Indicators for Habituated and Food-Conditioned Cascade Red Foxes in Mount Rainier National Park: Preliminary Assessment

U.S. Geological Survey Administrative Report to Mount Rainier National Park, U.S. National Park Service

Kurt J. Jenkins, Paul C. Griffin, and Mason E. Reid

Cover photo credit: Mason Reid, National Park Service. Cascade red foxes and park visitors in Mount Rainier National Park

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Mass	
gram (g)	0.03527	ounce (oz)

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By Kurt J. Jenkins, Paul C. Griffin, and Mason E. Reid[1]

[1] Mount Rainier National Park, U.S. National Park Service

Executive Summary

The Cascade red fox (*Vulpes vulpes cascadensis*) is a rare, endemic subspecies of red fox found only at high elevations in the Cascade Range in Washington State. Once found throughout the Cascade Range, the Cascade red fox is now found primarily in Mount Rainier National Park (MORA) and parts of the Gifford Pinchot National Forest. Due to its limited range, small population size, and several threats to the long-term viability of the population, the Cascade red fox is a candidate for Washington State listing as a Threatened or Endangered species.

Despite the small population size and concerns over the status of the population, Cascade red foxes frequently are seen around developed areas in MORA, particularly during winter, when foxes are commonly seen begging for food from park visitors near roads and visitor facilities. Because such food-conditioned behaviors pose risks to both foxes and humans, MORA has developed outreach programs to educate visitors about the harm associated with feeding wildlife, and is developing plans to use aversive conditioning techniques to deter foxes from begging for food. In 2012, we conducted a pilot study to preliminarily describe Cascade red fox movements in the Longmire to Paradise area of MORA, where the majority of the fox and human interactions have been observed. The objective of the study was to collect sufficient information to identify indicators that can be used to evaluate visitor use impacts on spatial use patterns of foxes during winter and measure the success of future aversive conditioning programs on fox distribution.

We captured three Cascade red foxes and fit them with small (about 140 g) global positioning system (GPS) radio transmitters programmed to record locations every 3.5 hours. One female (F068) and one male (M006) were captured on December 9, 2011, providing GPS data through July 30, 2012, and August 10, 2012, respectively. One male (M206) captured on April 5, 2012, provided data through May 4, 2012.

We depicted each fox's home range using a fixed-kernel estimator of its utilization distribution (UD), which is essentially a map of the intensity of each fox's use throughout its home range. Utilization distributions illustrated a high clustering of use near the Paradise area for foxes F068 and M006. Spatial use patterns of these two GPS-collared foxes were consistent with patterns expected of food conditioned and habituated animals. The UD for fox M206 revealed a bimodal distribution with activity centers near Longmire and in a wilderness area more than 5 kilometers (km) northwest of Longmire. That UD may reflect periods during which the fox was associated with the park development near Longmire, and times when the fox was using a more natural landscape. Foxes F068 and M006 had a high concentration of activity in June and July in one area that was within 50 meters (m) of the road (near Reflection Lakes), but not associated with any area maintained for winter use by park visitors. We were unable to determine why foxes used this area.

We developed a resource selection probability function (RSPF) model that predicted the relative probabilities of use by Cascade red foxes throughout the study area. The RSPF model was a function of environmental variables that we hypothesized might influence Cascade red fox distributions, including slope, elevation, distance to the main road, and distance to any area open to human use during winter. In the latter category, developed areas included Paradise, Longmire, Cougar Rock campground, the Nisqually Entrance, and other parking areas and roadside pullouts that are plowed in the winter. We evaluated eight models that compared environmental variables measured at locations used by the collared foxes to those at random locations throughout the area available to the foxes. The highest-ranked RSPF model predicted levels of Cascade red fox use that increased with elevation and decreased with increasing slope, and distance to a developed area.

Because Cascade red foxes are so frequently seen along park roads, we examined temporal patterns in the distances that Cascade red foxes were located from roads and developed areas. On average, foxes F068 and M006 were recorded closer to the Nisqually-Paradise Road (55 and 92 m, respectively) than fox M206 (1,545 m). Both foxes F068 and M006 were closer to the road during the day than they were at night. During daylight hours, fox M006 tended to be closer to developed areas on days that the road was open versus when it was closed. We found no clear differences in distances of these two foxes from roads during days when roads were open rather than closed.

We subjectively examined monthly and hourly trends in the distances that GPS-collared foxes were found from developed areas to help identify seasonal and diurnal periods when foxes were most likely interacting with park visitors, and when educational and aversive conditioning programs are likely to be most effective. These analyses are based on movements of foxes F068 and M006. Both these foxes tended to be most closely associated with park-developed areas during the mornings throughout winter and into the early spring. That finding should be viewed with the understanding that it is based on a very small sample size and that GPS-collared red foxes also used park developed areas during other times of day and seasons.

