Executive Summary

Island foxes (*Urocyon littoralis*) inhabit the six largest Channel Islands off the coast of southern California, with a separate subspecies recognized on each island: San Miguel Island fox (*U. l. littoralis*), San Nicolas Island fox (*U. l. dickeyi*), San Clemente Island fox (*U. l. clementae*), Santa Catalina Island fox (*U. l. catalinae*), Santa Rosa Island fox (*U. l. santarosae*), and Santa Cruz Island fox (*U. l. santacruzae*). Due to their limited geographic distribution and small population sizes, foxes on all six islands have been listed as Threatened by the State of California, and all subspecies except those on San Nicolas and San Clemente have been listed as Endangered by the U.S. Fish and Wildlife Service (USFWS) due to recent precipitous population declines and high risk of extinction.

Due to the persistent high risk of this island species, robust monitoring of fox populations and their threats is a key component of recovery and long-term management. This document presents a framework for population monitoring for five subspecies of island fox on San Miguel, San Nicolas, Santa Catalina, Santa Rosa, and Santa Cruz Islands. A monitoring framework previously developed for the U.S. Navy on San Clemente Island, in addition to years of monitoring and research on all six islands, provided the foundation for the current effort. This document thus represents the first comprehensive synthesis of monitoring data, objectives, and protocols across multiple Channel Islands with foxes.

Sections 1-3 of this report describe the considerations and approaches used to identify specific monitoring objectives, determine parameters to address these objectives, and develop protocols to measure these parameters. Sections 4-8 present illustrative island-specific examples of monitoring scenarios designed to address current monitoring objectives, but with different levels of effort and precision. We provide at least two alternative trapping scenarios for each island, along with expected precision (e.g., for resulting population estimates), effort required, and estimated habitat representation. It is expected that island managers will tailor and adapt protocols for on-the-ground use, based on their resources and priorities, understanding that there is generally a trade-off between monitoring intensity and information value.

Monitoring Objectives and Parameters

This framework reflects the culmination of years of investigation, discussion, and planning by the Island Fox Integrated Recovery Team, island managers, veterinarians, population modelers, statisticians, and other scientists who have contributed to the understanding of this charismatic species. The motivation for this effort was the recognition that monitoring objectives and protocols have varied among islands and over time. Going forward, the monitoring objectives for this framework address the essential core of information in which managers should invest, recognizing logistical and monetary constraints and the inherent trade-offs for precision. These objectives are:

1. Track recovery of fox populations relative to recovery criteria, which will be defined in the Recovery Plan for this species developed by the USFWS.
2. Determine when delisting is warranted (as defined in the USFWS Recovery Plan).

3. Guide island-specific management decisions such as those related to captive breeding, vaccination, eagle removal, and management of human activities.
4. Refine parameter estimates for population viability analyses (PVA), and facilitate other cross-island comparisons.

This framework incorporates the general philosophy of the Recovery Coordination Group (RCG), which emphasizes close tracking of fox mortality rates to identify the presence and intensity of the fox's primary threats, namely eagle predation and disease, and to rapidly detect new threats. Precise temporal-scale knowledge of mortality is vital for triggering management actions to control these threats. Mortality rates, especially for adults, exert the greatest influence on the risk of extinction for island foxes in population viability analyses, and observed mortality rates can be used to accurately predict future risk. Population size estimates and general trends in abundance can help corroborate conclusions regarding population status made from mortality data. While other philosophical approaches emphasize precise estimates of population size and abundance trends, our reliance on mortality rates derives from the commitment to monitor mortality precisely and the relationship between mortality rates and population status.

Tracking Recovery

Based on this general philosophy, management goals of island managers, and further input from population modelers and Technical Expertise Groups (TEG), the following monitoring parameters were targeted for the purpose of tracking and determining recovery:

- Annual mortality rates at high precision (with associated cause-specific mortality rates)─sufficient to detect an annual eagle-specific mortality rate of ≥2.5%, averaged over 3 years.
- Population trend (or lambda [λ]) at low to moderate precision, estimated from annual population estimates or from population models.
- Annual population size, with 80% confidence interval.

