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APPENDICES A–E

Prepared by

Esther S. Rubin and Brian S. Cohen

Appendix A

Univariate Representation Analysis of Existing and Proposed Trapping Scenarios on San Miguel Island

Introduction

This representation analysis examines how well existing and recommended trapping protocols represent habitat variation on San Miguel Island. The goal of evaluating existing protocols was to identify gaps in island representation that could be addressed in proposed trapping scenarios, and to provide a baseline comparison with which to evaluate proposed scenarios. This information is intended to provide managers with additional information on which to base decisions about trapping protocols. In addition, increased knowledge regarding habitat representation of each trapping scenario may help identify research needs relative to habitat use and selection. In this analysis, we examined habitat representation of four trapping scenarios: (a) grids trapped during 1993-1998, (b) grids trapped in 2006 (Map 4-1), (c) trapping Scenario B (Map 4-6), and (d) trapping Scenario C (Map 4-7). Scenario A (Map 4-5) was not evaluated, as it was assumed that that scenario would provide similar habitat representation as Scenario B, possibly with slightly better representation due to larger grid size.

Methods

We identified habitat variables currently available as GIS coverages or that could be created from existing GIS coverages, and for which we have empirical evidence or biological rationale to suspect that they may influence island fox habitat quality or population dynamics. Although we can not know or measure all habitat characteristics important to island foxes, we strived to maximize representation of the following habitat attributes that we can measure: vegetation type, slope, terrain ruggedness, distance to trails, distance to shoreline, distance to developed areas, and distance to freshwater sources. It is likely that other habitat characteristics also influence fox populations, but some of these will correlate highly with the variables we selected (e.g., distance to canyon bottoms would correlate strongly with our ruggedness index), and others are not currently available to measure (e.g., prey densities). This analysis should be viewed as preliminary, and we strongly recommend that future data from radio-collared foxes be used to evaluate and identify habitat features that influence fox densities or habitat selection.

We created data layers for each of the continuous variables (slope, terrain ruggedness, distance to trails, distance to shoreline, distance to developed areas, and distance to freshwater sources) in the following manner:

- Slope. We derived a slope layer from the USGS 30-m DEM. We chose to create a slope layer in degrees.
- Ruggedness. We created a Ruggedness raster layer using an Avenue script created and provided by Mark Sappington (National Park Service) and Kathy Longshore (U.S.

Geological Survey). This measure provides an index of ruggedness which ranges from 0 to 1, with 0 representing completely flat terrain and 1 representing the most rugged terrain. We used the USGS 30-m DEM as the basis for the algorithm, after converting its elevation values from feet to meters, and used a 90x90-m moving window to calculate ruggedness.

- Distance to shoreline. We created a raster layer of the distance-to-shoreline using the Distance ->Straight Line tool provided in the Spatial Analyst extension.
- Distance to trails. We created a raster layer of the distance to trails using the Distance ->Straight Line tool provided in the Spatial Analyst extension. The trails data layer was provided by the National Park Service.
- Distance to developed. We created a raster layer of the distance to developed areas using the Distance ->Straight Line tool provided in the Spatial Analyst extension.
- Distance to freshwater. Because a map of freshwater sources on San Miguel is not currently available, we used the USGS hydrology layer as a surrogate. This layer represents drainages and ravines, which may be more likely to contain surface freshwater or runoff than other areas, but are not guaranteed to provide water.
- Vegetation. We used a vegetation layer created and provided by the National Park Service. We examined the composition of vegetation across the entire island, and attempted to reduce the number of vegetation classifications to represent major vegetation types. The original and newly created classifications are shown in Table A-1.

Table A-1. Vegetation classifications on San Miguel Island, as originally classified and as grouped for analysis.

Original Classification	Representation of Original Classification on Island (%)	Vegetation as Categorized for Analysis
Island grassland	34.8	Island grassland
Haplopappus scrub	29.9	*Haplopappus* scrub
Beach and coastal dune	14.7	Beach and coastal dune
Unstabilized dune	11.8	Unstabilized dune
Coastal sage scrub	3.3	Other
Canyons	3.2	Other
Coastal bluff, sea-cliff phase	1.4	Other
Coastal bluff, Coreopsis phase	0.8	Other

Habitat characteristics were determined from two separate sets of random points; one distributed over the entire island and one distributed on trapped areas only. Trapped areas were defined as all locations within a 600-m buffer of a trap, excluding open water and avoiding double-counting of overlap areas for grids or traps <1,200 m apart. The 600-m buffer distance, added to represent the effective trap area of each trap, is equal to the mean of the mean maximum distances moved for each trapping session for all years for grids on San Clemente, Santa Cruz, San Miguel, and San Nicolas islands (V. Bakker, pers. comm.). The number of random points was chosen by first placing points along a systematic grid with 90-m spacing, to result in a density of 144 points/km^2, and then applying this density of points randomly to the island and the trapped area.

We used the Mann-Whitney test (Sokal and Rohlf 1995) to test whether continuous variables (slope, ruggedness, distance to trails, etc.) differed between the island and trapped areas. To compare the composition of vegetation types, we used a chi-square goodness of fit test (Fowler et al. 1998), to compare vegetation composition of the trapped area versus on the entire island. We also visually compared the distributions of habitat attributes on the island versus those on trapped areas.

Results and Discussion

1990s Trapping Protocol

During 1993-1998, foxes on San Miguel Island were trapped annually on three grids, with a total of 146 traps. Individual grid sizes were 7x7 traps (two grids) and 6x8 traps (one grid). Assuming a 600-m effective trap radius, the three grids collectively sampled approximately 49% of the island.

Habitat sampled by the 1990s protocol is less steep and less rugged than island-wide habitat (Table A-2, Figures A-1 and A-2). However, although these differences are statistically significant, it is possible that they are not biologically meaningful in terms of sampling fox presence and abundance. The difference in median slopes is less than 1 degree, which may have limited influence on fox habitat use. Absolute differences in mean and median ruggedness values were also very small. Most terrain on San Miguel Island is relatively gentle, and the difference in ruggedness values between trapped and island-wide areas is small compared to the possible range of this index, in which a value of 0 represents completely flat terrain and 1 represents the most rugged terrain. It is likely that the lack of sampling near the shoreline (see below) causes trapped areas to have lower slope and ruggedness compared to the entire island but the extent of this difference, in itself, may have little influence on fox habitat use.

Areas trapped with the 1990s protocol are significantly farther from the shoreline than island-wide areas (Table A-2, Figure A-3). Although means and medians differ by <200 m, which may not be relevant given travel distances observed in foxes, the distribution of these distances indicates that areas within approximately 500 m of the shoreline are under-sampled by the trapping grids (Figure A-3). This may have relevance to trapping results, as foxes living along the shoreline would have reduced probability of capture.

Areas sampled with the 1990s protocol are closer to trails, developed areas, and freshwater than are island-wide random points (Table A-2, Figures A-4, A-5, and A-6). Distance to developed areas is greatly skewed, with distances >2,500 m not sampled by trapping protocols. The difference in distance to trails is less pronounced, with means and medians differing by <100 m. The impacts of trails and developed areas on fox density and habitat use are unknown, but trap proximity to these features may have relevance if foxes select or avoid areas near trails or developed areas. Differences between island-wide and trapped areas in distance to freshwater differ by <150 m, suggesting that this difference may not have biological relevance, but the fact that a small portion of the island, >1,500 m from this surrogate for freshwater, was not sampled with this trapping protocol may have relevance (Figure A-6).

The 1990s trapping protocol samples each of the five categories used in this analysis but it does not sample them in proportion to their availability on the islands (Chi-square = 97.89, df = 3, p <0.01; Figure A-7). This is likely caused primarily by over-sampling grassland vegetation, and under-sampling beach and coastal dunes as well as unstabilized dunes.

Table A-2. Comparison of habitat attributes on island (n = 4,560 random points) versus in areas trapped areas with 1990s Protocol (n = 2,249 random points).

Habitat Measure	**Island Mean (sd)**	**Trapped Area Mean (sd)**	**Island Median**	**Trapped Area Median**	***Z***	***p***
Slope (degrees)	8.17 (7.08)	7.45 (6.75)	5.82	5.49	-3.53	<0.001
Ruggedness Index	0.0018 (0.0045)	0.0014 (0.0034)	0.0005	0.0004	-5.49	<0.001
Dist. to Shore (m)	672.15 (428.97)	816.90 (407.73)	617.74	794.29	-13.89	<0.001
Dist. to Trails (m)	543.97 (411.78)	478.50 (369.20)	465.73	408.04	-5.51	<0.001
Dist. to Developed (m)	1718.84 (896.93)	1179.71 (561.00)	1651.09	1152.56	-23.32	<0.001
Dist. to Freshwater (m)	444.18 (427.87)	319.60 (264.25)	296.98	234.31	-9.663	<0.001

2006 Trapping Protocol

In 2006, foxes on San Miguel were trapped in four grids, each with the dimension of 6x3 traps, for a total of 72 traps. Each grid was set along an east-west trail, with the middle line of six traps placed along a trail. Assuming a 600-m effective trap radius, the four grids collectively sample approximately 37% of the island.

In terms of habitat representation, this protocol exhibits the same general pattern as the 1990s protocol, in that this protocol samples habitat with lower slope and ruggedness than island-wide areas, and that sampled areas are farther from the shore, and closer to trails, developed areas, and freshwater than are island-wide areas (Table A-3, Figures A-1─A-6). As discussed above, some of these statistical differences may not have biological differences. For example, small absolute differences in slope and ruggedness may not have an influence on fox habitat use patterns. However, of the four protocols included in this analysis, areas sampled with this protocol differ the most from the island in some measures; this protocol measures areas farthest from the shore, and closest to trails, developed areas, and freshwater in comparison to island-wide areas. The finding that this scenario is biased towards trails is not surprising, since the center line of traps in the grids was purposely placed on trails. This may produce a bias if foxes are more likely to move along trails as compared to nearby non-trail areas.

Grids trapped in 2006 sample all five of the vegetation categories used in this analysis but do not represent them in proportion to expected distributions based on island-wide vegetation composition (Figure A-8; Chi-square = 293.32, df = 3, p<0.01). This is likely due primarily to over-sampling grasslands and under-sampling beach and coastal dune and unstabilized dune areas.

Table A-3. Comparison of habitat attributes on island (n = 4,560 random points) versus in areas trapped with 2006 Protocol (n = 1,689 random points).

Habitat Measure	Island Mean (sd)	Trapped Area Mean (sd)	Island Median	Trapped Area Median	*Z*	*p*
Slope (degrees)	8.17 (7.08)	6.96 (6.14)	5.82	5.239	-4.86	<0.001
Ruggedness Index	0.0018 (0.0045)	0.0014 (0.0036)	0.0005	0.0003	-7.69	<0.001
Dist. to Shore (m)	672.15 (428.97)	971.01 (396.95)	617.74	990.46	-24.34	<0.001
Dist. to Trails (m)	543.97 (411.78)	339.46 (219.21)	465.73	330.00	-16.06	<0.001
Dist. to Developed (m)	1718.84 (896.93)	1588.58 (783.22)	1651.09	1606.05	-4.13	<0.001
Dist. to Freshwater (m)	444.18 (427.87)	275.76 (201.01)	296.98	218.40	-11.87	<0.001

Scenario B

Assuming a 600-m effective trap radius, Scenario B samples approximately 54% of the island. When compared to island-wide areas, this scenario also samples areas with lower slope and ruggedness, and tended to sample areas farther from the shore and closer to trails (Table A-4, Figures A1, A-2, A-3, and A-4). As discussed in relation to the 1990s and 2006 protocols, these statistical differences may not have biological relevance, as the absolute differences are relatively small in relation to the scale of measurement (slope and ruggedness) or in relation to fox movement patterns (distance to shore and trails). However, as with the other trapping protocols, the fact that areas close to the shore are under-sampled may bias trapping results if fox density is different near the shore than in other areas. Areas sampled with this scenario did not differ from island-wide areas in distance to developed areas or to freshwater.

Proposed trapping Scenario B samples all five vegetation categories used in this analysis but does not sample them in proportion to their availability on the island (Figure A-9; Chi-square = 57.07, df = 3, p<0.01). Visually, this trapping scenario appears to represent most vegetation categories fairly well, but the observed statistical difference is most likely due to over-sampling island grasslands, and under-sampling unstabilized dunes.

Table A-4. Comparison of habitat attributes on island (n = 4,560 random points) versus in areas trapped with proposed trapping Scenario B (n = 2,458 random points).

Habitat Measure	**Island Mean (sd)**	**Trapped Area Mean (sd)**	**Island Median**	**Trapped Area Median**	***Z***	***p***
Slope (degrees)	8.17 (7.08)	6.83 (5.89)	5.82	5.01	-6.70	<0.001
Ruggedness Index	0.0018 (0.0045)	0.0013 (0.0033)	0.0005	0.0004	-5.38	<0.001
Dist. to Shore (m)	672.15 (428.97)	780.63 (392.64)	617.74	768.38	-11.54	<0.001
Dist. to Trails (m)	543.97 (411.78)	395.02 (297.24)	465.73	335.41	-13.29	<0.001
Dist. to Developed (m)	1718.84 (896.93)	1740.38 (965.76)	1651.09	1838.46	-1.01	3.13
Dist. to Freshwater (m)	444.18 (427.87)	434.31 (370.77)	296.98	313.21	-1.77	0.08

Scenario C

Assuming a 600-m effective trap radius, Scenario C samples approximately 51% of the island. As with the three other trapping protocols included in this analysis, this scenario also samples areas with lower slope and ruggedness (Table A-5, Figures A-1 and A-2). This scenario also tended to sample areas farther from the shore and closer to trails, developed areas, and freshwater (Table A-5, Figures A-3, A-4, A-5, and A-6). In all cases, however, median and mean distances of sampled areas differed from island-wide areas by <150 m, which may not have relevance in relation to distances moved by foxes. Areas sampled with this scenario differed from island-wide areas the least in terms of ruggedness and distance to the shore. However, areas close to the shore remain under-sampled.

Proposed trapping Scenario C samples all five vegetation categories used in this analysis but does not sample them in proportion to their availability on the island (Chi-square = 117.99, df=3, p<0.01). This statistical difference is likely due to over-sampling of island grassland and *Haplopappus* scrub, and under-sampling of unstabilized dunes and beach and coastal dunes (Figure A-10).

Conclusions

All four trapping scenarios included in this analysis sampled areas with lower slope and ruggedness than island-wide areas. This pattern will likely be observed in any feasible trapping protocol on San Miguel Island, since steep and rugged cliffs and bluffs near the shore can not safely be sampled. The absolute differences in slope and ruggedness between sampled and island-wide areas are small in all cases, however, and, as discussed above, these small differences may not have biological significance. Areas close to the shore are under-sampled with all protocols, which is also unavoidable with any feasible protocol, for the same safety reasons. Areas sampled with Scenario C resembled the island the most closely in distance to the shore and in ruggedness (two measures that are likely correlated). All scenarios sampled areas closer to trails, most likely due to the fact that trails occur closer to the middle of the island than to the shore. The 2006 protocol was most extreme in its bias towards areas near trails, which is not surprising since traps were purposely set along and near trails. This may bias trap results if foxes tend to move along trails or select areas near trails. Three of the protocols (1990s protocol, 2006 protocol, and Scenario C) also differed from island-wide areas in distance to developed areas. The significance of trapped areas being closer to developed areas is unknown but may be low, given the small physical footprint of developed areas on San Miguel Island. The same three protocols also trapped areas closer to freshwater. Because a map of freshwater sources was lacking for this island, we used the USGS hydrology layer as a surrogate. This layer represents drainages and ravines, which, in themselves may have relevance for foxes, in that the may provide valuable resources such as denning sites or foraging areas.

We suggest that future studies on habitat use and selection would provide valuable information on whether the above differences may bias trapping data. In the absence of further knowledge on fox habitat use and selection, it is not known which of the above measures has the most relevance to trapping protocols. Although Scenario C resembled the island most closely in terms of ruggedness and distance to shore, Scenario B sampled the island most adequately in terms of distance to developed areas and to freshwater, and it also differed the least from the island in representation of the five vegetation categories included in this analysis. It is likely that Scenario A, which is similar to Scenario B except for using slightly larger grids, would sample the island more effectively than Scenario B.

Table A-5. Comparison of habitat attributes on island (n = 4,560 random points) versus in areas trapped with proposed trapping Scenario C (n = 2,324 random points).

Habitat Measure	**Island Mean (sd)**	**Trapped Area Mean (sd)**	**Island Median**	**Trapped Area Median**	***Z***	***p***
Slope (degrees)	8.17 (7.08)	7.38 (6.38)	5.82	5.44	-3.76	<0.001
Ruggedness Index	0.0018 (0.0045)	0.0015 0.0036)	0.0005	0.0004	-4.42	<0.001
Dist. to Shore (m)	672.15 (428.97)	709.00 (362.74)	617.74	692.60	-5.52	<0.001
Dist. to Trails (m)	543.97 (411.78)	444.83 (359.61)	465.73	349.86	-9.18	<0.001
Dist. to Developed (m)	1718.84 (896.93)	1589.42 (902.86)	1651.09	1501.49	-5.11	<0.001
Dist. to Freshwater (m)	444.18 (427.87)	394.62 (374.87)	296.98	258.07	-3.82	<0.001

Literature Cited

Fowler, J., L. Cohen, and P. Jarvis. 1998. Practical Statistics for Field Biology. 2nd ed. John Wiley and Sons, New York, NY. 259pp.

Sokal, R.R., and F.J. Rohlf. 1995. Biometry: The Principles and Practices of Statistics in Biological Research. 3rd ed.. W.H. Freeman and Company, New York, NY. 887pp.

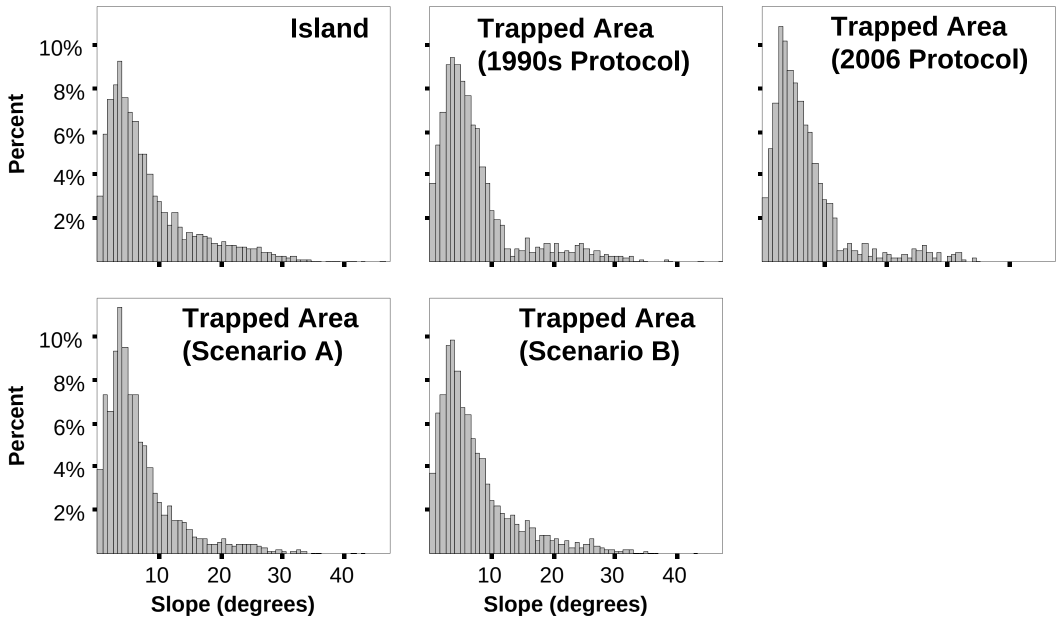

Figure A-1. Distribution of slope (as percent of random points) on San Miguel Island versus in areas trapped with four trapping scenarios (1990s Protocol, 2006 Protocol, Scenario B, and Scenario C).

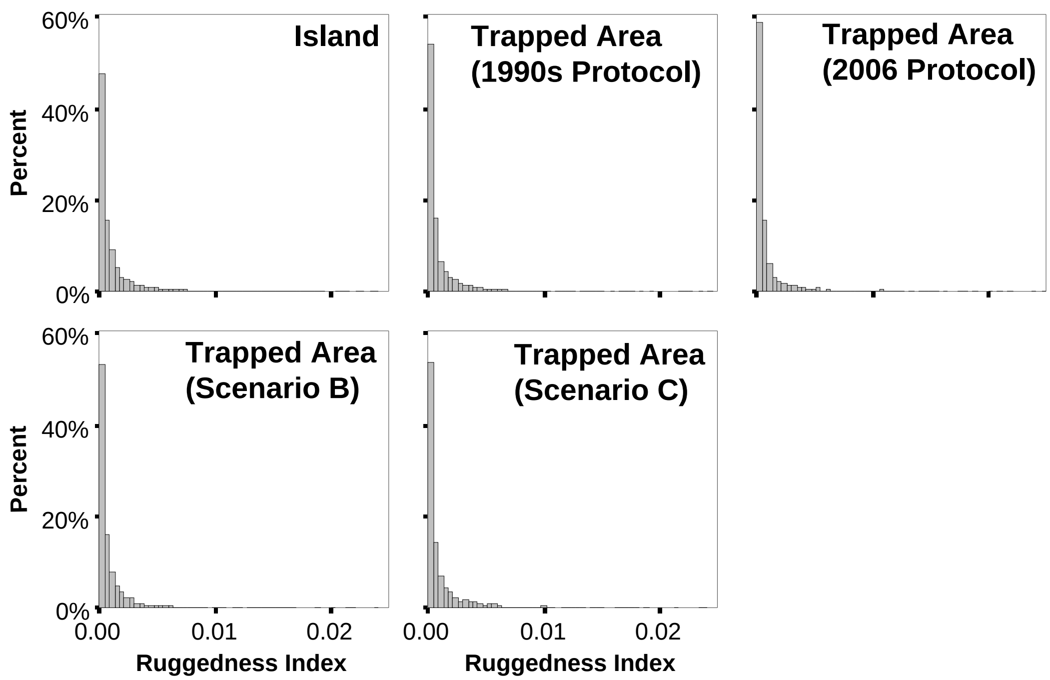

Figure A-2. Distribution of ruggedness (as percent of random points) on San Miguel Island versus in areas trapped with four trapping scenarios (1990s Protocol, 2006 Protocol, Scenario B, and Scenario C).

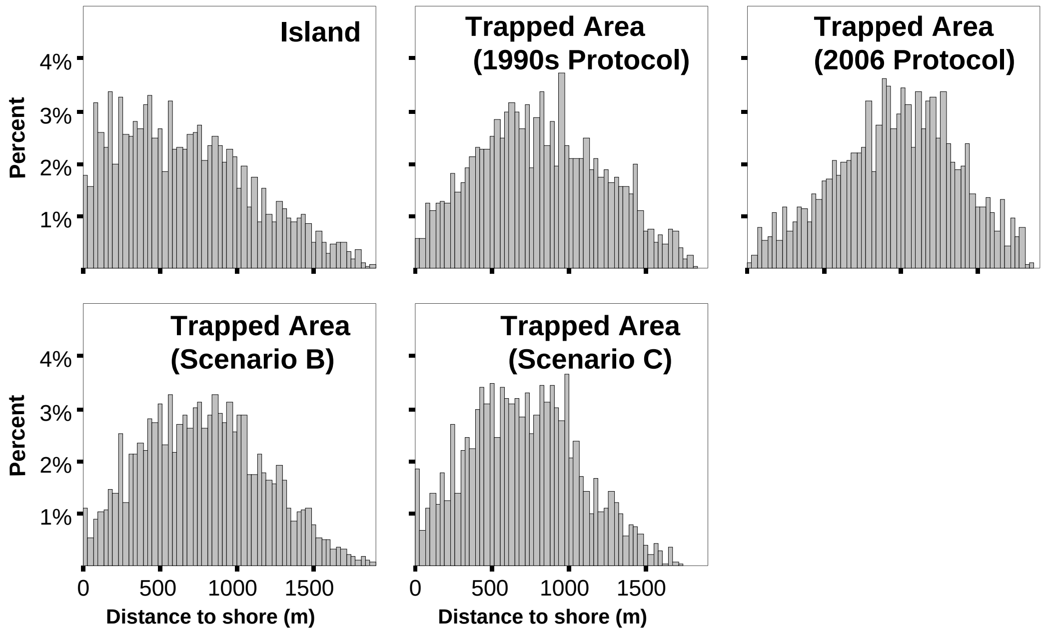

Figure A-3. Distribution of distance to the shore (in meters, as percent of random points) on San Miguel Island versus in areas trapped with four trapping scenarios (1990s Protocol, 2006 Protocol, Scenario B, and Scenario C).

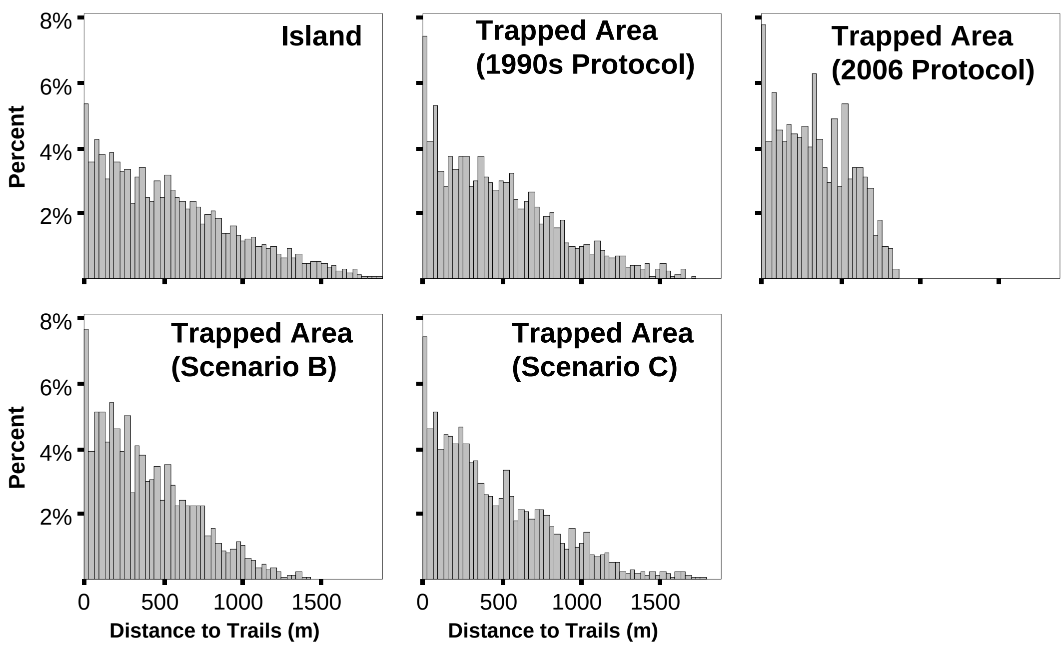

Figure A-4. Distribution of distance to trails (in meters, as percent of random points) on San Miguel Island versus in areas trapped with four trapping scenarios (1990s Protocol, 2006 Protocol, Scenario B, and Scenario C).

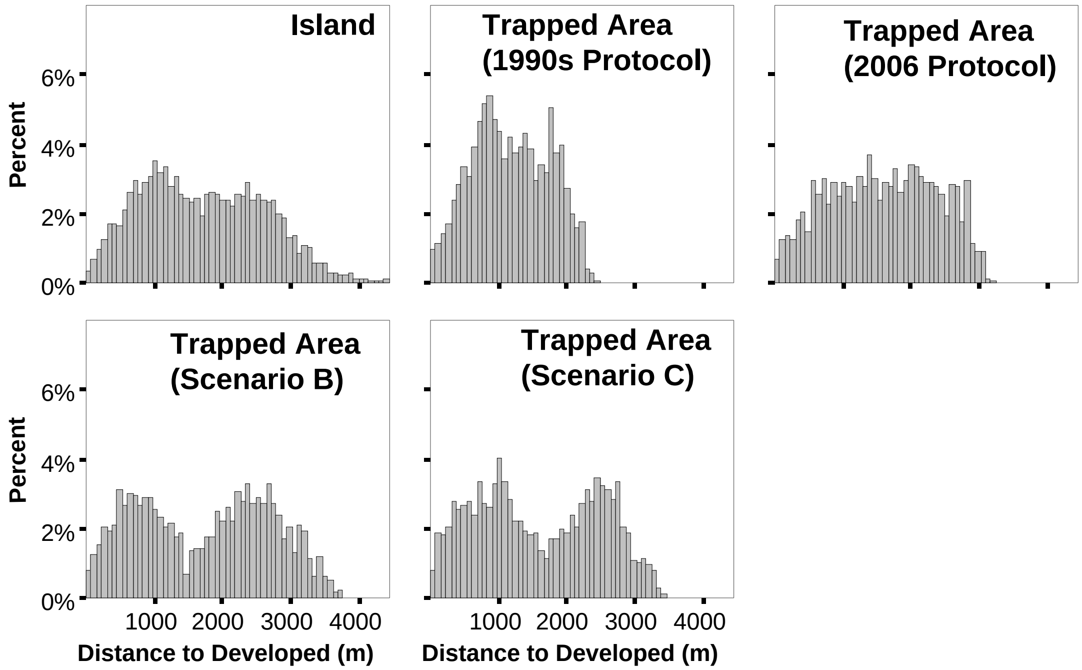

Figure A-5. Distribution of distance to developed areas (in meters, as percent of random points) on San Miguel Island versus in areas trapped with four trapping scenarios (1990s Protocol, 2006 Protocol, Scenario B, and Scenario C).

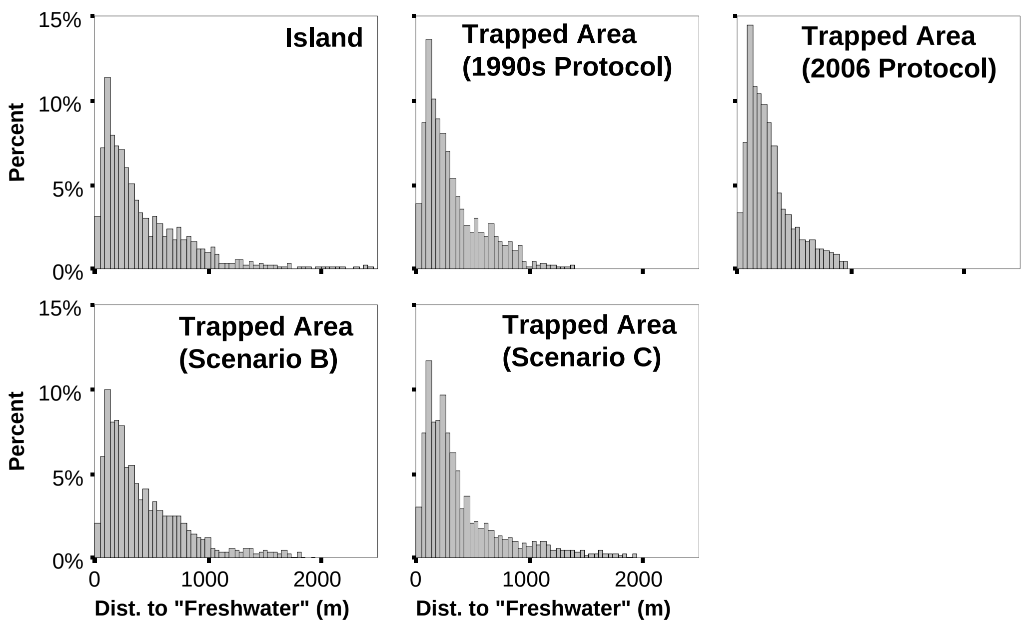

Figure A-6. Distribution of distance to freshwater (in meters, as percent of random points) on San Miguel Island versus in areas trapped with four trapping scenarios (1990s Protocol, 2006 Protocol, Scenario B, and Scenario C).

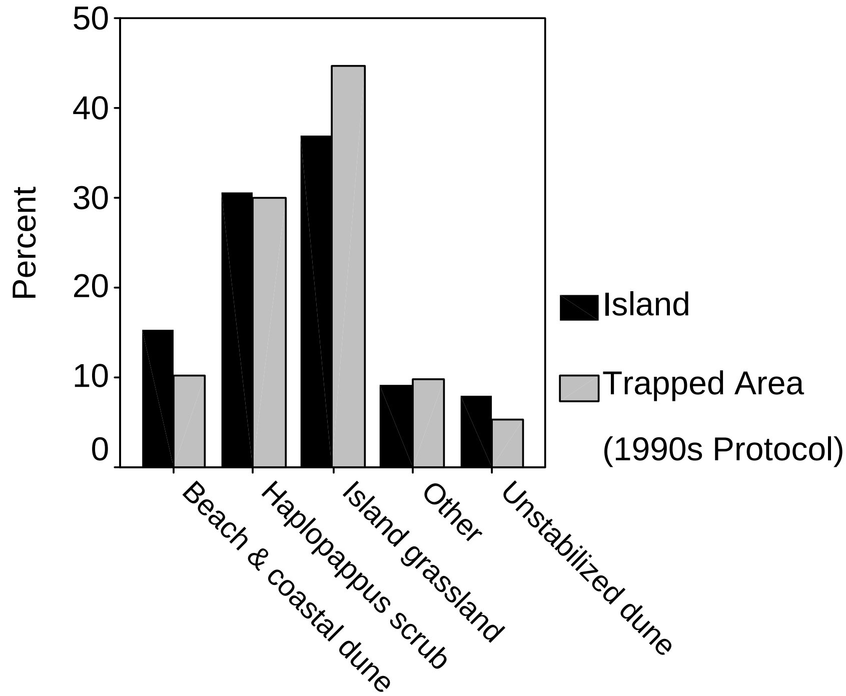

Figure A-7. Distribution of vegetation types (as percent of random points) on San Miguel Island versus areas trapped with the 1990s Protocol.

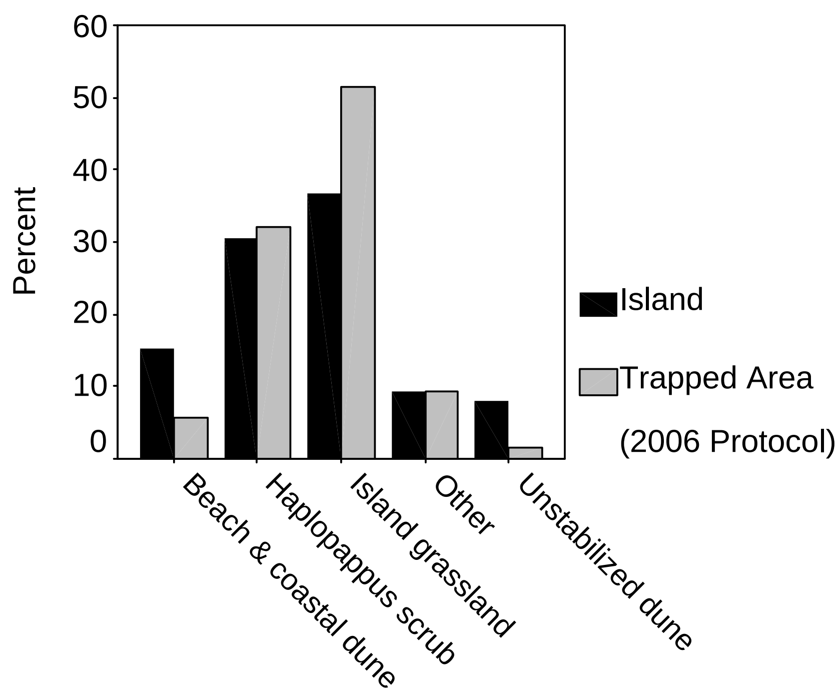

Figure A-8. Distribution of vegetation types (as percent of random points) on San Miguel Island versus areas trapped with the 2006 Protocol.

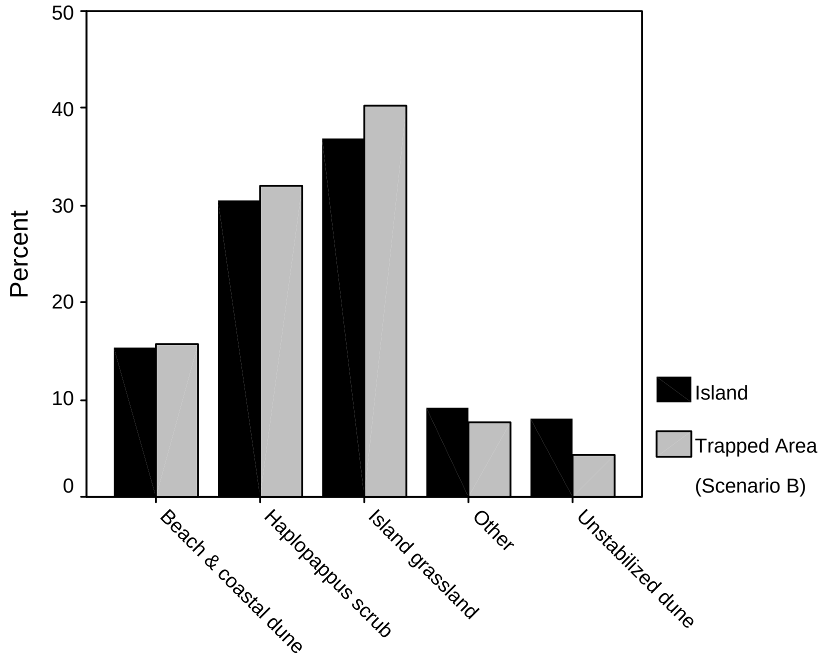

Figure A-9. Distribution of vegetation types (as percent of random points) on San Miguel Island versus areas trapped with Scenario B.

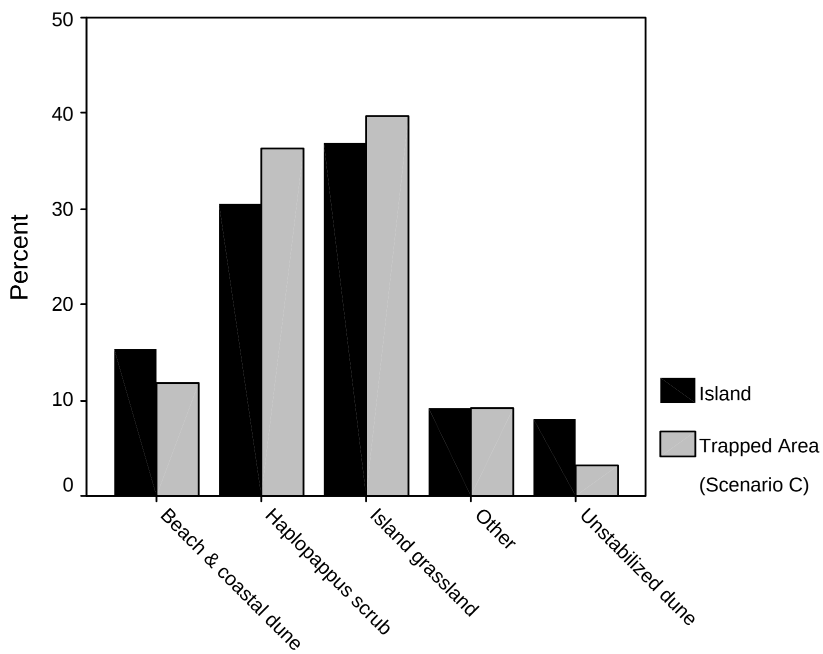

Figure A-10. Distribution of vegetation types (as percent of random points) on San Miguel Island versus areas trapped with Scenario C.

Appendix B

Univariate Representation Analysis of Existing and Proposed Trapping Scenarios on San Nicolas Island

Introduction

This representation analysis examines how well existing and proposed trapping protocols represent habitat variation on San Nicolas Island. The goal of evaluating existing protocols was to identify gaps in island representation that could be addressed in proposed trapping scenarios, and to provide a baseline comparison with which to evaluate proposed scenarios. This information is intended to provide managers with additional information on which to base decisions about trapping protocols. In addition, increased knowledge regarding habitat representation of each trapping scenario may help identify research needs relative to habitat use and selection.

Although three alternative trapping scenarios are proposed for San Nicolas Island in the main body of this report (Maps 5-5, 5-6, and 5-7), we only conducted representation analyses on two (Scenarios B and C). It is assumed that Scenario A would effectively sample the island, because the approach distributes and shifts traps widely across the island.

Methods

We identified habitat variables currently available as GIS coverages or that could be created from existing GIS coverages, and for which we have empirical evidence or biological rationale to suspect that they may influence island fox habitat quality or population dynamics. Although we can not know or measure all habitat characteristics important to island foxes, we strived to maximize representation of the following habitat attributes that we can measure: vegetation type, slope, terrain ruggedness, distance to paved roads, distance to shoreline, distance to developed areas, and distance to freshwater sources. It is likely that other habitat characteristics also influence fox populations, but some of these will correlate highly with the variables we selected (e.g., distance to canyon bottoms would correlate strongly with our ruggedness index), and others are not currently available to measure (e.g., cat densities or prey densities). This analysis should be viewed as preliminary, and we strongly recommend that future data from radio-collared foxes be used to evaluate and identify habitat features that influence fox densities or habitat selection.

We created data layers for each of the continuous variables (slope, terrain ruggedness, distance to paved roads, distance to shoreline, distance to developed areas, and distance to freshwater sources) in the following manner:

- Slope. We derived a slope layer from the USGS 30-m DEM. We chose to create a slope layer in degrees.

- Ruggedness. We created a Ruggedness raster layer using an Avenue script created and provided by Mark Sappington (National Park Service) and Kathy Longshore (U.S. Geological Survey). This measure provides an index of ruggedness which ranges from 0 to 1, with 0 representing completely flat terrain and 1 representing the most rugged terrain. We used the USGS 30-m DEM as the basis for the algorithm, after converting its elevation values from feet to meters, and used a 90x90-m moving window to calculate ruggedness.
- Distance to shoreline. We created a raster layer of the distance-to-shoreline using the Distance ->Straight Line tool provided in the Spatial Analyst extension.
- Distance to paved road. We created a raster layer of the distance to paved roads using the Distance ->Straight Line tool provided in the Spatial Analyst extension. The paved road data layer was provided by Grace Smith, U.S. Navy.
- Distance to developed. We created a raster layer of the distance to developed areas using the Distance ->Straight Line tool provided in the Spatial Analyst extension.
- Distance to freshwater. Because a map of freshwater sources on San Nicolas Island was not available, we used riparian and vernal pool vegetation as a surrogate for freshwater. These areas are not guaranteed to provide surface freshwater year-round, but could have a higher probability of providing this resource than other areas on the island.
- Vegetation. We used a vegetation layer provided by Grace Smith, U.S. Navy. We examined the composition of vegetation across the entire island, and attempted to reduce the number of vegetation classifications to represent major vegetation types. The original and newly created classifications are shown in Table B-1.

Table B-1. Vegetation classifications on San Nicolas Island, as originally classified and as grouped for analysis.

Original Classification	**Representation of Original Classification on Island (%)**	**Vegetation as Categorized for Analysis**
Coastal scrub	42.1	Coastal scrub
Barren	24.3	Barren
Grassland	12.2	Grassland
Coreopsis	9.5	*Coreopsis*
Inland dune	5.5	Inland dune
Developed	2.3	(not included in trap area)
Beach	1.6	Other
Riparian	1.4	Other
Coastal dune	1.0	Other
Coastal marsh	0.1	Other
Lupine	<0.1	Other
Pine trees	<0.1	Other
Vernal pool	<0.1	Other

Habitat characteristics were determined from two separate sets of random points; one distributed over the entire island and one distributed on trapped areas only. Trapped areas were defined as all locations within a 600-m buffer of a trap, excluding open water and avoiding double-counting of overlap areas for grids or traps <1,200 m apart. The 600-m buffer distance, added to represent the effective trap area of each trap, is equal to the mean of the mean maximum distances moved for each trapping session for all years for grids on San Clemente, Santa Cruz, San Miguel, and San Nicolas islands (V. Bakker, pers. comm.). The number of random points was chosen by first placing points along a systematic grid with 90-m spacing, to result in a density of 144 points/km^2, and then applying this density of points randomly to the island and the trapped area. For our evaluation of trapping scenarios, we randomly chose 5,000 of these points from the island as a comparison to trapped points.

We used the Mann-Whitney test (Sokal and Rohlf 1995) to test whether continuous variables (slope, ruggedness, distance to roads, etc.) differed between the island and trapped areas. To compare the composition of vegetation types, we used a chi-square goodness-of-fit test (Fowler et al. 1998), to compare vegetation composition of the trapped area versus island-wide areas. We also visually compared the distributions of habitat attributes on the island versus those on trapped areas.

Results and Discussion

Existing Trapping Protocols

Since 2000, island foxes on San Nicolas Island have been trapped annually in three trapping grids. Grids contain a total of 148 traps, with the following individual grid sizes: Skyline─5x10 traps, Tuft's─5x10 traps, Redeye─6x8 traps. Assuming a 600-m effective trap radius, the three grids collectively sample approximately 35% of the island (Map 5-1).

Trapped areas have significantly lower slope than the island, and examination of slope distribution on the island versus trapped areas indicates a tendency of the trapped areas to over-represent areas of gentle terrain with slopes of <10° (Table B-2, Figure B-1). However, this statistical significance may not necessarily represent biological significance, since mean and median slopes at island-wide points were only 1-2° steeper than trap-area points. It is possible that this slope difference, in itself, may have little or no influence on fox habitat use or density.

Trapped areas are also significantly less rugged than the overall island areas (Table B-2), and the distributions of ruggedness values in the island-wide and trapped points also suggests that trapped areas tend to over-sample the least rugged terrain on the island (Figure B-2). However, as in the case of slope, it is not known if this difference would have biological relevance to trapping results. The extent of this difference (0.003 versus 0.002) is extremely small compared to the range of the ruggedness index, which has a value of 0 for completely flat terrain and a value of 1 for extremely rugged terrain. These values suggest that both the island and trapped areas include mostly very gentle terrain.