Collectively, results from this preliminary study suggest there are several possibilities for monitoring changes in the distribution of Cascade red foxes relative to park roads and developed areas. The simplest indicator, which would not require ongoing telemetry studies, would be to monitor changes in the frequency of foxes observed by park staff along roadways and in park-developed areas. Frequency indicators are highly influenced by variations in survey and reporting effort (that is, the number of observers reporting and emphasis placed on reporting), so the most repeatable index would be produced from standardized surveys conducted throughout the winter. Preliminary indications from this report suggest that surveys conducted during daylight hours during December–January are likely to produce the greatest number of sightings. Extension of surveys to cover the entire winter (for example, November–March), however, would permit the evaluation of seasonal changes in fox associations with roads during the winter.

Ongoing use of GPS-telemetry would allow for a more comprehensive analysis of changes in fox distribution in response to educational programs aimed at deterring wildlife feeding by park visitors, or to aversive conditioning programs aimed at deterring begging behavior in foxes. If movements of foxes were monitored before and after aversive conditioning, for example, the simplest indicator of the effectiveness of aversive conditioning would be an increase in the post-treatment distance between the fox and areas developed for high human use. Aversive conditioning could be considered successful if a Cascade red fox that had a UD similar to foxes F068 or M006 before treatment were to shift its UD to areas away from human activity centers. Another useful metric suggested by these preliminary studies would include future examinations of RSPFs, specifically changes in the model coefficient for the effect of proximity to park-developed areas on probabilities of use. Monitoring temporal changes in the spatial overlap of UDs of individual foxes also would provide direct evidence of foxes changing distributions in relationship to future aversive conditioning. GPS-based telemetry is a useful tool for assessing changes in distribution patterns and behaviors of Cascade red foxes relative to visitor facilities and in relation to management efforts to reduce wildlife dependency on human foods. To improve interpretations of GPS telemetry data, however, future studies should assess the effects of potential biases in fix acquisition rates inherent in GPS telemetry systems associated with vegetation, terrain, and snow.

Introduction

The Cascade red fox (*Vulpes vulpes cascadensis*) is a rare, endemic subspecies of red fox found only at high elevations in the Cascade Range in Washington State. This native montane red fox is genetically, ecologically, and morphologically distinct from the non-native lowland red fox seen throughout low elevations in the West, and from two subspecies of montane foxes found south of the Columbia River (Sierra Nevada red fox; *Vulpes vulpes necator*) and east of the Cascade Range (Rocky Mountain red fox;*Vulpes vulpes macroura*) (Aubry and others, 2009; Sacks and others, 2010). Of the three montane fox subspecies, the Cascade red fox is the most evolutionarily isolated, with mitochondrial DNA sequences indicating more than 10,000 years of divergence (that is, since the end of the last ice age) from the Oregon population (Aubry and others, 2009; Sacks and others, 2010).

Mount Rainier National Park contains a significant portion of the known population of Cascade red foxes in Washington. Although Cascade red foxes were commonly sighted and trapped throughout the northern Cascades in the 1970s and 1980s (Aubry, 1983 and 1984), 8 years of intensive multi-year Canada lynx (*Lynx canadensis*) and wolverine (*Gulo gulo*) studies involving snowtracking and trapping in the last decade in prime Cascade red fox habitat failed to detect or capture a Cascade red fox in the northern Cascades (K. Aubry, U.S. Forest Service, oral comm., 2012). At present, Cascade red foxes are known to occur primarily in Mount Rainier National Park, the Goat Rocks Wilderness, and Mount Adams Wilderness (J. Akins and B. Sacks, University of California, Davis, unpub. data, 2012). Anecdotal evidence suggests that these subpopulations are small, and at risk of extirpation due to factors that threaten small populations, including demographic and genetic isolation and drift (Akçakaya and Sjögren-Gulve, 2000). The Cascade red fox might be further threatened by expanding coyote (*Canis latrans*) populations, which are known to supplant the smaller foxes from their range (Sargeant and Allen, 1989; Gosselink and others, 2007), and potential genetic introgression by non-native red foxes (Aubry, 1983; Sacks and others, 2010). As a result of these known threats, the Cascade red fox is currently a candidate for listing as a Threatened or Endangered species in Washington (*http://wdfw.wa.gov/conservation/endangered/species/cascade_red_fox.pdf*. Accessed 1/9/2014).

Despite the limited distribution and small numbers of Cascade red foxes throughout their historical range, the Cascade red fox is one of the most visible mammals during the winter and spring in Mount Rainier National Park. This apparent incongruity results from the fact that several Cascade red foxes have become highly food-conditioned (that is, dependent on human food sources), and habituated to human presence. Food-conditioning and habituation of Cascade red foxes represents a relatively new and only recently appreciated conservation concern. During the last few decades, Cascade red foxes have obtained food from park visitors, contractors, and employees along the road and parking areas between the Longmire administrative area and the Paradise developed area in MORA. During winter, foxes are frequently observed using roads and snow banks as travel corridors and denning habitat, and seeking food from visitors that stop to get a better view and to take photographs. Foxes are often seen resting atop snow banks in full view of the traffic below, ready to accept handouts. Begging foxes approach people, walk and rest on or immediately adjacent to roadways, and walk into roadways upon seeing a car stop. If no food is offered, the fox will leave and search for other potential food offerings, often dodging cars as drivers look for places to park.