In anticipation of a recovery plan for the island fox, the RCG, land managers, and population modelers proposed recovery criteria, with the following related to monitoring:

1. An island fox population must have no more than 5% risk of quasi-extinction over a 50-year period. This risk level must be based on the following:
   - The risk of extinction must be calculated based on the lower 80% confidence interval for a 3-year average of population size estimates, and the upper 80% confidence interval for a 3-year average of mortality rate estimates.
   - This risk level must be sustained for at least 5 years.
   - Quasi-extinction is defined as a population size of ≤30 individuals.
2. An island fox population trend must be increasing so that the average population estimate in year 5 is greater than that of year 1.
3. A golden eagle management strategy, approved by the land manager(s) charged with the recovery of an island fox population, must include monitoring protocols able to detect an

annual island fox mortality rate caused by golden eagle predation of ≥2.5%, averaged over 3 years.

These components of the proposed recovery criteria, together with the RCG philosophy, influenced the targeted precision of monitoring protocols in this framework, i.e., high precision in mortality rates but greater flexibility in precision of population and trend estimates. This framework provides protocols that estimate true population size (N), with an estimate indicated by a "hat" ($\hat{N}$).

Guiding Management

Island managers identified the following additional parameters needed to guide management decisions:

- Overall and cause-specific mortality rates by age and sex, to examine all causes of mortality (all islands).
- Habitat-specific density (San Nicolas, Santa Rosa, Santa Cruz).
- Habitat-specific survival (Santa Cruz).
- Reproduction measured in terms of annual recruitment (San Miguel, Santa Rosa).
- Disease and health profiles, as sampled from all dead foxes and from a subset of the living population, based on sampling protocols determined by the Fox Health TEG (all islands).

Population Sampling Considerations

Experts involved in developing a previous island fox monitoring framework for the U.S. Navy on San Clemente Island recommended trapping and radio telemetry as key components for islandwide fox monitoring to address mortality rates and causes. Trapping also provides the best means of estimating population sizes with known precision and confidence intervals. The use of GPS collars provides an additional means of monitoring habitat use and, possibly, mortality. To minimize stress to foxes, as well as labor and equipment costs, we recommend scenarios in which both these objectives may, for the most part, be met with one annual trapping effort, thereby making the best use of personnel resources and reducing disruption to foxes that might occur from multiple trapping efforts.

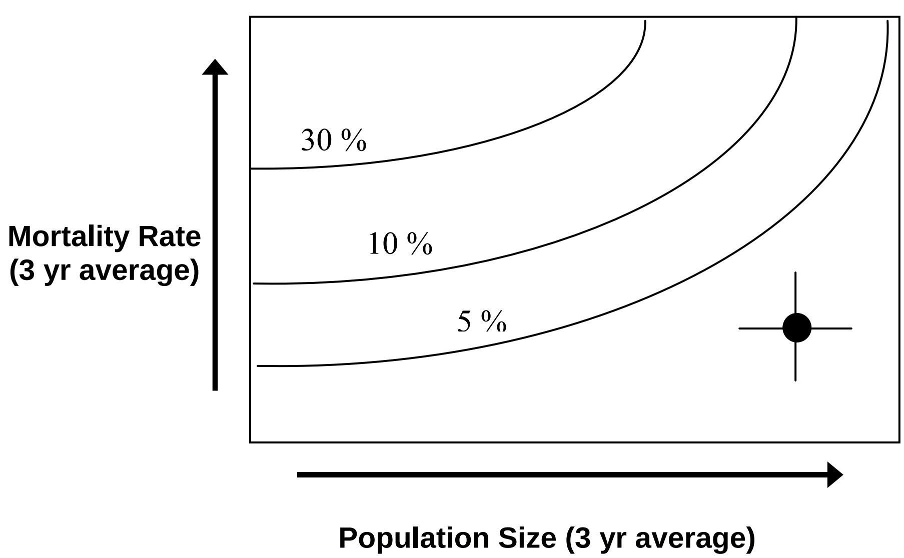
In determining specific trapping protocols, we considered a wide range of factors, including the ecology and behavior of the species, the logistical constraints on each island, and the selection of feasible monitoring methods that can provide the desired measurements in the most efficient and statistically robust manner. For island foxes, some key biological issues are their social structure (and existence of territories held by monogamous pairs), their ability to inhabit essentially every habitat type on the islands, and the timing of parturition. Access constraints on the islands, and concern for animal welfare, limit the choice and design of sampling protocols. Steep and rugged terrain, primitive road conditions or lack of roads, and large size of three of the islands make the use of large trapping grids infeasible, and ecologically sensitive areas seasonally restrict access to some areas for trapping.