Our analyses indicate that trapped areas are significantly farther from the shoreline than random points on the entire island (Table B-2). The distribution of this distance in trapped areas versus island-wide areas shows that areas close to the shore, particularly those <1,000 m from the shore, are under-represented in the current trapping protocols (Figure B-3). This may influence trapping results, because foxes living along the shore would have a reduced probability of being trapped, as 1,000 m exceeds the mean maximum distance moved as observed in existing trap data (V. Bakker, pers. comm.).

Areas currently trapped are located closer to paved roads and to developed areas than random points over the entire island (Table B-2, Figures B-4 and B-5). Although the absolute difference in these distances is not large (<200 m), it is possible that these differences may have biological significance. For example, density estimates may be influenced if, for example, foxes experience higher mortality near roads or if they are attracted to urban areas.

Trapped areas are also closer to freshwater sources, which were defined, on San Nicolas Island, as riparian or vernal pool vegetation (Table B-2). These areas are not guaranteed to provide surface freshwater year-round, but could have a higher probability of providing this resource than other areas on the island. Because the difference between median distances (a difference of about 90 meters) is small compared to daily fox movement distances, and the distributions of this measure in the two samples are somewhat similar (Figure B-6), it is likely that this difference may not have biological significance.

The current trapping protocol samples each of the 6 vegetation categories used in our analyses; however, the distribution of these categories is different in the trapped area than expected based on their distribution on the entire island (Chi-square = 659.768, df = 4, $p<0.01$). This appears to be due primarily to under-sampling of barren areas and *Coreopsis* vegetation, and over-sampling of coastal scrub and possibly inland dune areas (Figure B-7).

Table B-2. Comparison of habitat attributes on San Nicolas Island (n = 5,000 random points) versus area trapped with existing trapping protocol (n = 2,574 random points).

Habitat Measure	**Island Mean (sd)**	**Trapped Area Mean (sd)**	**Island Median**	**Trapped Area Median**	***Z***	***p***
Slope (degrees)	7.53 (6.21)	6.01 (5.24)	5.55	4.36	-10.92	<0.001
Ruggedness Index	0.015 (0.029)	0.009 (0.025)	0.003	0.002	-14.61	<0.001
Dist. to Shore (m)	1050.92 (693.88)	1456.13 (666.07)	959.50	1508.50	-23.50	<0.001
Dist. to Paved Roads (m)	572.98 (475.02)	386.47 (310.42)	442.00	314.00	-14.43	<0.001
Dist. to Developed (m)	580.20 (407.38)	447.00 (251.37)	505.00	425.00	-10.88	<0.001
Dist. to Freshwater (m)	875.25 (658.49)	760.66 (867.87)	738.00	674.00	-4.802	<0.001

Scenario B

Assuming a 600-m effective trap radius around each trap, Scenario B samples approximately 36% of San Nicolas Island (Map 5-6). Scenario B is similar to existing protocols in that sampled areas differ significantly from the island in continuous variables measured (Table B-3). As in the existing protocols, areas with low slope and ruggedness are over-sampled, but, as discussed in relation to existing protocols, the small absolute differences in these measures may not have biological relevance to fox habitat use (Figures B-1 and B-2). Sampled areas are also farther from the shore, and closer to roads, developed areas, and sources of freshwater than were random points on the island. It is not clear if differences in distance to roads, developed areas, and sources of freshwater have biological significance, however, since the absolute differences (when means and medians are examined) are <250 m (Table B-3, Figures B-4, B-5, and B-6). In terms of distance to the shore, this scenario also under-samples areas within 1000 meters of the shore, which could, as discussed above in relation to the existing protocol, cause bias in trap results if fox densities are different near the shore (Figure B-3).

In terms of vegetation sampled, this scenario provides an improvement over the existing protocol, because sampling includes more *Coreopsis* vegetation (Figures B-7 and B-8). However, this scenario still fails to represent all vegetation types in proportion to presence on the island (Chi-square = 518.32, df = 4, $p < 0.01$), most likely because it tends to over-sample Coastal Scrub and Grassland vegetation and under-sample Barren areas.

Table B-3. Comparison of habitat attributes on San Nicolas Island (n = 5,000 random points) versus area trapped with trapping Scenario B (n = 2,614 random points).

Habitat Measure	**Island Mean (sd)**	**Trapped Area Mean (sd)**	**Island Median**	**Trapped Area Median**	***Z***	***p***
Slope (degrees)	7.53 (6.21)	6.15 (5.24)	5.55	4.50	-9.34	<0.001
Ruggedness Index	0.015 (0.029)	0.001 (0.004)	0.003	0.0002	-48.63	<0.001
Dist. to Shore (m)	1050.92 (693.88)	1465.22 (682.01)	959.50	1593.50	-23.88	<0.001
Dist. to Paved Roads (m)	572.98 (475.02)	394.42 (323.55)	442.00	312.00	-14.09	<0.001
Dist. to Developed (m)	580.20 (407.38)	452.78 (300.81)	505.00	412.00	-11.57	<0.001
Dist. to Freshwater (m)	875.25 (658.49)	654.85 (465.93)	738.00	574.00	-12.13	<0.001

Scenario C

Assuming a 600-m effective trap radius around each trap, Scenario C samples approximately 39% of San Nicolas Island (Map5-7). Scenario C is similar to the existing protocol and Scenario B in that sampled areas differ significantly from the island in continuous variables measured (Table B-4). As discussed above, some of these statistical differences may not indicate biological differences. This scenario does, however, provide an improvement in that it more closely resembles the island in terms of distances to the shore, paved roads, developed areas, and sources of freshwater (Table B-4, Figures B-3, B-4, B-5, and B-6). It is similar to the existing protocol in terms of slopes measured, but differs more from the island in terms of ruggedness.

In terms of vegetation sampled, Scenario C provides better representation of vegetation than Scenario B or the existing protocol do, although a significant difference still exists between the island and trapped areas (Chi-square = 267.25, df = 4, *p* <0.01), with some under-sampling of *Coreopsis* and Barren areas, and over-sampling of Coastal Scrub and Grassland vegetation.

Table B-4. Comparison of habitat attributes on San Nicolas Island (n = 5,000 random points) versus area trapped with trapping Scenario C (n = 2,808 random points).

Habitat Measure	Island Mean (sd)	Trapped Area Mean (sd)	Island Median	Trapped Area Median	*Z*	*p*
Slope (degrees)	7.53 (6.21)	6.26 (5.25)	5.55	4.55	-10.92	<0.001
Ruggedness Index	0.015 (0.029)	0.002 (0.005)	0.003	0.0002	-45.83	<0.001
Dist. to Shore (m)	1050.92 (693.88)	1214.19 (753.48)	959.50	1100.50	-9.11	<0.001
Dist. to Paved Roads (m)	572.98 (475.02)	514.06 (431.29)	442.00	398.00	-4.05	<0.001
Dist. to Developed (m)	580.20 (407.38)	530.33 (387.41)	505.00	446.00	-5.47	<0.001
Dist. to Freshwater (m)	875.25 (658.49)	805.79 (572.21)	738.00	701.50	-2.96	0.003

Conclusions

The three scenarios examined in this appendix (existing trapping protocol, Scenario B, and Scenario C) all sample areas that differ statistically from random points on the island for all habitat measures examined. However, statistical differences do not necessarily indicate biologically relevant differences. For example, statistical differences were found in slope and ruggedness, with trapping areas representing areas with lower slope and ruggedness, but absolute differences were small and may not influence trapping results. Trapped areas also sampled areas closer to paved roads, developed areas, and sources of freshwater, but in all cases the actual differences were small relative to fox movement patterns so these differences may not bias trapping. It is possible, however, that small differences in distance to roads may influence trap results, if fox density differs near roads. In addition, under-sampling of areas close to the shore may bias trapping results if fox density is different close to the shore than in other areas. Scenario C most closely resembled the island in terms of distance to the shore and to roads, and in representation of vegetation categories, and overall provides a better representation of the island than the existing protocol or Scenario B, although differences do exist between Scenario C and island-wide areas. We suggest that future habitat selection studies should be conducted to examine if these differences might bias trap results. Proposed trapping Scenario A was not examined in this appendix because we assume that it will provide the best representation of habitat on San Nicolas Island, due to the extensive distribution and shifting of trap sites.

Literature Cited

Fowler, J., L. Cohen, and P. Jarvis. 1998. Practical Statistics for Field Biology. 2nd ed. John Wiley and Sons, New York, NY. 259pp.

Sokal, R.R., and F.J. Rohlf. 1995. Biometry: The Principles and Practices of Statistics in Biological Research. 3rd ed.. W.H. Freeman and Company, New York, NY. 887pp.

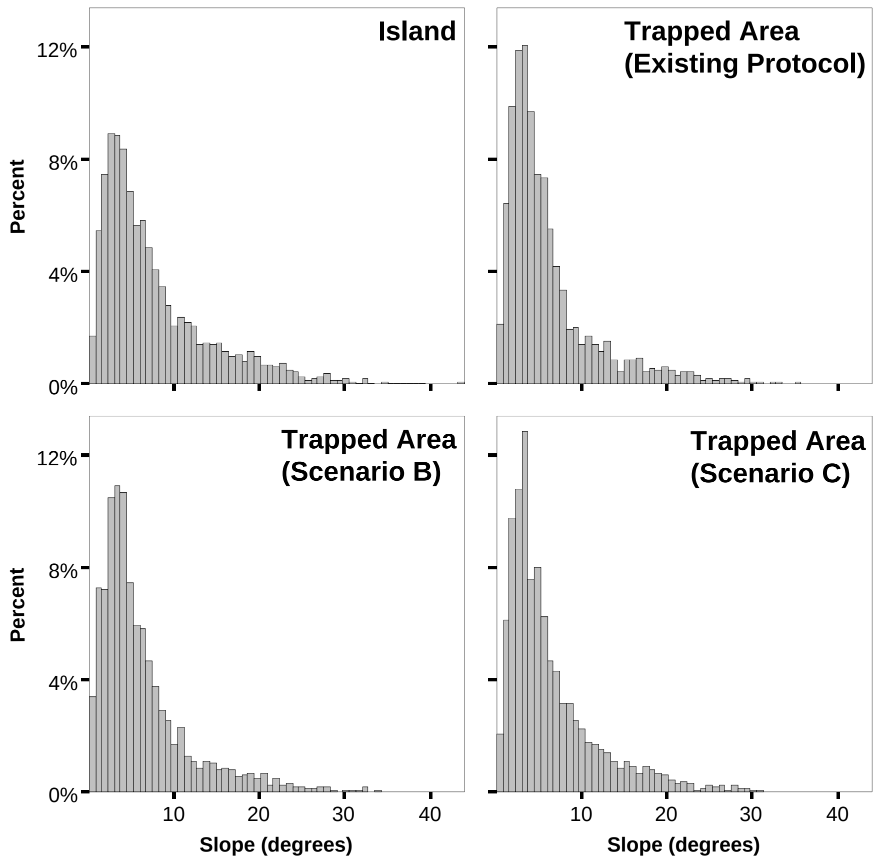

Figure B-1. Distribution of slope (as percent of total random points) on San Nicolas Island versus in areas trapped with three trapping scenarios (Existing Protocol, Scenario B, and Scenario C).

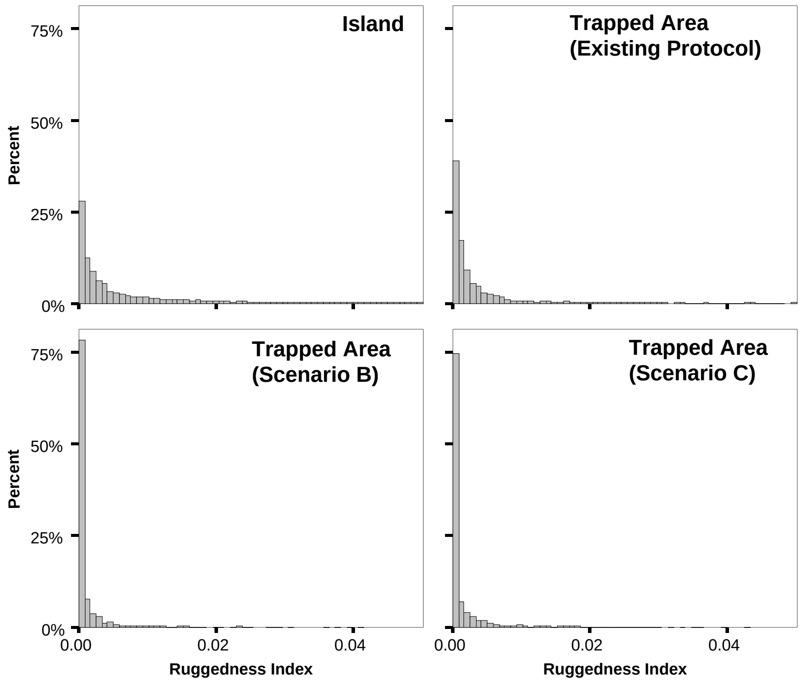

Figure B-2. Distribution of ruggedness index (as percent of total random points) on San Nicolas Island versus in areas trapped with three trapping scenarios (Existing Protocol, Scenario B, and Scenario C).

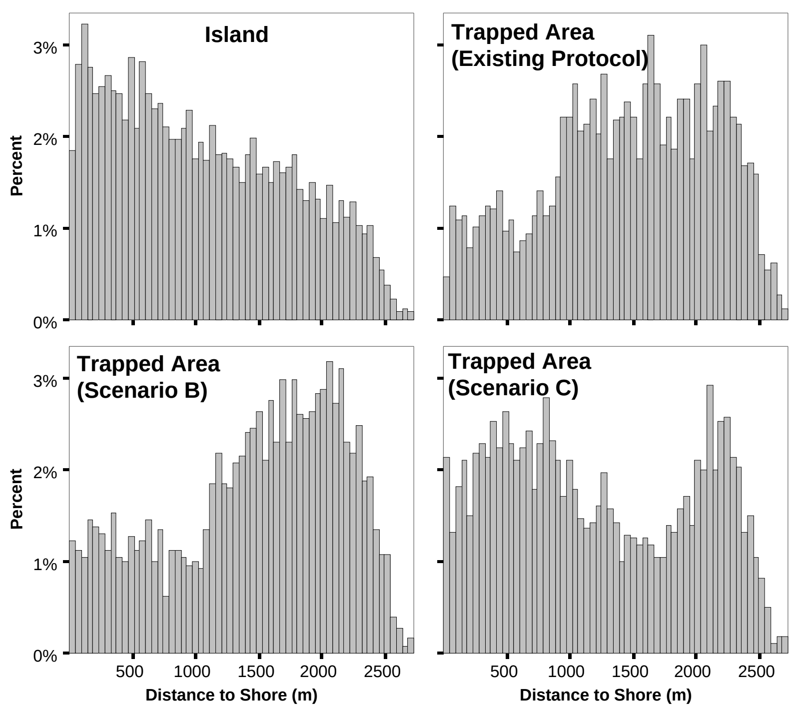

Figure B-3. Distribution of distance to shore (as percent of total random points) on San Nicolas Island versus in areas trapped with three trapping scenarios (Existing Protocol, Scenario B, and Scenario C).

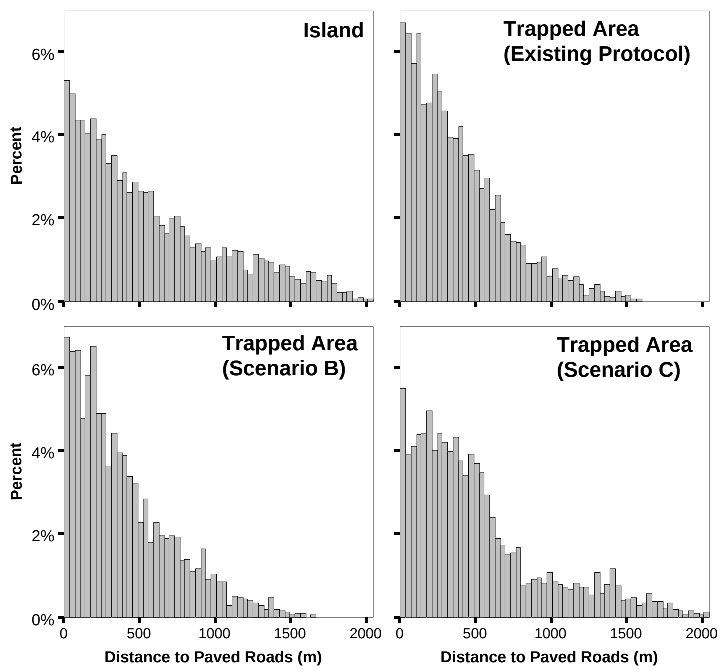

Figure B-4. Distribution of distance to paved roads (as percent of total random points) on San Nicolas Island versus in areas trapped with three trapping scenarios (Existing Protocol, Scenario B, and Scenario C).

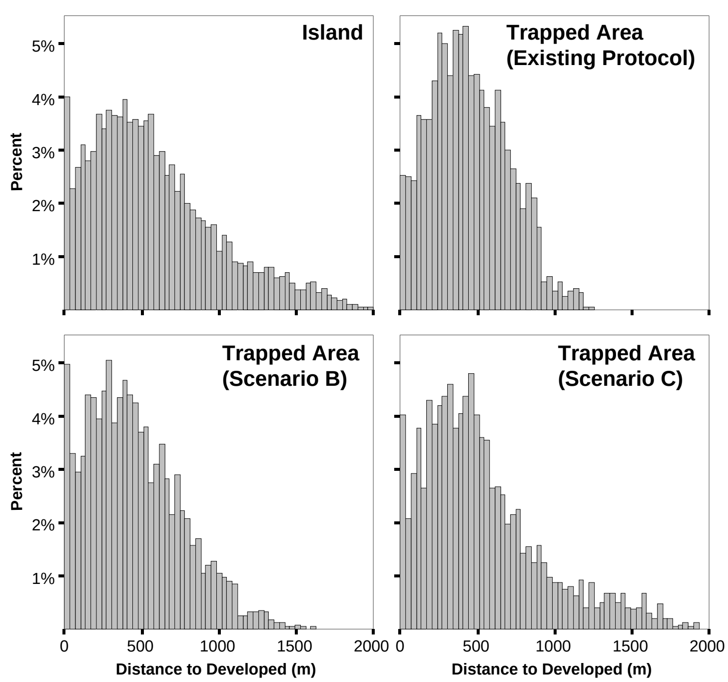

Figure B-5. Distribution of distance to developed areas (as percent of total random points) on San Nicolas Island versus in areas trapped with three trapping scenarios (Existing Protocol, Scenario B, and Scenario C).

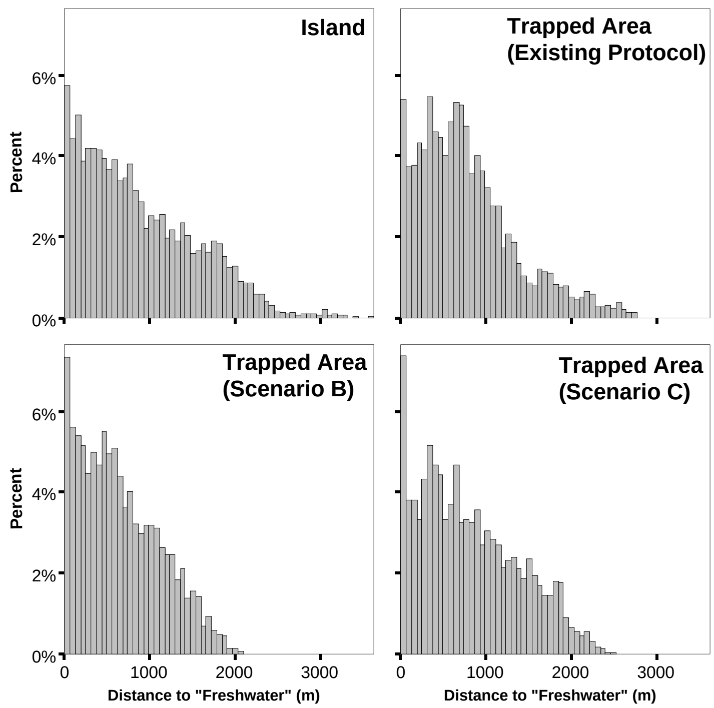

Figure B-6. Distribution of distance to freshwater (as percent of total random points) on San Nicolas Island versus in areas trapped with three trapping scenarios (Existing Protocol, Scenario B, and Scenario C).

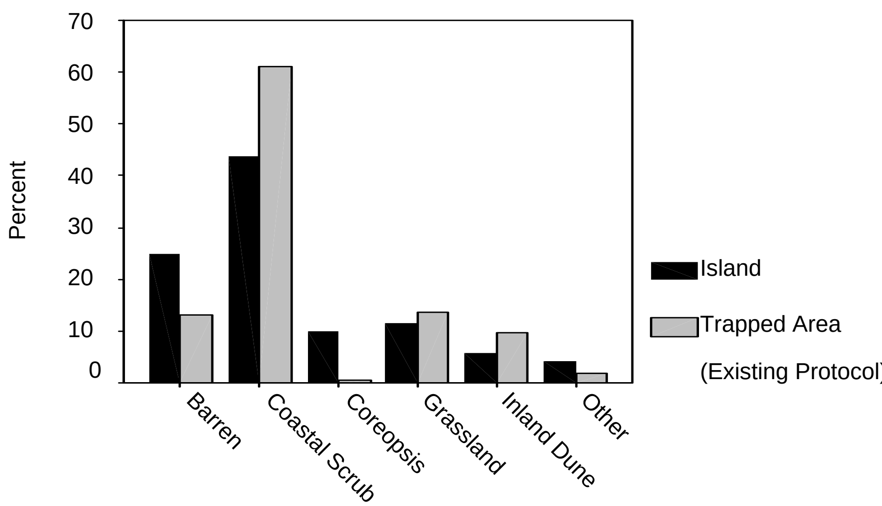

Figure B-7. Representation of vegetation types on San Nicolas Island versus area trapped with current protocol, based on classification at random points.

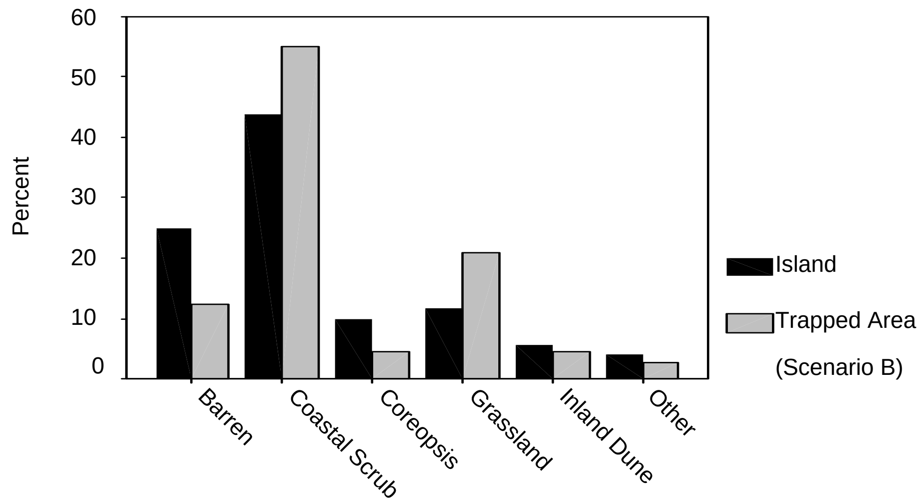

Figure B-8. Representation of vegetation types on San Nicolas Island versus area trapped with Scenario B, based on classification at random points.

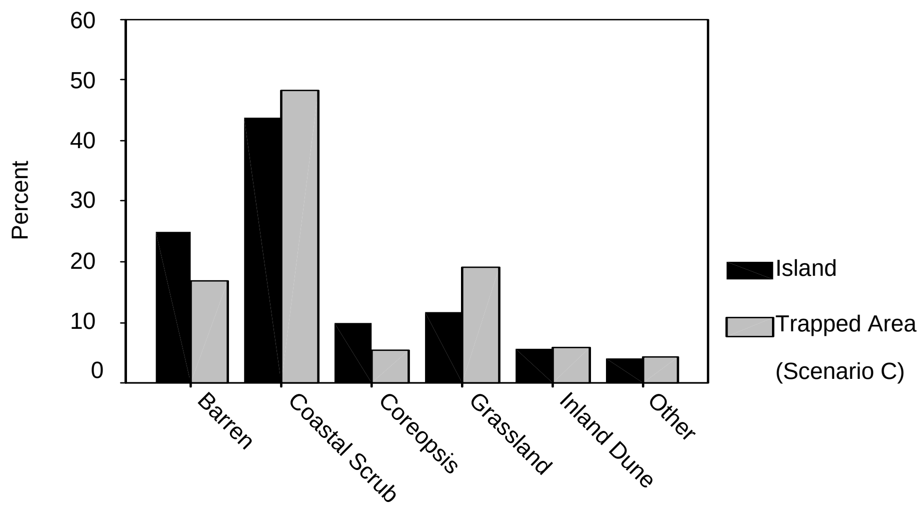

Figure B-9. Representation of vegetation types on San Nicolas Island versus area trapped with Scenario A, based on classification at random points.

Appendix C

Univariate Representation Analysis of Existing and Proposed Trapping Scenarios on Santa Catalina Island

Introduction

This representation analysis examines how well existing and recommended trapping protocols represent habitat variation on Santa Catalina Island. The goal of evaluating existing protocols was to identify gaps in island representation that could be addressed in proposed trapping scenarios, and to provide a baseline comparison with which to evaluate proposed scenarios. This information is intended to provide managers with additional information on which to base decisions about trapping protocols. In addition, increased knowledge regarding habitat representation of each trapping scenario may help identify research needs relative to habitat use and selection.

Methods

We identified habitat variables currently available as GIS coverages or that could be created from existing GIS coverages, and for which we have empirical evidence or biological rationale to suspect that they may influence island fox habitat quality or population dynamics. Although we can not know or measure all habitat characteristics important to island foxes, we strived to maximize representation of the following habitat attributes that we can measure: vegetation type, slope, terrain ruggedness, distance to paved roads, distance to shoreline, distance to developed areas, and distance to freshwater sources. It is likely that other habitat characteristics also influence fox populations, but some of these will correlate highly with the variables we selected (e.g., distance to canyon bottoms would correlate strongly with our ruggedness index), and others are not currently available to measure (e.g., cat densities or prey densities). This analysis should be viewed as preliminary, and we strongly recommend that future data from radio-collared foxes be used to evaluate and identify habitat features that influence fox densities or habitat selection.

We created data layers for each of the continuous variables (slope, terrain ruggedness, distance to paved roads, distance to shoreline, distance to developed areas, and distance to freshwater sources) in the following manner:

- Slope. We derived a slope layer from the USGS 30-m DEM. We chose to create a slope layer in degrees.
- Ruggedness. We created a Ruggedness raster layer using an Avenue script created and provided by Mark Sappington (National Park Service) and Kathy Longshore (U.S. Geological Survey). This measure provides an index of ruggedness which ranges from 0 to 1, with 0 representing completely flat terrain and 1 representing the most rugged

terrain. We used the USGS 30-m DEM as the basis for the algorithm, after converting its elevation values from feet to meters, and used a 90x90-m moving window to calculate ruggedness.

- Distance to shoreline. We created a raster layer of the distance-to-shoreline using the Distance ->Straight Line tool provided in the Spatial Analyst extension.
- Distance to roads. We created a raster layer of the distance to roads using the Distance ->Straight Line tool provided in the Spatial Analyst extension. The road data layer was provided by the Catalina Island Conservancy.
- Distance to developed. We created a raster layer of the distance to developed areas using the Distance ->Straight Line tool provided in the Spatial Analyst extension.
- Distance to freshwater. Because a map of freshwater sources on Santa Catalina Island was not available, we used the following vegetation types as a surrogate for freshwater: riparian herbaceous, southern riparian woodland, vernal pools, and reservoirs. These areas may be more likely to contain surface freshwater or runoff than other areas, but are not guaranteed to provide water.
- Vegetation. We used a vegetation layer created and provided by the Catalina Island Conservancy. We examined the composition of vegetation across the entire island, and attempted to reduce the number of vegetation classifications to represent major vegetation types. The original and newly created classifications are shown in Table C-1.

Table C-1. Vegetation classifications on Santa Catalina Island, as originally classified and as grouped for analysis.

Original Classification	**Representation of Original Classification on Island (%)**	**Vegetation as Categorized for Analysis**
Coastal Sage Scrub	38.736	Coastal Sage Scrub
Island Chaparral	30.450	Island Chaparral
Grassland	18.940	Grassland
Bare	9.019	Bare
Island Woodland	0.518	Other
Non-Native Herbaceous	0.514	Other
Southern Riparian Woodland	0.406	Other
Non-Native Scrub	0.338	Other
Southern Beach and Dune	0.296	Other
Non-Native Woodland	0.292	Other
Coastal Bluff Scrub	0.172	Other
Bare StreamBed	0.129	Other
Vernal Ponds & Reservoirs	0.111	Other
Riparian Herbaceous	0.061	Other
Coastal Marsh	0.008	Other
Maritime Cactus Scrub	0.007	Other
Mule Fat Scrub	0.003	Other

Habitat characteristics were determined from two separate sets of random points; one distributed over the entire island and one distributed on trapped areas only. Trapped areas were defined as all locations within a 600-m buffer of a trap, excluding open water and avoiding double-counting of overlap areas for grids or traps <1,200 m apart. The 600-m buffer distance, added to represent the effective trap area of each trap, is equal to the mean of the mean maximum distances moved for each trapping session for all years for grids on San Clemente, Santa Cruz, San Miguel, and San Nicolas islands (V. Bakker, pers. comm.). The number of random points was chosen by first placing points along a systematic grid with 90-m spacing, to result in a density of 144 points/km^2, and then applying this density of points randomly to the island and the trapped area. For our evaluation of trapping scenarios on the East End, we randomly chose 5.000 points from the island and from the trapped points, to reduce this large dataset for analysis. The West End of the island does not include paved roads or known sources of freshwater; therefore representation of these variables was not evaluated for the West End.

We used the Mann-Whitney test (Sokal and Rohlf 1995) to test whether continuous variables (slope, ruggedness, distance to roads, etc.) differed between the island and trapped areas. To compare the composition of vegetation types, we used a chi-square goodness of fit test (Fowler et al. 1998), to compare vegetation composition of the trapped area versus on the entire island. We also visually compared the distributions of habitat attributes on the island versus those on trapped areas.

Results and Discussion

Existing Trapping Protocols

East End

Assuming a 600-m effective trap radius around each trap, current trapping protocols sample approximately 79% of Santa Catalina Island's East End (Map 6-1). Even given this extensive trapping effort, sampled areas still differed statistically from island-wide areas in some habitat measures. Trapped areas had lower slope and ruggedness than random points on the East End (Table C-2, Figures C-1 and C-2). However, it is unknown if these statistical differences in these two measures, alone, have biological meaning. The difference in mean and median slopes was approximately 1 degree, which may not have relevance to fox habitat selection. In addition, the difference in median ruggedness (0.0067 versus 0.0059) was extremely small compared to the range of the ruggedness index, which has a value of 0 for completely flat terrain and a value of 1 for extremely rugged terrain.

Trapped areas were significantly farther from the shoreline than were random points on the East End (Table C-2, Figure C-3). The mean and median values differed, however, by <200 m, which may not have biological relevance if compared to island fox movement rates. Nonetheless, the distribution of this distance among random points in trapped areas versus those on the entire East End indicates that areas close to the shore, particularly those <1,000 m from the shore, are under-represented in the current trapping protocols (Figure C-3). This may influence trapping results, because foxes living along the shore would have a reduced probability of capture, as 1,000 m exceeds the mean maximum distance moved observed in previous trapping sessions (the mean of the mean maximum distances moved for each trapping session for all years for grids on San Clemente, Santa Cruz, San Miguel, and San Nicolas islands was 600 m; V. Bakker, pers.

comm.). Future habitat selection studies could shed light on whether this would bias trapping results high or low, by determining if areas close to the shore are selected or avoided.

Trapped areas were closer to vegetation surrogates for freshwater than random points distributed on the East End (Table C-2, Figure 6). However, means and medians differed by <150 m, suggesting that this difference may not have biological relevance. Again, habitat selection studies could shed light on this influence by determining if foxes select or avoid these areas.

Trapped and island-wide (East End) areas did not differ in terms of distance to roads or to developed areas (Table C-2, Figures C-4 and C-5). Trapping on the East End appeared to represent the five reclassified vegetation categories fairly closely (Figure C-7); however, there was a statistical difference between trapped areas and random points on the East End, with trapped areas slightly under-representing Barren areas, and slightly over-representing Grassland and Island Chaparral vegetation (Chi-square = 37.72, df = 4, p<0.01).

Table C-2. Comparison of habitat attributes on Santa Catalina Island's East End (n = 5000 random points) versus areas trapped with existing protocol on the East End (n = 5000 random points).

Habitat Measure	**Island Mean (sd)**	**Trapped Area Mean (sd)**	**Island Median**	**Trapped Area Median**	***Z***	***P***
Slope (degrees)	18.70 (9.00)	17.68 (8.37)	17.69	16.63	-5.08	<0.001
Ruggedness Index	0.0112 (0.0126)	0.0103 (0.0118)	0.0067	0.0059	-3.89	<0.001
Dist. to Shore (m)	1758.63 (1223.9)	1931.62 (1195.9)	1532.94	1725.85	-8.12	<0.001
Dist. to Paved Roads (m)	2914.85 (2255.9)	2906.03 (2206.9)	2336.92	2411.45	-0.10	0.92
Dist. to Developed (m)	1299.38 (878.39)	1321.05 (850.51)	1168.46	1189.26	-1.89	0.06
Dist. to Freshwater (m)	996.95 (690.17)	866.29 (588.74)	849.32	752.39	-8.14	<0.001

West End

Assuming a 600-m effective trap radius around each trap, current trapping protocols sample approximately 84% of Santa Catalina Island's West End (Map 6-1). However, even with such an extensive trapping effort, trapped areas were statistically less steep and rugged than those sampled by random points on the West End (Table C-3, Figures C-8 and C-9). However, just as on the East End, it is unknown if these statistical differences in these two measures, alone, have biological meaning. The difference in mean and median slopes is <1°, which probably does not, by itself, have relevance to fox habitat selection. In addition, difference in ruggedness are extremely small compared to the range of the ruggedness index, which has a value of 0 for completely flat terrain and a value of 1 for extremely rugged terrain, suggesting that this statistical difference may not have biological relevance.

Trapped areas were significantly farther from the shoreline than were areas sampled by random points on the West End (Table C-3, Figure C-10). However, the mean and median values differed only by approximately 100 m, which may not have biological relevance if compared to island fox movement rates. Nevertheless, the distribution of this distance (to the shoreline) in trapped areas versus those sampled by random points indicates that areas close to the shore, particularly those <500 m from the shore, are under-represented in the current trapping protocols, which may influence population estimates if foxes tend to select or avoid areas near the shoreline (Figure C-10).

Trapped areas were also closer to developed areas (Table C-3, Figure C-11), however the mean and median distances differed by less than 150 m, which, again, may have little biological relevance.

The West End of Santa Catalina does not include any paved roads or vegetation chosen as a surrogate for freshwater, therefore trapped and island-wide areas were not compared in relation to these two measures.

Trapped areas and areas sampled by random points differed significantly in terms of vegetation representation, with trapped areas tending to under-represent Barren and Coastal Sage Scrub areas, and tending to over-represent Grassland and Island Chaparral areas (Figure C-12).

Table C-3. Comparison of habitat attributes on Santa Catalina Island's West End (n = 3,799 random points) versus areas trapped with existing protocol on the West End (n = 3,205 random points).

Habitat Measure	**Island Mean (sd)**	**Trapped Area Mean (sd)**	**Island Median**	**Trapped Area Median**	***Z***	***P***
Slope (degrees)	22.27 (8.82)	21.51 (7.90)	21.66	21.30	-2.52	0.012
Ruggedness Index	0.0112 (0.0131)	0.0102 (0.0114)	0.0065	0.0059	-2.77	0.006
Dist. to Shore (m)	740.83 (492.57)	823.94 (493.11)	660.68	757.20	-7.32	<0.001
Dist. to Paved Roads (m)	---	---	---	---	---	---
Dist. to Developed (m)	1818.80 (1239.6)	1685.42 (1128.3)	1678.39	1540.60	-3.746	<0.001
Dist. to Freshwater (m)	---	---	---	---	---	---

Proposed Scenario A

East End

Assuming a 600-m effective trap radius around each trap, Scenario A samples approximately 28% of Santa Catalina Island's East End (Map 6-5). On the East End of the island, areas trapped with Scenario A had lower slope and ruggedness values than random points on the East End (Table C-4, Figures C-1 and C-2). However, as discussed above in relation to existing protocols, the small absolute differences in slope and ruggedness may not have relevance to fox sampling. Sampled areas were also farther from the shoreline, paved roads, and developed areas, and closer to freshwater, than areas sampled with random points (Table C-4, Figures C-3, C-4, C-5, C-6).

The absolute differences, whether means or medians are considered, were not greater than about 300 m, suggesting that this difference may not have biological relevance. However, visual examination of Figures C-3, C-4, C-5, and C-6, does suggest that some areas may be under-represented. For example, just as in the case of existing protocols, areas close to the shore appear to be under-represented.

Although Scenario A appeared to sample vegetation categories adequately (Figure C-13), a statistical difference was found to exist between trapped areas and areas sampled with random points (Chi-square = 67.95, df = 3, $p < 0.01$). This is apparently due to slight over-sampling of Coastal Sage Scrub and Grassland areas, and under-sampling of Barren and Island Chaparral areas.

Table C-4. Comparison of habitat attributes on Santa Catalina Island's East End (n = 5,000 random points) versus areas trapped in Scenario A on the East End (n = 5,000 random points).

Habitat Measure	**Island Mean (sd)**	**Trapped Area Mean (sd)**	**Island Median**	**Trapped Area Median**	***Z***	***P***
Slope (degrees)	18.70 (9.00)	16.57 (8.34)	17.69	15.48	-11.83	<0.001
Ruggedness Index	0.0112 (0.0126)	0.0095 (0.0110)	0.0067	0.0056	-6.85	<0.001
Dist. to Shore (m)	1758.63 (1223.9)	2078.94 (1284.4)	1532.94	1835.89	-12.67	<0.001
Dist. to Paved Roads (m)	2914.85 (2255.9)	2988.34 (2144.6)	2336.92	2552.65	-3.15	0.002
Dist. to Developed (m)	1299.38 (878.4)	1513.89 (896.7)	1168.46	1394.59	-12.60	<0.001
Dist. to Freshwater (m)	996.95 (690.2)	874.81 (631.31)	849.32	725.60	-8.74	<0.001

West End

Assuming a 600-m effective trap radius around each trap, Scenario A samples approximately 50% of Santa Catalina Island's West End (Map 6-5). On the West End of the island, areas trapped with Scenario A had lower slope and ruggedness values than areas sampled with random points (Table C-5, Figures C-8 and C-9). However, as discussed above, the small absolute differences in slope and ruggedness may not have relevance to fox sampling. Sampled areas were also farther from the shoreline and closer to developed areas than were random points on the West End (Table C-5, Figures C-10 and C-11). However, the absolute differences, whether means or medians are considered, were less than 300 meters, suggesting that this difference may not have biological relevance. However, visual examination of Figures C-10 and C-11 suggests that some areas may be under-represented. For example, just as in the case of existing protocols, areas close to the shore appear to be under-represented.

On the West End of the island, areas sampled by Scenario A also differed in terms of vegetation composition, as compared to areas sampled with random points (Chi-square = 144.89, df = 3, *p* <0.01). This appears to be due primarily to over-sampling of Grassland and Island Chaparral vegetation and under-sampling of Coast Sage Scrub vegetation (Figure C-14).

Table C-5. Comparison of habitat attributes on Santa Catalina Island's West End (n = 3,799 random points) versus areas trapped in Scenario A on the West End (n = 1,899 random points).

Habitat Measure	**Island Mean (sd)**	**Trapped Area Mean (sd)**	**Island Median**	**Trapped Area Median**	***Z***	***P***
Slope (degrees)	22.27 (8.82)	19.99 (7.29)	21.66	19.96	-8.68	<0.001
Ruggedness Index	0.0112 (0.0131)	0.0088 (0.0100)	0.0065	0.0049	-7.20	<0.001
Dist. to Shore (m)	740.83 (492.57)	860.74 (501.95)	660.68	842.14	-8.70	<0.001
Dist. to Paved Roads (m)	---	---	---	---	---	---
Dist. to Developed (m)	1818.80 (1239.6)	1640.51 (1168.11)	1678.39	1416.05	-4.80	<0.001
Dist. to Freshwater (m)	---	---	---	---	---	---

Proposed Scenario B

East End

Assuming a 600-m effective trap radius around each trap, Scenario B samples approximately 35% of Santa Catalina Island's East End (Map 6-6). Habitat representation was, in general, slightly better than that found for Scenario A. On the East End of the island, areas trapped with Scenario B had lower slope and ruggedness values than random points on the East End (Table C-6, Figures C-1 and C-2). However, as discussed above, the small absolute differences in slope and ruggedness may not have relevance to fox sampling. Sampled areas were also farther from the shoreline, paved roads, and developed areas, and closer to freshwater (Table C-6, Figures C-3, C-4, C-5, C-6). The absolute differences, whether means or medians are considered, were <400 m, suggesting that this difference may not have biological relevance in relation to island fox movement patterns. However, visual examination of Figures C-3, C-4, C-5, and C-6, does suggest that some areas may be under-represented. For example, just as in the case of existing protocols and Scenario A, areas close to the shore appear to be under-represented.

Although Scenario B appears to sample vegetation categories in proportion to availability on the East End (Figure C-15), a statistical difference was found to exist between trapped areas and areas sampled with random points on the East End (Chi-square = 64.58, df = 3, *p* <0.01). This is apparently due to slight over-sampling of Coastal Sage Scrub and Grassland areas, and under-sampling of Barren and Island Chaparral areas.

West End

Scenarios A and B are identical in relation to areas trapped on Santa Catalina Island's West End, because the number of trapping units and their locations are identical in the two scenarios in this part of the island. For this reason, results of habitat representation for Scenario B on the West End are identical to those for Scenario A shown above.

Table C-6. Comparison of habitat attributes on Santa Catalina Island's East End (n = 5,000 random points) versus areas trapped in Scenario B on the East End (n = 5,000 random points).

Habitat Measure	**Island Mean (sd)**	**Trapped Area Mean (sd)**	**Island Median**	**Trapped Area Median**	***Z***	***P***
Slope (degrees)	18.7 (9.00)	16.44 (8.08)	17.7	15.5	-12.18	<0.001
Ruggedness Index	0.0112 (0.013)	0.0093 (0.0113)	0.0067	0.0051	-9.42	<0.001
Dist. to Shore (m)	1758.6 (1223.9)	2026.2 (1206.8)	1532.9	1811.7	-11.83	<0.001
Dist. to Paved Roads (m)	2914.9 (2255.9)	3180.6 (2153.2)	2336.92	2695.8	-7.81	<0.001
Dist. to Developed (m)	1299.34 (878.4)	1416.7 (847.9)	1168.5	1282.1	-7.77	<0.001
Dist. to Freshwater (m)	996.95 (690.2)	822.4 (616.9)	849.3	679.5	-13.04	<0.001

Conclusions

Since 2000, Santa Catalina has been trapped with an extensive array of transects, including a total of 605 traps. This trapping effort samples approximately 79% and 84% of the East and West ends, respectively, if a 600-m effective trap radius is assumed. In general, existing protocols sample habitat variability on the island more effectively than Scenario A and B, no doubt due to the larger proportion of the island sampled. Scenarios A and B only sample 28% and 35% of the East End, respectively, while each samples 50% of the West End. Trapping Scenario B tended to sample the island more adequately than Scenario A. Statistically, areas sampled by all three trapping scenarios (including existing protocols) differ from random points on the island for all habitat measures examined, with the exception of distance to paved roads and developed areas on the East End of the island under existing trap protocols. However, as discussed above, statistical differences may not indicate biologically relevant differences. For example, statistical differences were found in slope and ruggedness but absolute differences were small and may not influence trapping results. In some cases, however, under-sampling of some areas, such as areas close to the shore, may bias trapping results if fox density is different close to the shore than in other areas. Increasing sampling in some areas, such as close to the shore, will remain problematic, however, due to logistic and safety issues, and this will likely mean that any logistically feasible protocol will also sample areas that area less steep and less rugged than island-wide areas. We suggest that future research focused on fox habitat use and selection should be conducted to test whether under- or over-sampling certain habitat characteristics is expected to bias trapping results.

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Sokal, R.R., and F.J. Rohlf. 1995. Biometry: The Principles and Practices of Statistics in Biological Research. 3rd ed.. W.H. Freeman and Company, New York, NY. 887pp.

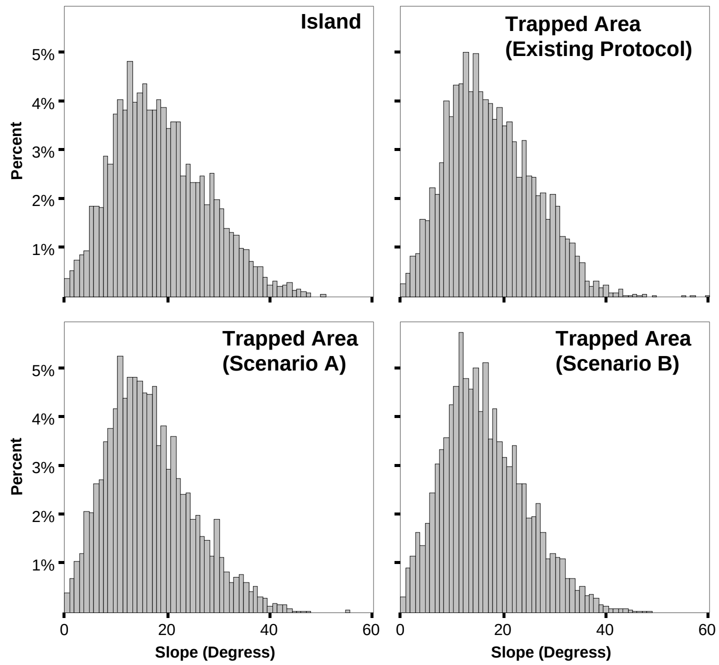

Figure C-1. Distribution of slope (as percent of total random points) on Santa Catalina Island's East End versus in areas trapped with three trapping scenarios on the East End (Existing Protocol, Scenario A, and Scenario B).

