes of adult foxes corresponding to younger and older, senescent adults, and establish trigger points for management actions.

As this demonstration project and study continues into its second year, we anticipate progress in three directions. First, we will implement many of the system improvements described above to increase the accuracy and efficiency of collecting and interpreting the telemetry data. Second, we will increase the spatial extent of monitoring across the island to look for habitats or areas where foxes may face greater mortality risks. We will also be able to look for seasonal patterns in mortality risk as we collect multiple years of monitoring data. Finally, we will incorporate these patterns, along with additional data on age-specific mortality rates, into refined trigger points for management actions. We expect that as these refinements are implemented, the monitoring system developed for San Nicolas Island foxes will serve as a leading example for the implementation of efficient and effective monitoring programs for species conservation on military bases and other publically and privately managed wildlands.

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Appendix 1. Data text file example.

Below is part of the text file collected from station 4 on September 1, 2006. Note three letter ID codes + survival check, *random letters or strings of letters (usually 'E' or 'I')*, edited ID codes, and **false ID codes or false edited ID codes**.

E IW TGT TGK TGU TGR TIM TKO TKR TIK TIW *I S I* TMS TKS TDI TKT TMO TKR TMU TKW *E N* TMT TIS TEW TEU TIR TIS TGT TGR TGM TGK TKO TIM TIE TIK TGU TIR TKT TDI TGR TMO TIK TKR *N E E* TMU TKT *II E T M S* TMT TKS TGO TMU TEG TEW TMI TIS TGM TKO TGT TIM TGK TGU TDI TIR TGR TMO TIK TKT TGT TKR TDM TDI TMO TMS TMU TGO *S I* IIS TDM TKW *EEI* *I* TEW TMT TIS TIW TGM TKO TEW *TA* TIM TGR TKT TGU TIK TIR TGT TDI TKR TMO TMS TMU TDM TGO TKW TIS TMT TKS TEU TIW TGM TKO TAD TIM TEW TIW *T E U* TKT TGR TIK TKO TGU TIR TIM TDI TKR TGT TMO TMS TGU TMU TDM TGO TKW TIS TIO TMT TMS TEG TGM TIS TKT TIW TAD TEU TGR TEW TIK TGM **TKN ESI EII** *EHEI ESE* EIS **ERK** EAD *E E E E N T E T E E E E E E T D R I E* TDR *E E EIE E E E E E E E E E E E E I E E DE E T T I E E E E E E E E E E EI E E E E ET E E E E E E EE N E E E E E E E EE EE ET E E E E ET E E E T T E E E E E E E E E E E ET E E E E TT E E E T E T EE EET E E E E E T E EE E E E E E E E E E E E E E E E E E E E E E E E E E EE E E E E TE E E E T E E E E E I E T E E E E E E E E E E E I E E E E E E E E E E E E E E E E E E E E E T T E E E E E E TE T E E E T T E E E E E T E E E E E E T E E E T E E E AT E E E E T E E E E T T E E E E EE E E E E E T E E E E E E E E E E E E E E T E T T E EEE TE T* **TEE ETE** *TIEI E E E E E E*

Appendix 2. International Morse code.

A	.–	M	––	Y	–.––	6	–....
B	–...	N	–.	Z	––..	7	––...
C	–.–.	O	–––	Ä	.–.–	8	–––..
D	–..	P	.––.	Ö	–––.	9	––––.
E	.	Q	––.–	Ü	..––	.	.–.–.–
F	..–.	R	.–.	Ch	––––	,	––..––
G	––.	S	...	0	–––––	?	..––..
H	....	T	–	1	.––––	!	..__.
I	..	U	..–	2	..–––	:	–––...
J	.–––	V	...–	3	...––	“	.–..–.
K	–.–	W	.––	4	....–	‘	.––––.
L	.–..	X	–..–	5	.....	=	–...–