The choice of trapping protocols involves tradeoffs between desired precision, feasibility and cost, and the extent of trapping; these, in turn, are influenced by the status of the population. For large populations with high survival, the risk of quasi-extinction is low; that is, these populations lie far from the 5% quasi-extinction isocline (Box ES-1). High precision in population estimates may be less important in such cases, compared to populations with smaller N and/or higher mortality, and managers may choose to reduce the extent of trapping and subsequently generate population estimates with lower precision (i.e., with CV >20%), thereby reducing costs, efforts, and potential risk and stress to foxes.

Our goal was to identify feasible trapping approaches for each island that would generate a statistically robust estimate with adequate precision and representation of island habitats. We provide recommended monitoring protocols that strive to estimate population size with a coefficient of variation (CV) of ≤20% when feasible. CV($\hat{N}$) is a measure of precision equal to the standard error of the estimate divided by the estimate itself. There is flexibility in the required precision of trend, and this level of precision will ultimately be decided by island managers, in their decision on trapping protocols. Although one standardized sampling approach across all islands would have been desirable, objectives and constraints differ somewhat across islands. Therefore, island-specific protocols must be tailored accordingly. The key parameters obtained from trapping should nevertheless be comparable among islands.

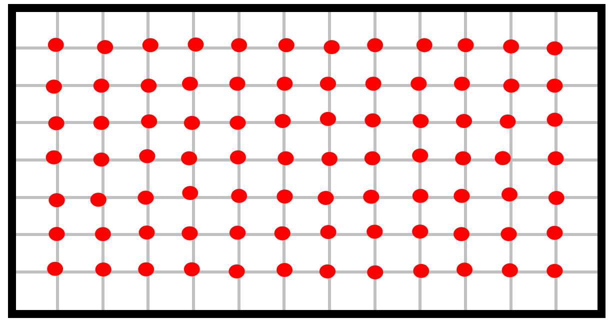
Box ES-1. Example of risk isoclines, with the status of a hypothetical population plotted.

The combination of a population's 3-year average size and mortality rate can be plotted to determine the population's status in relation to predetermined risk isoclines (shown here as 5, 10, and 30% risk isoclines). In this case, the population's status (shown as a point estimate along with 80% confidence intervals) is well below the isocline representing a 5% risk of quasi-extinction over 50 years, indicating a low level of risk.

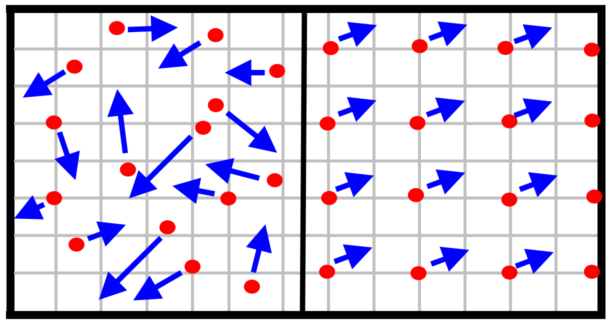


We considered five trapping approaches and configurations expected to provide robust parameter estimation for population size (and therefore also for trend):