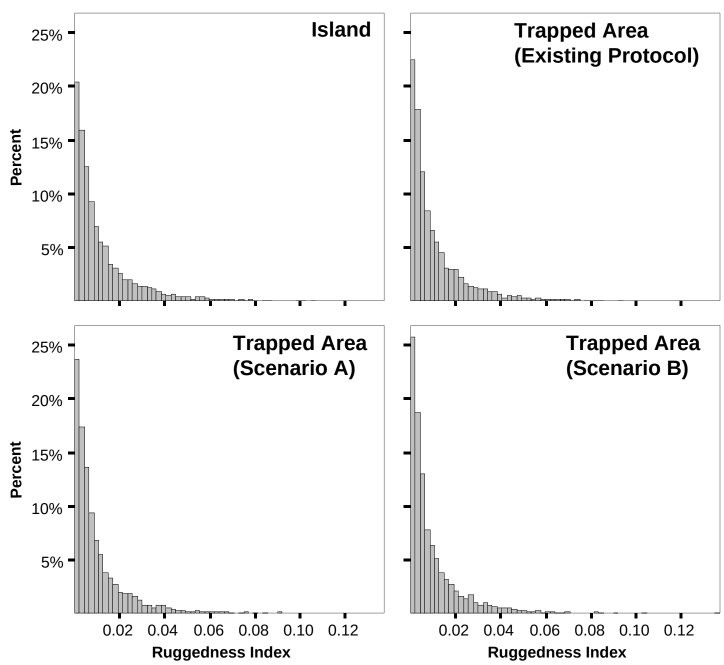

Figure C-2. Distribution of ruggedness index (as percent of total random points) on Santa Catalina Island's East End versus areas trapped with three trapping scenarios on the East End (Existing Protocol, Scenario A, Scenario B).

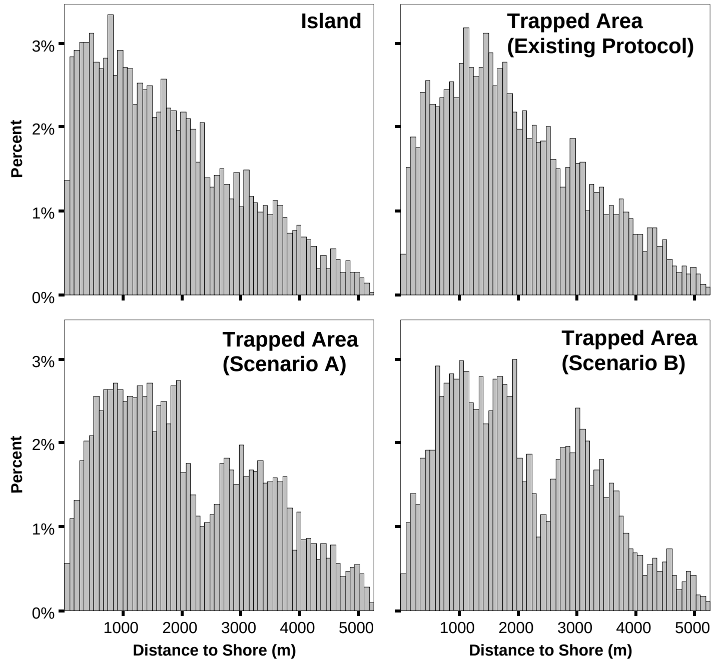

Figure C-3. Distribution of distance to the shoreline (as % of total random points) on Santa Catalina Island's East End versus areas trapped with three trapping scenarios on the East End (Existing Protocol, Scenario A, Scenario B).

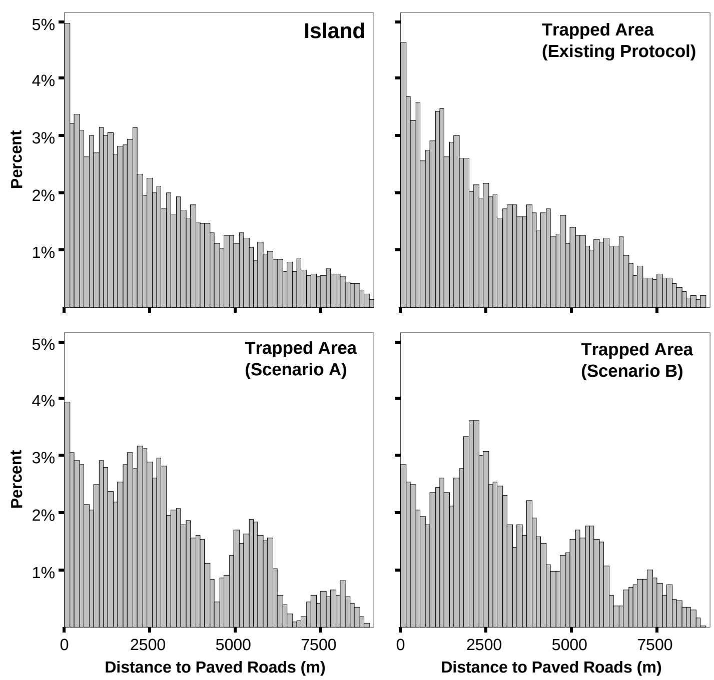

Figure C-4. Distribution of distance to paved roads (as % of total random points) on Santa Catalina Island's East End versus areas trapped with three trapping scenarios on the East End (Existing Protocol, Scenario A, Scenario B).

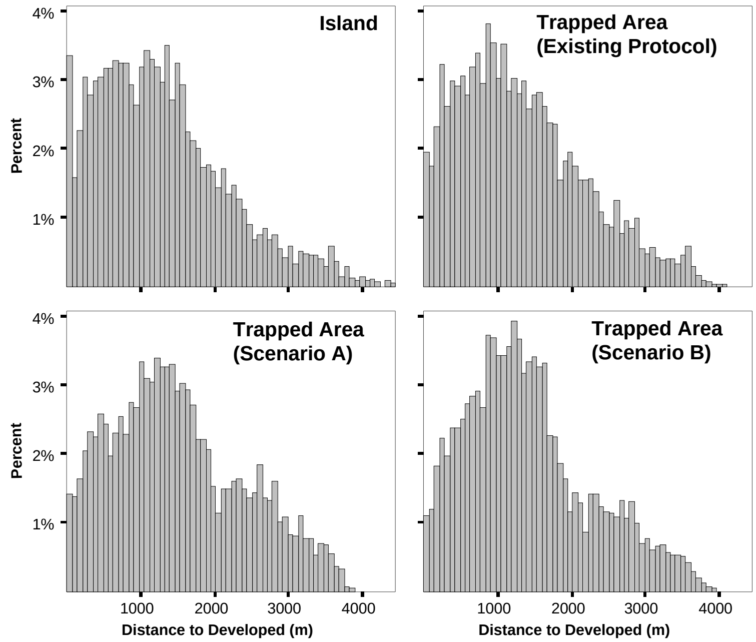

Figure C-5. Distribution of distance to developed areas (as % of total random points) on Santa Catalina Island's East End vs areas trapped with three trapping scenarios on the East End (Existing Protocol, Scenario A, Scenario B).

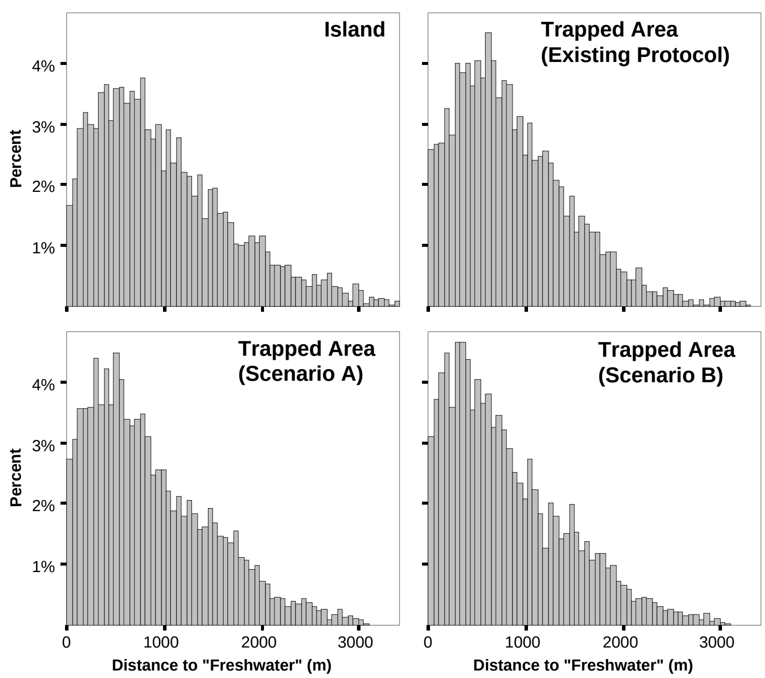

Figure C-6. Distribution of distance to freshwater (as percent of total random points) on Santa Catalina Island's East End versus areas trapped with three trapping scenarios (Existing Protocol, Scenario A, and Scenario B).

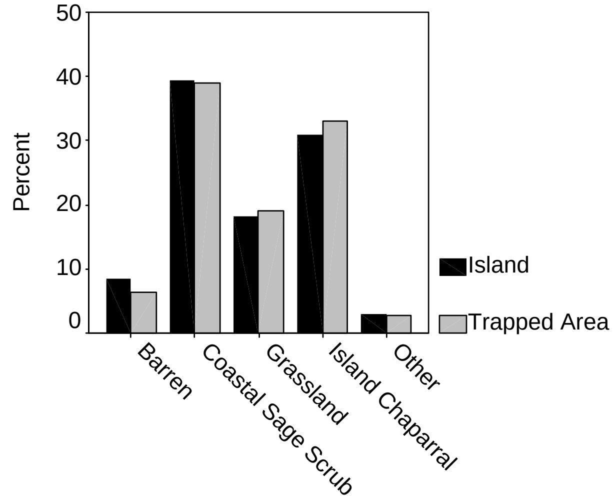

Figure C-7. Distribution of vegetation types (as percent of total random points) on Santa Catalina Island's East End versus areas trapped with Existing Protocol on the East End.

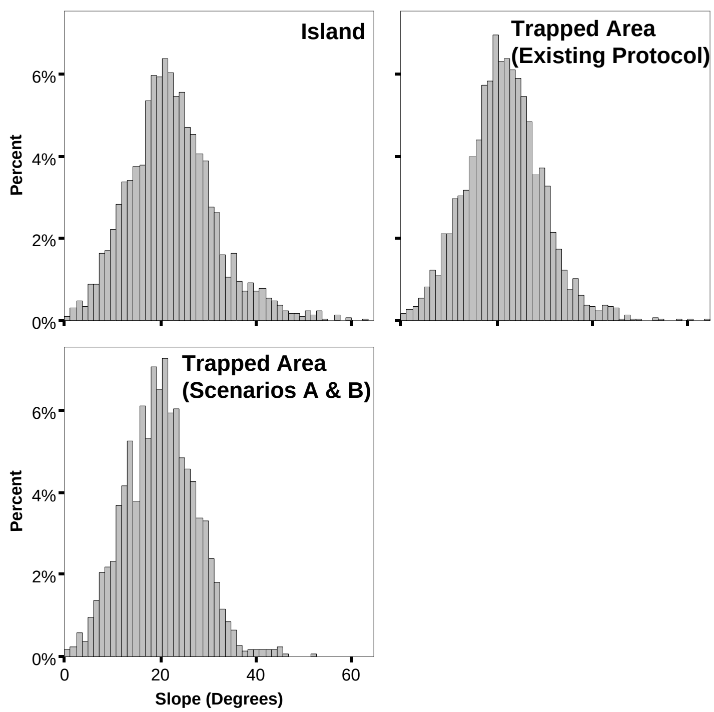

Figure C-8. Distribution of slope (as percent of total random points) on Santa Catalina Island's West End versus in areas trapped with three trapping scenarios on the West End (Existing Protocol, Scenario A, and Scenario B).

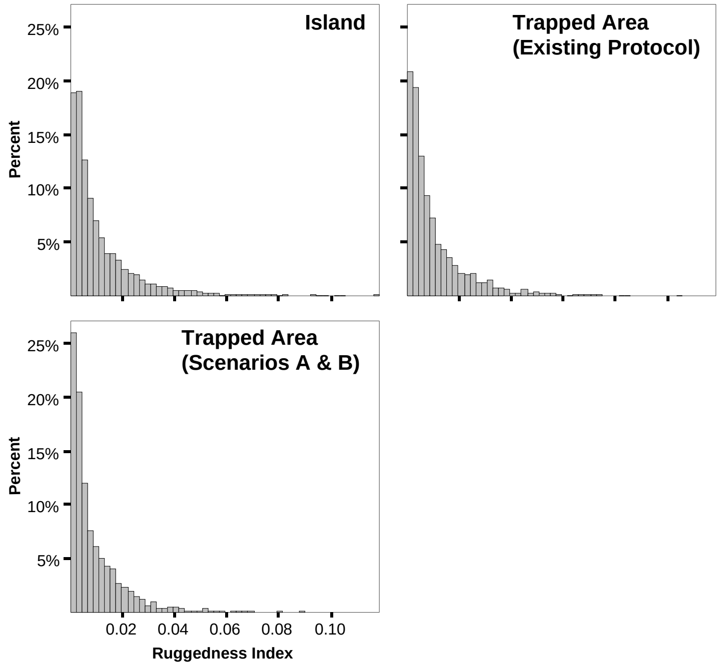

Figure C-9. Distribution of ruggedness index (as % of total random points) on Santa Catalina Island's West End versus areas trapped with three trapping scenarios on the West End (Existing Protocol, Scenario A, and Scenario B).

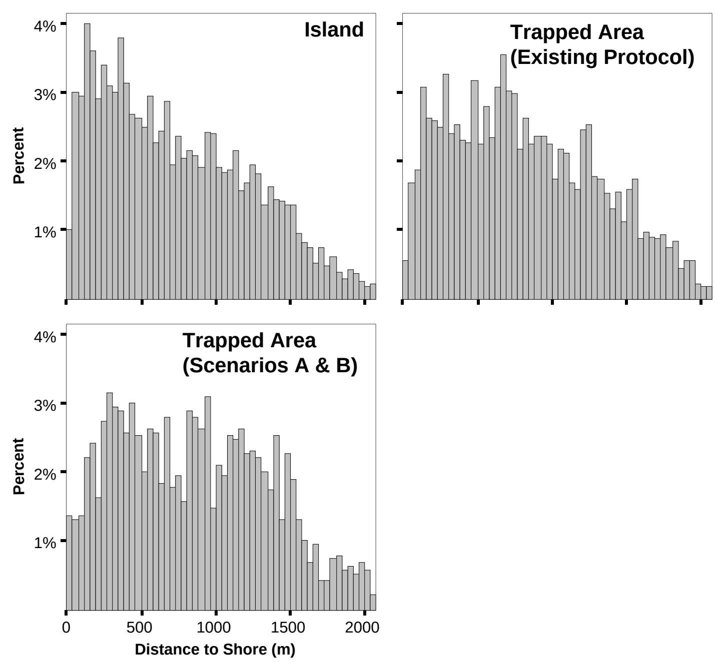

Figure C-10. Distribution of distance to shoreline (as % of total random points) on Santa Catalina Island's West End vs areas trapped with three trapping scenarios on the West End (Existing Protocol, Scenario A, and Scenario B).

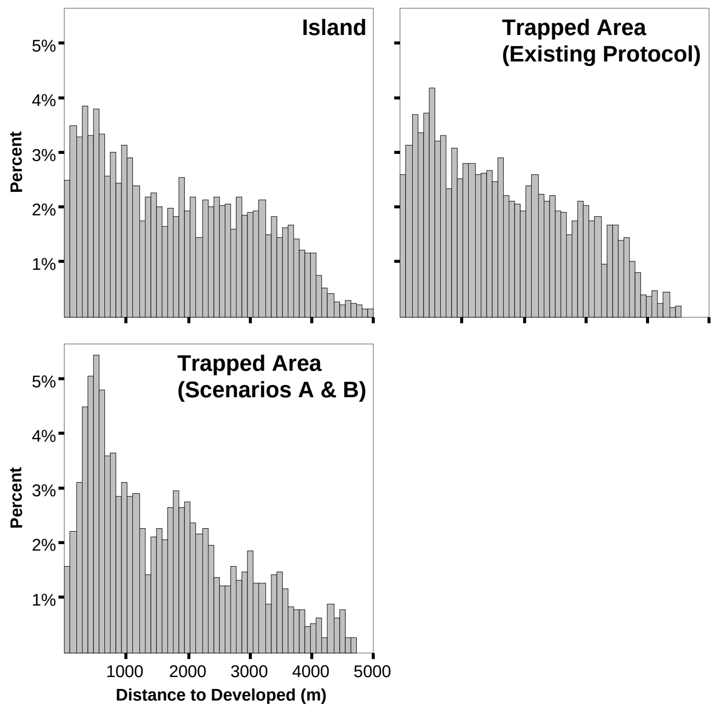

Figure C-11. Distribution of distance to developed areas (as percent of total random points) on Santa Catalina Island's West End vs areas trapped with three trapping scenarios on the West End (Existing Protocol, Scenario A, and Scenario B).

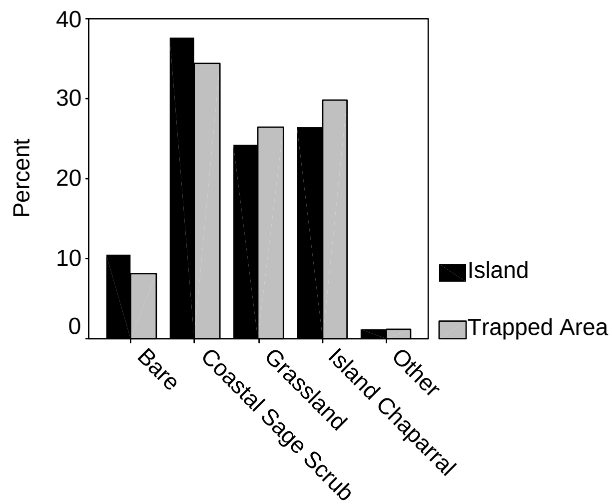

Figure C-12. Distribution of vegetation types (as percent of total random points) on Santa Catalina Island's West End versus areas trapped with Existing Protocol on the West End.

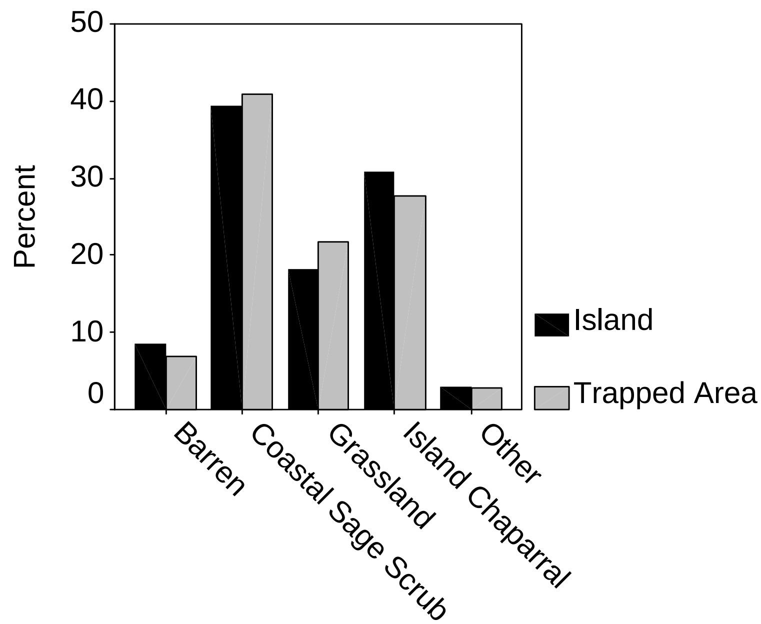

Figure C-13. Distribution of vegetation types (as percent of total random points) on Santa Catalina Island's East End versus areas trapped with Scenario A on the East End.

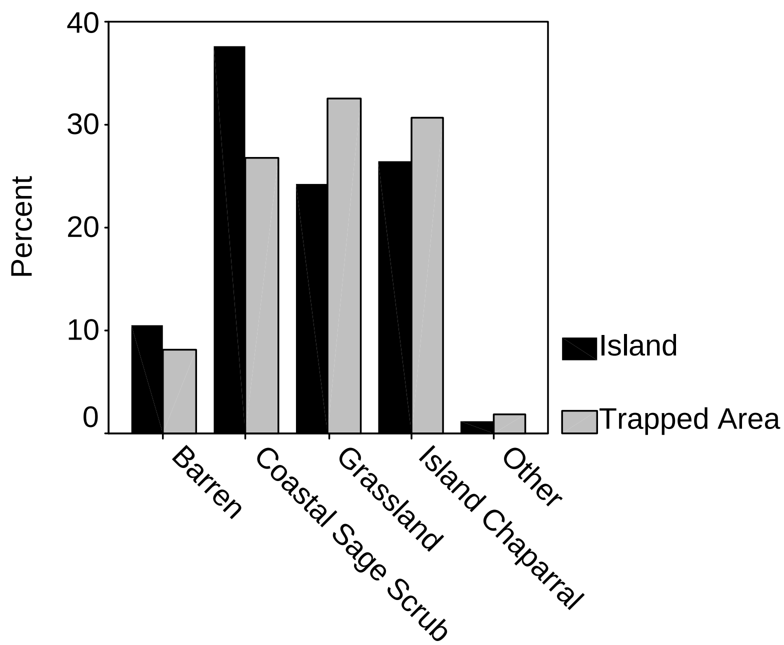

Figure C-14. Distribution of vegetation types (as percent of total random points) on Santa Catalina Island's West End versus areas trapped with Scenarios A/B on the West End.

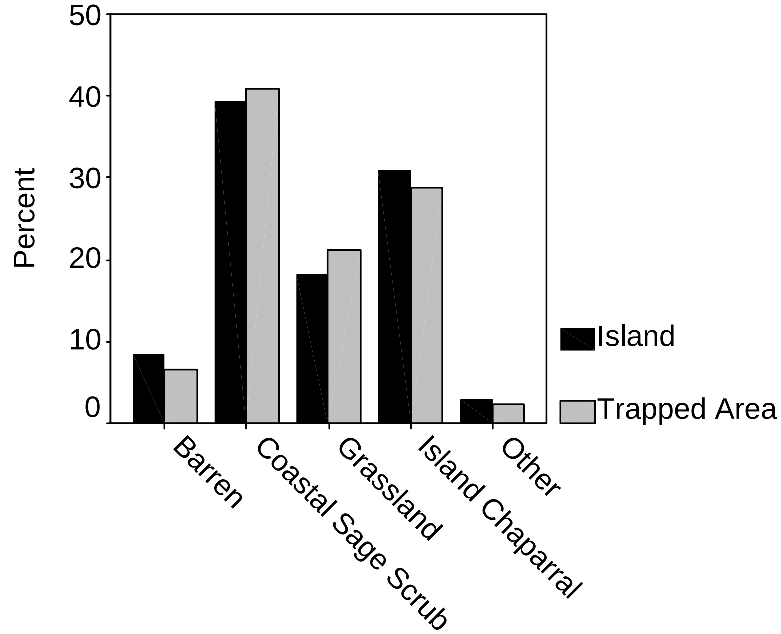

Figure C-15. Distribution of vegetation types (as percent of total random points) on Santa Catalina Island's East End versus areas trapped with Scenario B on the East End.

Appendix D

Univariate Representation Analysis of Proposed Trapping Scenarios on Santa Rosa Island

Introduction

This representation analysis examines how well recommended trapping protocols represent habitat variation on Santa Rosa Island. Because no standardized trapping protocol has been established for this island, we did not evaluate an existing protocol as we did on other islands. The goal of evaluating proposed trapping scenarios was to provide managers with additional information on which to base decisions about trapping protocols. In addition, increased knowledge regarding habitat representation of each trapping scenario may help identify research needs relative to habitat use and selection.

Methods

We identified habitat variables currently available as GIS coverages or that could be created from existing GIS coverages, and for which we have empirical evidence or biological rationale to suspect that they may influence island fox habitat quality or population dynamics. Although we can not know or measure all habitat characteristics important to island foxes, we strived to maximize representation of the following habitat attributes that we can measure: vegetation type, slope, terrain ruggedness, distance to paved roads, distance to shoreline, distance to developed areas, and distance to freshwater sources. It is likely that other habitat characteristics also influence fox populations, but some of these will correlate highly with the variables we selected (e.g., distance to canyon bottoms would correlate strongly with our ruggedness index), and others are not currently available to measure (e.g., cat densities or prey densities). This analysis should be viewed as preliminary, and we strongly recommend that future data from radio-collared foxes be used to evaluate and identify habitat features that influence fox densities or habitat selection.

We created data layers for each of the continuous variables (slope, terrain ruggedness, distance to paved roads, distance to shoreline, distance to developed areas, and distance to freshwater sources) in the following manner:

- Slope. We derived a slope layer from the USGS 30-m DEM. We chose to create a slope layer in degrees.
- Ruggedness. We created a Ruggedness raster layer using an Avenue script created and provided by Mark Sappington (National Park Service) and Kathy Longshore (U.S. Geological Survey). This measure provides an index of ruggedness which ranges from 0 to 1, with 0 representing completely flat terrain and 1 representing the most rugged terrain. We used the USGS 30-m DEM as the basis for the algorithm, after converting its elevation values from feet to meters, and used a 90x90-m moving window to calculate ruggedness.

- Distance to shoreline. We created a raster layer of the distance-to-shoreline using the Distance ->Straight Line tool provided in the Spatial Analyst extension.
- Distance to roads. We created a raster layer of the distance to roads using the Distance ->Straight Line tool provided in the Spatial Analyst extension. The road data layer was provided by NPS.
- Distance to developed. We created a raster layer of the distance to developed areas using the Distance ->Straight Line tool provided in the Spatial Analyst extension.
- Distance to freshwater. Because a map of freshwater sources on Santa Rosa Island is not currently available, we used the USGS hydrology layer as a surrogate. This layer represents drainages and ravines, which may be more likely to contain surface freshwater or runoff than other areas, but are not guaranteed to provide water.
- Vegetation. We used a vegetation layer created and provided by the National Park Service. We examined the composition of vegetation across the entire island, and attempted to reduce the number of vegetation classifications to represent major vegetation types. The original and newly created classifications are shown in Table D-1.

Table D-1. Vegetation classifications on Rosa Island, as originally classified and as grouped for analysis.

Original Classification	Representation of Original Classification on Island (%)	Vegetation as Categorized for Analysis
Grassland	69.99	Grassland
Coastal Sage Scrub	16.92	Coastal Sage Scrub
Bare	6.17	Bare
Chaparral	4.70	Chaparral
Lupine Scrub	0.91	Lupine/Caliche/Baccharis Scrub
Coastal Bluff	0.44	Other
Agricultural Area	0.24	Other
Caliche Scrub	0.22	Lupine/Caliche/Baccharis Scrub
Marsh	0.18	Other
Coastal Strand	0.11	Other
Mixed Woodland	0.11	Other
Torrey Pine	0.11	Other
Island Oak	0.07	Other
Unknown	0.05	Other
Baccharis Scrub	0.03	Lupine/Caliche/Baccharis Scrub
Pond	0.03	Other
Closed-cone Pine	0.01	Other
Eucalyptus	0.01	Other
Southern Riparian Woodland	0.01	Other
NPS Trailer	0.00	Other

Habitat characteristics were determined from two separate sets of random points; one distributed over the entire island and one distributed on trapped areas only. Trapped areas were defined as all locations within a 600-m buffer of a trap, excluding open water and avoiding double-counting of overlap areas for grids or traps <1,200 m apart. The 600-m buffer distance, added to represent the effective trap area of each trap, is equal to the mean of the mean maximum distances moved for each trapping session for all years for grids on San Clemente, San Miguel, San Nicolas, and Santa Cruz islands (V. Bakker, pers. comm.). The number of random points was chosen by first placing points along a systematic grid with 90-m spacing, to result in a density of 144 points/km^2, and then applying this density of points randomly to the island and the trapped area. For our analysis, we randomly chose 5,000 points from the island and from the trapped points.

We used the Mann-Whitney test (Sokal and Rohlf 1995) to test whether continuous variables (slope, ruggedness, distance to roads, etc.) differed between the island and trapped areas. To compare the composition of vegetation types, we used a chi-square goodness of fit test (Fowler et al. 1998), to compare vegetation composition of the trapped area versus on the entire island. We also visually compared the distributions of habitat attributes on the island versus those on trapped areas.

Results and Discussion

Scenario A

Assuming a 600-m effective trap radius around each trap, Scenario A samples approximately 30% of Santa Rosa Island (Map 7-5). This proposed trapping scenario differed from island-wide areas in all continuous habitat measures except for distance to developed areas (Table D-2). Sampled areas had lower slope and ruggedness than island-wide areas (Figures D-1 and D-2); however, the absolute differences were small and may not have biological significance. For example, the difference in mean and median slopes was <3°, while the differences in mean and median ruggedness indices were extremely small compared to the range of the ruggedness index, which has a value of 0 for completely flat terrain and a value of 1 for extremely rugged terrain.

Areas sampled by Scenario A were closer to the shore and to roads, and farther from freshwater (Table D-2, Figures D-3, D-4, and D-6). However, again, it is not known if these statistical differences would represent biological differences, because absolute differences between island-wide and trapped areas are relatively small compared to movement patterns observed in island foxes. For each of these measures, mean and median values of trapped areas differed from those of island-wide areas by <500 m.

Scenario A sampled all the vegetation categories included in this analysis, and visually appeared to represent the vegetation categories quite well (Figure D-7). However, a significant difference existed in the distribution of trapped areas versus island-wide areas (Chi-square = 61.28, df = 4, p <0.01), due to under-sampling of coastal sage scrub and slight over-sampling of the remaining categories.

Scenario B

Assuming a 600-m effective trap radius around each trap, Scenario B samples approximately 23% of Santa Rosa Island (Map 7-6). Areas sampled with this trapping scenario differed from island-wide areas in all continuous measures, with the exception of distance to roads (Table D-3). However, as discussed in relation to Scenario A above, it is not know if these statistical differences represent biological differences. Some habitat measures differed more with this scenario than with Scenario A. For example, median differences between island-wide and trapped areas differed by >700 m in distance to develop areas, and this could influence trap data if foxes avoid or select habitat near developed areas.

Scenario B sampled all vegetation categories included in this analysis, but didn't sample them in proportion to availability (Chi-square = 134.59, df = 4, p <0.01). This difference is due to under-sampling bare, chaparral, and coastal sage scrub areas, and over-sampling grassland and lupine/caliche/baccharis scrub areas (Figure D-8).

Table D-2. Comparison of habitat attributes on Santa Rosa Island (n = 5,000 random points) versus areas trapped with proposed trapping Scenario A (n = 5,000 random points).

Habitat Measure	**Island Mean (sd)**	**Trapped Area Mean (sd)**	**Island Median**	**Trapped Area Median**	***Z***	***p***
Slope (degrees)	13.71 (8.21)	11.79 (7.89)	13.17	10.66	-11.78	<0.001
Ruggedness Index	0.0072 (0.0092)	0.0053 (0.0075)	0.0039	0.0024	-13.09	<0.001
Dist. to Shore (m)	2103.25 (1548.4)	1748.93 (1349.16)	1758.01	1306.98	-10.63	<0.001
Dist. to Roads (m)	1348.04 (1226.3)	1368.24 (1371.71)	997.25	831.93	-3.94	<0.001
Dist. to Developed (m)	5002.55 (3169.1)	5187.02 (3490.35)	4455.74	4967.67	-1.36	0.174
Dist. to Freshwater (m)	417.36 (438.66)	466.67 (497.34)	300.00	330.00	-4.53	<0.001

Conclusions

Areas sampled by Scenarios A and B differ statistically from island wide-wide areas in all continuous habitat measures, with the exception of distance to developed areas, which does not differ between the island and Scenario A, and distance to roads, which doesn't differ between the island and Scenario B. It is possible, however, that these statistical differences may not indicate biological differences because, in most cases, absolute differences are quite small in relation to the scale of measurement (e.g., slope and ruggedness) or in comparison to fox movement distances (e.g., distance to the shore, distance to freshwater). For example, distance to freshwater is significantly different but medians and means of island-wide versus trapped areas differed by <50 m, which may not have relevance to fox habitat selection. Because a map of freshwater sources was lacking for this island, we used the USGS hydrology layer as a surrogate. This layer represents drainages and ravines, which, in themselves may have relevance for foxes, in that the may provide valuable resources such as denning sites or foraging areas. It is unknown if a difference of 50 m has relevance to selection or avoidance of ravines and drainages.

We suggest that future studies on habitat use and selection would provide valuable information on whether the above differences may bias trapping data. In the absence of further knowledge on fox habitat use and selection, it is not known which of the above measures has the most relevance to trapping protocols. Although Scenario B tends to resembled the island most closely in terms of slope, distance to roads and freshwater, and possibly ruggedness, Scenario A samples the island more adequately in terms of distance to the shore and develop areas, and in vegetation composition.

It is not surprising that trapped areas had lower slope and ruggedness than island-wide areas, since our placement of trapping units specifically avoided high slopes (those ≥30%, or 16.7°), for logistic and safety reasons. It is likely that any feasible trapping protocol for Santa Rosa Island would differ from island-wide areas in these two measures.

Table D-3. Comparison of habitat attributes on Santa Rosa Island (n = 5,000 random points) versus areas trapped with proposed trapping Scenario B (n = 5,000 random points).

Habitat Measure	**Island Mean (sd)**	**Trapped Area Mean (sd)**	**Island Median**	**Trapped Area Median**	***Z***	***p***
Slope (degrees)	13.71 (8.21)	12.38 (7.81)	13.17	11.69	-7.82	<0.001
Ruggedness Index	0.0072 (0.0092)	0.0055 (0.0076)	0.0039	0.0026	-11.04	<0.001
Dist. to Shore (m)	2103.25 (1548.4)	1684.78 (1350.59)	1758.01	1261.43	-13.06	<0.001
Dist. to Roads (m)	1348.04 (1226.3)	1348.95 (1164.96)	997.25	933.38	-0.956	0.339
Dist. to Developed (m)	5002.55 (3169.1)	5270.82 (3113.77)	4455.74	5161.61	-5.65	<0.001
Dist. to Freshwater (m)	417.36 (438.66)	445.21 (485.89)	300.00	318.90	-2.51	0.012

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Sokal, R.R., and F.J. Rohlf. 1995. Biometry: The Principles and Practices of Statistics in Biological Research. 3rd ed.. W.H. Freeman and Company, New York, NY. 887pp.

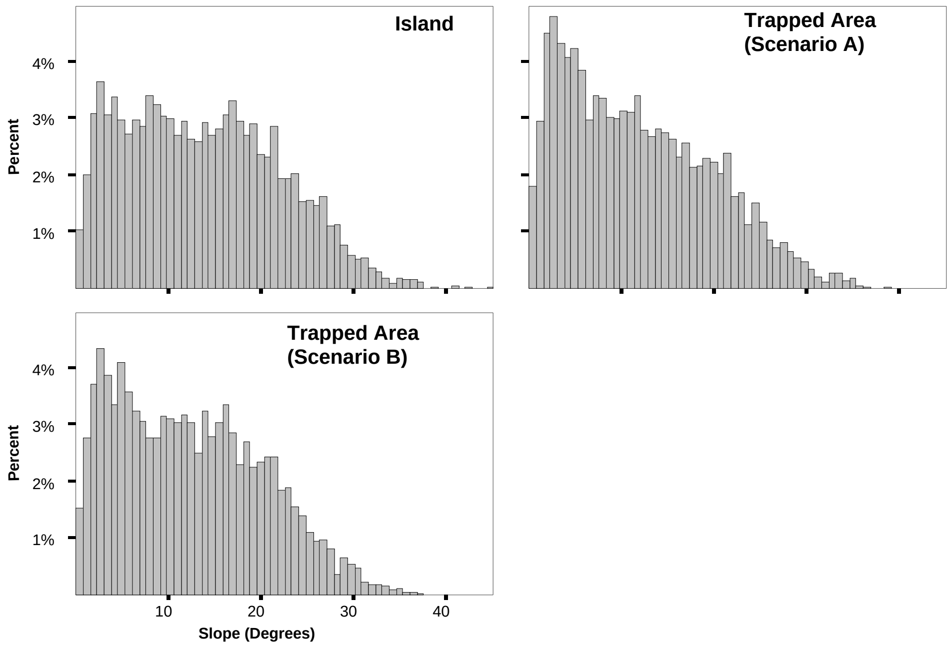


Figure D-1. Distribution of slope (as percent of random points) on Santa Rosa Island versus in areas trapped with proposed trapping Scenarios A and B.

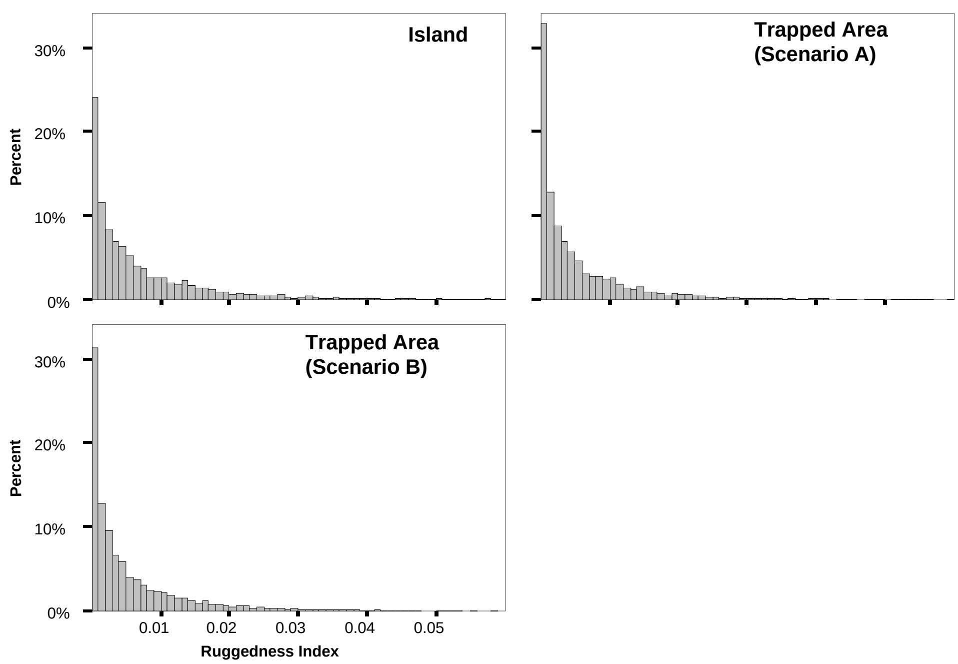


Figure D-2. Distribution of ruggedness (as percent of random points) on Santa Rosa Island versus in areas trapped with proposed trapping Scenarios A and B.

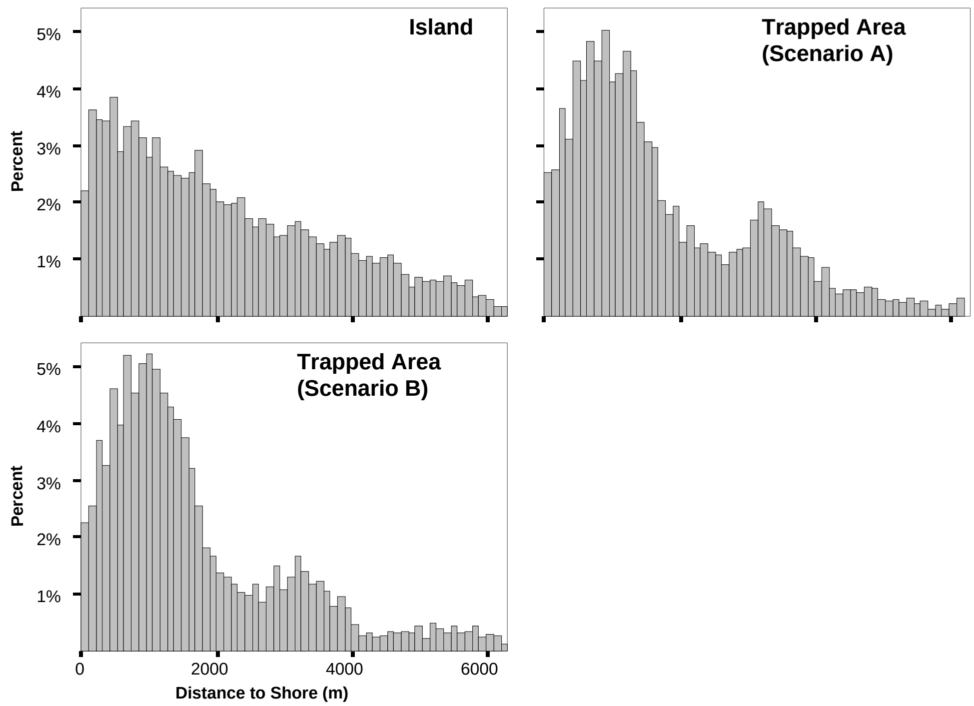


Figure D-3. Distribution of distance to shore (as percent of random points) on Santa Rosa Island versus in areas trapped with proposed trapping Scenarios A and B.

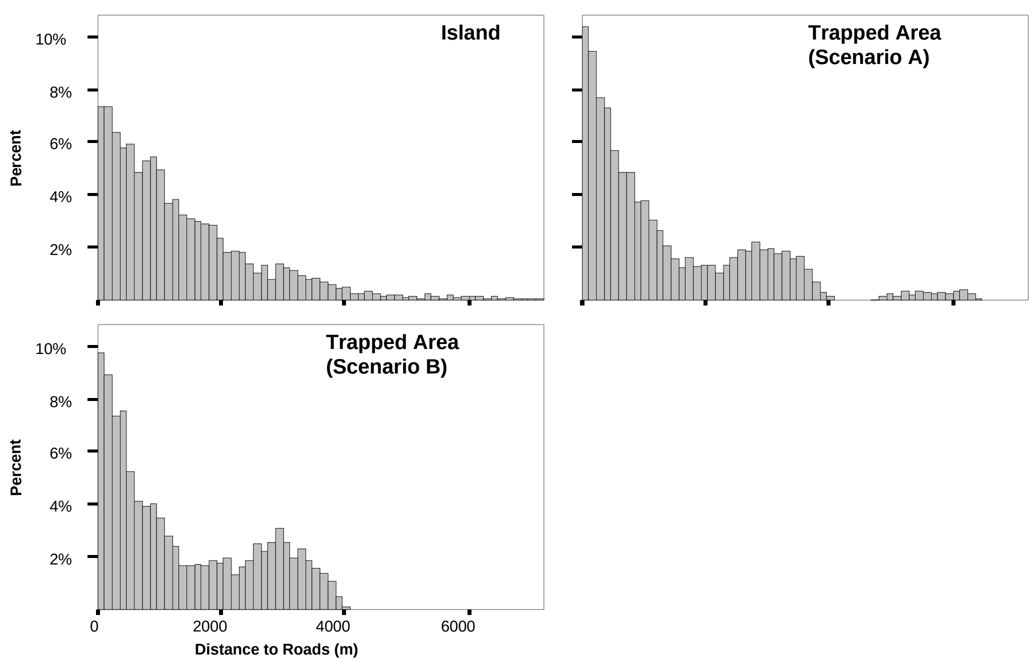


Figure D-4. Distribution of distance to roads (as percent of random points) on Santa Rosa Island versus in areas trapped with proposed trapping Scenarios A and B.

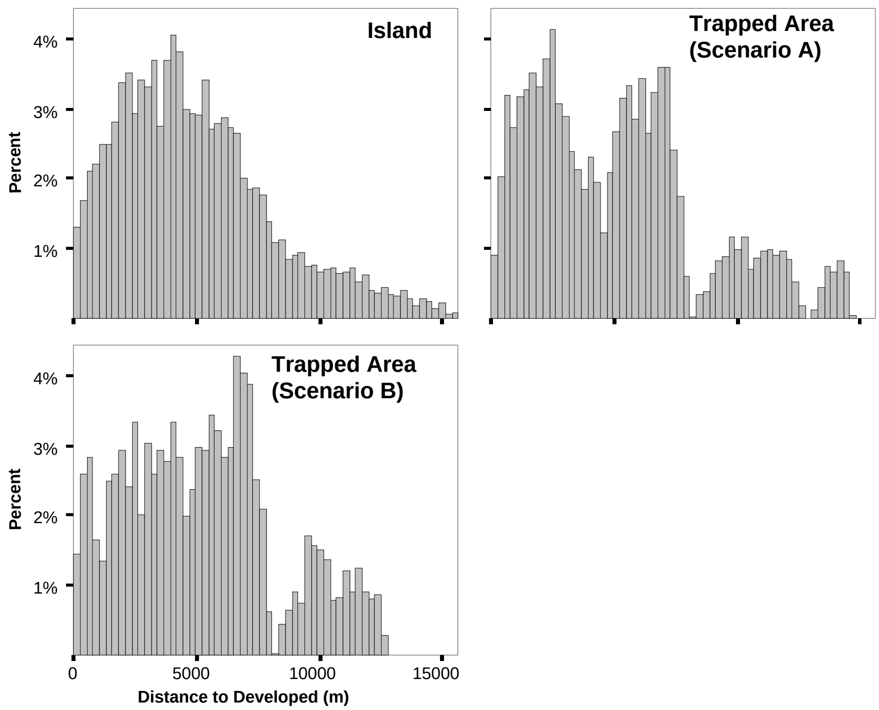


Figure D-5. Distribution of distance to developed areas (as percent of random points) on Santa Rosa Island versus in areas trapped with proposed trapping Scenarios A and B.