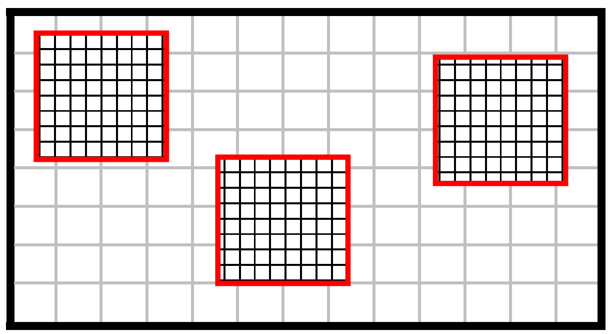
1. Island-wide systematic trapping. This was an option explored for San Clemente Island, in which traps are placed systematically and evenly on the island, <600 meters apart to allow for equal capture probability among all foxes. Population estimates are generated via mark-recapture methods with the entire island considered the effective trap area.



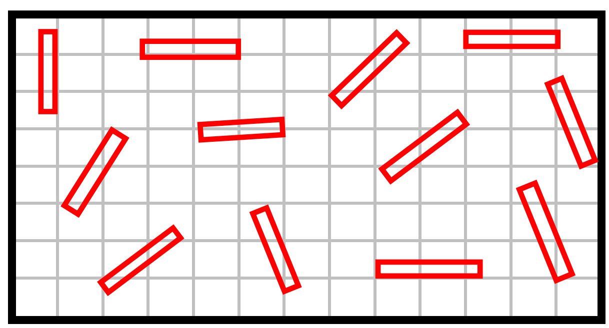
2. Island-wide random trapping. Traps are placed randomly or systematically on a grid (with ≤1200-meter spacing) and moved to new random locations individually or randomly as a shifted grid (up to ½ inter-trap distance), respectively, before each trapping occasion. Population estimates are generated via mark-recapture methods with the entire island considered the effective trap area.



3. Traditional trapping grids. Population size is extrapolated from local grid densities, based on (a) mark-recapture estimates of local abundance in combination with estimated local effective trap area (from distances moved by recaptured animals) or (b) spatially explicit capture-recapture methods, using movement and detection patterns alone.



4. Multiple small trapping "units." Population size is extrapolated from local units via spatially-explicit capture-recapture methods. Traditional mark-recapture methods cannot yield precise density estimates for transect-shaped units due to edge effects.



Island-wide systematic trapping is not feasible due to the large number of traps that would be necessary. We did not consider linear transect trapping, protocols currently used on Santa Catalina and Santa Cruz islands, because there is no statistically valid method for estimating the effective trap area around transects from trap data, thereby making it difficult to estimate density. We used simulation and analyses to examine and compare expected precision of other trapping configurations and protocols (e.g., number of traps, number of nights trapped). To account for spatial heterogeneity in local densities, we focused on protocols that use statistically rigorous sampling design, with trap layout determined by random, stratified, or systematic with random origin placement. For each island, we examined various trapping scenarios for expected precision, required field effort, and likely representation of habitat variability on the island, and compared them with required effort, statistical robustness, and representation of habitat variability of existing protocols.

Recognizing trade-offs between effort, feasibility, and the desire to maximize precision and habitat representation on each island, we selected two to three scenarios for each island, conducted a habitat representation analysis on two scenarios for each island, and present these as examples of potential trapping scenarios. Scenarios are presented as examples of effort and expected precision. With an understanding of the trade-offs presented in the example scenarios, managers can tailor one of these protocols to be used on their respective islands.

Changing population status may allow managers to reduce trapping effort. First, because precision scales with population size, precision goals may be reached with reduced effort at larger population sizes. Additionally, managers may desire to reduce precision targets as population status improves, such as when a population is large and has high survival. In these cases, reduced trapping may be desirable because of reduced cost and reduced risk of stress and disruption to foxes. In the case of multiple small trapping "units," this may be accomplished by reducing the number of units trapped on the island. Trap effort can, alternatively, be reduced by maintaining the same number of units and reducing the number of nights trapped. In addition to loss of precision, these decisions should consider labor and time saved by each option and the loss of habitat representation that will occur if units are removed.