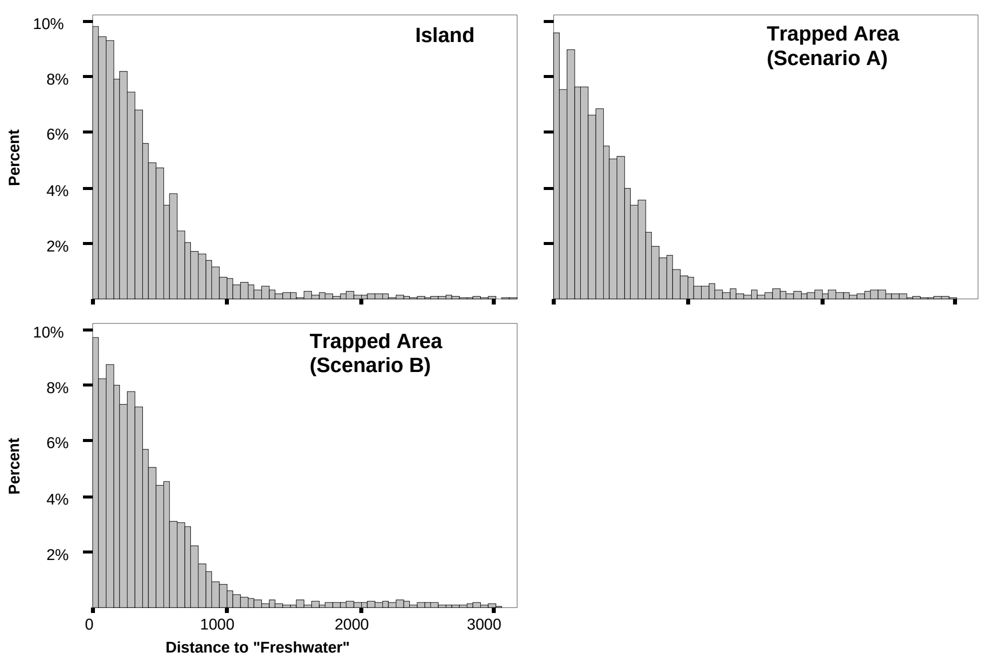


Figure D-6. Distribution of freshwater (as percent of random points) on Santa Rosa Island versus in areas trapped with proposed trapping Scenarios A and B.

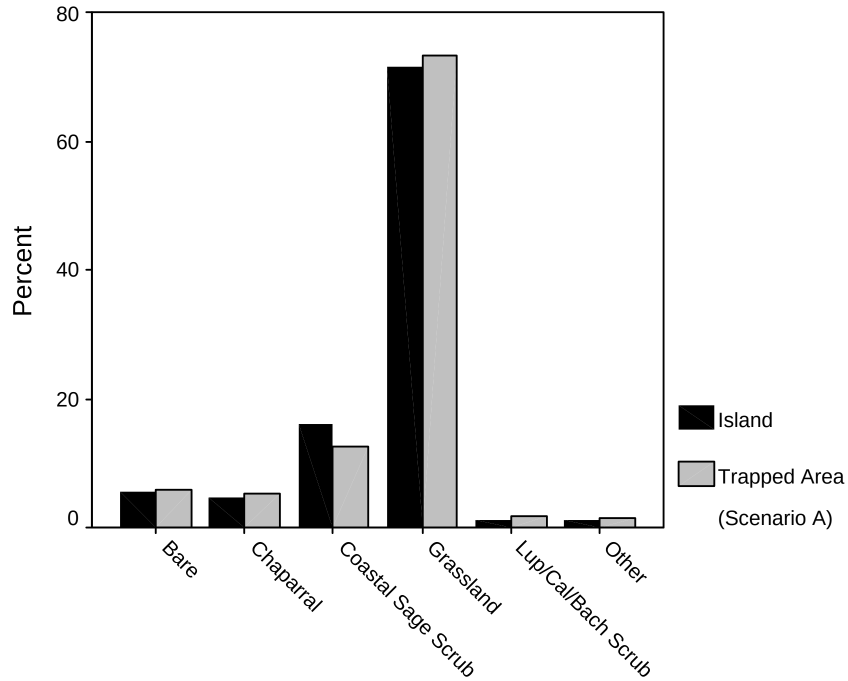


Figure D-7. Distribution of vegetation types (as percent of random points) on Santa Rosa Island versus in areas trapped with Scenario A.

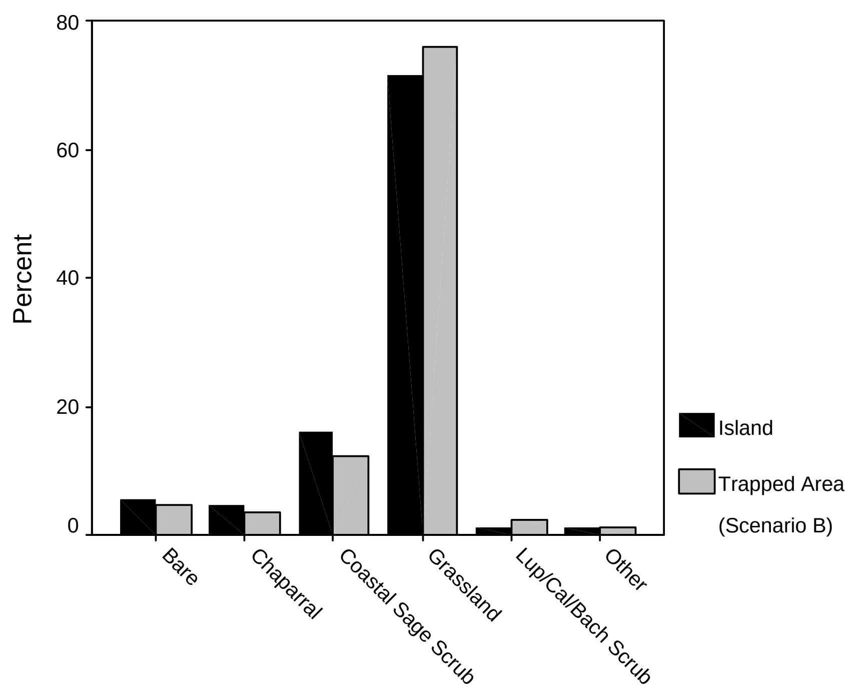


Figure D-8. Distribution of vegetation types (as percent of random points) on Santa Rosa Island versus in areas trapped with Scenario B.

Appendix E

Univariate Representation Analysis of Existing and Proposed Trapping Scenarios on Santa Cruz Island

Introduction

This representation analysis examines how well existing and recommended trapping protocols represent habitat variation on Santa Cruz Island. The goal of evaluating the existing protocol was to identify gaps in island representation that could be addressed in proposed trapping scenarios, and to provide a baseline comparison with which to evaluate proposed scenarios. This information is intended to provide managers with additional information on which to base decisions about trapping protocols. In addition, increased knowledge regarding habitat representation of each trapping scenario may help identify research needs relative to habitat use and selection.

Methods

We identified habitat variables currently available as GIS coverages or that could be created from existing GIS coverages, and for which we have empirical evidence or biological rationale to suspect that they may influence island fox habitat quality or population dynamics. Although we can not know or measure all habitat characteristics important to island foxes, we strived to maximize representation of the following habitat attributes that we can measure: vegetation type, slope, terrain ruggedness, distance to paved roads, distance to shoreline, distance to developed areas, and distance to freshwater sources. It is likely that other habitat characteristics also influence fox populations, but some of these will correlate highly with the variables we selected (e.g., distance to canyon bottoms would correlate strongly with our ruggedness index), and others are not currently available to measure (e.g., prey densities). This analysis should be viewed as preliminary, and we strongly recommend that future data from radiocollared foxes be used to evaluate and identify habitat features that influence fox densities or habitat selection.

We created data layers for each of the continuous variables (slope, terrain ruggedness, distance to paved roads, distance to shoreline, distance to developed areas, and distance to freshwater sources) in the following manner:

- Slope. We derived a slope layer from the USGS 30-m DEM. We chose to create a slope layer in degrees.
- Ruggedness. We created a Ruggedness raster layer using an Avenue script created and provided by Mark Sappington (National Park Service) and Kathy Longshore (U.S. Geological Survey). This measure provides an index of ruggedness which ranges from 0 to 1, with 0 representing completely flat terrain and 1 representing the most rugged terrain. We used the USGS 30-m DEM as the basis for the algorithm, after converting its

elevation values from feet to meters, and used a 90x90-m moving window to calculate ruggedness.

- Distance to shoreline. We created a raster layer of the distance-to-shoreline using the Distance ->Straight Line tool provided in the Spatial Analyst extension.
- Distance to roads. We created a raster layer of the distance to roads using the Distance ->Straight Line tool provided in the Spatial Analyst extension.
- Distance to developed. We created a raster layer of the distance to developed areas using the Distance ->Straight Line tool provided in the Spatial Analyst extension.
- Vegetation. We used a vegetation layer created and provided by The Nature Conservancy. We examined the composition of vegetation across the entire island, and attempted to reduce the number of vegetation classifications to represent major vegetation types. The original and newly created classifications are shown in Table E-1.

Although we evaluated the distance of trapped areas to sources of freshwater for the other four islands, we opted to exclude this measure from the Santa Cruz Island analysis. This decision was based on the fact that a large number of un-mapped springs and seeps occurred on the island. For other islands, in the absence of actual water data, we used selected vegetation associations as surrogates for freshwater. However, the vegetation map for Santa Cruz, which also included locations of seeps and springs, was known to greatly underestimate the number of water sources on the island. Given that this would include a large known error into the analysis we excluded this measure.

Habitat characteristics were determined from two separate sets of random points; one distributed over the entire island and one distributed on trapped areas only. Trapped areas were defined as all locations within a 600-m buffer of a trap, excluding open water and avoiding double-counting of overlap areas for grids or traps <1,200 m apart. The 600-m buffer distance, added to represent the effective trap area of each trap, is equal to the mean of the mean maximum distances moved for each trapping session for all years for grids on San Clemente, Santa Cruz, San Miguel, and San Nicolas islands (V. Bakker, pers. comm.). The number of random points was chosen by first placing points along a systematic grid with 90-m spacing, to result in a density of 144 points/km^2, and then applying this density of points randomly to the island and the trapped area. For our analysis, we randomly chose 5,000 points from the island and from the trapped points.

We used the Mann-Whitney test (Sokal and Rohlf 1995) to test whether continuous variables (slope, ruggedness, distance to roads, etc.) differed between the island and trapped areas. To compare the composition of vegetation types, we used a chi-square goodness of fit test (Fowler et al. 1998), to compare vegetation composition of the trapped area versus on the entire island. We also visually compared the distributions of habitat attributes on the island versus those on trapped areas.

Table E-1. Vegetation classifications on Santa Cruz Island, as originally classified and as grouped for analyses.

Original Classification	Vegetation as Categorized for Analysis
Forests and Woodlands	
Temperate Broadleaf Sclerophyll Evergreen Forest	Forests/Woodlands-non-conifer
Ironwood Alliance	Forests/Woodlands-non-conifer
Eucalyptus Stands	Forests/Woodlands-non-conifer
Island Cherry-(Island Scrub Oak-Toyon)	Forests/Woodlands-non-conifer
Temperate Needleleaf Evergreen Forests	Forests/Woodlands-conifer
Introduced Pines or Cypress	Forests/Woodlands-conifer
Bishop Pine Alliance	Forests/Woodlands-conifer
Temporarily Flooded Cold Season Deciduous Forests	Forests/Woodlands-non-conifer
Big Leaf Maple Alliance	Forests/Woodlands-non-conifer
Fremont Cottonwood-Black Cottonwood Superalliance	Forests/Woodlands-non-conifer
Cold Season Deciduous Forests	Forests/Woodlands-non-conifer
Xeric Sclerophyll Evergreen Woodlands	Forests/Woodlands-non-conifer
Coast Live Oak Alliance	Forests/Woodlands-non-conifer
Canyon Live Oak Alliance	Forests/Woodlands-non-conifer
Cold Season Deciduous Woodlands	
Shrublands	
Temperate Broadleaf Sclerophyll Evergreen Shrublands	Evergreen Shrublands
McMinn's Manzanita	Evergreen Shrublands
Chamise Alliance	Evergreen Shrublands
Island Scrub Oak Alliance	Evergreen Shrublands
Island Manzanita Alliance	Evergreen Shrublands
Birch-leaf Mountain Mahogany Alliance	Evergreen Shrublands
Lemonadeberry Alliance	Evergreen Shrublands
Temperate Microphyllous Evergreen Shrublands	Evergreen Shrublands
Coyote Brush Alliance	Evergreen Shrublands
Mulefat Alliance	Evergreen Shrublands
Temperate Xeric Mixed Drought-Deciduous Shrublands	Deciduous Shrublands
Coastal Bluff Scrub Habitat	Deciduous Shrublands
Australian Saltbush	Deciduous Shrublands
Inland Bluff Scrub Habitat	Deciduous Shrublands
California Sagebrush Alliance	Deciduous Shrublands
Santa Cruz Island Buckwheat Alliance	Deciduous Shrublands
Saint Catherine's Lace Alliance	Deciduous Shrublands
Island Bush Monkeyflower-Island Bristleweed-Paintbrush	Deciduous Shrublands
Temporarily Flooded Cold Season Deciduous Shrublands	Deciduous Shrublands
Mixed Arroyo Willow-Mule Fat	Deciduous Shrublands
Arroyo Willow Alliance	Deciduous Shrublands
Herbaceous	
Saturated Temperate Perennial Graminoids	Herbaceous-non-fennel
Bulrush-Cattail	Herbaceous-non-fennel
Seasonally or Temporarily Flooded Graminoids	Herbaceous-non-fennel
Seasonally/Temp. Flooded Sprs., Seeps, Vernal Pools	Herbaceous-non-fennel
Tall Temperate Annual Graminoids	Herbaceous-non-fennel
Fennel	Herbaceous-fennel
California Annual Grasslands Alliance	Herbaceous-non-fennel

Original Classification	Vegetation as Categorized for Analysis
Giant Wildrye–Creeping Wildrye Superalliance	Herbaceous-non-fennel
Tall Temperate Perennial Graminoids	Herbaceous-non-fennel
Coastal Salt Pan	Herbaceous-non-fennel
Needlegrass	Herbaceous-non-fennel
Silver Beachbur-Beach Sand-Verbena Alliance	Herbaceous-non-fennel
Harding Grass	Herbaceous-non-fennel
Tidally Flooded Grasslands	Herbaceous-non-fennel
Saltgrass Alliance	Herbaceous-non-fennel
Tall Temperate Forblands	Herbaceous-non-fennel
Sea Blite-San Miguel Island Locoweed	Herbaceous-non-fennel
Tejon Mild Aster-(Coastal Goldenbush)	Herbaceous-non-fennel
Bracken Fern Alliance	Herbaceous-non-fennel
Land Use─Sparsely or Unvegetated	
Built-up	Other
Agriculture	Other
Sparsely Vegetated or Unvegetated Areas	Sparse Vegetation
Landslides	Sparse Vegetation
Cliffs-Rock Outcrops-Steep Eroded Slopes	Sparse Vegetation
Stream Beds and Flats	Sparse Vegetation
Water	Other
Planted Trees and Shrubs	Other
Unknown	Other

Results and Discussion

Existing Trapping Protocols

The current trapping protocol on Santa Cruz Island includes an extensive set of transects placed along roads, trails, ridge-tops, and canyon bottoms, which has been trapped since 2001. Assuming a 600-m effective trap radius around each trap, the current protocol samples approximately 45% of the island (Map 8-1).

Trapped areas have significantly lower slope than island-wide areas. However, this statistical significance may not have biological significance, since slope values at island-wide points are only slightly higher than at points in trapped areas, with a difference of <2° in median slopes (Table E-2). In addition, distributions of the two datasets do not show obvious differences (Figure E-1). Ruggedness values at random points did not differ between island and trapped areas (Table E-2, Figure E-2).

Trapped areas are significantly farther from the shoreline than island-wide areas (Table E-2, Figure E-3), but this difference is relatively small (<250 m if means are compared) in relation to fox movement patterns and may, therefore, not have biological relevance.

Areas sampled by the existing protocol are significantly closer to roads and to developed areas than island-wide areas, with trapped and island-wide areas differing by 700-1,100 m on average (Table E-2). Distributions of these measures show that areas within a few hundred meters of roads and within approximately 1 km of developed areas are over-sampled (Figures E-4 and E-5). This is not surprising since most trapping transects are located along roads, and developed areas are associated with roads. It is possible that these differences may have biological significance and may influence density estimates. For example, density estimates may be influenced if, for example, foxes experience higher mortality near roads, if they use roads as travel routes, or if they are attracted to or avoid developed areas. Future research on habitat selection relative to distance to roads and developed areas should examine whether this difference would bias density and abundance estimates, and whether this bias would be low or high.

The existing trapping protocol samples all vegetation categories on the island (based on our collapsed categories) but does not sample them in proportion to their availability on the island (Chi-square = 358.46, df = 6, p <0.01), due primarily to under-sampling of deciduous shrublands and over-sampling of evergreen shrublands (Figure E-6).

Table E-2. Comparison of habitat attributes on Santa Cruz Island (n = 5,000 random points) versus areas trapped with the current trapping protocol (n = 5,000 random points).

Habitat Measure	Island Mean (sd)	Trapped Area Mean (sd)	Island Median	Trapped Area Median	*Z*	*p*
Slope (degrees)	19.82 (9.06)	17.88 (8.50)	19.79	17.84	-10.75	<0.001
Ruggedness Index	0.054 (0.059)	0.053 (0.055)	0.032	0.033	-0.65	0.513
Dist. to Shore (m)	1707.3 (1275.1)	1943.5 (1357.3)	1422.5	1584.3	-8.66	<0.001
Dist. to Roads (m)	2151.8 (1715.5)	1380.4 (1581.9)	1800.6	677.8	-25.85	<0.001
Dist. to Developed (m)	2974.2 (1809.5)	2161.8 (1659.8)	2810.6	1626.1	-23.34	<0.001

Scenario A

Proposed trapping Scenario A includes 24 units made up of 12 traps each (with a configuration of 2x6 traps). Assuming a 600-m effective trap radius around each trap, Scenario A samples approximately 25% of the island (Map 8-5). Scenario A is similar to the existing protocol in that it tends to sample areas with lower slope, but with similar ruggedness, as the island (Table E-3, Figures E-1 and E-2). As discussed in relation to the existing protocol, the small absolute difference in mean and median slopes may not have relevance to fox trapping. This scenario also samples areas that are closer to roads and developed areas than are island-wide areas, but differs from the existing protocol in that sampled areas are closer to the shore than are island-wide areas (Table E-3, Figures E-3, E-4, and E-5). These differences are relatively small, however, with island-wide and sampled areas differing by <400 m for all three measures (regardless of whether means or medians are examined). It is not known if this difference has biological relevance, and we suggest that future research on habitat use and selection should examine whether this could bias trap results.

Proposed trapping Scenario A samples all the vegetation categories used in this analysis, but does not sample them in proportion to their availability on the island (Chi-square = 277.49, df=6, p <0.01). This scenario tends to under-sample deciduous shrublands and forests/woodlands-non-conifer, and over-sample evergreen shrublands, forests/woodlands-conifer, and non-fennel herbaceous areas (Figure E-7).

Table E-3. Comparison of habitat attributes on Santa Cruz Island (n = 5,000 random points) versus areas trapped with trapping Scenario A (n = 5,000 random points).

Habitat Measure	Island Mean (sd)	Trapped Area Mean (sd)	Island Median	Trapped Area Median	*Z*	*p*
Slope (degrees)	19.82 (9.06)	17.39 (8.21)	19.79	16.98	-13.63	<0.001
Ruggedness Index	0.054 (0.059)	0.052 (0.055)	0.032	0.032	-1.31	0.191
Dist. to Shore (m)	1707.3 (1275.1)	1592.7 (1246.8)	1422.5	1204.9	-4.72	<0.001
Dist. to Roads (m)	2151.8 (1715.5)	2055.9 (1793.9)	1800.6	1571.8	-4.24	<0.001
Dist. to Developed (m)	2974.2 (1809.5)	2677.5 (1832.9)	2810.6	2437.4	-8.83	<0.001

Scenario B

Proposed trapping Scenario B includes 18 units made up of 12 traps each (with a configuration of 2x6 traps). Assuming a 600-m effective trap radius around each trap, Scenario B samples approximately 19% of the island (Map 8-6). Scenario B samples areas with lower slope and lower ruggedness than island-wide areas (Table E-4, Figures E-1 and E-2). As discussed in relation to the existing protocol and Scenario A, however, the small absolute difference in mean and median slopes may not have relevance to fox trapping. The absolute differences in ruggedness are extremely small compared to the range of the ruggedness index, which has a value of 0 for completely flat terrain and a value of 1 for extremely rugged terrain, suggesting that this statistical difference may also not have biological relevance.

Areas sampled with this scenario are significantly closer to roads than are island-wide areas (Table E-4), but island-wide and sampled areas differed by <250 m (regardless of whether means or medians are examined), suggesting that this difference may not have biological relevance. Areas sampled by Scenario B did not differ statistically from island-wide areas in distance to the shore or in distance to developed areas.

Proposed trapping Scenario B samples all the vegetation categories used in this analysis, but does not sample them in proportion to their availability on the island (Chi-square = 377.35, df=6, p <0.01). This scenario also tends to under-sample deciduous shrublands and forests/woodlands-non-conifer, and over-sample evergreen shrublands, forests/woodlands-conifer, and herbaceous areas (Figure E-8).

Table E-4. Comparison of habitat attributes on Santa Cruz Island (n = 5,000 random points) versus areas trapped with trapping Scenario B (n = 5,000 random points).

Habitat Measure	Island Mean (sd)	Trapped Area Mean (sd)	Island Median	Trapped Area Median	*Z*	*p*
Slope (degrees)	19.82 (9.06)	17.19 (8.03)	19.79	16.83	-14.72	<0.001
Ruggedness Index	0.054 (0.059)	0.049 (0.054)	0.032	0.030	-3.40	0.001
Dist. to Shore (m)	1707.3 (1275.1)	1716.2 (1317.7)	1422.5	1380.3	-0.39	0.690
Dist. to Roads (m)	2151.8 (1715.5)	2362.0 (1878.8)	1800.6	2031.6	-4.41	<0.001
Dist. to Developed (m)	2974.2 (1809.5)	3025.9 (1833.4)	2810.6	2979.4	-1.15	0.248

Conclusions

Areas sampled by all three trapping scenarios have lower slope than island-wide areas, and Scenario B sampled areas with lower ruggedness. This is not surprising, since logistic and safety constraints required that traps were not placed in steep and rugged terrain. These differences may not have an influence on trap result, however, because absolute differences were small, as discussed above (Tables E-2, E-3, and E-4). The existing trapping protocol and Scenario A both sample areas that differ from island-wide areas in distance to the shore but the absolute differences are small relative to fox movement patterns and may, therefore, not have biological relevance. Although all three trapping scenarios sampled areas closer to roads (as was expected, as traps were placed in proximity to roads for logistic reasons) and to developed areas, compared to island-wide areas, this difference was most extreme in the existing protocol (Table E-2). It is possible that this biases trap results, if foxes select or avoid areas close to roads and developed areas. We therefore suggest that radiocollared foxes should be used to examine patterns of habitat use and selection, to determine if such difference might bias trap results. Although all three trap scenarios did not sample vegetation categories in proportion to their availability on the island, Scenario A sampled these most adequately. Again, habitat selection studies would provide data useful to understanding potential biases associated with these differences.

Literature Cited

Fowler, J., L. Cohen, and P. Jarvis. 1998. Practical Statistics for Field Biology. 2nd ed. John Wiley and Sons, New York, NY. 259pp.

Sokal, R.R., and F.J. Rohlf. 1995. Biometry: The Principles and Practices of Statistics in Biological Research. 3rd ed.. W.H. Freeman and Company, New York, NY. 887pp.

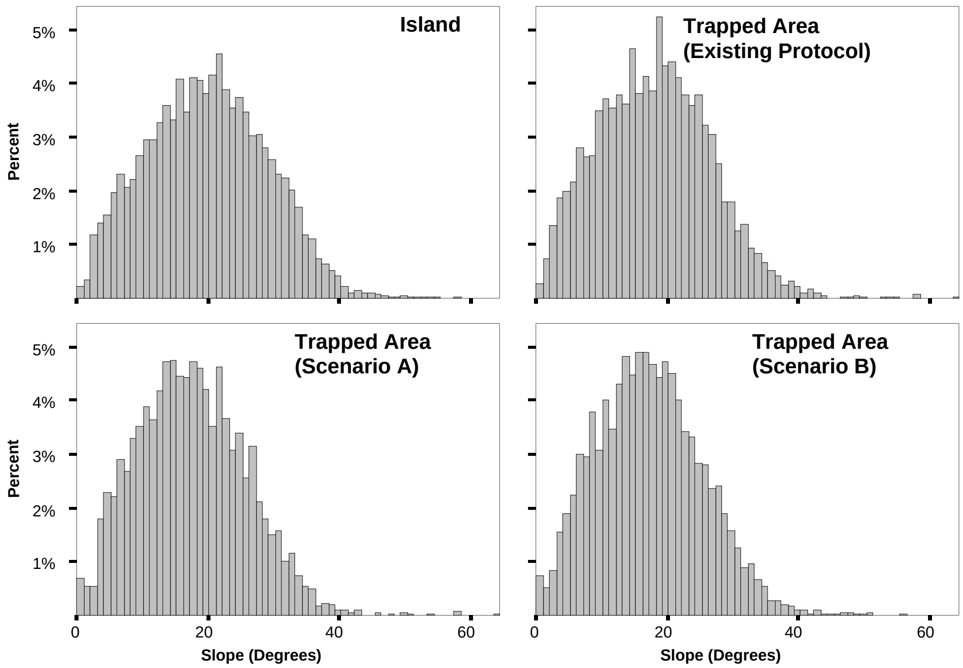


Figure E-1. Distribution of slope (as percent of random points) on Santa Cruz Island versus in areas trapped with three trapping scenarios (Existing Protocol, Scenario A, and Scenario B).

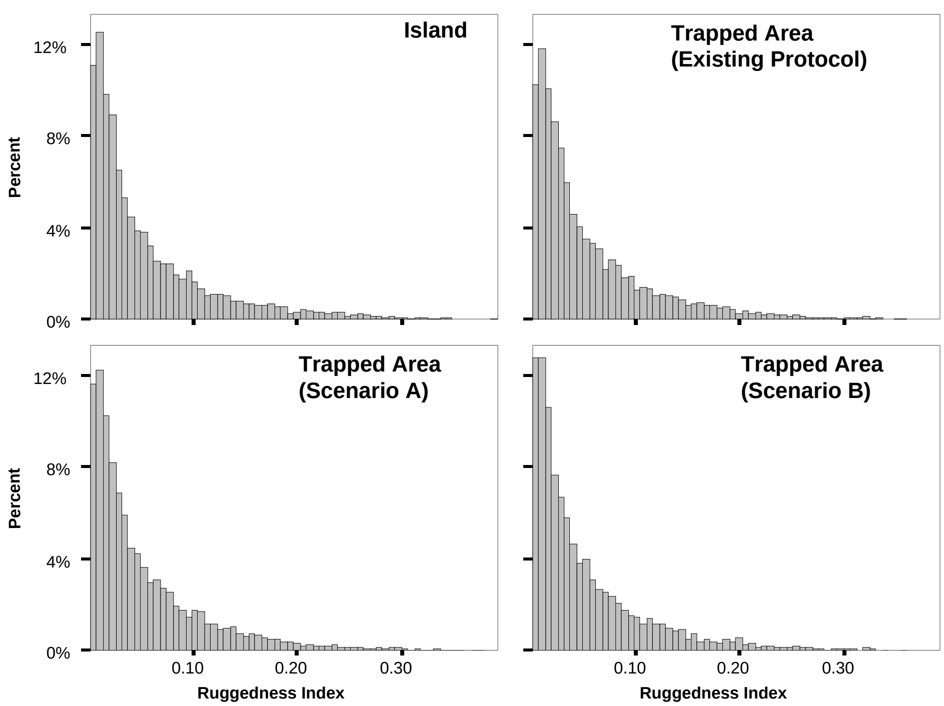


Figure E-2. Distribution of ruggedness (as percent of random points) on Santa Cruz Island versus in areas trapped with three trapping scenarios (Existing Protocol, Scenario A, and Scenario B).

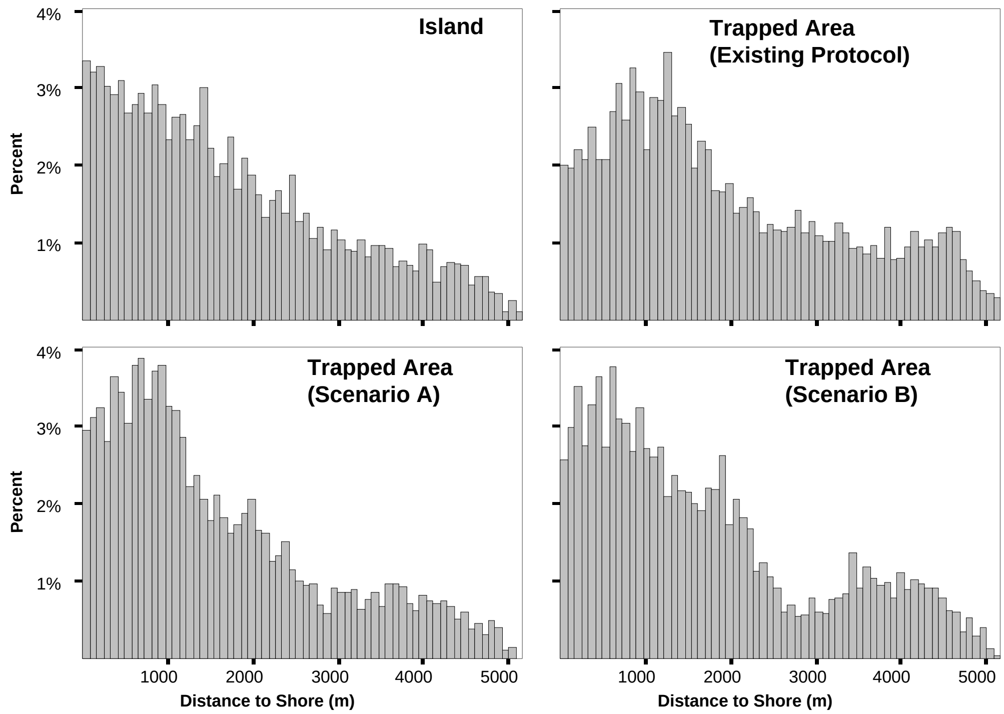


Figure E-3. Distribution of distance to shore (as percent of random points) on Santa Cruz Island versus in areas trapped with three trapping scenarios (Existing Protocol, Scenario A, and Scenario B).

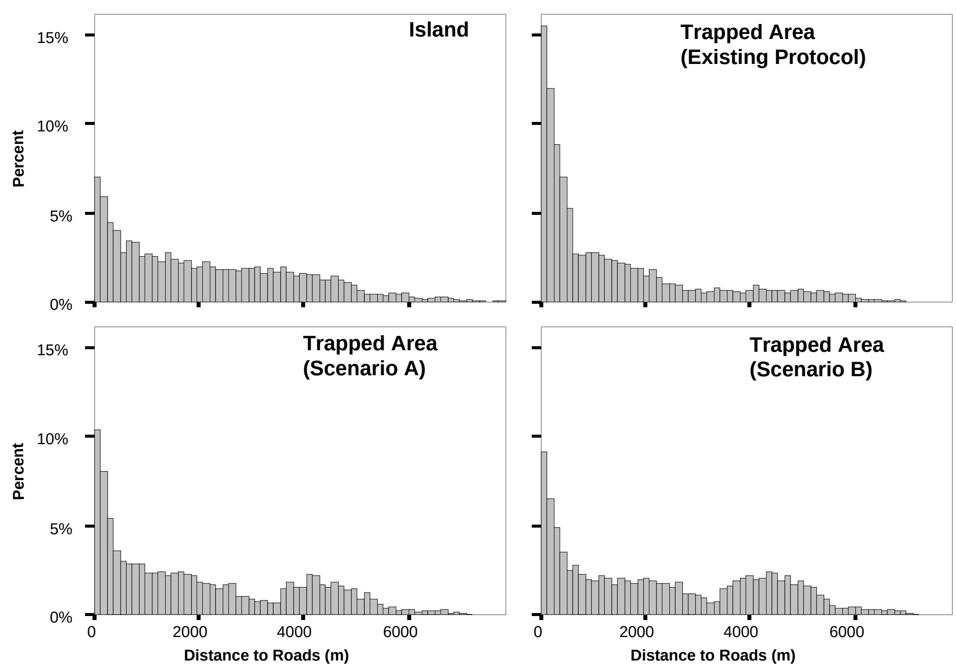


Figure E-4. Distribution of distance to roads (as percent of random points) on Santa Cruz Island versus in areas trapped with three trapping scenarios (Existing Protocol, Scenario A, and Scenario B).

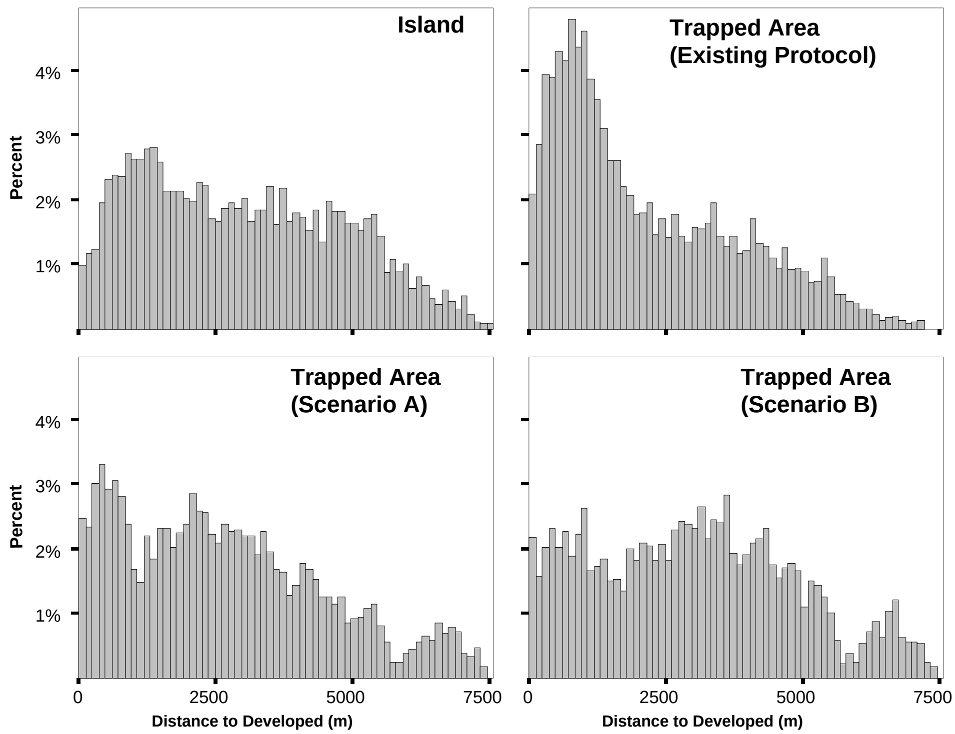


Figure E-5. Distribution of distance to developed areas (as percent of random points) on Santa Cruz Island versus in areas trapped with three trapping scenarios (Existing Protocol, Scenario A, and Scenario B).

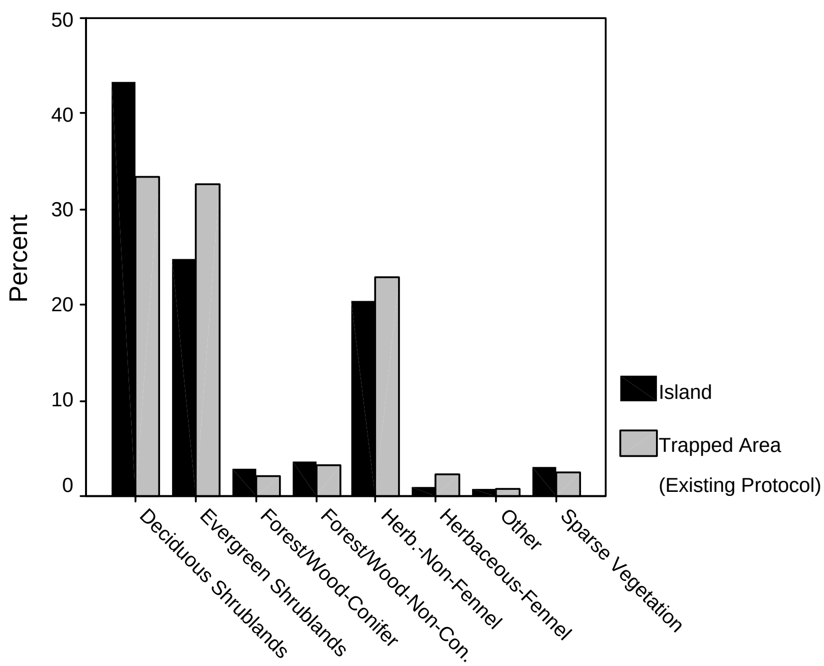


Figure E-6. Distribution of vegetation types (as percent of random points) on Santa Cruz Island versus in areas trapped with Existing Protocol.

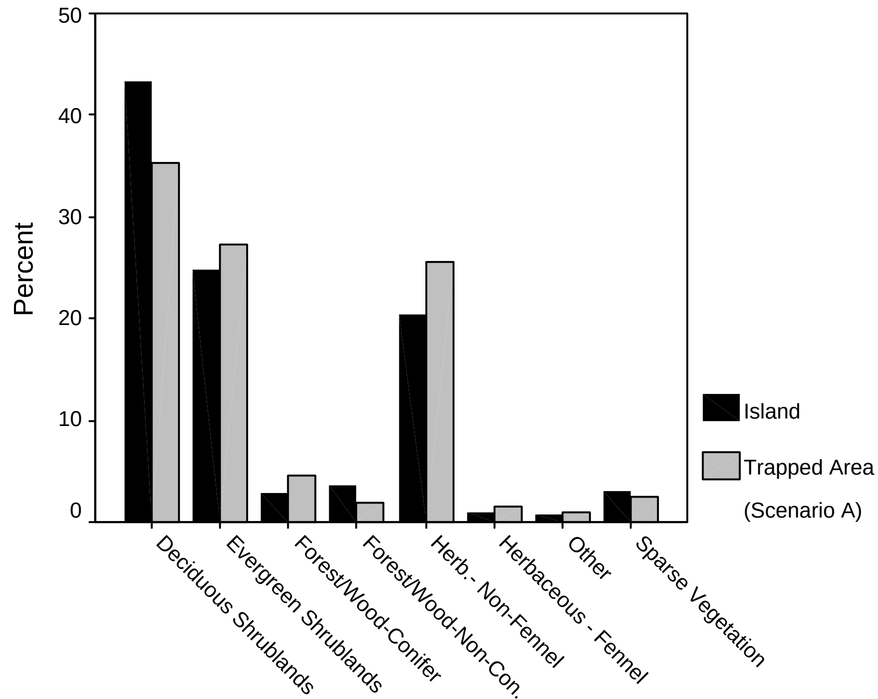


Figure E-7. Distribution of vegetation types (as percent of random points) on Santa Cruz Island versus in areas trapped with trapping Scenario A.

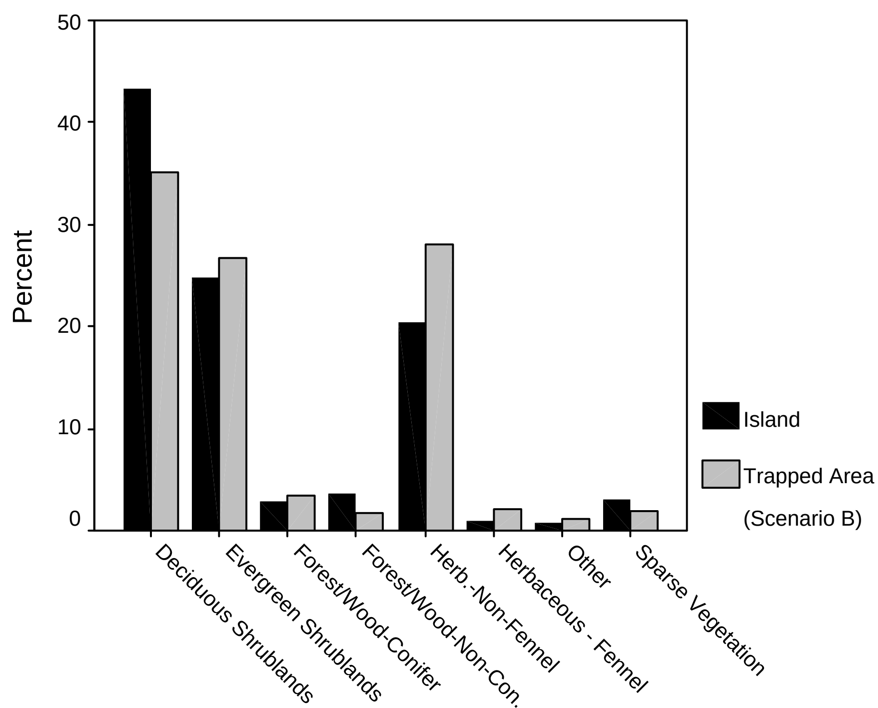


Figure E-8. Distribution of vegetation types (as percent of random points) on Santa Cruz Island versus in areas trapped with trapping Scenario B.

APPENDICES F–J

Prepared by

Vickie J. Bakker

Appendix F

Multivariate Analysis of Habitat Characteristics of Existing and Proposed Trapping Scenarios on San Miguel Island

Introduction

The monitoring plan in the main body of this report proposes a new design for mark-recapture trapping of island foxes on San Miguel Island to increase the efficiency and robustness of monitoring efforts and to achieve new monitoring goals. Under this plan, trapping would consist of a dispersed set of small trapping units (2x6 traps or 5x6 traps). Historically, island foxes have been trapped using mark-recapture trapping methods with traps arrayed in some type of grid formation. This appendix uses multivariate statistical methods to evaluate the degree to which current and proposed trapping locations sample the range of variation on the island for features hypothesized to be important to foxes. The intent of this analysis is to add to the interpretations of the univariate representation analyses by using principal components analysis (PCA) to focus on groups of habitat attributes that tend occur together.

Methods

Six continuous variables were identified as likely to influence fox habitat quality on San Miguel Island─slope, ruggedness, distance to trails, distance to human development, distance to shoreline, and distance to freshwater. These habitat characteristics were extracted from a GIS at randomly located points at a density of ~144 points/km^2), and trapped areas (existing and proposed) were sampled similarly. Trapped areas were defined as all locations within a 600-m buffer of a trap station. The buffer was added to characterize the entire area likely to be used by foxes entering traps including areas used by foxes living adjacent to grids and captured in perimeter traps. The 600-m buffer is equal to the mean of the mean maximum distances moved for each trapping session for all years for grids on San Clemente, Santa Cruz, San Miguel, and San Nicolas Islands. Additional details on methods of habitat characterization for San Miguel Island can be found in Appendix A.

To compare the multivariate attributes of trapped areas to those of the entire island, I performed a principal components analysis (SAS Proc Princomp; SAS Institute Inc. 2005) on the island-wide habitat data and compared mean principal component scores for trapped areas to those of island-wide areas overall and by vegetation type. The latter analysis was performed to assess whether the representativeness of trapped areas was influenced by sampling targeted at certain vegetation types that might have biased habitat characteristics. Variables were mean-centered and standardized prior to conducting the PCA (i.e., PCA used the correlation matrix). To allow a visual assessment of the habitat sampled by the trapped areas, I plotted the mean PC scores for both trapped and island-wide areas. I focus on detecting and describing the major differences in the attributes of trapped areas compared to the islands as a whole as evidenced by separation of 95% confidence intervals on the mean PC scores (while recognizing that separation of confidence intervals is a conservative metric for assessing difference (Schenker and Gentleman

2001). Habitat variables were transformed as necessary to achieve approximately normal distributions to improve the normality of PC scores, which is assumed when using PC scores for hypothesis tests. See Figure J-1 in Appendix J for an example of how PCA classifies multivariate habitat types.

PCA identifies patterns within multivariate data, eliminates correlation among data, and reduces the dimensionality of multivariate data to simplify analyses. PCA can add to univariate assessments of representation by focusing on groups of habitat attributes that tend occur together, such as steep rugged shoreline, thereby refining the types of areas that are under or overrepresented.

Results and Discussion

PCA interpretations. Nearly 40% of the variation in terrain variables is accounted for by the first principal component, which is more than twice the second principal component. Use of four PCs can describe the island and trapping areas thoroughly (Table F-1).

Table F-1. Eigenvalues of the correlation matrix for PCA on terrain attributes on San Miguel Island.

Principal component	Eigenvalue	Proportion of variance	Cumulative variance
1	2.4	0.393	0.393
2	1.1	0.182	0.575
3	1.0	0.162	0.737
4	0.8	0.126	0.862
5	0.5	0.083	0.946
6	0.3	0.054	1.000

PC1 is represents areas that are steep and rugged, close to shoreline, and far from trails and development, referred to here as “Remote shoreline.” PC2 is characterizes areas that are far from freshwater drainages and far from developed areas, referred to as “Dry remote terrain.” PC3 represents areas that are close to freshwater drainages but far from trails and development, referred to as “Off-trail remote drainages.” Finally, PC4 is heavily influenced by areas far from development and shoreline but close to trails and is referred to as “Remote interior trails.”

Table F-2. Eigenvectors for PCA on terrain attributes on San Miguel Island.

	Principal Component 1	2	3	4
	Steep rugged off-trail shoreline	**Dry remote terrain**	**Off-trail remote drainages**	**Remote interior trails**
Slope[1]	0.52	-0.26	-0.23	0.20
Ruggedness[2]	0.51	-0.26	-0.27	0.30
Distance to…				
Trails[3]	0.40	0.21	0.48	-0.53
Development[3]	0.29	0.48	0.51	0.60
Shoreline[3]	-0.47	-0.15	0.21	0.47
Freshwater[2]	-0.03	0.75	-0.59	0.04

[1] Cube-root transformed [2] ln transformed [3] Square-root transformed

Representation analysis using PCA

Overall. Both the large grids of the 1990s and the current small grids under-represent all PCs, under-sampling steep rugged remote shoreline (PC1), remote areas far from drainages (PC2), remote drainages far from trails (PC3), and remote trails in the interior (PC4, Figure F-1). Proposed Scenario B similarly under-samples steep remote shoreline but is unbiased with respect to all other multivariate habitat types except for remote interior trails, which are over-sampled. Finally, proposed Scenario C adequately represents most multivariate habitat types including steep rugged remote shoreline but under-samples terrain far from drainages and development, such as those found near the center of the island.

By vegetation type. Existing grids under-sample steep rugged off-trail shoreline (PC1) and dry remote terrain (PC2) for all vegetation type except for grassland habitats, where recent grids better sample these habitat complexes (Figure F-2). In contrast, both proposed scenarios sample more atypical grassland habitat on PC1 (Figure F-3). Scenario B under-samples steep rugged off-trail shoreline across vegetation types, while Scenario C displays less bias within each vegetation type and none in *Haplopappus* scrub resulting in no bias overall. The opposite situation occurs with dry remote terrain, where Scenario B generally displays less sampling bias within each habitat type, resulting in no overall bias.

Conclusions

Both the large grids of the 1990s and the current small grids under-represent all multivariate habitat types, under-sampling steep rugged remote shoreline and areas remote from development regardless of proximity to drainages and trails. Proposed trapping scenarios better represent the island. Scenario B under-samples steep rugged remote shoreline and over-samples remote interior trails but is otherwise unbiased. Scenario C adequately represents most multivariate habitat types including steep rugged remote shoreline but under-samples terrain far from drainages and development. Overall, Scenario C provides the most representative sampling of multivariate habitat types. Biases in multivariate habitat sampled by proposed scenarios likely results from logistical constraints placed on trap unit location to ensure feasibility of the trapping effort. Regardless of scenario chosen, density and demographic rates in disproportionately sampled habitat types should be compared to overall island-wide patterns to assure that habitat biases do not bias monitoring program results.

Literature Cited

SAS Institute Inc. 2005. SAS/STAT user's guide. Release 8.02 edition. SAS Institute, Inc., Cary, NC.

Schenker, N., and J.F. Gentleman. 2001. On judging the significance of differences by examining the overlap between confidence intervals. The American Statistician **55**:182-186.

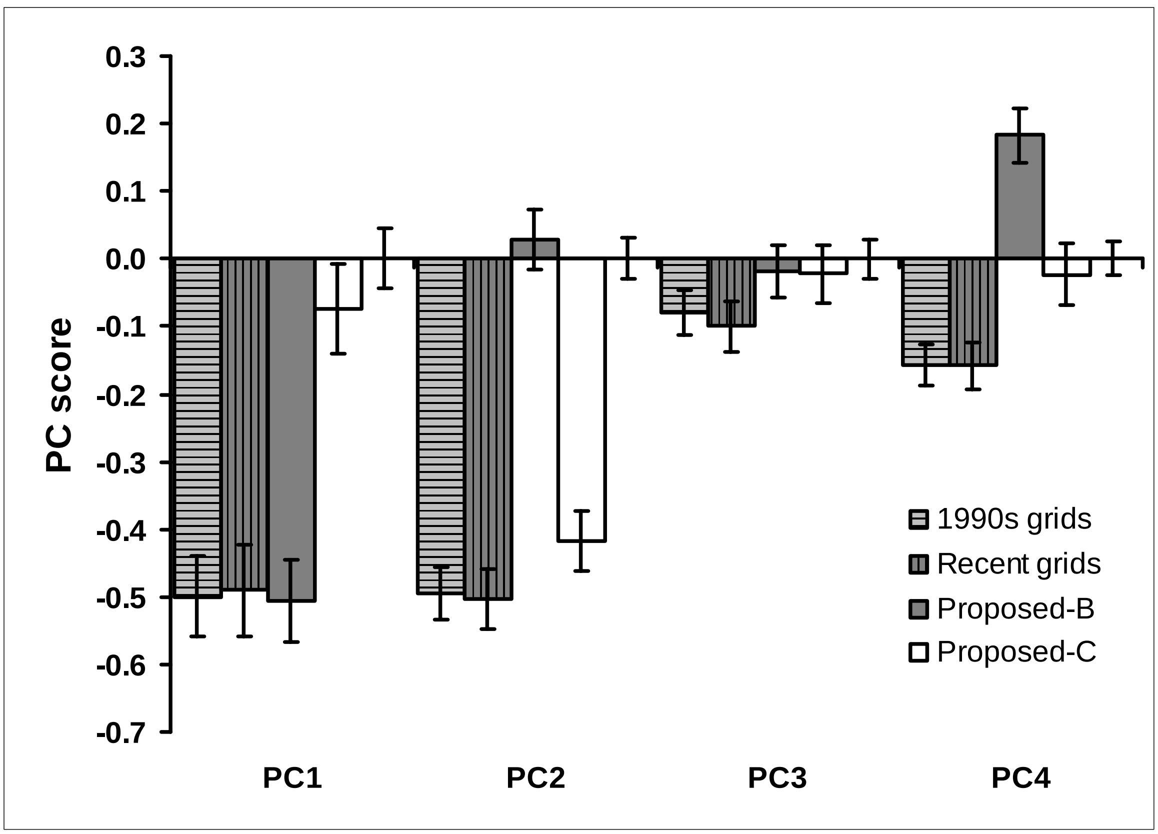


Figure F-1: Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas trapped for island foxes with large grids in the 1990s, with recent smaller grids, and with proposed trapping Scenarios B and C. Also shown are confidence intervals for island-wide PC scores; the island-wide mean for each PC is 0 because PCA was performed on island data and variables were mean centered and standardized prior to analysis. PC1 is remote shoreline areas, PC2 is dry remote terrain, and PC3 is off-trail remote drainages. PC4 is remote interior trails.

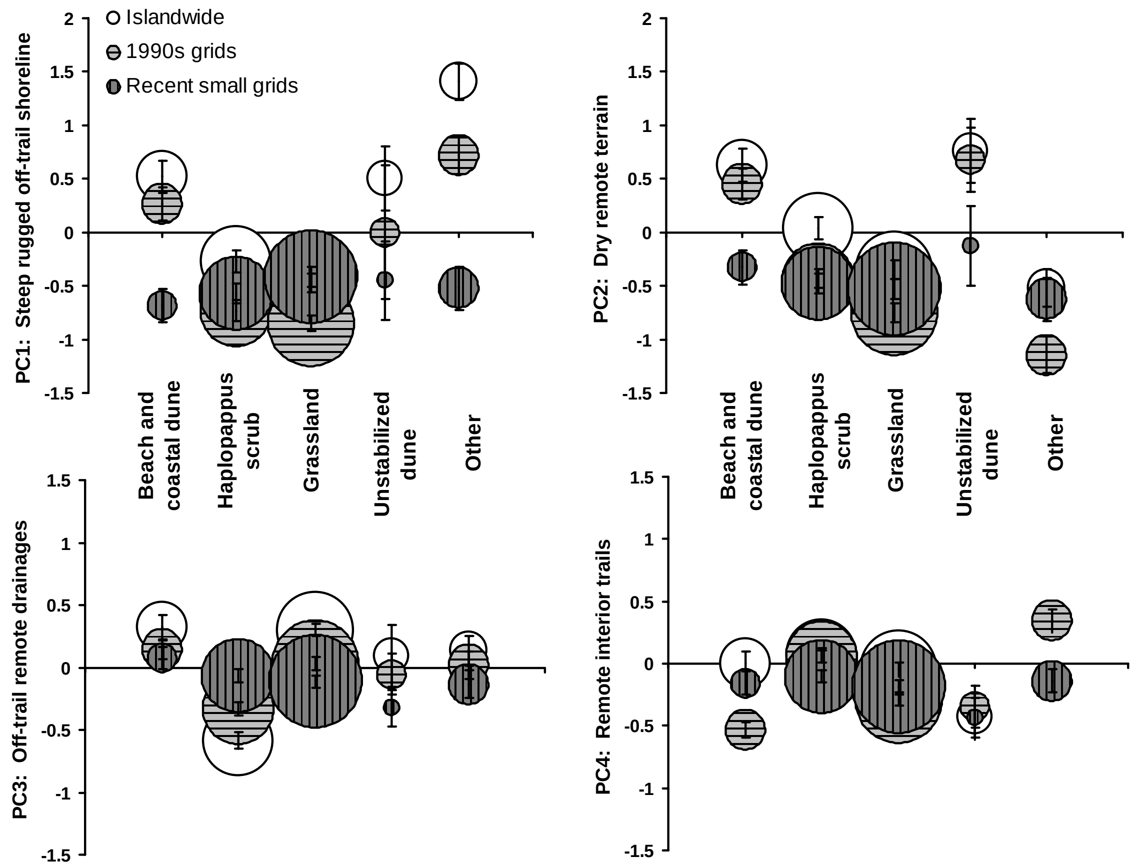


Figure F-2. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas in areas trapped for island foxes with large grids in the 1990s and with recent smaller grids relative to the entire island by vegetation type. Marker size is weighted by proportional coverage of each vegetation type.

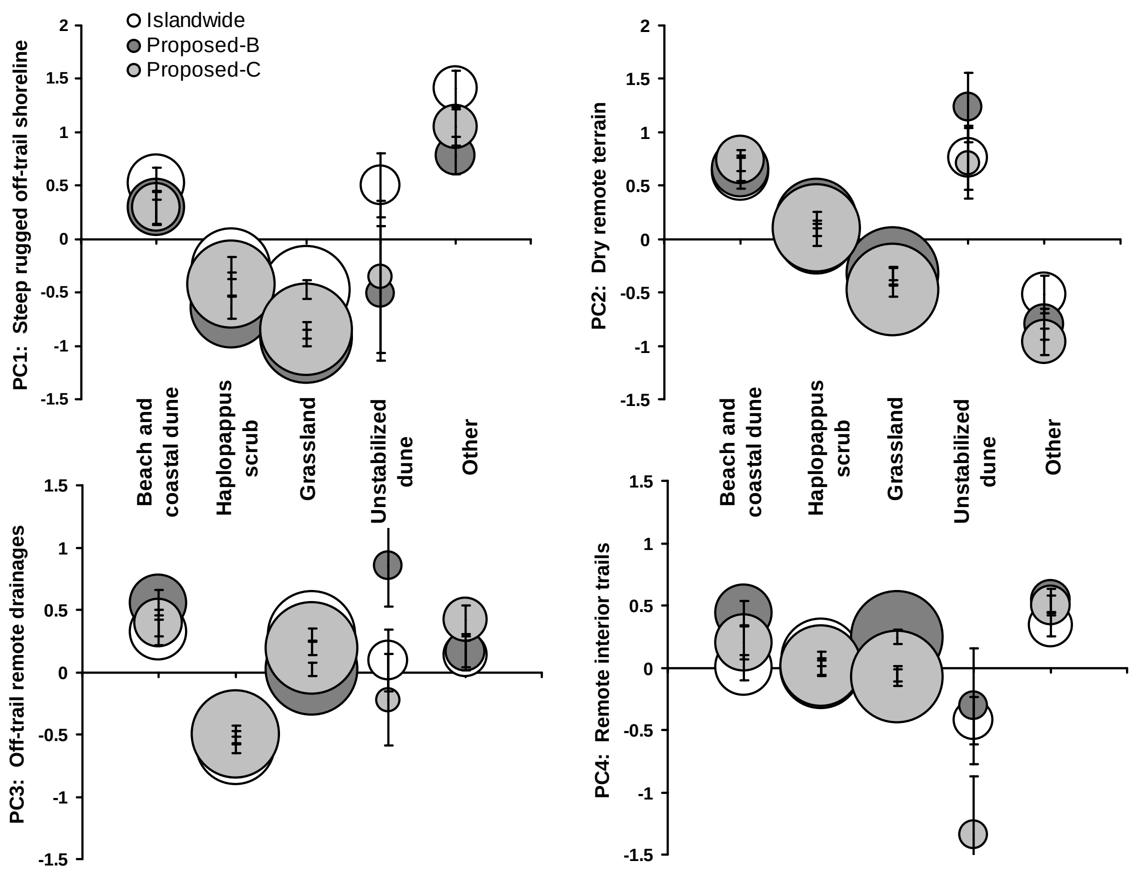


Figure F-3. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas proposed for trapping under Scenarios B and C grids relative to the entire island by vegetation type. Marker size is weighted by proportional coverage of each vegetation type.

Appendix G

Multivariate Analysis of Habitat Characteristics of Existing and Proposed Trapping Scenarios on San Nicolas Island

Introduction

The monitoring plan in the main body of this report proposes a new design for mark-recapture trapping of island foxes on San Nicolas Island to increase the efficiency and robustness of monitoring efforts and to achieve new monitoring goals. Under this plan, trapping would consist of a dispersed set of small trapping units (2x6 traps or 6x6 traps). Historically, island foxes have been trapped using mark-recapture trapping methods with traps arrayed in large grids. This appendix uses multivariate statistical methods to evaluate the degree to which current and proposed trapping locations sample the range of variation on the island for features hypothesized to be important to foxes. The intent of this analysis is to add to the interpretations of the univariate representation analyses by using principal components analysis (PCA) to focus on groups of habitat attributes that tend occur together.

Methods

Six continuous variables were identified as likely to influence fox habitat quality on San Nicolas Island─slope, ruggedness, distance to trails, distance to human development, distance to shoreline, and distance to freshwater. These habitat characteristics were extracted from a GIS at randomly located points at a density of ~144 points/km^2), and trapped areas (existing and proposed) were sampled similarly. Trapped areas were defined as all locations within a 600-m buffer of a trap station. The buffer was added to characterize the entire area likely to be used by foxes entering traps including areas used by foxes living adjacent to grids and captured in perimeter traps. The 600-m buffer is equal to the mean of the mean maximum distances moved for each trapping session for all years for grids on San Clemente, Santa Cruz, San Miguel, and San Nicolas Islands. Additional details on methods of habitat characterization for San Nicolas Island can be found in Appendix B.

To compare the multivariate attributes of trapped areas to those of the entire island, I performed a principal components analysis (SAS Proc Princomp; SAS Institute Inc. 2005) on the island-wide habitat data and compared mean principal component scores for trapped areas to those of island-wide areas overall and by vegetation type. The latter analysis was performed to assess whether the representativeness of trapped areas was influenced by sampling targeted at certain vegetation types that might have biased habitat characteristics. Variables were mean-centered and standardized prior to conducting the PCA (i.e., PCA used the correlation matrix). To allow a visual assessment of the habitat sampled by the trapped areas, I plotted the mean PC scores for both trapped and island-wide areas. I focus on detecting and describing the major differences in the attributes of trapped areas compared to the islands as a whole as evidenced by separation of 95% confidence intervals on the mean PC scores (while recognizing that separation of confidence intervals is a conservative metric for assessing difference (Schenker and Gentleman

2001). Habitat variables were transformed as necessary to achieve approximately normal distributions to improve the normality of PC scores, which is assumed when using PC scores for hypothesis tests. See Figure J-1 in Appendix J for an example of how PCA classifies multivariate habitat types.

PCA identifies patterns within multivariate data, eliminates correlation among data, and reduces the dimensionality of multivariate data to simplify analyses. PCA can add to univariate assessments of representation by focusing on groups of habitat attributes that tend occur together, such as steep rugged shoreline, thereby refining the types of areas that are under or overrepresented.

Results and Discussion

PCA interpretations. Nearly 50% of the variation in the terrain variable is accounted for by the first principal component. Using three or four PCs describes the island thoroughly (Table G-1).

Table G-1. Eigenvalues of the correlation matrix for PCA on habitat attributes on San Nicolas Island.

Principal component	**Eigenvalue**	**Proportion of variance**	**Cumulative variance**
1	2.907	0.485	0.485
2	1.268	0.211	0.696
3	0.742	0.124	0.820
4	0.503	0.084	0.903
5	0.300	0.050	0.953
6	0.280	0.047	1.000

PC1 contained approximately equal loadings from all variables, and thus it represents areas that are steep and rugged, far from paved roads, development and freshwater but close to shoreline (Table G-2), referred to here as “Dry steep rugged remote shoreline.” PC2 accounts for steep and rugged terrain near freshwater sources, labeled here as “Steep rugged drainages.” PC3 represents areas far from paved roads, development, and shoreline but close to freshwater, referred to as “Remote interior drainages.” Finally, PC4 represents lands far from shoreline and freshwater and is labeled “Dry interior.”

Table G-2. Eigenvectors for PCA on habitat attributes on San Nicolas Island.

	Principal Component			
	1	2	3	4
	Dry steep rugged remote shoreline	**Steep rugged drainages**	**Remote interior drainages**	**Dry interior**
Slope[1]	0.36	0.61	-0.02	0.17
Ruggedness[1]	0.38	0.57	-0.19	-0.01
Distance to…				
Paved roads[2]	0.48	-0.21	0.39	0.02
Development[3]	0.45	-0.19	0.59	-0.07
Shoreline[3]	-0.41	0.24	0.50	0.70
Freshwater[3]	0.37	-0.41	-0.46	0.68

[1]ln transformed [2] Cube-root transformed [3] Square-root transformed

Representation analysis using PCA

Overall. Existing grid trapping has underrepresented PC1 and modestly overrepresented PC4 (Figure G-1). Thus, dry rugged remote shoreline is under-sampled, although once accounting for topography linked to proximity to shoreline and development, steep and rugged terrain is not under-sampled (PC2, Figure G-1). Interior areas far from drainages are somewhat over-sampled (PC4, Figure G-1). Proposed trapping scenarios under-represent steep and rugged terrain of all types (PC1 and PC2) and modestly over-represent interior terrain of all types (PC3 and 4, Figure G-1). Scenario C appears to do a slightly better overall job representing multivariate habitat types on the island.

By vegetation type. Trapping areas appear to sample the major vegetation types roughly in proportion to their occurrence on the island, although *Coreopsi*s vegetation is clearly under-sampled (Figure G-2). Within each vegetation type, trapping grids consistently under-represent PC1 and over-represent PC4, similar to overall island-wide patterns (Figure G-2). Interestingly, the lack of bias in sampling PC2 and PC3 arises partly from positive and negative biases within many vegetation types, although there was no bias for coast scrub, the most extensive vegetation type.

Proposed Scenarios B and C appear to sample the major vegetation types roughly in proportion to their occurrence on the island including better representation of *Coreopsis* vegetation (Figure G-3). Within major vegetation types, both proposed trapping scenarios generally under-represent PC1 and PC2 and over-represent PC3 and 4, similar to overall island-wide patterns (Figure G-3). However, Scenario C represents barren vegetation with little bias with respect to rough remote shoreline (PC1), and Scenario B adequately represents steep rugged drainages in barren vegetation types.

Conclusions

Existing grid trapping has underrepresented dry rugged remote shoreline, although once accounting for topography linked to proximity to shoreline and development, steep and rugged terrain was not under-sampled. Interior areas far from drainages are currently somewhat over-sampled. Proposed trapping scenarios under-represent steep and rugged terrain of all types, and modestly over-represent interior terrain of all types. Overall, Scenario C appears to do a slightly better overall job representing multivariate habitat types on the island. Biases in multivariate habitat sampled by proposed scenarios likely result from logistical constraints placed on trap unit location to ensure feasibility of the trapping effort. Density and demographic rates in disproportionately sampled habitat types should be compared to overall island-wide patterns to assure that these biases do not bias monitoring program results.

Literature Cited

SAS Institute Inc. 2005. SAS/STAT user's guide. Release 8.02 edition. SAS Institute, Inc., Cary, NC.

Schenker, N., and J.F. Gentleman. 2001. On judging the significance of differences by examining the overlap between confidence intervals. The American Statistician **55**:182-186.

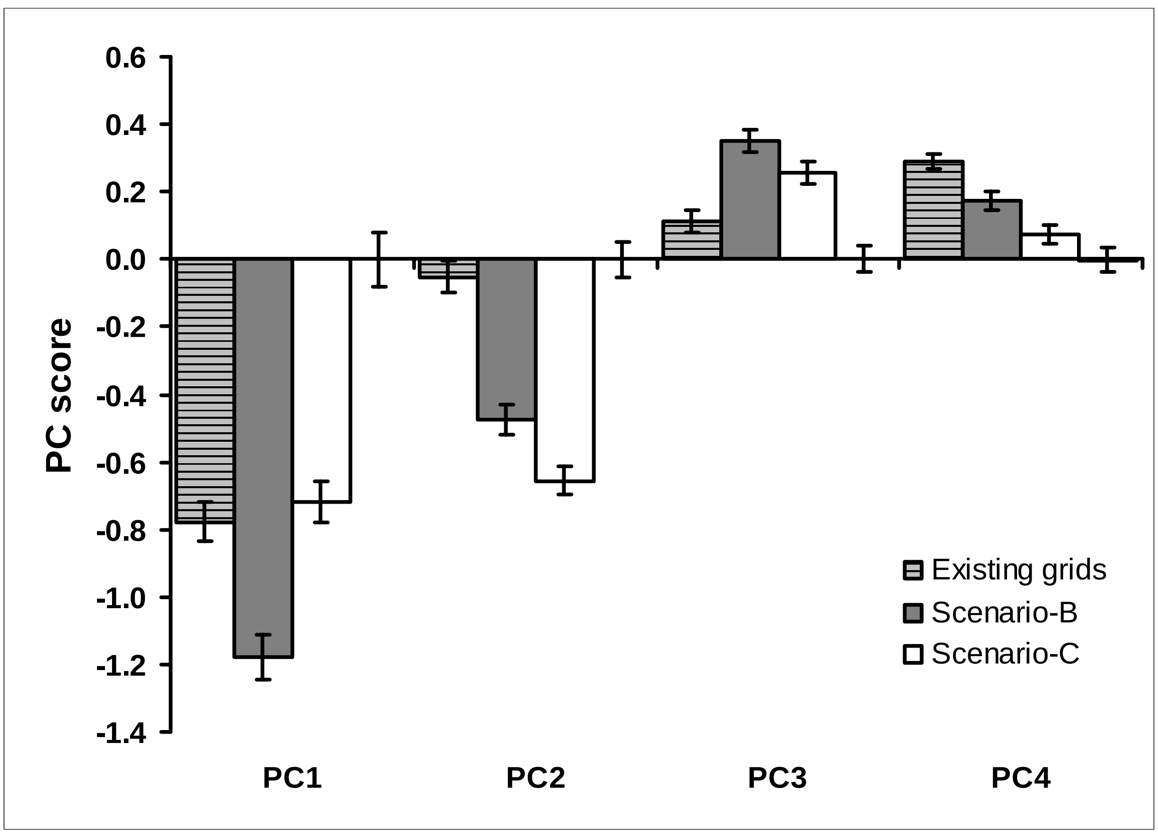


Figure G-1. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas currently trapped for island foxes and those proposed for trapping under Scenarios B and C. Also shown are confidence intervals for island-wide PC scores; the island-wide mean for each PC is 0 because PCA was performed on island data and variables were mean centered and standardized prior to analysis. PC1 is dry remote rugged shoreline. PC2 is steep and rugged drainages. PC3 is remote interior drainages. PC4 is dry interior.

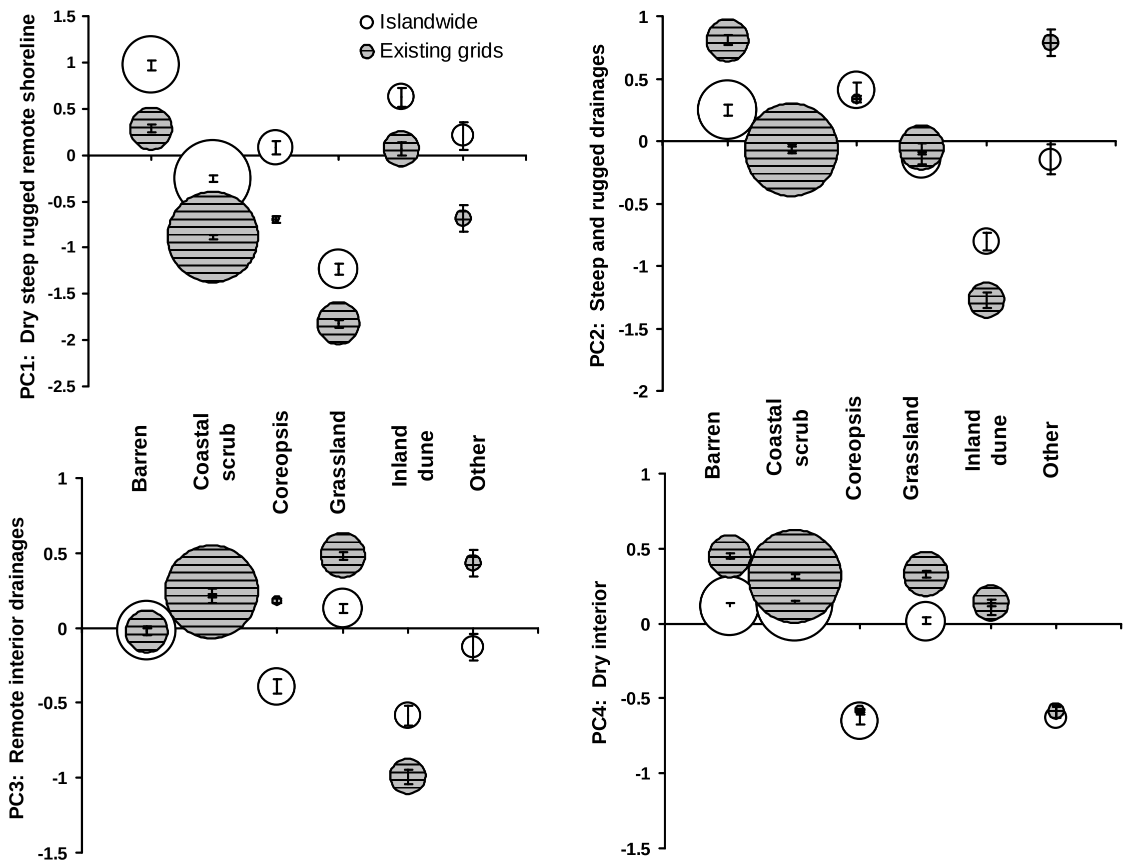


Figure G-2. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas currently trapped by existing grids relative to the entire island by vegetation type for PC1-4. Marker size is weighted by proportional coverage of each vegetation type.

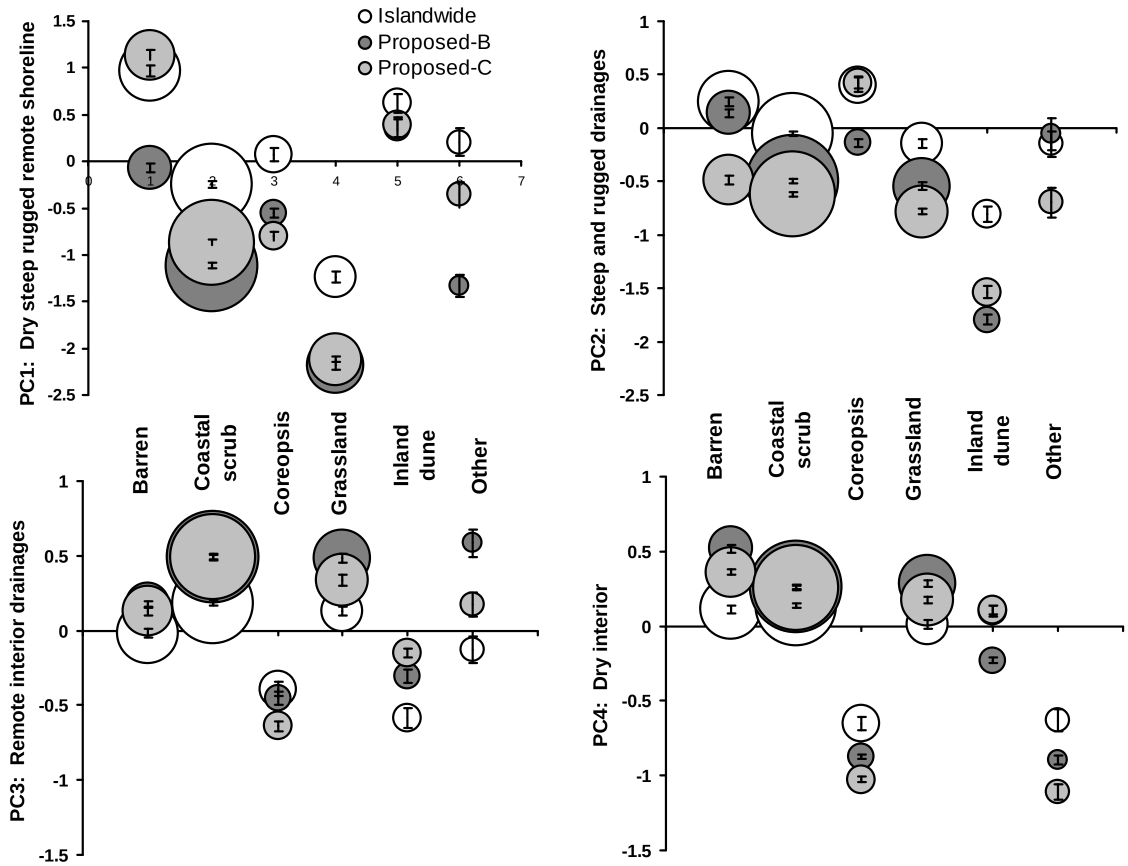


Figure G-3. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas proposed for trapping under Scenarios B and C relative to the entire island by vegetation type for PC1-4. Marker size is weighted by proportional coverage of each vegetation type.

Appendix H

Multivariate Analysis of Habitat Characteristics of Existing and Proposed Trapping Scenarios on Santa Catalina Island

Introduction

The monitoring plan in the main body of this report proposes a new design for mark-recapture trapping of island foxes on Santa Catalina Island to increase the efficiency and robustness of monitoring efforts and to achieve new monitoring goals. Under this plan, trapping would consist of a dispersed set of small trapping units (2x6 traps). Historically, island foxes have been trapped using mark-recapture trapping methods with traps arrayed in single line transects throughout Santa Catalina Island. This appendix uses multivariate statistical methods to evaluate the degree to which current and proposed trapping locations sample the range of variation on the island for features hypothesized to be important to foxes. The intent of this analysis is to add to the interpretations of the univariate representation analyses by using principal components analysis (PCA) to focus on groups of habitat attributes that tend occur together.

Methods

Because foxes in the areas west of Two Harbors on Santa Catalina Island are considered to be an isolated population, separate sampling plans are proposed for eastern and western parts of the island. Thus, two separate analyses of representativeness were conducted. Six continuous variables were identified as likely to influence fox habitat quality on the East End of Santa Catalina Island—slope, ruggedness, distance to paved roadways, distance to human development, distance to freshwater, and distance to shoreline. Distances to freshwater and paved roads were not considered for the West End of Santa Catalina Island because neither freshwater nor paved roads were found there. These habitat characteristics were extracted from a GIS at randomly located points at a density of ~144 points/km^2), and trapped areas (existing and proposed) were sampled similarly. Trapped areas were defined as all locations within a 600-m buffer of a trap station. The buffer was added to characterize the entire area likely to be used by foxes entering traps including areas used by foxes living adjacent to grids and captured in perimeter traps. The 600-m buffer is equal to the mean of the mean maximum distances moved for each trapping session for all years for grids on San Clemente, Santa Cruz, San Miguel, and San Nicolas Islands. Additional details on methods of habitat characterization for Santa Catalina Island can be found in Appendix C.

To compare the multivariate attributes of trapped areas to those of the entire island, I performed a principal components analysis (SAS Proc Princomp; SAS Institute Inc. 2005) on the island-wide habitat data and compared mean principal component scores for trapped areas to those of island-wide areas overall and by vegetation type. The latter analysis was performed to assess whether the representativeness of trapped areas was influenced by sampling targeted at certain vegetation types that might have biased habitat characteristics. Variables were mean-centered and standardized prior to conducting the PCA (i.e., PCA used the correlation matrix). To allow a visual assessment of the habitat sampled by the trapped areas, I plotted the mean PC scores for both trapped and island-wide areas. I focus on detecting and describing the major differences in the attributes of trapped areas compared to the islands as a whole as evidenced by separation of 95% confidence intervals on the mean PC scores (while recognizing that separation of confidence intervals is a conservative metric for assessing difference (Schenker and Gentleman 2001). Habitat variables were transformed as necessary to achieve approximately normal distributions to improve the normality of PC scores, which is assumed when using PC scores for hypothesis tests.

PCA identifies patterns within multivariate data, eliminates correlation among data, and reduces the dimensionality of multivariate data to simplify analyses. PCA can add to univariate assessments of representation by focusing on groups of habitat attributes that tend occur together, such as steep rugged shoreline, thereby refining the types of areas that are under or overrepresented. See Figure J-1 in Appendix J for an example of how PCA classifies multivariate habitat types.

Results and discussion

Santa Catalina Island—East End

PCA interpretations. Four principal components accounts for 85% of the variation on the east side of the island (Table H-1).

Table H-1. Eigenvalues of the correlation matrix for PCA on habitat attributes on the East End of Santa Catalina Island.

Principal component	Eigenvalue	Proportion of variance	Cumulative variance
1	1.87	0.31	0.312
2	1.51	0.25	0.564
3	1.01	0.17	0.732
4	0.72	0.12	0.852
5	0.54	0.09	0.941
6	0.35	0.06	1.000

More than 30% of the variation in the habitat attributes on the East End of Santa Catalina Island is accounted for by PC1, which contained positive loadings from areas that are steep, far from freshwater and development, and close to shoreline (Table H-2). Thus PC1, which generally characterizes steep escarpments on the island's perimeter, is referred to as "Dry remote steep shoreline." PC2 accounts for smooth and level areas remote from development, and is labeled as "Remote and gentle terrain." PC3 represents rugged terrain far from shore and development and is referred to as "Remote rugged interior." Finally, PC4 represents lands that are steep but not rugged.

Table H-2. Eigenvectors for PCA on habitat attributes on the East End of Santa Catalina Island.

	Principal Component			
	1	2	3	4
	Dry remote steep shoreline	**Remote and gentle terrain**	**Remote rugged interior**	**Steep and smooth**
Slope[1]	0.36	-0.39	0.21	0.81
Ruggedness[2]	0.09	-0.43	0.70	-0.48
Distance to…				
Paved roads[3]	0.21	0.65	0.18	0.06
Development[1]	0.41	0.46	0.40	0.01
Shoreline[3]	-0.52	0.12	0.51	0.24
Freshwater[1]	0.61	-0.13	-0.13	-0.23

[1] Square-root transformed [2] ln transformed [3] Cube-root transformed

Representation analysis using PCA

Overall. Existing trapping under-represents PC1 and modestly over-represents PC2 (Figure H-1). Thus, existing trapping under-samples the island's steep escarpment far from development and tends to over-sample more gentle terrain far from development. All other habitat types appear to be well represented by current trapping. Proposed Scenarios A and B similarly under-sample PC1, the island's steep escarpment far from development. In contrast to existing trapping however, proposed scenarios significantly over-sample gentle terrain far from development and rugged interior terrain far from development, thereby indicating a general under-sampling of paved roads and development regardless of terrain type. Scenario A represents the multivariate attributes of the island modestly better than Scenario B.

By vegetation type. Both existing and proposed trapping scenarios generally sample vegetation in proportion to its occurrence. For all, trap locations within each vegetation type represent habitat attributes consistent with overall patterns (Figures H-2 and H-3). Thus, existing trap locations within each vegetation type sample atypical locations with respect to key habitat attributes, favoring locations with farther from remote shoreline and closer to remote and gentle terrain. Proposed scenarios show similar patterns but over-represent remote terrain of all types.

Santa Catalina Island—West End

PCA interpretations. Over a third of the variation in habitat attributes on the West End of Santa Catalina Island is accounted for by the first principal component (Table H-3), and three PCs characterize nearly 85% of the variation.

Table H-3. Eigenvalues of the correlation matrix for PCA on habitat attributes on the West End of Santa Catalina Island.

Principal component	Eigenvalue	Proportion of variance	Cumulative variance
1	1.40	0.350	0.350
2	1.03	0.257	0.607
3	0.95	0.236	0.843
4	0.63	0.157	1.000

PC1 represents areas with steep slopes far from development and is labeled "Steep and remote terrain" (Table H-4). PC2 is strongly influenced by areas far from shore and by rugged areas and is labeled "Rugged interior." PC3 represents gentle terrain, especially those lands far from development and shoreline ("Gentle remote interior").

Table H-4. Eigenvectors for PCA on habitat attributes on the West End of Santa Catalina Island.

	Principal Component		
	1	**2**	**3**
	Steep and remote terrain	**Rugged interior**	**Gentle remote interior**
Slope[1]	0.69	-0.11	0.11
Ruggedness[2]	0.29	0.48	-0.83
Distance to…			
Development[2]	0.61	0.26	0.43
Shoreline[3]	-0.27	0.83	0.35

[1] Square-root transformed [2]ln transformed [3] Cube-root transformed

Representation analysis using PCA

Overall. Existing transect trapping on the West End of Santa Catalina Island has modestly under-represented PC1 and has tended to over-represent the PC 2 (Figure H-4). Thus, steep terrain far from development (far from the town of Two Harbors) is under-sampled with current trapping, and there is minor over-sampling of interior areas, especially rugged interior. Proposed Scenario A (and B, which is identical) under-represents steep and remote terrain (PC1) more substantially than existing transects and over-represents gentle terrain in the remote interior (PC3) more significantly. However, the proposed scenario is unbiased with respect to rugged interior lands (PC2).

By vegetation type. Both existing and proposed scenarios generally sample vegetation in proportion to its occurrence. Avoidance of steep remote terrain by both existing and proposed trapping scenarios appears to arise largely from avoidance of these attributes within barren and coastal sage scrub habitats (PC1, Figures H-5 and H-6). Over-sampling of rugged interior by existing transects is also most pronounced in barren and coastal sage scrub habitat. Finally overrepresentation of gentle remote interior terrain tends to occur across all habitat types.

Conclusions

On the East End of Santa Catalina Island, both existing and proposed trapping scenarios under-sample the island's steep escarpment far from development. Proposed scenarios also significantly over-sample areas far from paved roads and development regardless of slope and ruggedness. Scenario A represents the multivariate attributes of the island modestly better than Scenario B. On the West End of the island, existing and proposed trapping scenarios again under-sample steep terrain far from development, with the proposed scenario more substantially biased in this regard. Existing transects over-sample rugged interior habitat, while the proposed scenario over-samples gentle remote interior. Biases in multivariate habitat sampled by proposed scenarios likely result from logistical constraints placed on trap unit location to ensure feasibility of the trapping effort. Density and demographic rates in disproportionately sampled habitat types should be compared to overall island-wide patterns to assure that monitoring program results are not biased.

Literature Cited

SAS Institute Inc. 2005. SAS/STAT user's guide. Release 8.02 edition. SAS Institute, Inc., Cary, NC.

Schenker, N., and J.F. Gentleman. 2001. On judging the significance of differences by examining the overlap between confidence intervals. The American Statistician **55**:182-186.

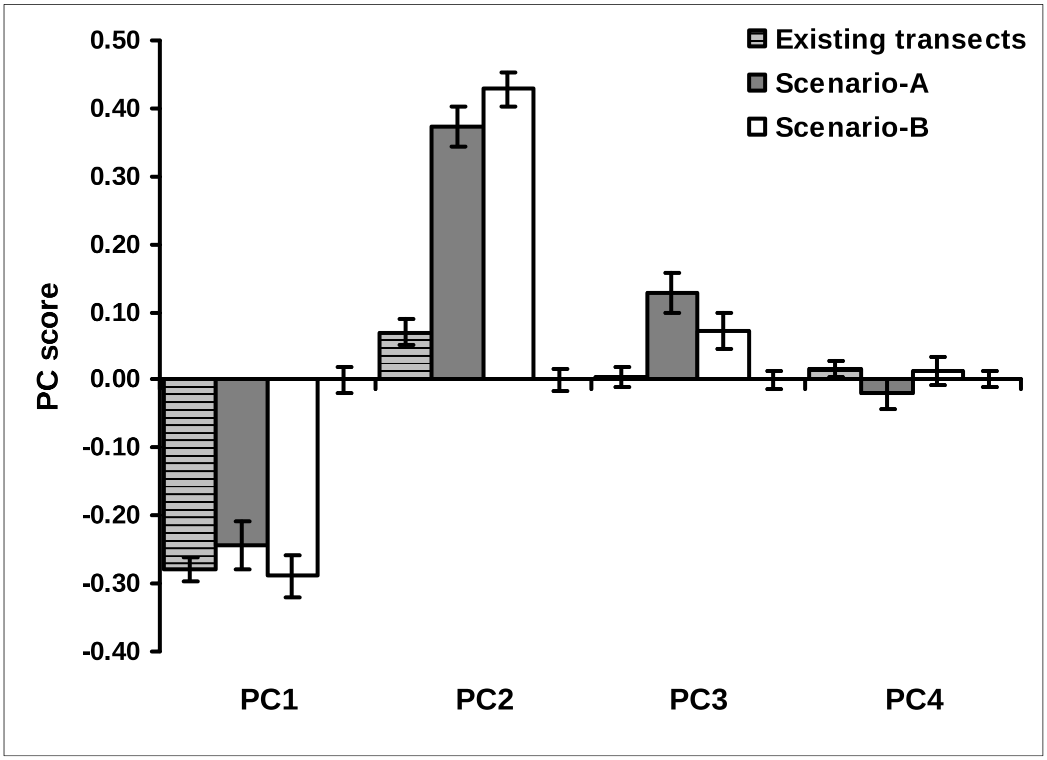


Figure H-1. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas currently trapped for island foxes and those proposed for trapping under Scenarios A and B. Also shown are confidence intervals for East End (i.e., island-wide) PC scores; the island-wide mean for each PC is 0 because PCA was performed on island data and variables were mean centered and standardized prior to analysis. PC1 characterizes dry steep shoreline. PC2 is influenced by remote gentle terrain. PC3 represents remote rugged interior. PC4 is influenced by steep smooth terrain.

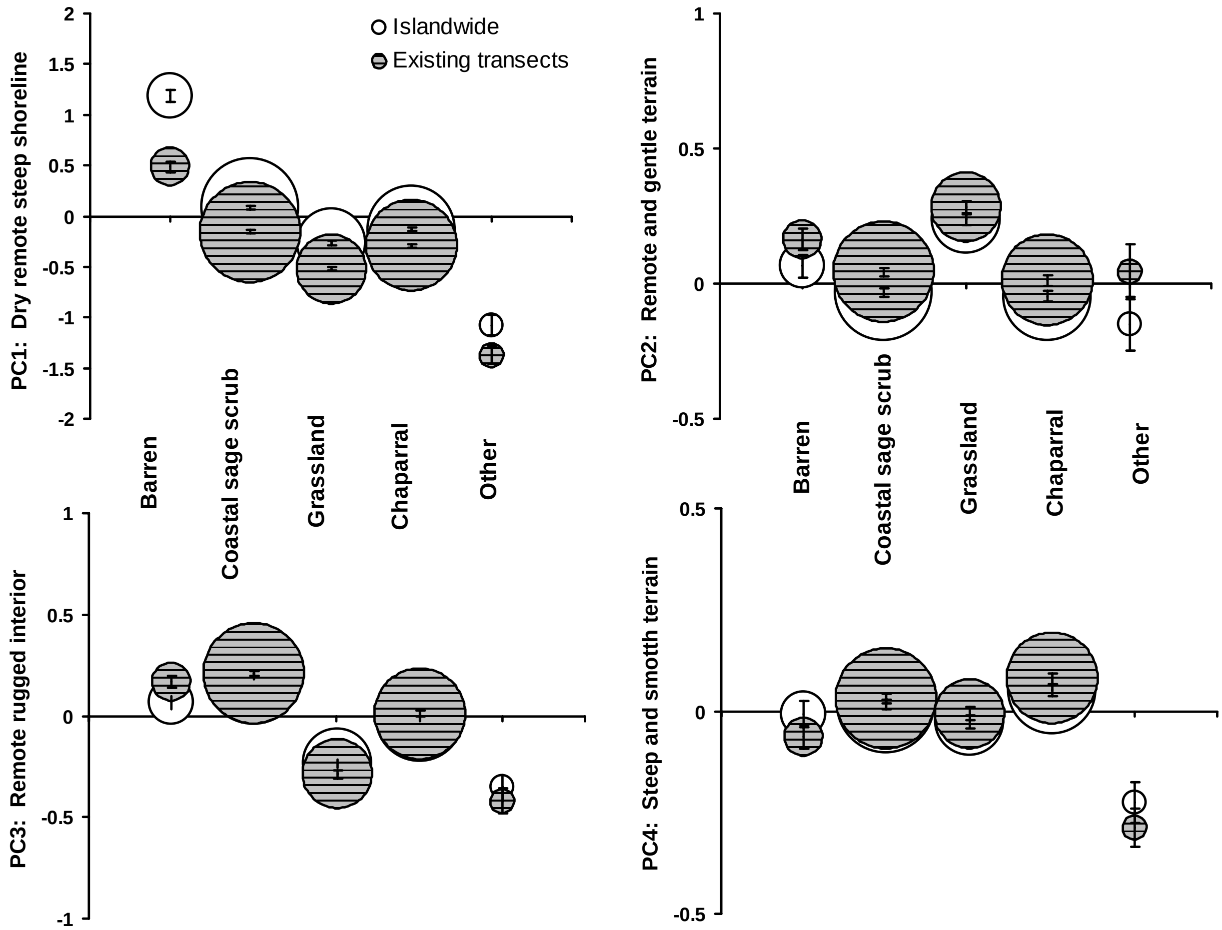


Figure H-2. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas currently trapped by existing transects relative to the entire East End of Santa Catalina Island by vegetation type for PC1-4. Marker size is weighted by proportional coverage of each vegetation type.