Survival Monitoring

The risks of eagle predation and disease create the primary need for survival monitoring, as demonstrated by the near loss of subspecies on the northern islands (due to eagle predation) and on Santa Catalina Island (apparently due to disease). Because the detection of either eagle predation or disease would trigger management actions (e.g., eagle removal, vaccination, or capturing foxes for quarantine), survival monitoring must be continuous and occur in "real time," which requires frequent year-round monitoring of radiocollared animals on each island. These two risks influence the required number of collared animals and the frequency at which they need to be monitored.

Simulations suggest that an eagle-specific mortality rate of $\geq$2.5%, averaged over a 3-year period, can be detected if at least 40 radiocollared foxes are monitored frequently on each island. The Fox Health TEG advised that, ideally, the 40 animals should be checked every 24 hours; at a minimum, signals from the 40 animals should be monitored every 2-3 days in the winter months and every 1-2 days in the summer, as high temperatures can quickly deteriorate the condition of a carcass and compromise the ability to obtain meaningful necropsy results. Although less frequent monitoring (such as once per week) may be adequate for monitoring eagle predation (i.e., carcasses would likely be investigated rapidly enough to determine this cause of death), it would not be adequate for disease surveillance.

The choice of which 40 animals to collar is also an important decision, and we suggest the following guidelines:

1. Collared animals should be distributed across each island, rather than being clumped in one area, to best sample survival that may vary geographically and to detect disease outbreaks prior to spread.
2. Collared animals should represent all age classes.
3. Collared animals should include approximately equal numbers of males and females.
4. As suggested by the Fox Health TEG, animals monitored for survival should not be vaccinated against disease, as they should represent true sentinels for disease. The Fox Health TEG and population modelers recommend that a subset of animals on each island be vaccinated against rabies and canine distemper. The role of the 40 monitored animals is, therefore, to detect: (a) disease outbreaks other than rabies or distemper (i.e., diseases for which the population is not protected via vaccination), (b) a rabies or distemper outbreak so that unvaccinated animals could be vaccinated and that vaccine efficacy among vaccinated animals could be evaluated, and (c) other causes of mortality such as eagle kills, vehicular trauma, or dog attacks.

Ideally, a new set of 40 collars should be applied every year during annual census trapping, to maintain a sample of animals representative of the population and to reduce the chance of bias if the same cohort of animals is tracked for multiple years.

To facilitate monitoring collared animals at the suggested frequency, island managers should collaborate in evaluating the feasibility and cost-effectiveness of (a) aerial monitoring via plane or helicopter, through a joint contract of services, (b) monitoring via remote receivers, and (c) monitoring via GPS collars, with potential cost-savings for bulk purchase.

Data Management and Integration

Data generated from long-term monitoring are valuable for understanding factors influencing island fox populations. Monitoring is also intended to generate comparable data for comparisons and analyses across islands. It is therefore critical that data be collected, stored, and managed in a standardized manner that will allow for accurate and efficient use, both within and across islands.

To generate data useful for exploring the dynamics of fox populations, this monitoring should also include standardized and long-term collection of other biotic and abiotic data, such as:

- Climate and local weather patterns
- Abundance and distribution of other species
- Disease profiles among other species
- Vegetation characteristics
- Other environmental health parameters (e.g., road traffic, rodenticide use, human activities).

These data should be compiled and managed in a way that allows future integration and analyses with fox population data. To increase the usefulness of datasets, collection and management of data should be coordinated across islands.

Research Modules and Outstanding Questions

Recommendations presented in this report are part of an adaptive framework intended to provide the basis for future refinement of monitoring protocols. Refinements will be required over time as monitoring objectives and needs change, e.g., as population size and threats to foxes change over time, as our knowledge of fox ecology grows, and as new analytical techniques allow improvement of monitoring protocols.

Monitoring protocols outlined in this report will produce long-term standardized demographic data on island foxes which will provide a context for additional research on island fox biology, environmental factors affecting the viability and dynamics of fox populations, and management intervention. Research results may, in turn, be used to refine future monitoring protocols or analyses of monitoring data. In this report, we discuss several recommended research topics for each island. These include:

- Changes in vegetation communities and species composition
- Habitat and space use by foxes
- Fox community dynamics
- Disease and health
- Factors influencing fox survival
- Reproduction and early pup survival
- Ecological relationships with skunks and feral cats
- Effectiveness of remote telemetry stations and camera stations
- Analytical approaches, including indices of trend
- Surveys of human perspectives and education
- Impacts of traffic, rodenticide use, and nonnative herbivores

Through the collaborative process of developing this monitoring framework, several concepts and questions have emerged that warrant additional evaluation in the continuous quest to improve field protocols and analytical approaches and make conservation efforts more cost-effective. Some of these are outlined below.

1. <u>What is the most cost-effective means of monitoring foxes for survival using known fate methods</u>? This can include one or more of the following: ground monitoring, aerial monitoring, monitoring via remote receivers, monitoring of GPS collars. The choice will depend on a monetary cost analysis and an evaluation of the ever-improving technologies of GPS collars and remote receivers. For remote receivers, such an evaluation should include determining actual, in-field detection ranges for telemetry signals as a function of

terrain, location, and tower heights, and a viewshed analysis to determine the number and locations of towers needed to monitor the island adequately. Although the choice can be island-specific, the most efficient solution may result from coordinated exploration of options by managers of all islands.

2. What proportion of monitored animals should be vaccinated? The current recommendation is that monitored animals should not be vaccinated, allowing them to be true sentinels for disease outbreaks. However, the Fox Health TEG, with assistance from population modelers, has yet to determine the total number of animals to be vaccinated on each island. This decision will, in turn, dictate how many unvaccinated animals are available as sentinels. This is particularly important for small populations.

3. How does the presence of skunks influence the effectiveness and optimal design of trapping protocols? Recent trap data from Santa Rosa and Santa Cruz islands indicate an increase in trap success in capturing skunks. This reduces the availability of traps to foxes and has implications for the precision of estimates derived from trap data. Further research is needed to determine how to best account for this effect, and how the prior capture of a skunk influences subsequent capture of a fox in the same trap.

4. Can locational data from collared animals be used to provide additional options for analyzing trap data? A potential approach for estimating density with the use of radiocollared animals is to combine telemetry data with trapping data. Generally, this approach calls for delineating the area associated with a trapping unit, determining the proportion of locations within the trapping area for radiocollared animals, and estimating density for each unit based on the relationship between the proportion of locations within the trapping unit and probability of capture. This method requires further development for optimal design to assess how precision would vary with different grid sizes, trapping durations, numbers of radiocollared foxes, telemetry location frequencies, and telemetry location precision.

5. Can trap protocols and analysis of trap data be improved with increased knowledge of fox behavior and movement patterns? In our analysis of potential trap protocols, trap detection parameters were refined with the use of existing data from multiple islands; however, increased understanding of the behavior of foxes in relation to trapping could improve the choice of trapping protocols and the analysis of trap data. For example, it may be possible to more adequately model trap-happy behavior and incorporate this into density estimation models. Similarly, fox movement behavior may influence the appropriate methods of data analysis. For example, further research should be conducted to evaluate whether home range shape (e.g., elongated home ranges due to movement along roads, trails, and ridges) influences or biases density estimates, and how trap protocols may account for such potential influences.

Beyond Recovery

Questions remain about the ecology and optimal sampling designs for island foxes. Their isolation, small population sizes, and apparent low historic exposure to disease, coupled with human-caused changes to their environments, mean that island foxes will always be vulnerable to extinction due to demographic and environmental stochasticity. Thus, robust monitoring of fox populations, while key to recovery of federally listed species, will also continue to be a necessary component of island management beyond recovery.

As a result of changing threats and status of island fox populations, and with the collection of additional data and continued collaborations, monitoring objectives and protocols may evolve and be adapted to obtain more cost-effective, useful, and robust information. We hope the data that is generated from these monitoring programs will stimulate further research that contributes to the management of this species.