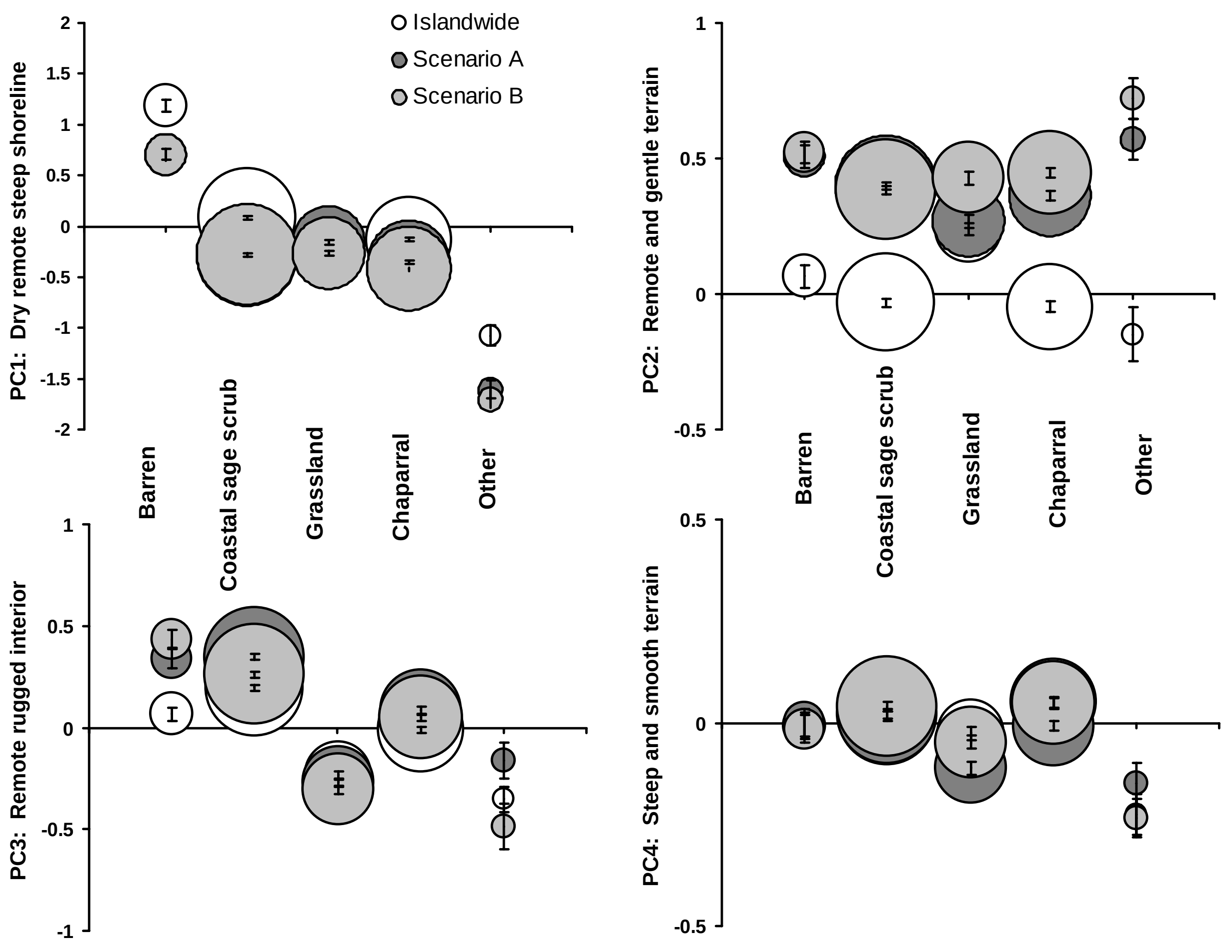


Figure H-3. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas proposed for trapping under Scenarios A and B relative to the entire East End of Santa Catalina Island by vegetation type for PC1-4. Marker size is weighted by proportional coverage of each vegetation type.

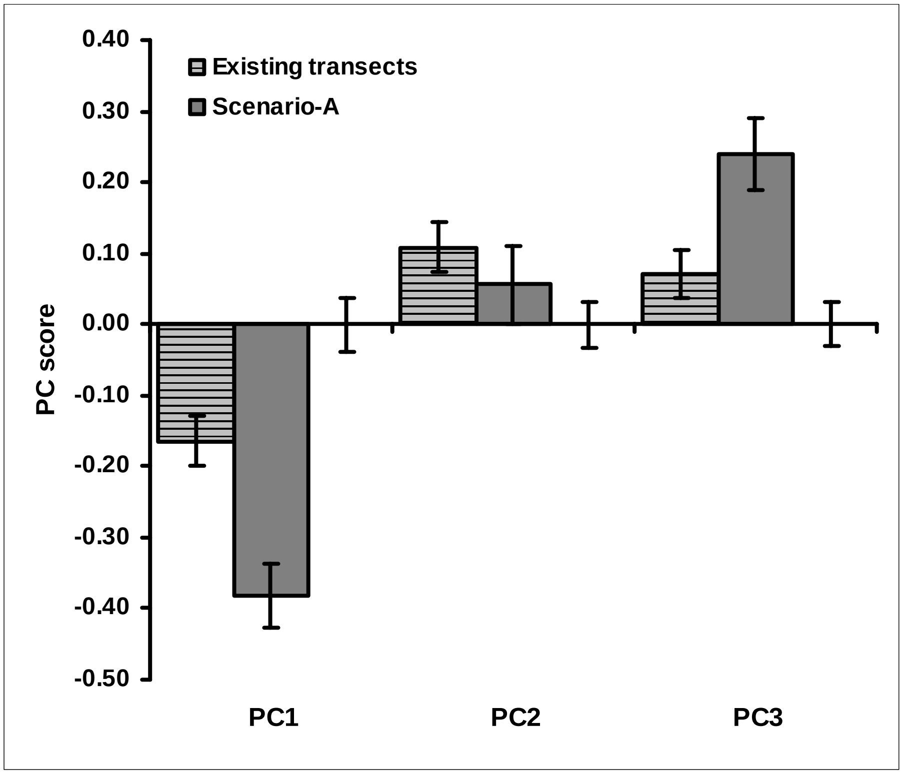


Figure H-4. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas currently trapped for island foxes and those proposed for trapping under Scenario A. Also shown are confidence intervals for West End (i.e., island-wide) PC scores; the island-wide mean for each PC is 0 because PCA was performed on island data and variables were mean centered and standardized prior to analysis. PC1 represents steep and remote terrain. PC2 is characterizes rugged interior. PC3 represents gentle remote interior.

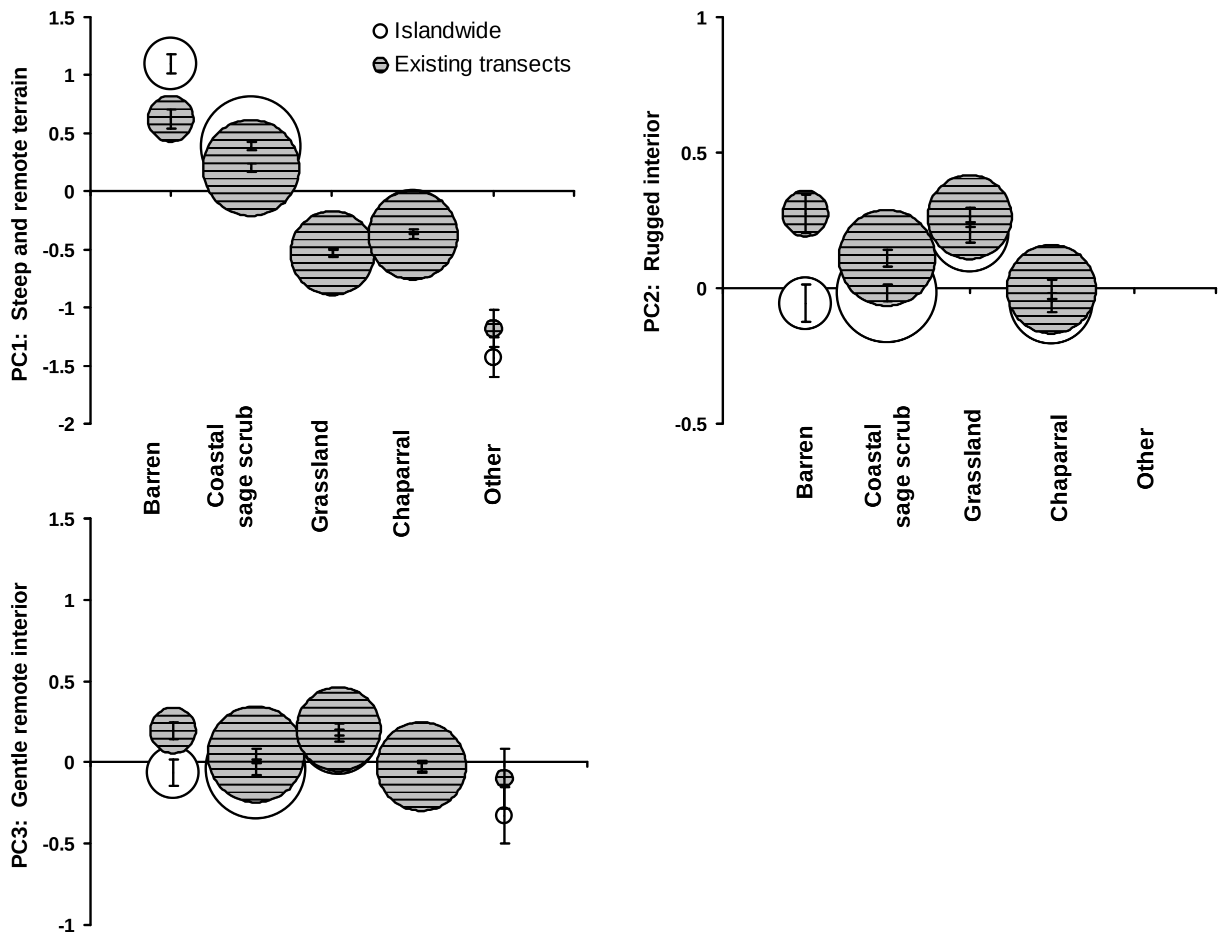


Figure H-5. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas currently trapped by existing transects relative to the entire West End of Santa Catalina Island by vegetation type for PC1-3. Marker size is weighted by proportional coverage of each vegetation type.

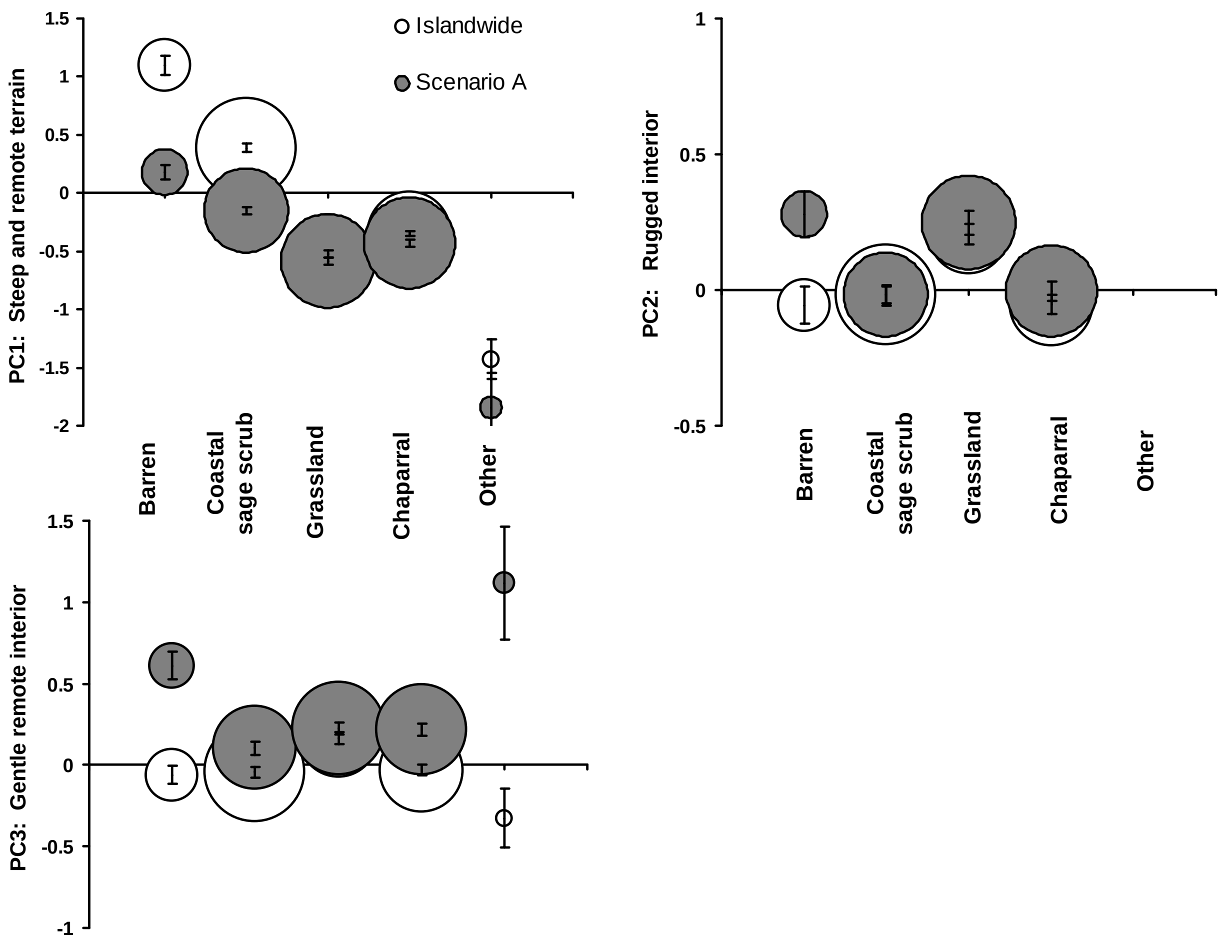


Figure H-6. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas proposed for trapping under Scenario A relative to the entire West End of Santa Catalina Island by vegetation type for PC1-3. Marker size is weighted by proportional coverage of each vegetation type.

Appendix I

Multivariate Analysis of Habitat Characteristics of Proposed Trapping Scenarios on Santa Rosa Island

Introduction

The monitoring plan in the main body of this report proposes a design for mark-recapture trapping of island foxes on Santa Rosa Island to achieve new monitoring goals for recovering foxes. Under this plan, trapping would consist of a dispersed set of small trapping units (2x6 traps). This appendix uses multivariate statistical methods to evaluate the degree to which proposed trapping locations sample the range of variation on the island for features hypothesized to be important to foxes. The intent of this analysis is to add to the interpretations of the univariate representation analyses by using principal components analysis (PCA) to focus on groups of habitat attributes that tend occur together.

Methods

Six continuous variables were identified as likely to influence fox habitat quality on Santa Rosa Island─slope, ruggedness, distance to roadways, distance to human development, distance to freshwater, and distance to shoreline. These habitat characteristics were extracted from a GIS at randomly located points at a density of ~144 points/km^2), and trapped areas were sampled similarly. Trapped areas were defined as all locations within a 600-m buffer of a trap station. The buffer was added to characterize the entire area likely to be used by foxes entering traps including areas used by foxes living adjacent to grids and captured in perimeter traps. The 600-m buffer is equal to the mean of the mean maximum distances moved for each trapping session for all years for grids on San Clemente, Santa Cruz, San Miguel, and San Nicolas Islands. Additional details on methods of habitat characterization for Santa Rosa Island can be found in Appendix D.

To compare the multivariate attributes of trapped areas to those of the entire island, I performed a principal components analysis (SAS Proc Princomp; SAS Institute Inc. 2005) on the island-wide habitat data and compared mean principal component scores for trapped areas to those of island-wide areas overall and by vegetation type. The latter analysis was performed to assess whether the representativeness of trapped areas was influenced by sampling targeted at certain vegetation types that might have biased habitat characteristics. Variables were mean-centered and standardized prior to conducting the PCA (i.e., PCA used the correlation matrix). To allow a visual assessment of the habitat sampled by the trapped areas, I plotted the mean PC scores for both trapped and island-wide areas. I focus on detecting and describing the major differences in the attributes of trapped areas compared to the islands as a whole as evidenced by separation of 95% confidence intervals on the mean PC scores (while recognizing that separation of confidence intervals is a conservative metric for assessing difference (Schenker and Gentleman 2001). Habitat variables were transformed as necessary to achieve approximately normal distributions to improve the normality of PC scores, which is assumed when using PC scores for hypothesis tests.

PCA identifies patterns within multivariate data, eliminates correlation among data, and reduces the dimensionality of multivariate data to simplify analyses. PCA can add to univariate assessments of representation by focusing on groups of habitat attributes that tend occur together, such as steep rugged shoreline, thereby refining the types of areas that are under or overrepresented. See Figure J-1 in Appendix J for an example of how PCA classifies multivariate habitat types.

Results and discussion

PCA interpretations. Four principal components accounts for 85% of the variation on the island (Table I-1).

Table I-1. Eigenvalues of the correlation matrix for PCA on habitat attributes on Santa Rosa Island.

Principal component	Eigenvalue	Proportion of variance	Cumulative variance
1	2.33	0.39	0.388
2	1.13	0.19	0.576
3	0.91	0.15	0.727
4	0.73	0.12	0.848
5	0.51	0.08	0.933
6	0.4	0.07	1.000

Nearly 40% of the variation in the habitat attributes on Santa Rosa Island is accounted for by PC1, which contained positive loadings from steep and rugged interior areas that are close to roads and development (Table I-2). PC2 accounts for steep, rugged, and remote terrain. PC3 represents steep terrain far from drainages and is referred to as “Steep and dry.” Finally, PC4 represents lands that are far from shoreline, drainages, and development and is referred to as “Dry remote interior.”

Table I-2. Eigenvectors for PCA on habitat attributes on Santa Rosa Island.

	Principal Component			
	1	**2**	**3**	**4**
	Steep rugged interior near roads and development	**Steep and rugged far from roads and development**	**Steep shoreline far from freshwater**	**Remote interior far from freshwater**
Slope[1]	0.39	0.45	0.48	0.00
Ruggedness[2]	0.45	0.43	0.18	0.00
Distance to…				
Paved roads[2]	-0.43	0.58	0.04	0.00
Development[1]	-0.44	0.44	-0.27	0.38
Shoreline[2]	0.42	-0.03	-0.35	0.77
Freshwater[1]	-0.31	-0.28	0.73	0.51

[1] Square-root transformed [2] Cube-root transformed

Representation analysis using PCA

Overall. Both proposed scenarios under-represent PC1 and PC2 (Figure I-1). Thus, steep terrain is under-sampled, regardless of proximity to roads and development. Steep terrain far from drainages appears better sampled (i.e., PC3), suggesting that avoidance of canyons may have contributed to this pattern. Bias away from very steep terrain is unsurprising given that selection criteria attempted to excessive slopes. Finally, inland areas far from drainages and development also modestly under-sampled PC4 (Figure I-1). Both proposed scenarios appear to perform similarly in terms of multivariate representation, although Scenario B samples steep rugged remote terrain somewhat better. The enhanced overall representativeness of Scenario B is achieved by removing trapping units in areas with low slope and close to development rather than by increased sampling of steep rugged remote terrain. Thus, the added trapping grids in Scenario A do not increase the representativeness of the sampling effort.

By vegetation type. Trap locations within the dominant vegetation types, grassland and coastal sage scrub, consistently under-sample PC1, PC2, and PC3 mirroring the overall island-wide patterns (Figure I-2). Thus, trap locations within each vegetation type sample atypical locations with respect to key habitat attributes, favoring locations with gentler terrain closer to shoreline.

Conclusions

Steep terrain on Santa Rosa Island is under-sampled by both proposed trapping scenarios. This bias towards level terrain occurs regardless of proximity to development and roads. Steep terrain far from drainages, however, appears better sampled (i.e., PC3), suggesting that avoidance of canyons may have contributed to this pattern. Unlike many other islands, steep shoreline areas are not underrepresented by either proposed trapping scenario on Santa Rosa Island. Both proposed scenarios appear to perform similarly in terms of multivariate representation, although Scenario B samples steep rugged remote terrain somewhat better. Thus, the additional trapping grids in Scenario A do not increase the multivariate representativeness of this sampling design. Biases in multivariate habitat sampled by proposed scenarios likely result from logistical constraints placed on trap unit location to ensure feasibility of the trapping effort. Density and demographic rates in disproportionately sampled habitat types should be compared to overall island-wide patterns to assure that these biases do not bias monitoring program results.

Literature Cited

SAS Institute Inc. 2005. SAS/STAT user's guide. Release 8.02 edition. SAS Institute, Inc., Cary, NC.

Schenker, N., and J.F. Gentleman. 2001. On judging the significance of differences by examining the overlap between confidence intervals. The American Statistician **55**:182-186.

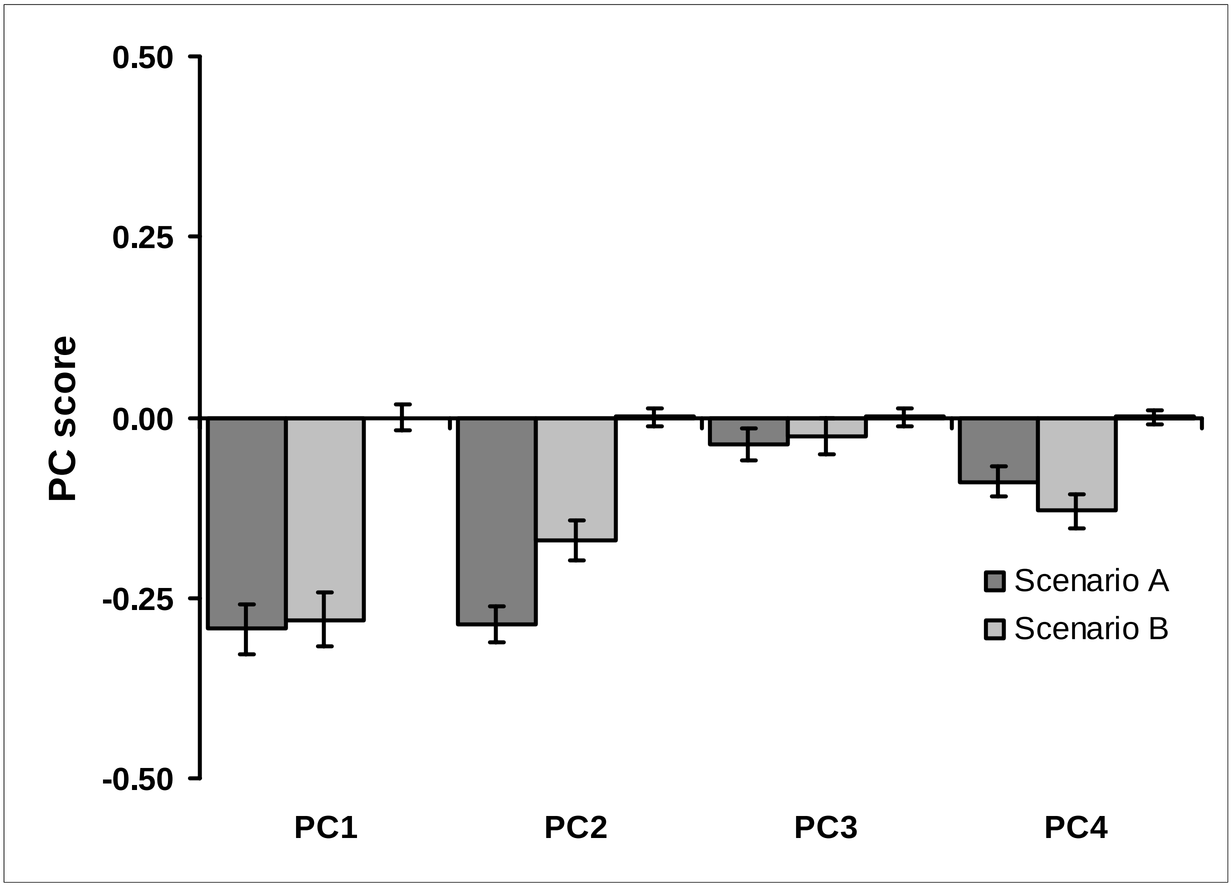


Figure I-1. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas proposed for trapping under Scenarios A and B relative to the entire island. Also shown are confidence intervals for island-wide PC scores; the island-wide mean for each PC is 0 because PCA was performed on island data and variables were mean centered and standardized prior to analysis. PC1 is steep, rugged interior near roads and development. PC2 is steep and rugged far from roads and development. PC3 is steep shoreline far from freshwater. PC4 is remote interior far from freshwater.

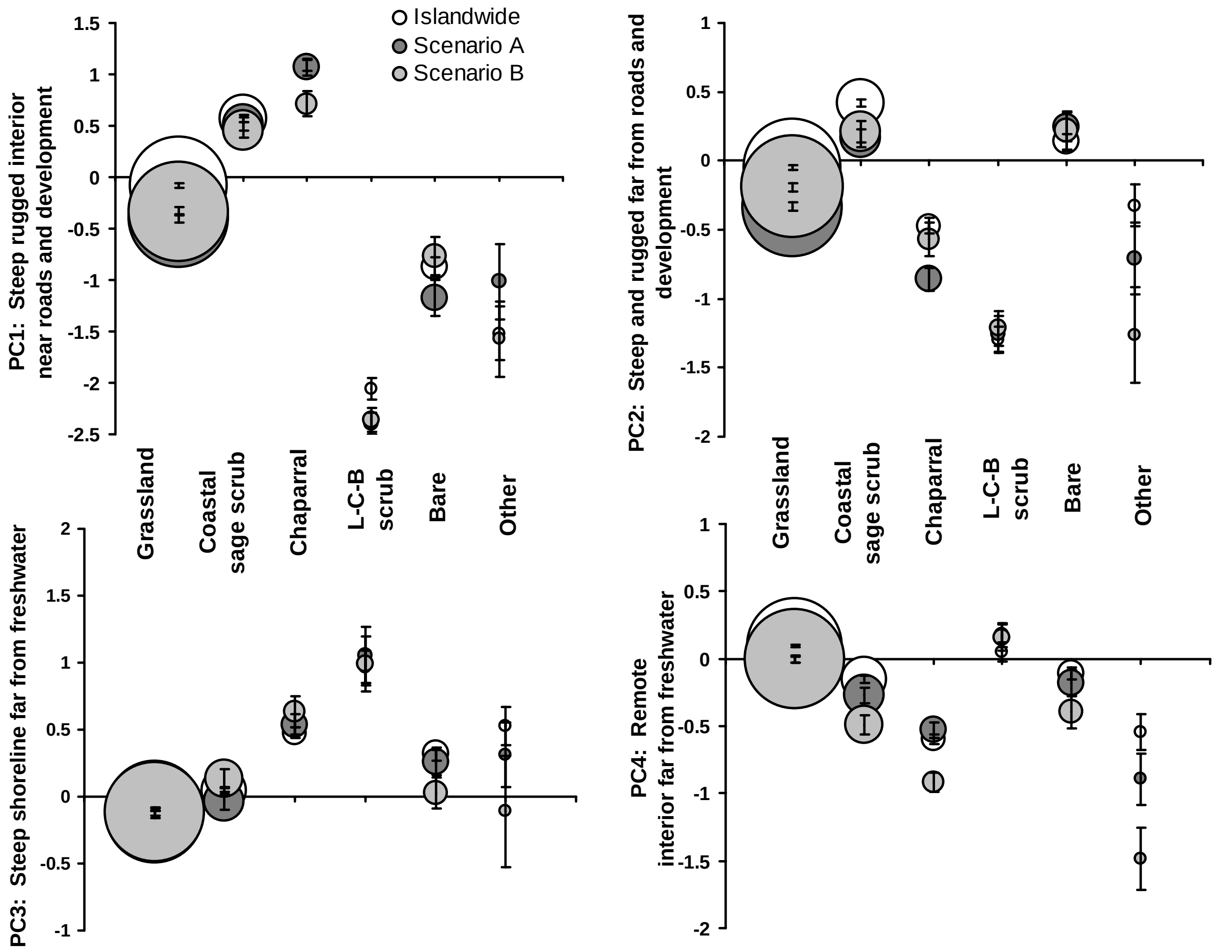


Figure I-2. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas proposed for trapping under Scenarios A and B relative to the entire island by vegetation type for PC1─PC4. Marker size is weighted by proportional coverage of each vegetation type. L-C-B scrub is Lupine/Caliche/Baccharis Scrub.

Appendix J

Multivariate Analysis of Habitat Characteristics of Existing and Proposed Trapping Scenarios on Santa Cruz Island

Introduction

The monitoring plan in the main body of this report proposes a new design for mark-recapture trapping of island foxes on Santa Cruz Island to increase the efficiency and robustness of monitoring efforts and to achieve new monitoring goals. Under this plan, trapping would consist of a dispersed set of small trapping units (2x6 traps). Historically, island foxes have been trapped using mark-recapture trapping methods with traps arrayed in single line transects throughout the island. This appendix uses multivariate statistical methods to evaluate the degree to which current and proposed trapping locations sample the range of variation on the island for features hypothesized to be important to foxes. The intent of this analysis is to add to the interpretations of the univariate representation analyses by using principal components analysis (PCA) to focus on groups of habitat attributes that tend occur together.

Methods

Five continuous variables were identified as likely to influence fox habitat quality on Santa Cruz Island─slope, ruggedness, distance to roadways, distance to human development, and distance to shoreline. These habitat characteristics were extracted from a GIS at randomly located points at a density of ~144 points/km^2), and trapped areas (existing and proposed) were sampled similarly. Trapped areas were defined as all locations within a 600-m buffer of a trap station. The buffer was added to characterize the entire area likely to be used by foxes entering traps including areas used by foxes living adjacent to grids and captured in perimeter traps. The 600-m buffer is equal to the mean of the mean maximum distances moved for each trapping session for all years for grids on San Clemente, Santa Cruz, San Miguel, and San Nicolas Islands. Additional details on methods of habitat characterization for Santa Cruz Island can be found in Appendix E.

To compare the multivariate attributes of trapped areas to those of the entire island, I performed a principal components analysis (SAS Proc Princomp; SAS Institute Inc. 2005) on the island-wide habitat data and compared mean principal component scores for trapped areas to those of island-wide areas overall and by vegetation type. The latter analysis was performed to assess whether the representativeness of trapped areas was influenced by sampling targeted at certain vegetation types that might have biased habitat characteristics. Variables were mean-centered and standardized prior to conducting the PCA (i.e., PCA used the correlation matrix). To allow a visual assessment of the habitat sampled by the trapped areas, I plotted the mean PC scores for both trapped and island-wide areas. I focus on detecting and describing the major differences in the attributes of trapped areas compared to the islands as a whole as evidenced by separation of 95% confidence intervals on the mean PC scores (while recognizing that separation of confidence intervals is a conservative metric for assessing difference (Schenker and Gentleman 2001). Habitat variables were transformed as necessary to achieve approximately normal distributions to improve the normality of PC scores, which is assumed when using PC scores for hypothesis tests.

PCA identifies patterns within multivariate data, eliminates correlation among data, and reduces the dimensionality of multivariate data to simplify analyses. PCA can add to univariate assessments of representation by focusing on groups of habitat attributes that tend occur together, such as steep rugged shoreline, thereby refining the types of areas that are under or over-represented.

Results and Discussion

PCA interpretations. The first principal component accounts for 36% of the variation in habitat variables and three PCs describe nearly 80% of the overall variation on the island (Table J-1).

Table J-1. Eigenvalues of the correlation matrix for PCA on habitat attributes on Santa Cruz Island

Principal component	Eigenvalue	Proportion of variance	Cumulative variance
1	1.79	0.36	0.358
2	1.19	0.24	0.596
3	0.93	0.19	0.782
4	0.83	0.17	0.948
5	0.26	0.05	1

PC1 represents areas that are far from roads and development but close to shoreline (Table J-2); referred to here as “Unroaded remote shoreline.” PC2 accounts for steep and rugged terrain far from development and shoreline, label here as “Remote steep and rugged interior.” Finally, PC3 is heavily influenced by rugged areas with low slopes, labeled “Flat rugged terrain.”

Table J-2. Eigenvectors for PCA on habitat attributes on Santa Cruz Island

	Principal Component		
	1	**2**	**3**
	Unroaded remote shoreline	**Remote steep and rugged interior**	**Flat rugged terrain**
Slope	0.12	0.52	-0.76
Ruggedness[1]	-0.11	0.58	0.62
Distance to…			
Roads[2]	0.69	0.00	0.14
Development[3]	0.51	0.43	0.11
Shoreline[3]	-0.48	0.45	-0.02

[1]ln transformed [2] Cube-root transformed [3] Square-root transformed

Representation analysis using PCA

Overall. Existing transect trapping on Santa Cruz Island has underrepresented unroaded remote shoreline areas, such as those found on the north and west ends and the south side of the island (Figures J-1 and J-2). Existing transects have also under-sampled remote rough interior areas but well represented rugged terrain on flatter ground (Figures J-1 and J-2). Proposed Scenario A also under-samples unroaded remote shoreline, but achieves substantially better coverage of these areas than existing transects, while Scenario B is unbiased with respect to unroaded remote shoreline. Scenarios A and B perform similarly to existing transects in under-sampling remote steep and rugged interior areas. In addition, both over-sample flat rugged terrain. The observed biases are unsurprising and seem to reflect selection criteria, in which trapping units are linked to roadways and very steep areas are avoided to ensure the feasibility of sampling.

By vegetation type. Existing and proposed trapping areas appear to sample vegetation types in a manner roughly proportional to their occurrence. Under-sampling of unroaded remote shoreline occurs systematically in all vegetation types for existing transects and proposed Scenario A (Figures J-3 and J-4). Scenario B, in contrast, samples remote shoreline in a representative manner but over-samples this feature within herbaceous vegetation and under-samples it within all minor vegetation types. For existing and proposed trapping areas, remote rough interior is under-sampled in most vegetation types, except for herbaceous vegetation, where habitat attributes reflect those of the vegetation type as a whole. Finally, flat rugged terrain is well represented within major habitat types by existing trapping locations, but generally over-sampled across habitat types by proposed scenarios.

Conclusions

Existing transects and proposed Scenario A under-represent unroaded remote shoreline characteristic of areas on the north, west, and the south sides of the island, while Scenario B represents this feature consistent with its overall presence on the island. Existing transects and both proposed scenarios under-sample remote steep and rugged interior areas to a similar degree. Proposed scenarios over-sample rugged terrain on flatter ground. Overall, Scenario B appears to represent the habitat characteristics of the island best, despite fewer trapping units overall. This efficiency is achieved because most of the additional trapping units comprising Scenario A occur in areas that are closer to roads and development, which tend to be over-sampled. Biases in multivariate habitat sampled by proposed scenarios likely result from logistical constraints placed on trap unit location to ensure feasibility of the trapping effort. Density and demographic rates in disproportionately sampled habitat types should be compared to overall island-wide patterns to assure that these biases do not bias monitoring program results.

Literature Cited

SAS Institute Inc. 2005. SAS/STAT user's guide. Release 8.02 edition. SAS Institute, Inc., Cary, NC.

Schenker, N., and J.F. Gentleman. 2001. On judging the significance of differences by examining the overlap between confidence intervals. The American Statistician **55**:182-186.

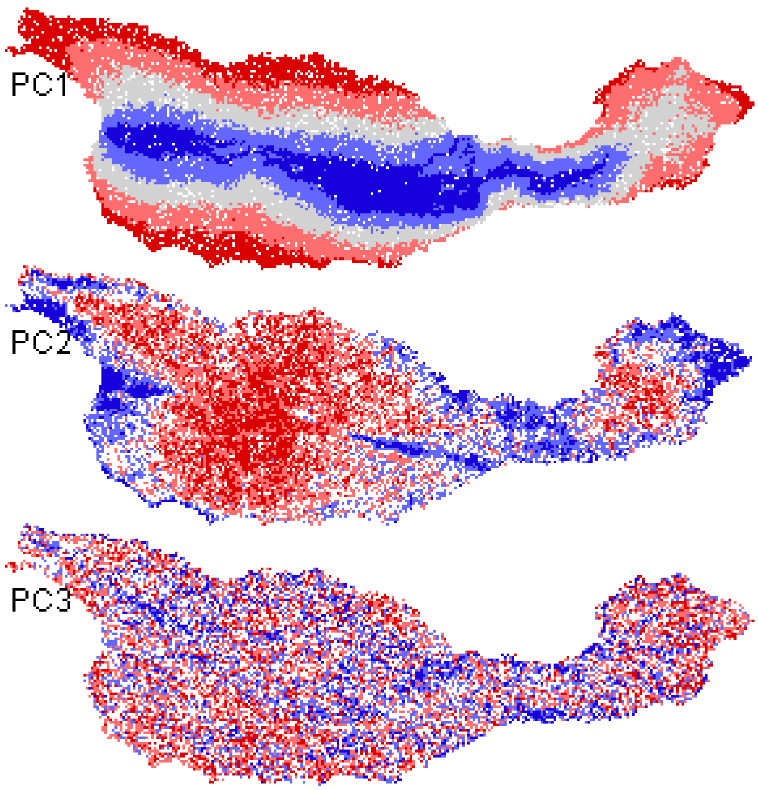


Figure J-1. Example of how PCA differentiates multivariate habitat types. Red indicates high values for a particular PC while blue indicates low values. PC1 is remote shoreline areas, PC2 is remote, steep, and rugged interior lands, and PC3 is flat rugged terrain

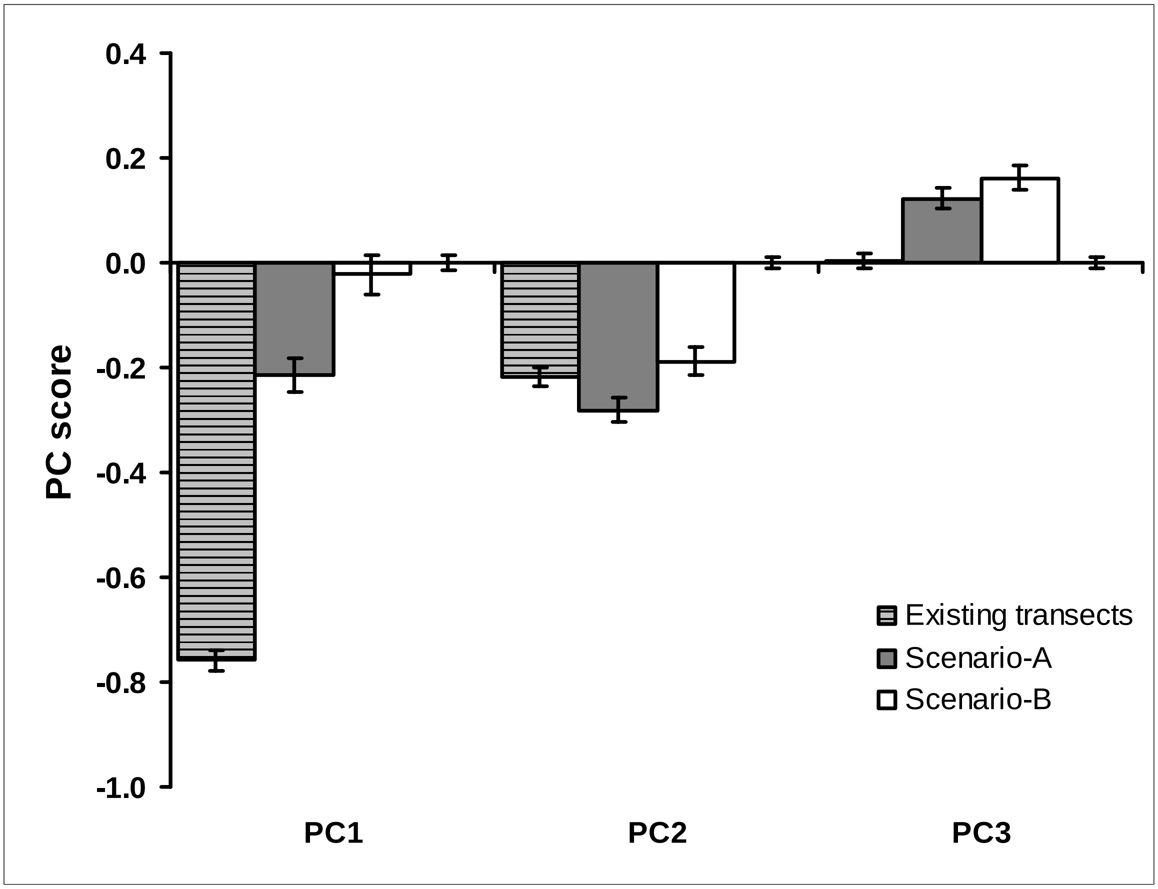


Figure J-2. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas currently trapped for island foxes and those proposed for trapping under Scenarios A and B. Also shown are confidence intervals for island-wide PC scores; the island-wide mean for each PC is 0 because PCA was performed on island data and variables were mean centered and standardized prior to analysis. PC1 is remote shoreline areas, PC2 is remote, steep, and rugged interior lands, and PC3 is flat rugged terrain

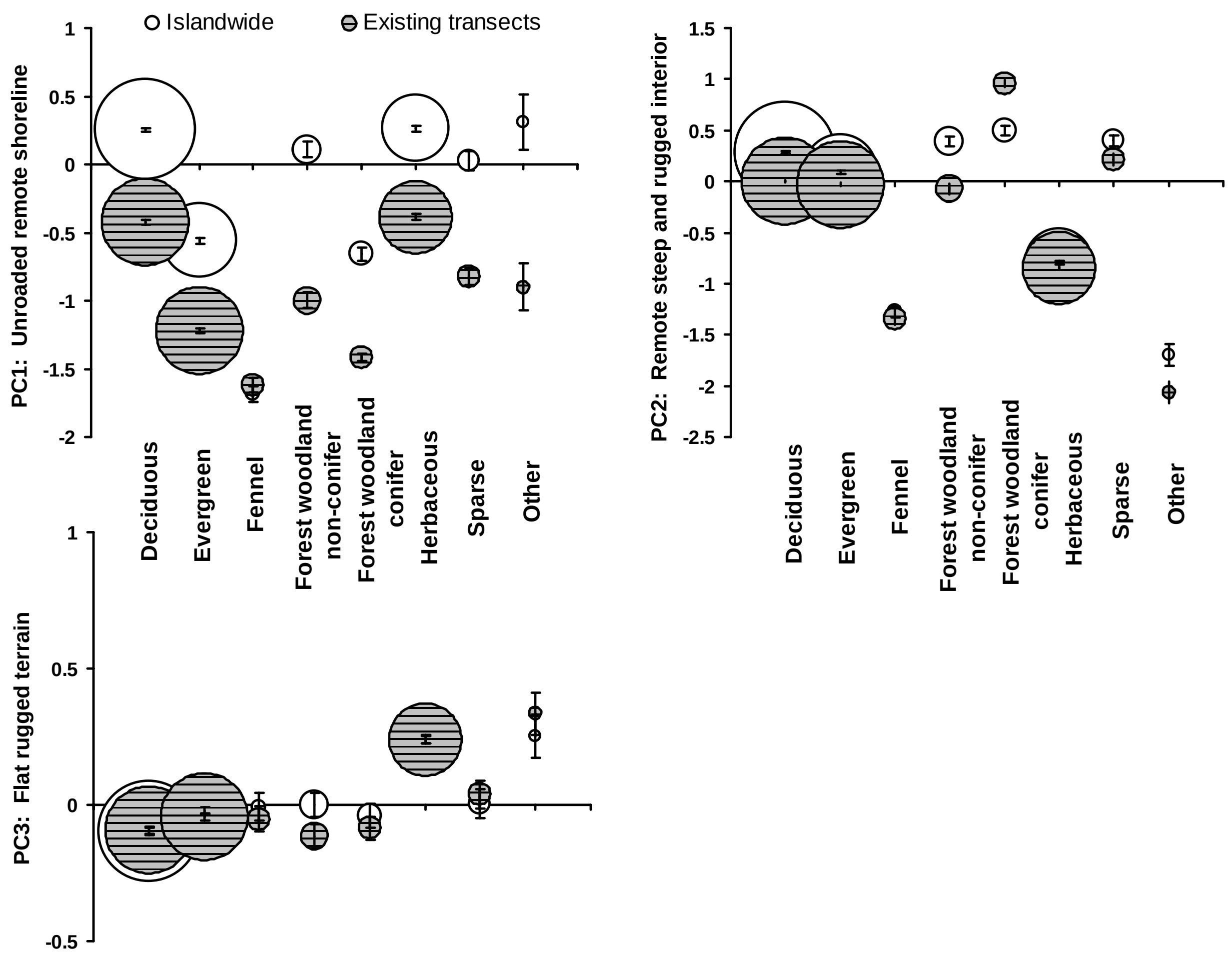


Figure J-3. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas currently trapped by existing transects relative to the entire island by vegetation type for PC1, PC2, and PC3. Marker size is weighted by proportional coverage of each vegetation type.

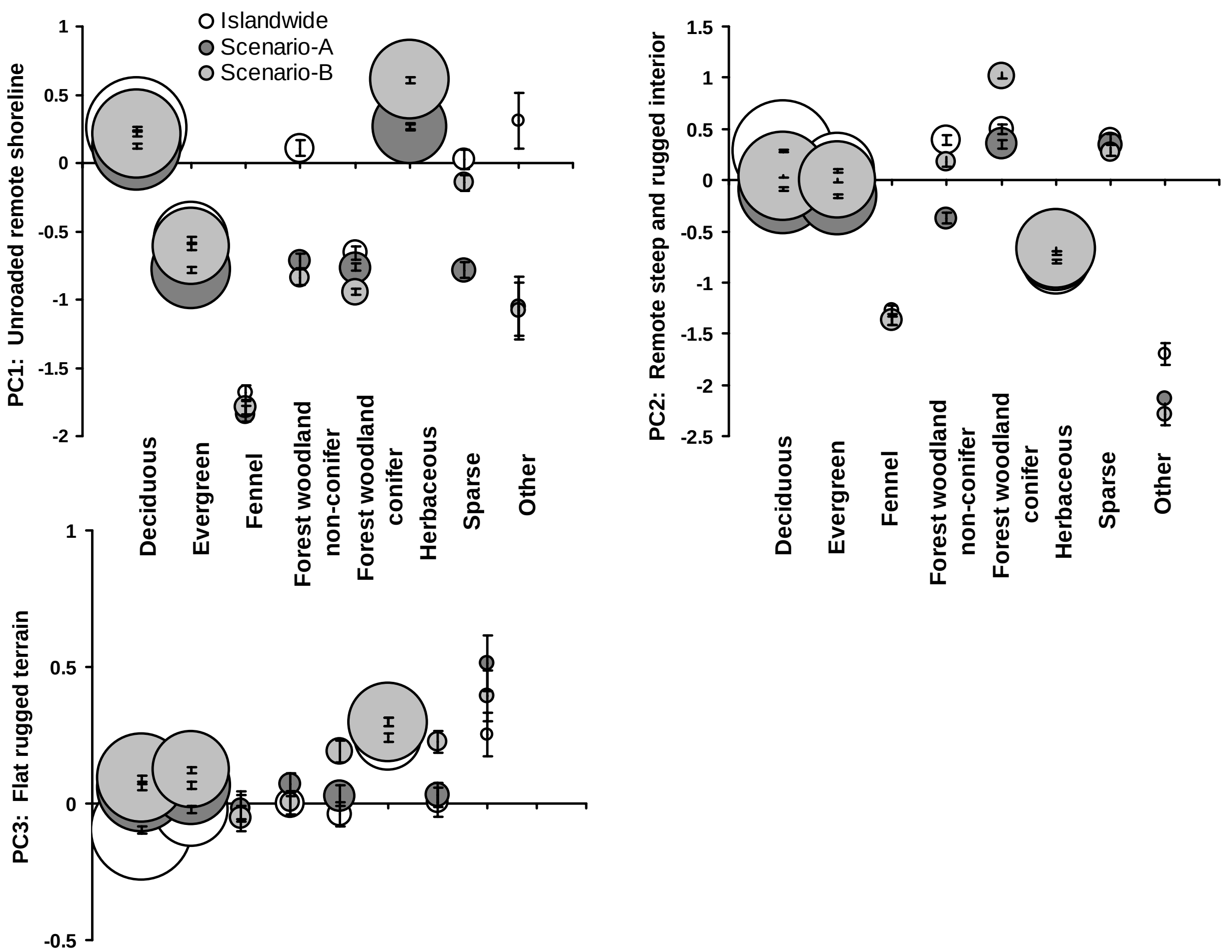


Figure J-4. Comparison of mean (± 95% confidence intervals) PC scores for habitat attributes in areas proposed for trapping under Scenarios A and B relative to the entire island by vegetation type for PC1, PC2, and PC3. Marker size is weighted by proportional coverage of each vegetation type.

APPENDICES K–M

Prepared by

Murray Efford
University of Otago, New Zealand
March 2007
murray.efford@stonebow.otago.ac.nz
Ph +64 3 476 4668

Note: These appendices summarize exploratory analyses conducted in support of recommendations in the main framework report and are not intended to be stand-alone documents.

Appendix K

Monitoring Island Fox Populations by Trapping and Spatially Explicit Capture-Recapture: Options for San Miguel Island

The aim is to evaluate three trapping options for San Miguel, two of them based on the present trap protocol, and the other a local implementation of the trapping unit design addressed in the main report. Initially, options were limited to a maximum of 288 trap nights per year, but it became clear that this is inadequate. After feedback from CBI, further options were added with 5 grids of 18, 24, 30 or 36 traps, trapped over 6 nights.

Simulations

Various grid shapes and sizes for 4-6 nights, evaluated in terms of expected number of recaptures.

A single file was used for each layout, but the grids were spaced far apart (4 km) and detection was truncated at 2 km, so the trial represents independent trapping of grids, consistent with sequential trapping as occurs in reality. Note that the large spacing between grids was merely a convenient way of conducting the simulations to achieve independence.

In Addendum A, CBI had requested an evaluation of the present design in which closely spaced grids are trapped sequentially (Scenario 1; Figure K-1). On reflection, it is not clear how to analyse such data, and they cannot easily be simulated. In essence there is negligible difference between Scenarios 1 and 2 proposed in Addendum A. I simulated Scenario 2 in which grids are treated as independent, and are far enough apart that between-grid movements are rare.

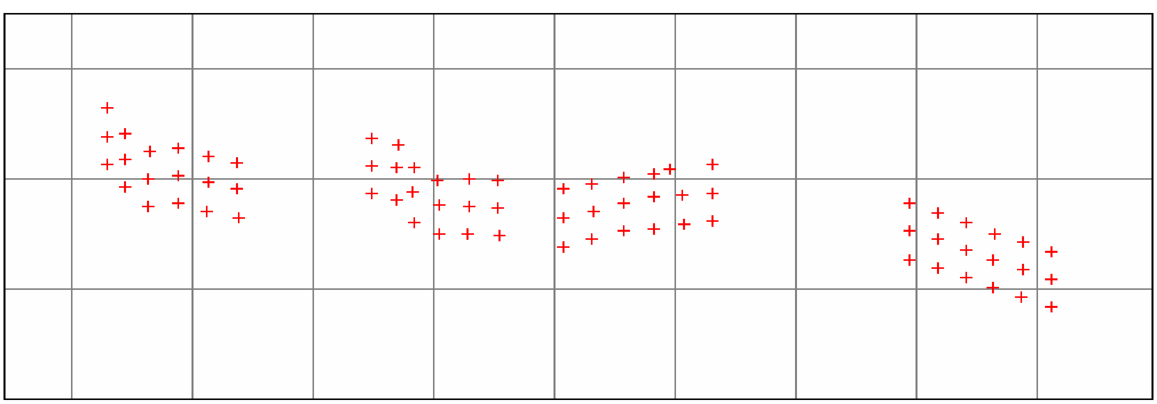


Figure K-1. San Miguel's present grids. 72 traps in 4 grids. Trap spacing nominally 200 m, but, by my calculation, actual mean distance to nearest trap is 227 m. 1-km squares.

Parameter values from trapping on San Miguel (±1SE)

Historical trapping data on San Miguel span both high and low densities.

1. T. Coonan 2006 sent directly to M. Efford. Asynchronous data analysed as synchronous. D = 1.91 ± 0.44, g0 = 0.092 ± 0.023, σ = 573 ± 77 [Halfnormal detection]. The large estimate of σ reflects large between-grid 'movements' in the data; it is difficult to know whether these reflect large short-term (4-day) home ranges or dispersal or a few itinerant foxes. We choose not to rely on this estimate of the detection function.
2. V. Bakker's analysis of 6-years of data from the 14x7 SMWC grid. Density was low (<4 / km^2) in the second half of the study, when detectability was also low (average for years 4–6: g_0 = 0.06, σ = 279).
3. V. Bakker's analysis of 3 years of data from the 6x8 DLB grid spanning 1 high density year and 2 lower density years. The pooled estimates were g_0 = 0.08, σ = 206.

Estimates from other islands commonly give larger estimates of g_0 & σ. For San Miguel simulations I have used the new benchmark detection parameter values as a 'best case' (g_0 = 0.08, σ = 300) and two more pessimistic scenarios.

Table K-1. Detection scenarios for San Miguel. Halfnormal detection function.

SM scenario	***D***	g_0	**σ**	**Note**
1	2	0.08	300	Best case
2	2	0.06	300	
3	2	0.06	200	Worst case

Table K-2. Summary of layouts.

	Number	**Layout**	**Spacing**	**No. of nights**	**Trap nights**	**Note**
1	4	3 x 6	200	4	288	Similar to status quo
2	4	3 x 6	250	4	288	Increased spacing
3	6	2 x 6	200	4	288	
4	6	2 x 6	200	6	432	
5	8	2 x 6	200	6	576	
6	5	3 x 6	200	6	540	
7	5	4 x 6	200	6	720	
8	5	5 x 6	200	6	900	
9	5	6 x 6	200	6	1080	

Results and Interpretation

None of the layouts with 288 trap nights per year produces enough recaptures for capture-recapture analysis (Table K-3). In part this is because the second and third detection scenarios are quite pessimistic, but the first one is quite plausible. Even with double the number of trap nights, there are not enough recaptures (target of approximately 33 recaptures for CV ≤20%). The target is reached when trapping is extended to 5 grids of at least 30 traps each and trapping is conducted for 6 nights.

Table K-3. Simulated average numbers of individuals and numbers of within-grid recaptures for grid layouts as in Table K-2. Detection scenarios 1–3 as in Table K-1; numbers incorporate the layout numbers from Table K-2 after the decimal place.

Scenario	No.of grids	Layout	Nights	Trap-nights	Animals	Recaptures	Recaptures per trap-night
1.1	4	3 x 6	4	288	13.8	7.5	.026
1.2	4	3 x 6	4	288	15.1	6.8	.024
1.3	6	2 x 6	4	288	15.8	6.4	.022
1.4	6	2 x 6	6	432	20.1	13.4	.031
1.5	8	2 x 6	6	576	26.5	17.8	.031
1.6	5	3 x 6	6	540	21.0	18.5	.034
1.7	5	4 x 6	6	720	25.0	26.1	.036
1.8	5	5 x 6	6	900	29.2	33.6	.037
1.9	5	6 x 6	6	1080	33.0	41.2	.038
2.1	4	3 x 6	4	288	11.7	4.9	.017
2.2	4	3 x 6	4	288	13.0	4.6	.016
2.3	6	2 x 6	4	288	13.2	4.1	.014
2.4	6	2 x 6	6	432	17.2	9.0	.021
2.5	8	2 x 6	6	576	22.9	11.7	.020
2.6	5	3 x 6	6	540	18.7	13.0	.024
2.7	5	4 x 6	6	720	22.3	18.7	.026
2.8	5	5 x 6	6	900	26.0	23.9	.027
2.9	5	6 x 6	6	1080	29.7	29.6	.027
3.1	4	3 x 6	4	288	6.0	1.8	.006
3.2	4	3 x 6	4	288	6.6	1.5	.005
3.3	6	2 x 6	4	288	6.6	1.5	.005
3.4	6	2 x 6	6	432	8.8	3.4	.008
3.5	8	2 x 6	6	576	11.6	4.4	.008
3.6	5	3 x 6	6	540	10.0	4.9	.009
3.7	5	4 x 6	6	720	12.6	7.1	.010
3.8	5	5 x 6	6	900	15.1	9.1	.010
3.9	5	6 x 6	6	1080	17.5	11.2	.010

Addendum A

Simulations of trapping regimes for island foxes on San Miguel using an island-wide grid

The aim of these simulations was to evaluate island-wide trapping options for a small island such as San Miguel. Previous simulations had shown island-wide trapping was impractical for Santa Cruz (about 251 km^2). Island-wide trapping is attractive because it avoids the need to extrapolate from sampled areas to the whole, which entails estimation of density at the scale of each grid or transect. Its main drawbacks are

- the need to shift traps to randomize access by foxes to traps: repeated trapping at fixed sites samples the local population, not the whole.
- the large distances that must be traversed off-road.

Simulated trapping grid

A digitized coastline of San Miguel was provided by B. Cohen, TNC.
The island has an area of 38.6 km^2.

The same three scenarios were used for D, g(0), σ as on Santa Cruz.

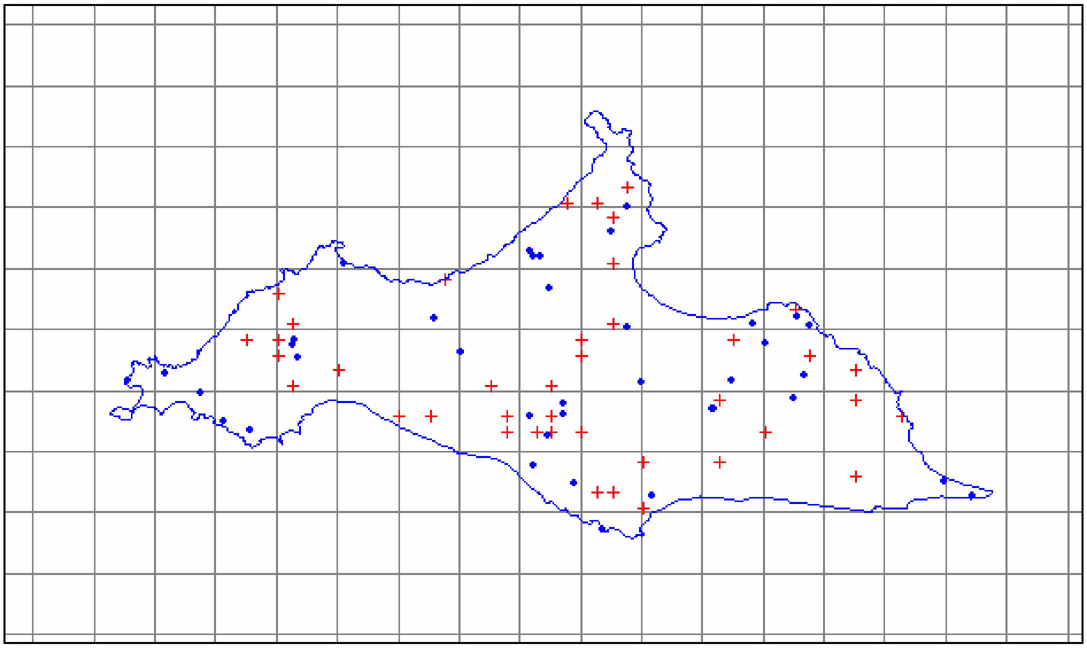
Simulations were grouped in two trials, one with random selection of sites from a 250-m grid, and the other with a fixed trap spacing but randomly shifted origin. The emphasis here is on the second trial as this delivered slightly better precision.

100 replicate simulations were performed for each combination. Detection was assumed to follow a halfnormal function.

San Miguel Trial 1

Daily select a new random subset of these trap sites.
Sampling fraction chosen to give 40 traps.
5 or 15 trapping nights.

Scenario	**D km^{-2}**	**No. of foxes**	**g(0)**	**σ m**	**Grid spacing m**	**Sampling fraction**	**No. of traps**	**Nights**
1.1	1	38.6	0.05	600	250	0.06472	40	5
1.2					250	0.06472	40	15
2.1	4	154.4	0.1	300	250	0.06472	40	5
2.2					250	0.06472	40	15
3.1	4	154.4	0.2	300	250	0.06472	40	5
3.2					250	0.06472	40	15



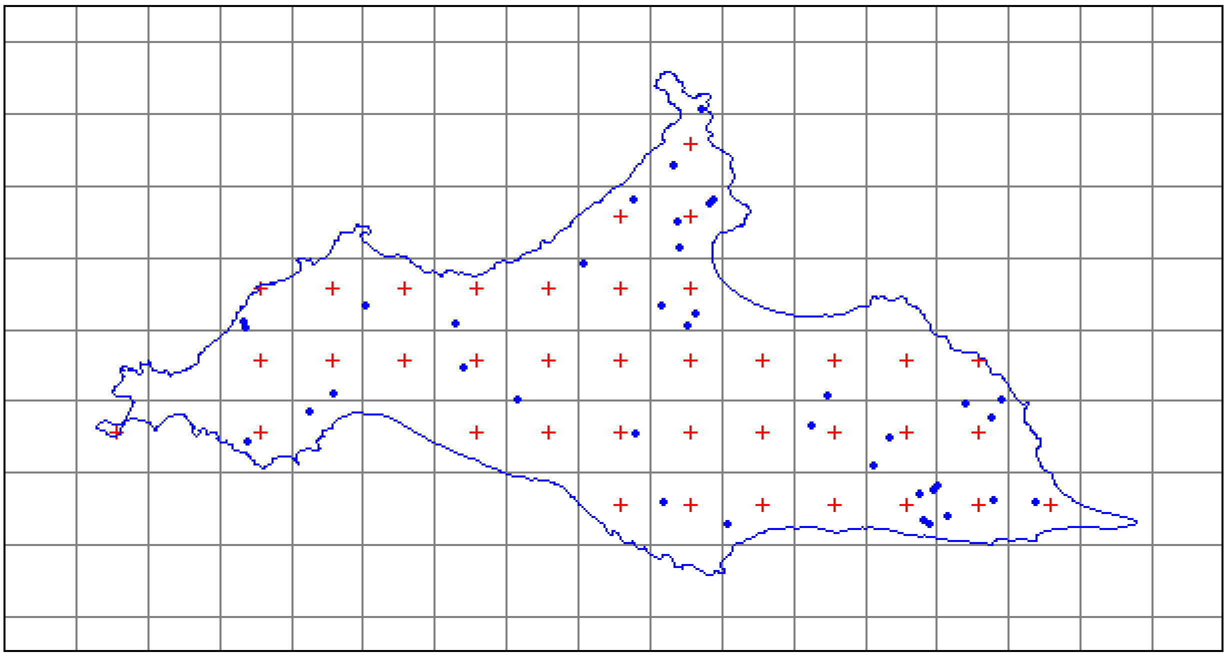
Example: Trial 1, Scenario 1, 40 traps selected at random from 250-m grid (red crosses), ≈38 random foxes (gridlines 1-km spacing).

San Miguel Trial 2

Daily shift entire grid by a random distance in x- and y- directions. 'Jittering' is uniform on the range ± 0.5 × trap spacing.
Trap numbers are approximate because some shifts move grid points onshore or offshore.
5 or 15 trapping nights.

Scenario	**D km^{-2}**	**No. of foxes**	**g(0)**	**σ m**	**Grid spacing m**	**Jitter m**	**No. of traps**	**Nights**
1.1	1	38.6	0.05	600	500	± 250	152	5
1.2					750	± 375	67	5
1.3					1000	± 500	39	5
1.4					500	± 250	152	15
1.5					750	± 375	67	15
1.6					1000	± 500	39	15
2.1	4	154.4	0.1	300	500	± 250	152	5
2.2					750	± 375	67	5
2.3					1000	± 500	39	5
2.4					500	± 250	152	15
2.5					750	± 375	67	15
2.6					1000	± 500	39	15
3.1	4	154.4	0.2	300	500	± 250	152	5

Scenario	D km^{-2}	No. of foxes	g(0)	σ m	Grid spacing m	Jitter m	No. of traps	Nights
3.2					750	± 375	67	5
3.3					1000	± 500	39	5
3.4					500	± 250	152	15
3.5					750	± 375	67	15
3.6					1000	± 500	39	15



Example: Trial 2, Scenario 1.3, 38 traps at 1,000-m spacing (red crosses), ≈38 random foxes (gridlines 1-km spacing)

San Miguel Trial 3

This was a targeted trial to evaluate the effect of progressively increasing the number of trap nights. Settings otherwise followed Trial 2 Scenario 2.3.

Analysis
A null capture-recapture model was fitted because jittered trap placement should have largely eliminated heterogeneity.

Results

Table. San Miguel Trial 1.

Density	g0	σ	NTraps	Spacing	Occasions	Nhat	RelBias%	CVNhat%
1	0.05	600	40	[250]	5	41.4	7.4	52.0
1	0.05	600	40	[250]	15	37.8	-2.1	13.7
4	0.1	300	40	[250]	5	193.9	25.6	57.3
4	0.1	300	40	[250]	15	154.5	0.1	14.8
4	0.2	300	40	[250]	5	155.4	0.7	26.8
4	0.2	300	40	[250]	15	149.4	-3.2	6.9

Table. San Miguel Trial 2.

Density	g0	σ	NTraps	Spacing	Occasions	Nhat	RelBias%	CVNhat%
1	0.05	600	151	500	5	38.8	0.6	7.1
1	0.05	600	69	750	5	38.3	-0.8	21.3
1	0.05	600	39	1000	5	44.9	16.4	44.1
1	0.05	600	151	500	15	37.6	-2.4	0.6
1	0.05	600	69	750	15	37.8	-2.0	4.2
1	0.05	600	39	1000	15	37.5	-3.0	10.2
4	0.1	300	151	500	5	153.3	-0.7	9.7
4	0.1	300	69	750	5	154.8	0.3	24.8
4	0.1	300	39	1000	5	179.9	16.5	50.1
4	0.1	300	151	500	15	154.1	-0.2	1.8
4	0.1	300	69	750	15	153.8	-0.3	6.4
4	0.1	300	39	1000	15	155.6	0.8	13.0
4	0.2	300	151	500	5	153.4	-0.6	4.0
4	0.2	300	69	750	5	157.5	2.0	12.1
4	0.2	300	39	1000	5	171.5	11.1	25.1
4	0.2	300	151	500	15	151.7	-1.7	0.4
4	0.2	300	69	750	15	154.2	-0.1	2.5
4	0.2	300	39	1000	15	155.3	0.6	6.0

Highlighting emphasises the most attractive option in each table.

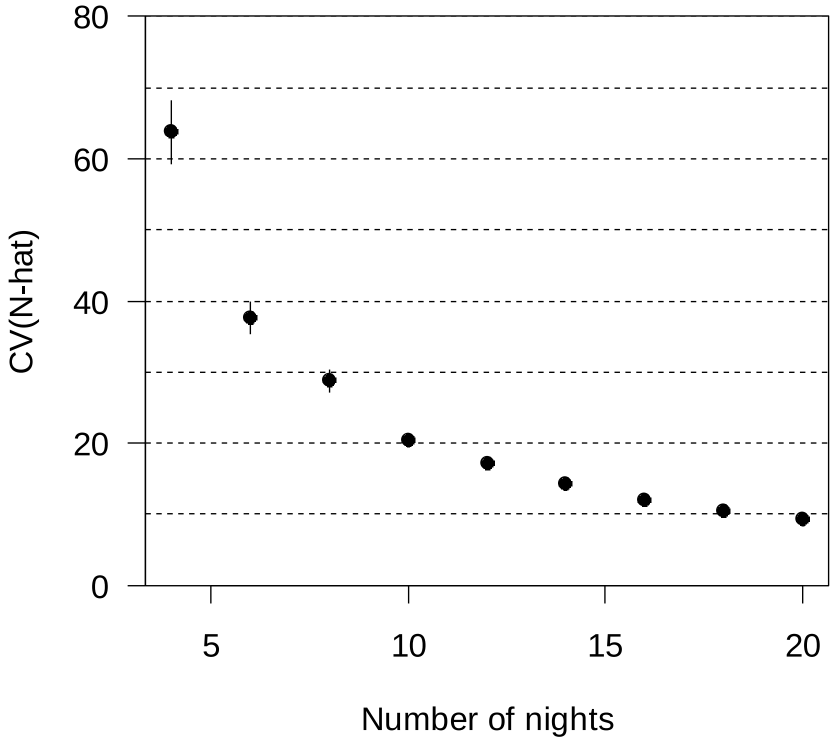


Fig. Precision as a function of increasing number of trapping nights for jittered 1,000-m grid on San Miguel. D = 4.0 / km^2, g(0) = 0.1, σ = 300 m. (Results from Trial 3). Vertical bars are 95% CI for CV(N-hat) across replicates (n = 100).

Interpretation
Bias is a problem here only under conditions that produce unacceptably imprecise estimates, so it is sufficient to evaluate the different regimes in terms of precision.

Very precise estimates may be obtained for some parameter sets with a large jittered grid over 5 nights, but (i) high precision is not guaranteed and (ii) it is probably impractical to 'jitter' such a large grid daily.

Extending trapping over 15 nights produces good results even with as few as 39 traps if these are relocated daily, either to random points on a 250-m grid (Trial 1) or by shifting the entire grid as a unit (Trial 2).

Appendix L

Simulations of Trapping Regimes for Island Foxes on San Nicolas Island Using an Island-wide Grid, and with Variations on the Present Grid Trapping

Trial 1

Simulations

A digitized coastline was provided by B. Cohen, TNC.
San Nicolas has an area of 58.3 km^2.

Three scenarios were used for simulations, two used the new 'standard' detection parameters $g_0 = 0.08$, $\sigma = 300$ m with differing density ($D = 1{,}4$ / km^2, and the third had high density and low sigma to match the possible current situation on San Nicolas ($D = 9$ / km^2, $g_0 = 0.1$, $\sigma = 200$ m). Detection was assumed to follow a halfnormal function.

Table L-1. Detection scenarios for San Nicolas Island.

SN scenario	***D***	g_0	**Σ**
1a	1	0.08	300
2a	4	0.08	300
3	9	0.1	200

For each simulation a grid of traps spaced at 750 m, 1,000 m, or 1,250 m was overlaid on the coastline and uniformly 'jittered' by half the trap spacing each day. Sites falling in the sea were rejected. 200 replicate simulations were performed for each parameter combination.

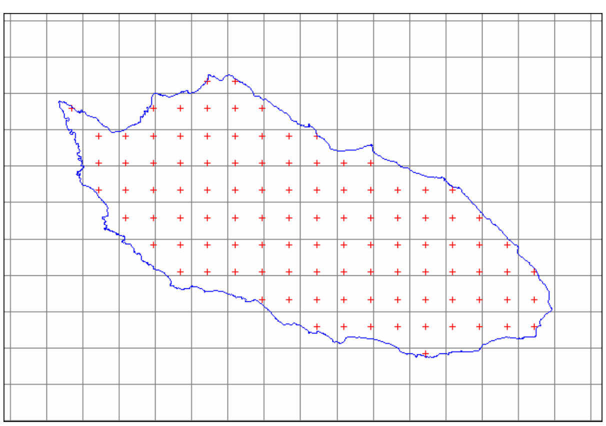


Figure L-1. Example of jittered overlay of traps at 750-m spacing on San Nicolas Island.

A null capture-recapture model (M_0) was fitted to estimate *N* because jittered trap placement should have largely eliminated heterogeneity.

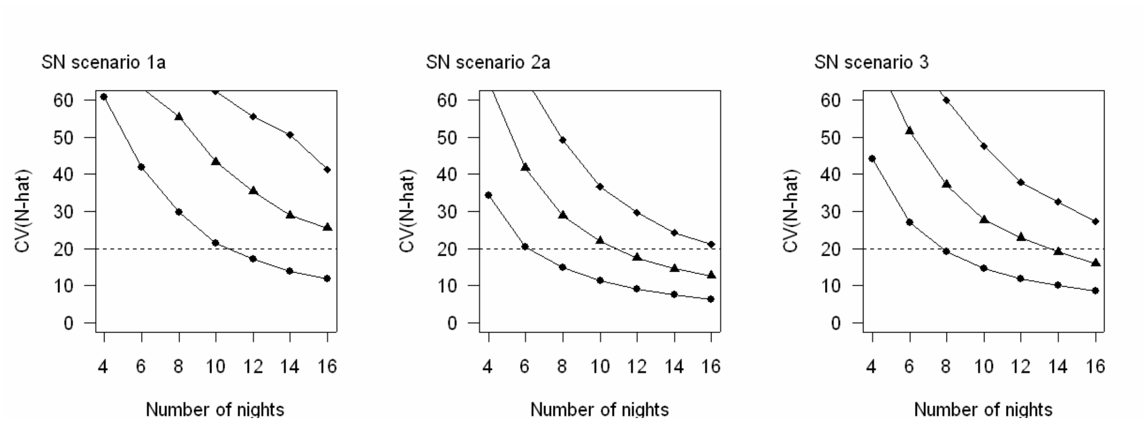


Figure L-2. Precision of estimated population size with jittered island-wide grids for San Nicolas Island. Circles 750-m trap spacing; triangles 1,000 m trap spacing; diamonds 1,250 m trap spacing.

Results and interpretation

Precision is summarised in Figure 2. Data and R code for plotting are in the file 'san nicolas task 2 simulations.spl'.

Adequate precision (CV(*N*-hat) <20%) is achieved only with a large number of traps (Scenario 2a: average 104 traps at 750 m spacing for 6 nights, or average 58 traps at 1,000 m spacing for 11 nights). This partly reflects the larger size of San Nicolas compared to San Miguel.

Bias in *N*-hat was noticeable for large trap spacings when σ was small (the third scenario) (median relative bias +1%, +3%, +16% for spacing 750 m, 1,000 m, 1,250 m) but otherwise median RB(*N*-hat) < 10% (see data file).

Trial 2

Simulations

Various grid shapes and sizes for 4-6 nights, evaluated in terms of expected number of recaptures.

A single file was used for each layout, but the grids were spaced far apart (4 km) and detection was truncated at 2 km, so the trial represents independent trapping of grids, consistent with sequential trapping as occurs in reality. Note that the large grid spacing was *only* a convenient way of conducting the simulations to achieve independence.

Table L-2. Summary of grids. Trap spacing 250 m in each case.

	Number	Layout	No. of nights	Trap nights	Note
1	3	5 x 10	6	900	Similar to status quo
2	4	6 x 8	6	1152	Extra grid
3	4	5 x 10	6	1200	Extra grid
4	5	6 x 6	5	900	Smaller grids
5	10	4 x 6	4	960	Smaller grids
6	5	10 x 10 hollow	5	900	A novelty cf (4)
7	12	2 x 6	6	864	
8	18	2 x 6	4	864	

Results and interpretation

Table L-3. Simulated average numbers of individuals and numbers of within-grid recaptures for eight grid layouts. Trap spacing 250m except for 2x6 units (200 m). Detection scenarios 1–3 were as for Trial 1 in Table L-1; numbers incorporate the layout numbers from Table L-2 after the decimal place.

Scenario	Grids	Layout	Nights	Trap nights	No. of animals	No. of recaptures	Recaptures per trap night
1.1	3	5 x 10	6	900	15	17	0.019
1.2	4	6 x 8	6	1152	19	22	0.019
1.3	4	5 x 10	6	1200	21	23	0.019
1.4	5	6 x 6	5	900	18	15	0.017
1.5	10	4 x 6	4	960	24	12	0.013
1.6	5	10 x 10 H	5	900	27	10	0.011
1.7	12	2 x 6	6	864	20	14	0.017
1.8	18	2 x 6	4	864	24	10	0.011
2.1	3	5 x 10	6	900	60	63	0.070
2.2	4	6 x 8	6	1152	76	81	0.071
2.3	4	5 x 10	6	1200	82	87	0.072
2.4	5	6 x 6	5	900	71	55	0.061
2.5	10	4 x 6	4	960	93	47	0.049
2.6	5	10 x 10 H	5	900	103	35	0.039
2.7	12	2 x 6	6	864	79	51	0.059
2.8	18	2 x 6	4	864	95	37	0.042
3.1	3	5 x 10	6	900	95	69	0.077
3.2	4	6 x 8	6	1152	121	90	0.078
3.3	4	5 x 10	6	1200	125	93	0.077
3.4	5	6 x 6	5	900	107	59	0.066

Scenario	Grids	Layout	Nights	Trap nights	No. of animals	No. of recaptures	Recaptures per trap night
3.5	10	4 x 6	4	960	130	49	0.051
3.6	5	10 x 10 H	5	900	139	38	0.043
3.7	12	2 x 6	6	864	101	59	0.068
3.8	18	2 x 6	4	864	119	41	0.047

Any of the conventional grid layouts 1–5 appears sufficient to provide an expected number of recaptures over 33, the presumed threshold for CV(D-hat) < 20%, for scenarios with $D = 4/km^2$ or $D = 9/km^2$. At low densities ($1/km^2$) none of the grid trapping regimes will produce enough recaptures with the (possibly conservative) g0 = 0.08, sigma = 300 m detection scenario.

Hollow grids span a larger area and catch more animals, but give fewer recaptures. They do not offer an advantage here, especially if it is hard to fit the grids in.

Small units (12 traps in two parallel rows) have the advantage of flexibility. They should be trapped for 6 nights to achieve the target number of recaptures.

For any layout, increasing the number of nights increases the number of recaptures per trap night. In this sense, 6 nights is about 40% more efficient than 4 nights.

Appendix M

Monitoring Island Fox Populations by Trapping and Spatially-Explicit Capture–Recapture: Options for Santa Cruz, Santa Rosa, and Santa Catalina

Note: An incorrect Santa Cruz Island density estimate was provided to Dr. Murray for this report; therefore, specific references to Santa Cruz Island densities in this appendix should be disregarded. All other interpretations referring to specific densities remain valid, and references to Santa Cruz Island densities in the main report are accurate.

Summary

Trapping with 9 loops or paired lines of 12 traps at 200 m spacing for 6 nights (648 trap nights) is predicted to yield the desired relative precision (CV ≤0.2) for an estimate of island population size when the fox population density is 4 km^{-2}, regardless of the size of island. Less effort is needed when density is higher. At low density (<1 km^{-2}) the required precision may be achieved only with extreme effort (>24 units of 12 traps for 6 nights).

Introduction

The aim is to design monitoring programs based on live-trapping and capture–recapture that deliver the required minimum precision for the population of foxes on each island (or part thereof in the case of Santa Catalina). The required precision is a CV[1] of 20% for the estimated population size *N*.

This report is about optimal methods for estimating local density (i.e. average density $\hat{D}$ of the fox population at the particular sites selected for sampling within each island). The ultimate interest is in the whole-island $\hat{N}$ and its estimated precision. Given $\hat{N} = \hat{D}A$, where *A* is the area of habitat on the island (assumed known), the relative precision (CV) of $\hat{N}$ is numerically equal to the relative precision of $\hat{D}$[2]. This justifies the focus on $\mathrm{CV}(\hat{D})$.

Whether a given trap layout achieves the required precision depends strongly on absolute population density and trappability. Two populations are believed currently (2005/2006) to be at very low density (Santa Cruz 0.6 km^{-2}, Santa Rosa 0.2 km^{-2}), two are at moderate density (San Miguel 1.6 km^{-2}, Santa Catalina 1.9 km^{-2}), and one is at high density (San Nicolas 9.4 km^{-2}).

[1] CV is the coefficient of variation of the estimate, i.e., the estimated sampling error of the estimate divided by the estimate itself.
[2] This strictly assumes that the relative precision of average density includes uncertainty due to the placement of sites in a non-uniform population. Local density varies among sites; the methods used here assume that variation is Poisson-distributed (variance = mean).

Except for differences due to density and trappability we expect one design (size, shape and number of trap lines; number of trapping nights) to be statistically optimal for all islands, as the same target has been set for $\mathrm{CV}(\hat{D})$ *on all islands.*

Approach to Design

We want to estimate average local density from lines or clusters of single-catch traps operated over several days. The following strategy was used to optimise the design:

1. Determine the most efficient local trap layout (shape of line, trap spacing) in terms of the number of fox recaptures expected per trap.
2. Model the precision of estimated average density as a function of the absolute number of recaptures using the selected local trap layout.
3. Determine the target number of recaptures needed to achieve the desired CV.
4. Determine the optimal means of achieving the target number of recaptures (number of units per island and number of trapping occasions) by further simulations.
5. Confirm that the optimised design yields the required CV by further simulations with full density estimation.

Only steps 2 and 5 involve the slow process of estimating density from simulated data. Steps 1, 3, and 4 use number of recaptures as a surrogate for the precision of density estimates.

Density and trappability scenarios

Trappability (more precisely, the parameters g_0 and σ of the spatial detection function) is likely to vary with habitat and density. Despite the considerable effort that has gone into trapping foxes so far, we cannot be confident about trappability at low density when it is most critical.

Previous simulations (reports of Nov–Dec 2006) used either three scenarios with a halfnormal detection function based on 'typical' points within scatterplots of previous estimates, or three scenarios with a uniform detection function.

The uniform scenarios were constructed to give a plausible inverse relation between density and territory size (assuming non-overlapping territories occupy all habitat and each territory is occupied by two foxes); they are retained as Scenarios 1–3 in the set used here (Table M-1).

The original halfnormal scenarios are replaced here with two that combine a 'best estimate' based on analyses conducted by Vickie Bakker of populations at low to moderate density on San Miguel, Santa Cruz, and other islands (Scenarios 4,5 in Table M-1).

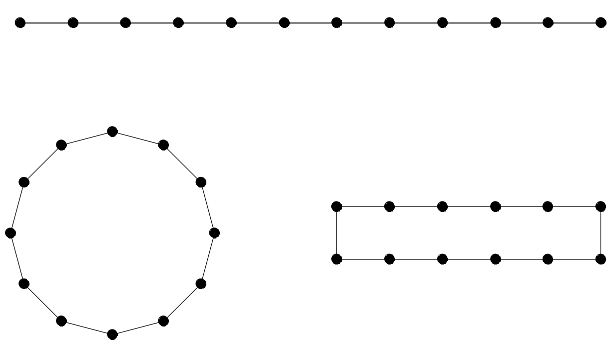
These scenarios are arbitrary and may be the weakest link in the simulations.

Table M-1. Density and trappability scenarios for simulations

Scenario	Detection model	Density km^{-2}	g_0	σ m	Range size km^2
1	Uniform	4	0.150	400	0.5
2	Uniform	2	0.075	564	1.0
3	Uniform	1.33	0.050	691	1.5
4	Halfnormal	1	0.080	300	—
5	Halfnormal	4	0.080	300	—

1 Optimal trap layout

Three trap layouts were chosen for comparison (circle, a single line, and parallel lines spaced the same distance apart as traps along each line):



Each layout was simulated with 10 traps at spacings of 200 m, 250 m, and 300m. The total number of traps was also varied in increments of 2 from 10 to 20 with 200 m spacing for each layout. Results are tabulated in Appendix M-1 and summarised (in part) in Figure M-1. They may be summarized:

- Smaller trap spacing and greater trap number are slightly more efficient, but the differences are slight.
- Paired lines and circles are preferred over single lines (increase in number of recaptures 12%, 18%, 20%, 23%, 30% for scenarios 1–5, averaged over different spacing and number of traps).
- Paired lines are similar to circles (change in number of recaptures –4%, 1%, 3%, 3%, 4% for scenarios 1–5).

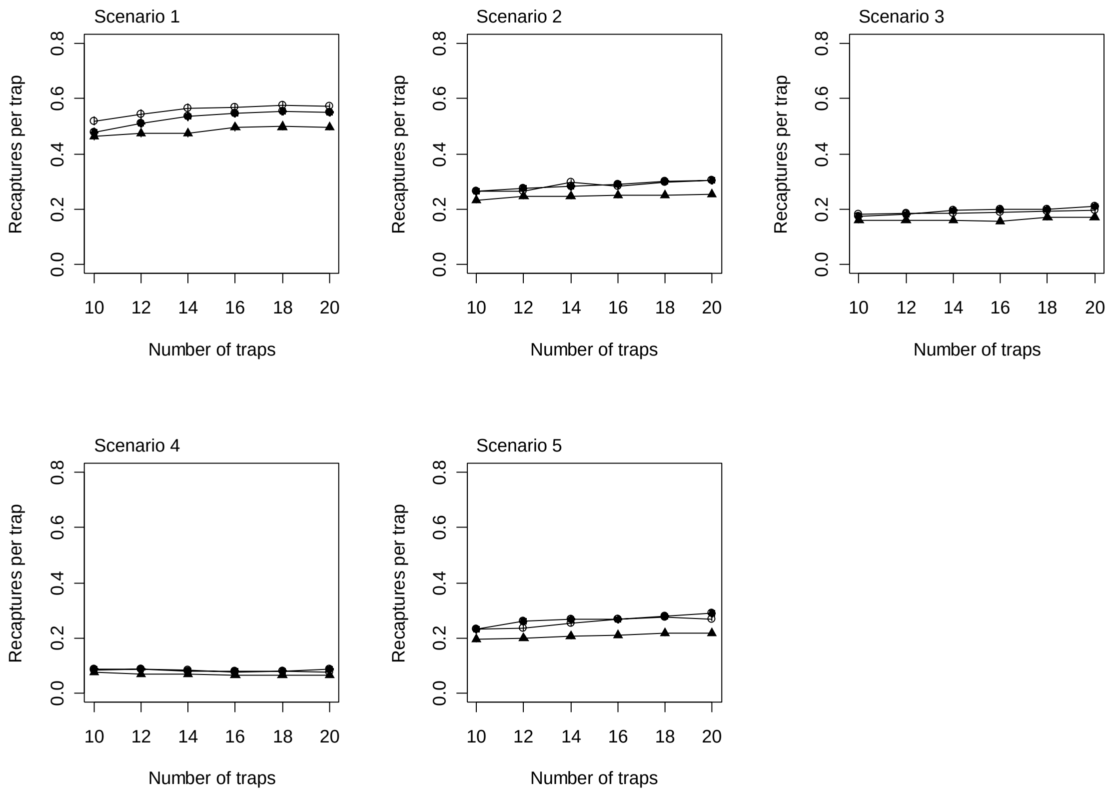


Figure M-1. Effect of trap layout on predicted number of recaptures over 6 nights; spacing 200 m throughout. ○ circle, ● paired lines, ▲ single line. Raw data in Appendix 1.

The differences between circles and paired lines with varying trap number and spacing are too slight for any single design to be described as ‘optimal’ on statistical grounds. Paired lines are likely to be convenient in the field; if a more open loop is preferred for operational reasons then we can be confident its sampling properties will be close to those of paired lines. Further simulations therefore use only paired lines.

The basic trapping unit is defined as twelve[3] traps arranged in two lines at a spacing of 200 m. Spacing may be increased to 250 m with only a marginal loss in terms of recaptures.

2 Precision vs number of recaptures

A general relationship was established between of the maximum likelihood density estimate (Borchers and Efford in revision) and the number of recaptures in a survey by simulating with three trapping intensities chosen to yield estimated precision near the target value. The observed pattern (Figure M-2) is similar to that from other studies with spatially explicit capture–recapture (see, e.g., Efford et al. 2004 for forest birds in mist nets).

[3] The number of traps is increased over the minimum of 10 in the draft report because of worries about bias when units are small relative to range size, and because the new scenarios 4,5 are more conservative, indicating a need for more traps in total.

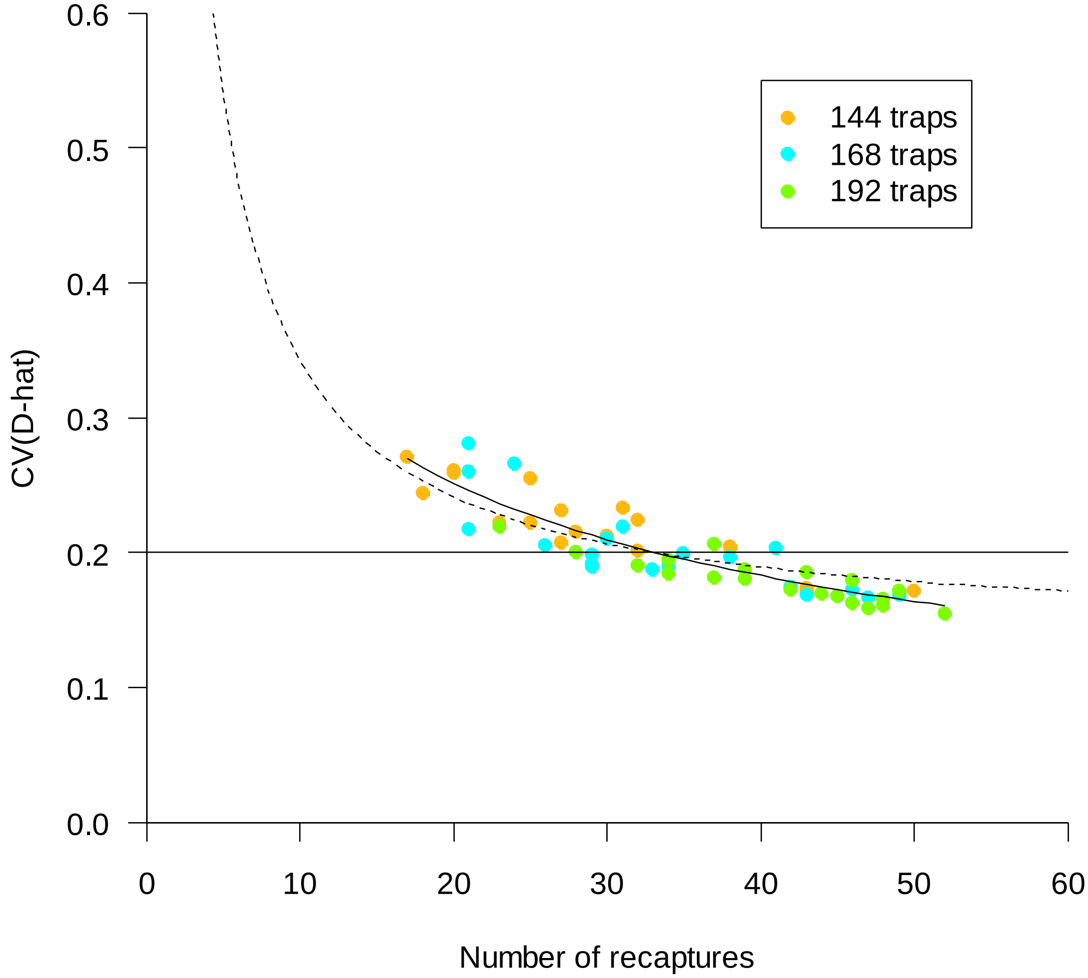


Figure M-2. Precision of density estimate as a function of the number of recaptures. Simulated data for 6 occasions and varying numbers of traps (traps were arranged in 12 units of 12, 14 or 16 traps each). $D = 2\ \text{km}^{-2}$, $g_0 = 0.08$, $\sigma = 300$ m (halfnormal). Solid curve fitted by nonlinear least squares $\text{CV}(\hat{D}) = 0.894m^{-0.297} - 0.116$, where m is number of recaptures; the curve intersects $\text{CV}(\hat{D})$=0.2 at 33.2 recaptures. Dashed curve $\text{CV}(\hat{D}) = 1.88\ m^{-0.96} + 0.13$ was fitted to a combination of present data points and those from previous simulations (data not shown).

Table M-2. Summary of simulations for Figure M-2. Mean ± SE from 20 replicates.

No. of traps	**Recaptures**	$\text{CV}(\hat{D})$
144	30 ± 2	0.220 ± 0.006
168	33 ± 2	0.203 ± 0.007
192	41 ± 2	0.180 ± 0.004

3 Target number of recaptures

From Figure M-2 we expect $CV(\hat{D}) \leq 0.20$ when the number of recaptures exceeds 33. Variation in study design, density, and trappability have only a small effect on this target. Figure M-2 also illustrates that for any one design the actual estimate of precision will vary from survey to survey even if density is constant. To buffer against this variation and ensure the target $CV(\hat{D}) \leq 0.20$ is met in most years, I recommend that trapping aims to achieve 40 recaptures on average.

4 Means of achieving target

Given a fixed design for the trapping units (12 traps in a loop or parallel line at a spacing of 200 m or perhaps 250 m), we ask how many units need to be set over how many nights to achieve the target number of recaptures. This again depends on density and trappability, so we compare multiple scenarios by simulation (Figure M-3).

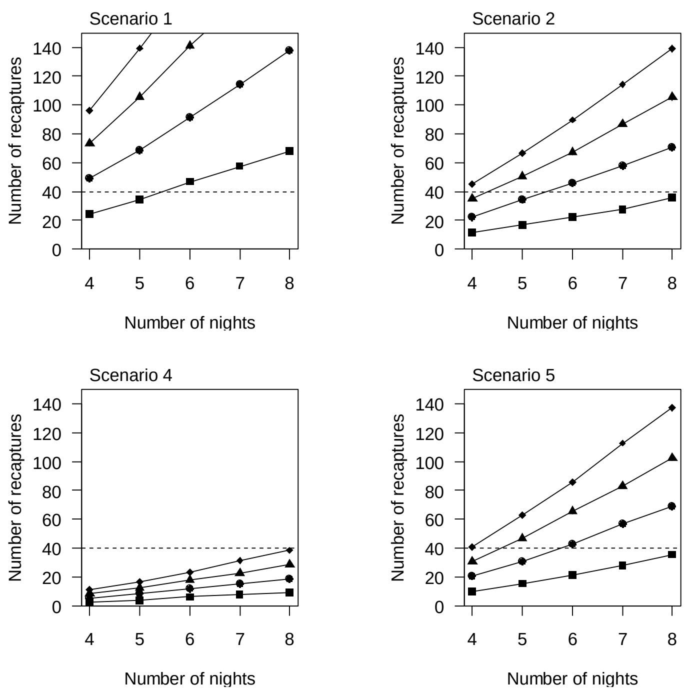


Figure M-3. Effect of trapping effort on number of recaptures. Trials with varying numbers of 12-trap paired-line trapping units trapped for varying numbers of nights. ■ 5 units, ● 10 units, ▲ 15 units, ◆ 20 units. Each point is the mean of 1000 simulations. Dashed line indicates the target of 40 recaptures. Scenarios (varying combinations of density and trappability) are given in Table M-1.

We conclude from these simulations that

- The minimum effort (5 units over 4 nights) fails under all scenarios.
- Under the most challenging scenario (D = 1/km^2, g_0 = 0.08, σ = 300 m) none of the tested levels of effort is sufficient to meet the target.

- Trapping for longer is an efficient way of adding recaptures and improving precision under all scenarios (because a greater fraction of captures are recaptures).

The number of trapping units required to meet the target of 40 recaptures was interpolated from the simulation output for varying durations of trapping (Table M-3).

Table M-3. Number of 12-trap units required to achieve target of 40 recaptures.

Nights	**Scenario**				
	1	**2**	**3**	**4**	**5**
4	8	18	>20	>20	20
5	6	12	19	>20	13
6	<5	9	14	>20	9
7	<5	7	11	>20	7
8	<5	6	9	>20	6

We infer that the requirement of $CV(\hat{D}) \leq 20\%$ is expected to be met at densities of 1.33, 2 and 4 foxes km^{-2} when 14, 9 and 5 lines respectively are trapped over 6-nights (Scenarios 1–3; shaded cells in Table M-3). For the remaining two scenarios in which detection parameters were constant ($g_0 = 0.08$ and σ(halfnormal) = 300 m), no trapping regime was adequate at 1 fox km^{-2}, but the required precision could be achieved with 9.4 units over 6 nights at 4 foxes km^{-2}.

We do not have reliable estimates of the detection parameters for very low density such as on Santa Cruz and Santa Rosa in 2005/06 (<1 km^{-2}). On the assumption that detection parameters are unchanged from the standard low-density scenario (4), the number of lines should be doubled for each halving of density (Figure M-4). The required number of units may be calculated for each of the five islands given current estimates of density (Table M-4).

Table M-4. Number of 12-trap units that should be trapped for 6 nights to achieve 40 recaptures (based on Fig. M-4).

Island	**Density km^{-2} 2005/2006**	**No. of units**
Santa Rosa	0.2	–
Santa Cruz	0.6	63
San Miguel	1.6	24
Santa Catalina	1.9	20
San Nicolas	9.4	4

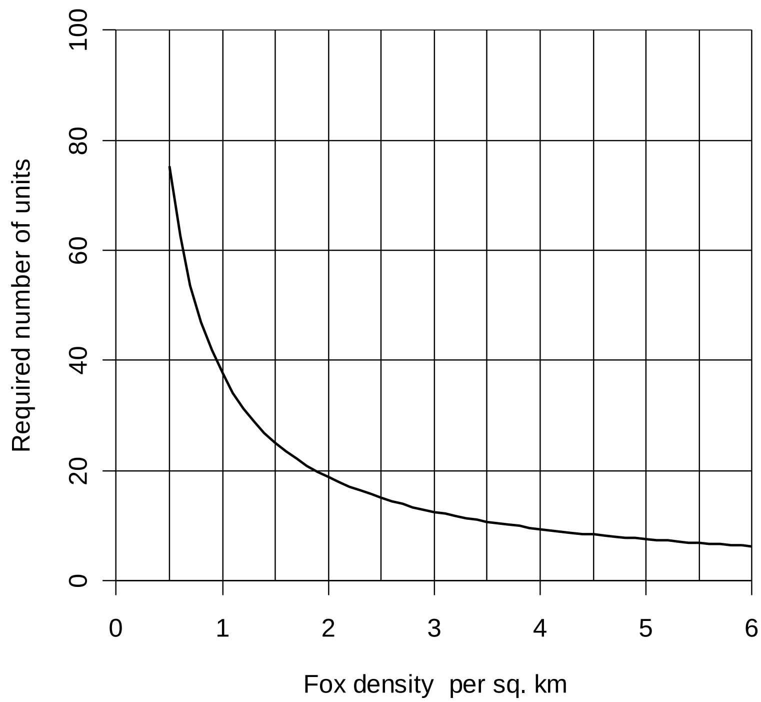


Figure M-4. Projected number of 12-trap units trapped for 6 nights needed to deliver 40 recaptures over a range of low densities, given detection parameters g_0 = 0.08 and σ = 300 m. Based on 9.4 units required for Scenario 5, assuming a linear relationship between density and number of recaptures. The curve has the equation $y = 37.6/x$.

At high density (e.g., San Nicolas 2005/06, 9.4 km^{-2}) the precision target will be exceeded.

5 Density estimation with optimised design

Simulation were performed to confirm the behaviour of the density estimator when a population of 4.0 km^{-2} was sampled with the recommended intensity (9 12-trap units for 6 nights = 648 trap nights). Detection parameters were g_0 = 0.08, σ(halfnormal) = 300 m. Trap units were assumed to be spaced far enough apart (1000 m in the simulations) that capture of an individual fox in more than one unit was very rare. The fitted model used a halfnormal detection function.

Table M-5. Estimates from simulated sampling with 9 12 trap units for 6 nights when true average density is 4 km^{-2}.

Estimate	**Mean ± SE**
Number of individuals	57.1 ± 0.6
Number of recaptures	39.6 ± 0.8
$\hat{D}$ km^{-2}	4.26 ± 0.07
CV($\hat{D}$)	0.186 ± 0.002
$\hat{g}_0$	0.075 ± 0.002
$\hat{\sigma}$ (halfnormal) m	296 ± 3

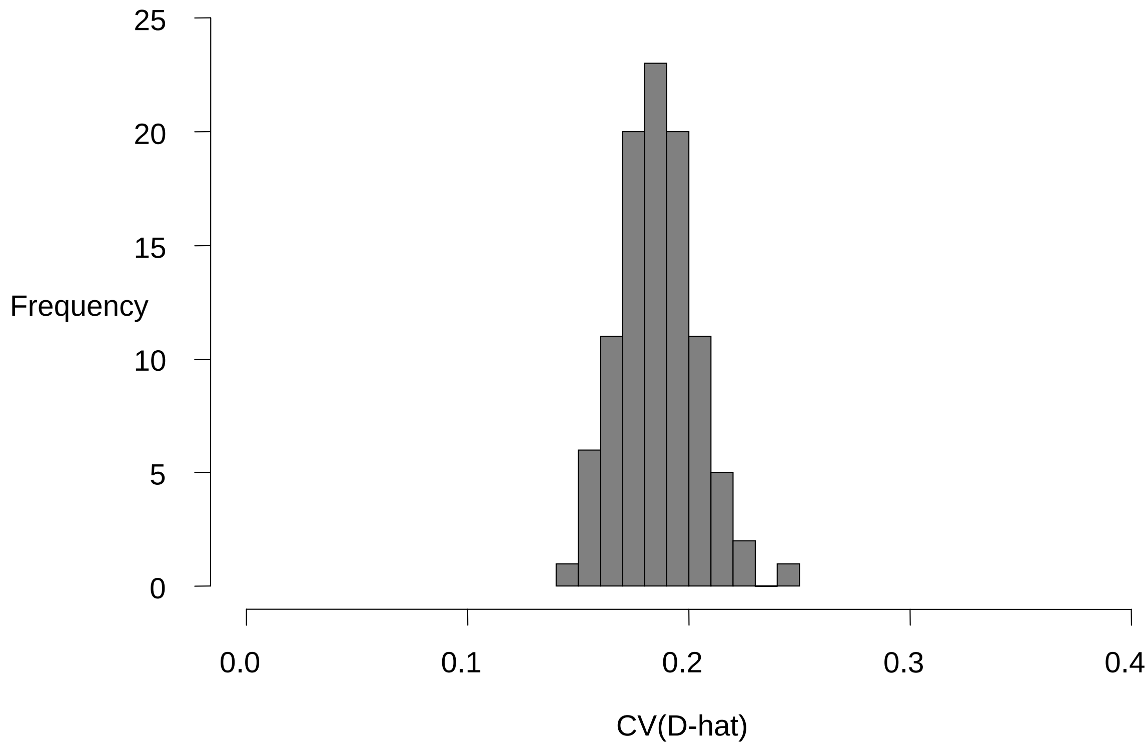


Figure M-5. Distribution of estimated precision of density estimate from 100 simulated datasets.

The estimated density showed a slight positive bias of about 6%. This is small compared with the expected sampling error, and can probably be ignored. (Other trials suggest that the bias disappears almost entirely when each unit contains 14 or more traps, but this result has not been formalized). Performance was otherwise as expected, with both the mean number of recaptures and $\mathrm{CV}(\hat{D})$ coming close to target. $\mathrm{CV}(\hat{D})$ was quite tightly distributed around its mean (Figure M-5). Nevertheless, the estimated $\mathrm{CV}(\hat{D})$ exceeded 0.2 in 19 simulations out of 100.

Derived plots

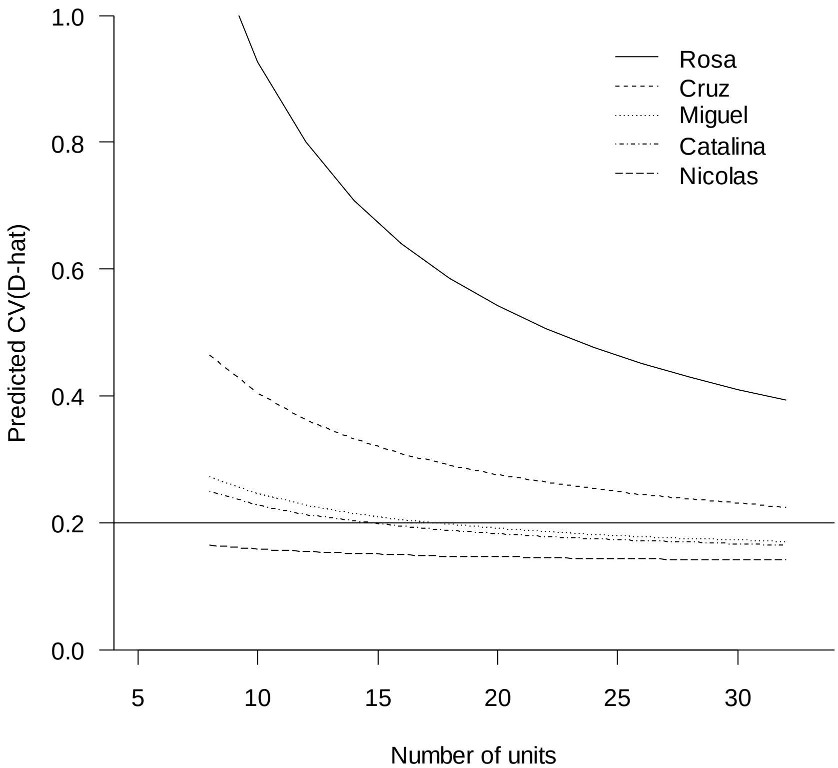


Figure M-6. Predicted precision of density estimate as a function of the number of 12-trap units trapped for 6 nights, given detection parameters g_0 = 0.08 and σ = 300 m. Each island was assumed to be at its 2005/2006 estimated density (Santa Rosa 0.2 km^{-2}, Santa Cruz 0.6 km^{-2}, San Miguel 1.6 km^{-2}, Santa Catalina 1.9 km^{-2} and San Nicolas 9.4 km^{-2}). CV was inferred from mean number of simulated recaptures *m* using CV = 1.88 $m^{-0.96}$ + 0.13 (cf Figure M-2). This curve is conservative for large sampling effort (i.e., correct CV is usually less than shown when CV<0.2) and the flatness of curves below the CV=0.2 line is therefore partly an artifact.

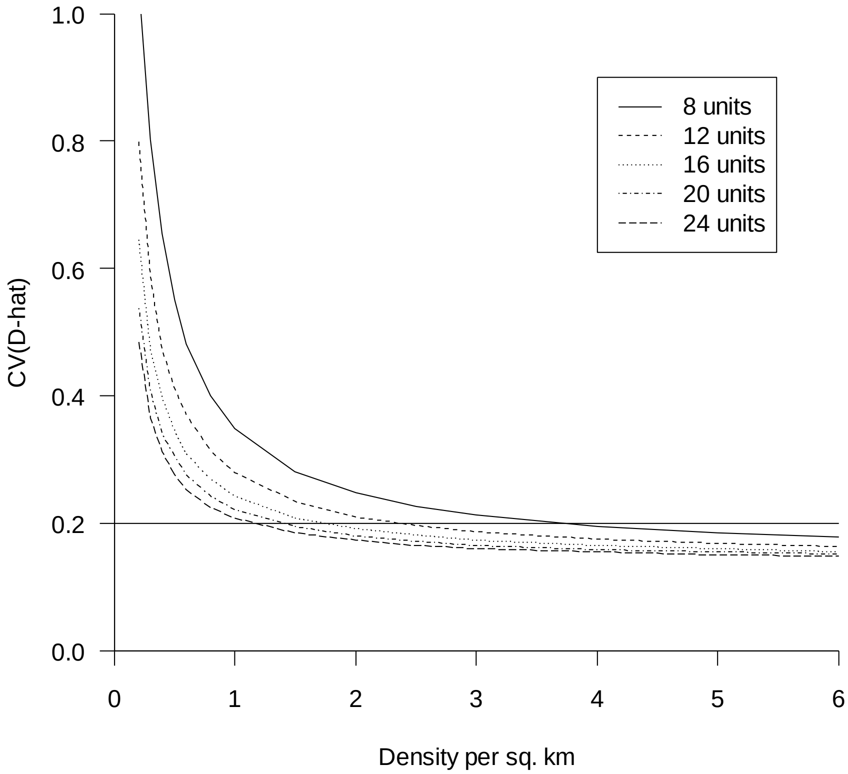


Figure M-7. Predicted precision of density estimate as a function of population density for varying numbers of 12 trap units trapped for 6 nights, given detection parameters g_0 = 0.08 and σ = 300 m. CV was inferred from mean number of simulated recaptures as in Figure M-6.

Other Comments

Scaling up from density to $\hat{N}$ should ideally be based on a probability design (e.g. random stratified or systematic) for local sampling to ensure that local density is representative of the island. Difficulties of movement off-road are said to preclude a rigorous sampling design. A partial alternative is to model the distribution of foxes. This may entail either a simple assumption of a uniform or random (Poisson) distribution across the island, or a more elaborate model of density as a function of habitat. All results reported here assume a Poisson distribution of foxes across each island.

It is commonly believed that subjectively selected sites (i.e. an 'undesigned' survey) can give unbiased estimates of trend over time. This view is mistaken because subjectively selected sites may be biased with respect either to habitat or to current population density. Either bias has the potential to produce misleading estimates of trend. Operating live-traps for island foxes away from roads is certainly arduous and relatively expensive, but this must be balanced against the dubious value of data obtained along roads.

It is important to avoid intentional or unintentional bias in the selection of sites for sampling, even if sampling does not follow a probability design overall. This may be achieved by random placement along the road network (where one exists). The potential bias is then reduced to the difference between sites near roads and far from roads, which should be evaluated by comparing the habitat in the ‘accessible’ and ‘inaccessible’ strata and, ideally, by stratified sampling of foxes themselves.

As the brief was to optimize the use of traps to monitor foxes, this report does not evaluate possible alternative methods (distance line transects, scat counts, mark-resight etc.). It is possible (but uncertain) that these methods may be better than capture–recapture for extremely low density populations.

References

Borchers, D.L., and M.G. Efford. In revision. Spatially explicit maximum likelihood methods for capture–recapture studies. Biometrics.

Efford, M.G., D.K. Dawson, C.S. Robbins. 2004. DENSITY: software for analyzing capture–recapture data from passive detector arrays. Animal Biodiversity and Conservation 27:217–228.

Appendix M-1. Effect of trap-line geometry on average predicted number of recaptures per trap over a 6-night trapping session, using single-catch traps. Mean of 1000 replicates.

			Recaptures per trap				
Geometry	**N traps**	**Spacing**	**Density & detection scenario***				
			1	**2**	**3**	**4**	**5**
Circle	10	200m	0.519	0.263	0.180	0.082	0.233
Circle	10	250m	0.510	0.253	0.164	0.084	0.223
Circle	10	300m	0.479	0.253	0.152	0.076	0.204
Circle	12	200m	0.543	0.265	0.185	0.086	0.237
Circle	14	200m	0.566	0.297	0.186	0.084	0.254
Circle	16	200m	0.571	0.283	0.190	0.077	0.269
Circle	18	200m	0.577	0.298	0.193	0.079	0.275
Circle	20	200m	0.572	0.303	0.196	0.076	0.269
Line	10	200m	0.464	0.233	0.160	0.077	0.196
Line	10	250m	0.434	0.224	0.145	0.071	0.174
Line	10	300m	0.395	0.200	0.128	0.064	0.154
Line	12	200m	0.475	0.246	0.160	0.068	0.201
Line	14	200m	0.474	0.246	0.159	0.068	0.206
Line	16	200m	0.497	0.251	0.157	0.065	0.211
Line	18	200m	0.498	0.251	0.169	0.065	0.216
Line	20	200m	0.497	0.254	0.170	0.065	0.219
Paired lines	10	200m	0.480	0.266	0.173	0.088	0.231
Paired lines	10	250m	0.491	0.266	0.174	0.082	0.231
Paired lines	10	300m	0.503	0.248	0.160	0.081	0.219
Paired lines	12	200m	0.512	0.277	0.182	0.088	0.261
Paired lines	14	200m	0.535	0.282	0.195	0.080	0.268
Paired lines	16	200m	0.546	0.292	0.199	0.080	0.269
Paired lines	18	200m	0.553	0.302	0.201	0.079	0.278
Paired lines	20	200m	0.551	0.303	0.209	0.087	0.290

* Scenarios in Table M-1

Appendix N

Number of Radiocollared Individuals Required to Detect Eagle Mortality

Prepared by

Dan Doak
University of California, Santa Cruz

Introduction

The following document estimates the number of radiocollared foxes needed to ensure that eagle-caused mortalities were actually rare, rather than just unseen due to low sample sizes. For the purposes of this document, the objective of the sampling program is assumed to be detection of a mortality rate due to eagles of ≥0.025 (2.5 %) per year. This is the approximate mortality rate associated with one eagle for low to moderate fox densities during the buildup of eagles in the 1990s. Greater rates of mortality are dangerous if fox populations are not large.

Here I estimate the sampling effort required to assure that mortality rates are low enough to be safe, <u>when we don't see any eagle-caused deaths</u>. That is, I assume that no eagle-caused deaths are observed for a year or more and the question is "does that mean we can be sure mortality rates are below the critical threshold of 2.5% annually?"

Basic Calculations

N = number of collared foxes
m* = 0.025 (the critical annual mortality rate)
p* = 1-m* (the annual probability of not being killed by an eagle)

Using binomial probabilities,

Prob(no eagle-caused deaths, with N collars and m*) = $(1\text{-m*})^N$

Using this, we can calculate the probability of seeing zero deaths for any m ≤m*, (vs. mortality higher than m*) by integrating and dividing to get a cumulative probability:

$$\Pr(m \le m^* \mid N) = \frac{\int_0^{p^*} (1-p)^N \, dp}{\int_0^1 (1-p)^N \, dp} = 1 - \left(1 - p^*\right)^{N+1}$$

Results

Achieving the desired power to detect eagle predation increases with N (Figure N-1), but required effort is substantial, with 118 collars needed over the long term to be 95% sure that eagle-caused mortality risk is at or below 0.025 when no predation is observed.

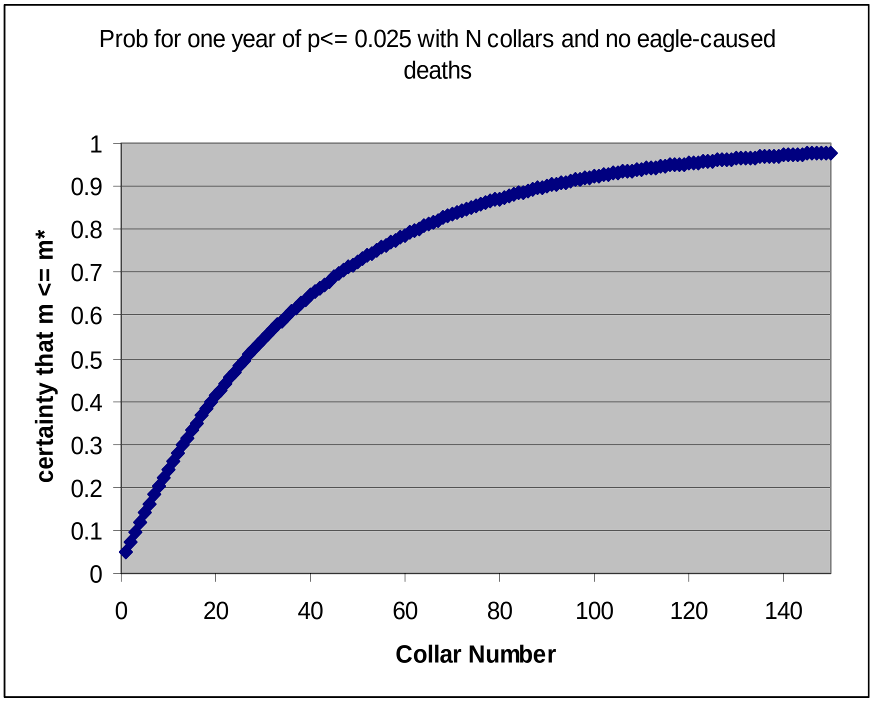


Figure N-1. Relationship between number of radiocollared foxes and certainty that true annual mortality rate is at or below 0.025 when no eagle-caused mortalities are observed.

However, we can instead track mortality rates averaged over longer time intervals. Each collared fox in each year is a separate observation, so we can roughly assume that we can use each collar-year as an independent observation and use multiple years of data to make a judgment about eagle-caused mortality. This changes the certainty criterion for low eagle mortality detection to "the certainty that mortality is on average at or below 0.025 over a 3-year time period." With this, we can reconstruct the probabilities, assuming that we have at least N collars in each year of the 3 years, which results in lower sample size requirements to achieve the revised criterion (Figure N-2). Specifically, only 40 collars are needed to yield a greater than 95% confidence that average mortality rates over 3 years are at or below 0.025

While there is nothing magical about a 3-year average for this criterion focused on detecting eagle mortality, it is nonetheless consistent with use of a 3-year average for the criterion focused on the extinction risk isoclines.

Finally, once a fox population is recovered, and thus at higher numbers, this detection criterion may be rather stringent, especially if the factors thought to drive eagle arrival have been eliminated. Thus, we can ask the same question but for a higher m* value. Figure N-3 contrasts the collars needed to assure 95% confidence for m*=0.025 and m*=0.05. For m*=0.05, only 20 or more collars will ensure 95% confidence.

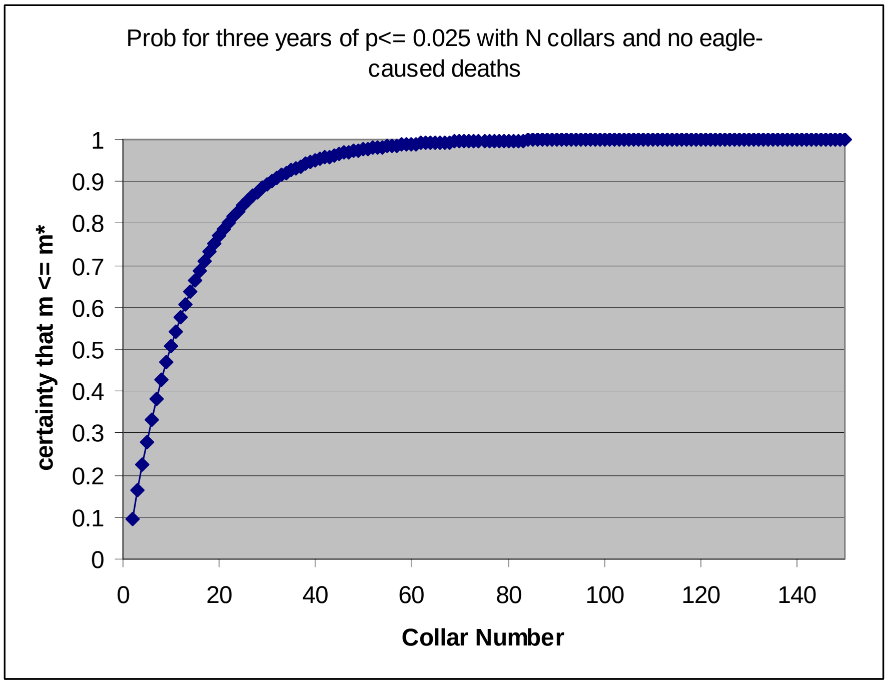


Figure N-2. Relationship between number of radiocollared foxes and certainty that true annual mortality rate, averaged over three years, is at or below 0.025 when no eagle-caused mortalities are observed.

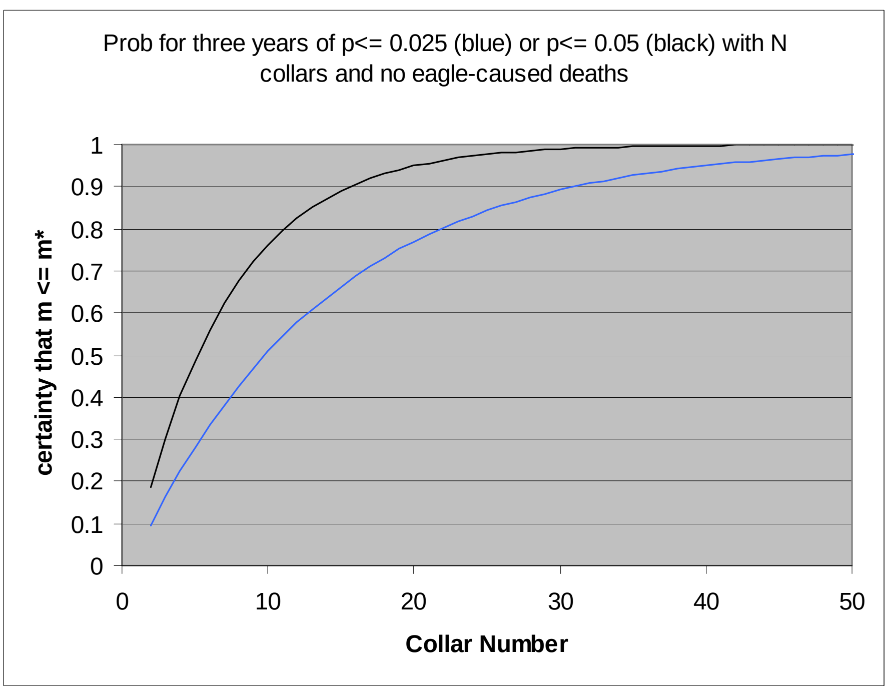


Figure N-3. Relationship between number of radiocollared foxes and certainty that true mortality rate, averaged over three years, is at or below 0.025 or 0.05 when no eagle-caused mortalities are observed.

Appendix O

Independent Statistical Review of the Monitoring Framework

The Nature Conservancy invited Dr. Gary White (Colorado State University) to provide an independent review of the draft island fox monitoring framework. Dr. White's review is included in its entirety at the end of this appendix. The following are excerpts from that review with responses that address Dr. White's comments. We carefully considered all of Dr. White's suggestions and corrections and incorporated them into the revised report as appropriate, thereby enhancing the quality of the report.

Comment 1. *I am concerned about the performance of the estimators used in Program DENSITY because of the strong assumptions required by the method used. This method assumes a constant home range size for all animals (because σ is assumed constant), and that there is little if any habitat heterogeneity (again because σ is constant in all directions). ... To summarize arguments pro and con for the 2 different monitoring schemes, the proposed monitoring scheme using DENSITY is open to bias from a necessarily simplistic model to achieve an estimate of density. Reasons include lack of models for behavioral response to capture, individual heterogeneity, and temporal variation. Other issues include constant home range size across all individuals, and no heterogeneity in habitat.*

We agree that this would be a concern if indeed σ (the movement parameter) and g0 (the detection parameter) were assumed constant. However, in the latest version of DENSITY (version 4.0), both σ and g0 can be varied through time, across space, or using session covariates. Both variables can also incorporate behavioral response to capture, individual heterogeneity, or trap-specific covariates. Some of these options are not yet implemented in the publicly available version of the program, but they are currently being developed.

Our analyses of existing grid data suggest that, even without incorporating these various forms of heterogeneity, program DENSITY yields fairly similar estimates to those of standard mark-recapture techniques using one MMDM as a buffer strip width (data not shown in report). While these results give us confidence in the methods of spatially explicit capture-recapture (SECR) analyses, we acknowledge that elongated home ranges due to movements along roads, trails, and ridges may violate the assumption that movement is constant in all directions, or that 2x6 grid configuration may alter or sample behavior in a way that biases results, a complication that would affect both traditional mark-recapture techniques and SECR. For this reason we will add recommendations for further evaluation of this possibility via future research. These evaluations should examine the implications of various home range shapes using locational data collected via GPS collars and/or computer simulation.

Comment 2. *I believe an approach superior to the DENSITY model can be developed given the data from these 40 radio-collared animals.*

This is an interesting suggestion that sounds like it could be developed into a solid method; however, it would require further development and may, for several reasons, not be feasible for our purposes:

- One part of this estimator calls for the proportion of time each collared fox spends on a grid. This requires more effort than the mortality checks we are recommending in our protocols (which require obtaining a radio signal from each animal every 1-2 days), and even the currently recommended intensity of monitoring will present a challenge for most of the islands. The added effort (either in field time to obtain locations via VHF collars or in the cost of using GPS collars) needs to be evaluated in comparison to potential benefits of this approach.
- The approach suggested by Dr. White would require that a substantial number of collared foxes are clustered in the vicinity of trapping grids. Although grid size requirements need to be evaluated, Dr. White suggested that units larger than 2x6 traps are required, which would result in fewer trapping locations on the island. The need to monitor animals for mortality, in contrast, suggests that animals should be distributed across the island. Given limited resources (for equipment and personnel), it is unlikely that managers could afford to both distribute collars for mortality monitoring and collar an additional set of animals in the vicinity of a few large grids.
- This method would require 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. Preliminary simulations by M. Efford suggest that this method may be less efficient than spatially explicit mark-recapture methods implemented in program DENSITY (i.e., it may require greater effort to obtain the same precision), but we will suggest this development as part of a research module, including evaluation via simulation and field investigation (an island such as San Clemente Island, where large grids are currently being trapped might be an appropriate location for such an investigation).

Comment 3. *...scattering traps across the island and moving them each night for 3–4 nights to achieve a sample of marked animals, followed by another 3–4 of trapping to get the ratio of marked to unmarked foxes would produce a Lincoln-Petersen estimator.*

We are not sure how or if this suggestion differs from the island-wide random trapping that we investigated thoroughly in our analyses (Appendices K, L, and M). We agree that this would be an ideal method to obtain an island-wide estimate. However, the effort involved (to set a large number of traps and move them frequently) to obtain an adequate number of recaptures makes this an infeasible method for all but possibly the two smallest islands. The manager of one of the two small islands (San Miguel) determined that this would be beyond their field crew capabilities, and we have suggested this as one scenario to be considered for the other small island (San Nicolas Island).

Comment 4. *My feeling is that 3–4 larger grids would provide better power to detect population changes than the more numerous 2 x 6 grids scattered around the island, mainly because the data are better able to generate models that can detect changes in capture probabilities from behavioral response to capture and individual heterogeneity. ... Annual estimates of recruitment and rate of population change (λ) can be estimated with the Pradel model from larger trapping grids.*

We agree that there are some advantages to using larger grids, such as (a) more flexibility to use traditional mark-recapture methods in addition to methods used in program DENSITY, and (b) facilitation of pilot tests of the radiocollar-based method Dr. White suggests.

However, as mentioned above and in the draft monitoring plan, there are several reasons why we chose not to recommend large grids on three of the five islands:

- Biologists and managers of the three large islands have told us that the steep and rugged island terrain precludes use of large grids in all but a few restricted locations, due to safety and logistic constraints.
- Larger grids may make it harder to detect area- or habitat-specific problems.
- If we did use a small number of large grids, they would likely be biased towards gentle terrain, and they would be less representative of the entire island than many small grids would collectively be.
- If we used a small number of large grids, there would need to be additional trapping across the island to collar animals for survival monitoring which, in the current recommended protocols, would likely be accomplished in the trapping on small units.

The first reason stated above is the primary driving factor in our decision to avoid large grids. Our recommended protocols would not be useful if we recommended something that the managers and biologists say would not be feasible on their island(s). In addition, the proposed recovery criteria dictate that monitoring focus on obtaining estimates of mortality rates and island-wide population size, with less emphasis on measuring trend. We have modified the text to clarify this, and to better explain the basis of this goal.

Responses to selected other issues

1. *Question about timing of trapping and whether we will be capturing young of the year*.

By late June/early July, young of the year will be captured, although their capture probabilities will likely vary for a number of reasons, including their ages. We can also use signs of lactation as a rough index of proportion of females reproducing. As Dr. White mentioned, we can also assess recruitment from the previous year by looking at yearlings trapped. After long discussions with biologists and veterinarians, we concluded that we can not trap earlier in the year because of risk to nursing pups being separated from their mothers. This is a strong concern voiced by the veterinarians involved in fox monitoring. We recognize that additional data on reproduction may have to come from other methods (e.g., cameras).

2. *Note the correct spelling of 'Lincoln-Petersen'….*

We have corrected this oversight.

3. *Several places in the document allude to using capture success or MNKA as a useful index for detecting trends. I would disagree... You could expect to see large differences in capture probabilities across time because of changes in the environment, even though fox populations have not changed. Hence, capture success might remain the same even though the population is declining, or capture success might decline even though the population is remaining stable. I suggest that even with sparse data, you can correct for changes in capture probabilities by combining data across trapping grids, years, or even islands, and make this argument in White (2005).*

We agree that capture success alone should generally not be used as an index, and have modified the text to clarify this and to advise against using MNKA at all. The Density software provides for the combining of capture probability (detection function) parameters across time and space, and this is a good way to deal with sparse capture-recapture data.

4. *There are 2 different Crooks (1994) citations, but these are not distinguished in the text.*

We have corrected this oversight.

5. *One additional recommendation is to use the known fate model in MARK to perform survival estimates for radio-collared foxes, rather than the simple Kaplan-Meier estimator.*

We occasionally reported on estimates made by others using the Kaplan Meier method, but we agree with this suggestion and will state this explicitly in the monitoring plan.

Comments on "A Population Monitoring Framework for Five Subspecies of Island Fox (*Urocyon littoralis*)"

Gary C. White, Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, Colorado 80523 USA. gwhite@cnr.colostate.edu

The report represents a tremendous amount of work and I'm impressed at the thoroughness of the process that the authors obviously went through to arrive at the proposed monitoring scheme. A large number of options were considered. Clearly considerable time, energy, and expense went into the preparation of this document.

I have 2 major comments concerning the proposed monitoring scheme for the 5 islands. First, I'm not convinced that 2 × 6 trapping grids are the best approach to monitoring on the larger islands. I am concerned about the performance of the estimators used in Program DENSITY because of the strong assumptions required by the method used. This method assumes a constant home range size for all animals (because σ is assumed constant), and that there is little if any habitat heterogeneity (again because σ is constant in all directions). I am unsure how well this approach will work given what I interpreted as fairly large changes in vegetation on these islands. As described below, you have considerable additional data with which to improve the approach.

Second, the proposed protocols are requesting that 40 foxes be radio-collared each year during the trapping period. I believe an approach superior to the DENSITY model can be developed given the data from these 40 radio-collared animals. Rather than trying to estimate the area of a trapping grid and then construct density as $\widehat{D} = {}^{\widehat{N}}/_{\hat{A}}$ (as almost all past approaches have done), I would propose fixing A by delineating the trapping grid, and then determining the proportion of time that radio-collared foxes then spend on the grid. To use this approach, grids larger than the proposed 2 × 6 should be used. The estimator I would suggest can be extended to include individual heterogeneity in both capture probabilities and in proportion of time spend on the grid area. Define $\widetilde{p_i}$ as the proportion of time animal i spends on the grid, and p_i^* as the probability that an animal is captured 1 or more times on the trapping grid, with $p_i^* = 1 - \prod_{j=1}^{t}(1 - \hat{p}_j)$ for t trapping occasions. Then for the M_{t+1} unique animals captured on the grid, density is estimated as $\widehat{D} = \sum_{i=1}^{M_{t+1}} \frac{\widetilde{p_i}}{p_i^*}$. A logical extension of this estimator is to estimate both $\widetilde{p_i}$ and p_i^* as functions of the distance to the edge (DTE) of the grid estimated from the mean capture coordinates of a fox's capture locations, because DTE would be a logical predictor of both capture probabilities (foxes on the edge of the grid would have less of their home range on the grid) and probability of occurring on the grid. The resulting estimator is then

$$\widehat{D} = \sum_{i=1}^{M_{t+1}} \frac{\widetilde{p_i}(DTE_i)}{p_i^*(DTE_i)}.$$

In the case of $\widetilde{p_i}$, a logistic regression equation can be fitted using the data for radio-collared animals, and this equation used to predict the value for animals that did not receive a radio collar based on DTE and/or other individual covariates such as age and gender. If the Huggins (1989, 1991) estimator is used to estimate population size (implemented in Program MARK, White and Burnham [1999]), the distance to edge of the grid covariate can also be used to estimate p_i^*, as well as other individual-specific covariates, such as age and sex. If enough capture occasions are available, then the Pledger mixture models (Pledger 2000) can be used to achieve the model M_{tbh} (White 2007). Therefore, issues of behavioral response to capture and individual heterogeneity can be modeled for both $\widetilde{p_i}$ and p_i^*. The proposed model with $\widetilde{p_i}$ and p_i^* is an extension of the linear model proposed in White and Shenk (2001). What appeals to me the most about this proposal is that your protocol already calls for intensive monitoring of radio-collared animals, so the collection of location data on whether radio-collared foxes continue to occupy the trapping grid is not additional effort just to estimate density, particularly with the proposed automatic monitoring systems or with GPS collars.

However, one advantage of the 2 × 6 trapping grids is that better spatial coverage of the islands is achieved. However, I'm not sure that this is a great advantage. No matter how traps are placed, the potential to get a completely valid island-wide estimate of *N* seems small. This admission does appear in the report, in that some cliff areas are considered too dangerous to sample, and other areas are too remote to sample. If you are willing to ignore the potential bias of behavioral response to capture (these foxes appear to be trap happy, and are attracted to bait) and individual heterogeneity, then scattering traps across the island and moving them each night for 3–4 nights to achieve a sample of marked animals, followed by another 3–4 of trapping to get the ratio of marked to unmarked foxes would produce a Lincoln-Petersen estimator. By pooling multiple occasions, higher capture probabilities are achieved. But the cost of this estimator is the lack of robustness to behavioral response to capture (likely a serious bias with these animals and the Lincoln-Petersen estimator) and to individual heterogeneity that cannot be explained by individual covariates (maybe less important if capture probabilities are high), plus your inability to truly sample all of the inhabited area of each of the islands.

Thus, I am suggesting that you should not claim that a completely valid island-wide estimate of *N* (and hence D) is the goal, but rather to monitor the island population with a protocol that has high power to detect trends in population size. My feeling is that 3–4 larger grids would provide better power to detect population changes than the more numerous 2 × 6 grids scattered around the island, mainly because the data are better able to generate models that can detect changes in capture probabilities from behavioral response to capture and individual heterogeneity. Further, larger grids will provide you with a measure of annual recruitment (and an associated annual estimate of λ) if the data are analyzed with the Pradel (1996) model, for which a robust-design version is currently available in MARK. Also, there is considerable development work being done to extend this model.

To summarize arguments pro and con for the 2 different monitoring schemes, the proposed monitoring scheme using DENSITY is open to bias from a necessarily simplistic model to achieve an estimate of density. Reasons include lack of models for behavioral response to capture, individual heterogeneity, and temporal variation. Other issues include constant home range size across all individuals, and no heterogeneity in habitat. However, the $\tilde{p}_i$ and p_i^* scheme I've proposed requires larger grids, and so lacks some of the "representativeness" that is achieved by scattering 2 × 6 trapping grids across the islands. In addition, collection of location data post trapping may require enough additional effort to preclude the effort. Annual estimates of recruitment and rate of population change (λ) can be estimated with the Pradel model from larger trapping grids.

The following are some more minor issues that I think worth mentioning.

1. By trapping in late June and July, you are not capturing young of the year, correct? I wonder if you don't want to monitor annual recruitment more carefully. By trapping in the late June-July period, you would obtain recruitment of yearlings (13 months old) to the breeding population, which is a useful measure. However, you may not detect a failure of reproduction for the year.
2. Note the correct spelling of "Lincoln-Petersen". Carl Petersen was Danish. Unfortunately, the literature is full of incorrect spellings.
3. Several places in the document allude to using capture success or MNKA as a useful index for detecting trends. I would disagree – capture success is a function of the capture probability parameter estimated in the capture-recapture models, and is undoubtedly a function of the health of the foxes, and the quantity and quality of their nutrition. You could expect to see large differences in capture probabilities across time because of changes in the environment, even though fox populations have not changed. Hence, capture success might remain the same even though the population is declining, or capture success might decline even though the population is remaining stable. I suggest that even with sparse data, you can correct for changes in capture probabilities by combining data across trapping grids, years, or even islands, and make this argument in White (2005).
4. There are 2 different Crooks (1994) citations, but these are not distinguished in the text.

One additional recommendation is to use the known fate model in MARK to perform survival estimates for radio-collared foxes, rather than the simple Kaplan-Meier estimator. The known fate model in MARK is a maximum likelihood extension of the K-M estimator, but allows the modeling of survival as a function of covariates, and model selection and model averaging. The K-M estimator only allows the simple *S*(*t*) model. Use of the continuous time estimators, such as the Cox proportional hazards model, assume that the time of death is known exactly. Such is generally not the case with radio-tracking data. When continuous time data are made discrete and analyzed with the known fate model (equivalent to a logistic regression model), little precision is lost, and more biologically realistic models are achieved.

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