Negative effects of food conditioning, including direct mortality or reduced fitness, could adversely affect this small subpopulation of Cascade red foxes in MORA. The potential effects of food-conditioning and habituation on the population are poorly understood, but recent carnivore surveys conducted throughout the park suggest that Cascade red foxes remain rare in MORA (Reid and others, 2010). Based on distinctive coloration and pelage, the NPS has identified a minimum of four food-conditioned foxes that seek handouts from visitors in the Longmire and Paradise areas. Park managers suspect that food-conditioning has altered the normal spatial distribution and movement patterns of several foxes, and also has influenced the choice of denning locations for some individuals. There have been four known fox dens located within 75 m of the Longmire-Paradise Road. In 2010 and 2012, one pair denned less than 5 m from the roadway, where foxes obtained food handouts and caused numerous traffic jams. Since 2004, there have been five known cases of foxes being struck by a vehicle, with at least two pups killed (National Park Service, unpub. data, 2012), suggesting that mortality associated with food-conditioned behaviors may be consequential in this small subpopulation.

In addition to potential effects of food conditioning to the survival and fitness of Cascade red foxes, there are human safety issues associated with habituated wildlife that aggressively seek food handouts from park visitors. In particular, there are risks associated with food-conditioned foxes scratching or biting park visitors, and potentially transmitting infectious diseases. Moreover, food conditioning and habituation of red foxes causes traffic congestion on park roads during winter and increases the potential for traffic accidents and risks of human injury.

In recent years, MORA has made a concerted effort to address these problems by increasing public education and law enforcement efforts. Rangers and interpretive staff regularly contact park visitors in parking areas where foxes are frequently seen, and have increased the number of formal presentations at evening programs, all aimed at improving awareness of problems associated with food-conditioned wildlife. In 2009–2012, MORA implemented a “Keep Wildlife Wild” weekend involving training of volunteer staff to dispense feeding messages parkwide, and a “Don’t Speed or Feed” weekend where visitors were educated about the links between habituated/food-conditioned wildlife and wildlife losses due to vehicles. In addition to these educational efforts, law enforcement rangers have increased the numbers of citations issued for feeding foxes and leaving food unsecured, to increase public awareness and reduce illegal feeding.

Despite these educational efforts, food-conditioned foxes are still observed along roads that are open to park visitors during winter in MORA, and the overall effectiveness of educational efforts is poorly understood. New solutions aimed at directly modifying food-conditioned behaviors are being sought by the NPS. MORA is currently slated to receive regional funding to begin a pilot program of applying aversive conditioning tools with the goal of modifying food-conditioned behaviors of Cascade red foxes in the developed corridor from Longmire to Paradise in MORA. The methods considered for application include chasing away foxes, the use of loud noise (that is, compressed air horns), water guns, and potentially the use of capsicum (that is, pepper) spray. Research is needed to assess the success of ongoing visitor education efforts and the application of aversive conditioning methods aimed at reducing food-conditioned behaviors of Cascade red foxes in MORA.

Project Goals and Objectives

We conducted this preliminary project to begin evaluating indicators of fox spatial associations with visitor facilities at MORA. We were funded by the National Park Service's Federal Lands Recreation Enhancement Act program to provide answers to the following questions and, thus, to improve management of fox/human interactions in the park:

- How do human foods and activity affect use of home range?
- To what extent are parking lots and roadways used by foxes?
- What are the specific locations (that is, road pullouts and other human developed areas), months, and times of day where management efforts could be most effective in reducing fox dependence on human food sources?

Our objectives were to:

- Determine home ranges and areas of concentrated activity of food-conditioned foxes,
- Examine environmental factors associated with fox distribution, and
- Examine seasonal and diurnal trends in the proximity of red fox locations to human use areas.

Data collected in this project will begin to build a baseline of information documenting the movement patterns of food-conditioned foxes within the park, and will provide park managers with preliminary information that might be used to focus visitor educational programs at the times and places where they are most likely to be effective. Analyses of these foxes' movements also will be useful in designing future research to determine whether future aversive conditioning and educational programs are effective in changing the overall distribution patterns of foxes in developed areas of the park over a longer time frame.

Description of Study Area

The study area was the southwestern part of Mount Rainier National Park, including the Nisqually entrance station, the NPS administrative area in Longmire, visitor facilities at Paradise (elevation 1,605 m) (fig. 1), and the road corridor from the Nisqually entrance station to Paradise (that is, Nisqually-Paradise Road). Paradise is the primary destination for most of the almost 2 million park visitors each year. The Paradise area receives the greatest visitation on weekends, mostly day-users from the Seattle-Tacoma metropolitan area. During winter, when fox-human interactions are highest, Paradise contains the only open facilities in the park, other than the NPS administrative area in Longmire (elevation 835 m). Other developed areas that we considered to be of potentially high human use were parking lots and roadside pullouts that were maintained open during winter (fig. 1).

The road to Paradise is commonly closed due to heavy snows (snow depth commonly reaches 460 cm by April 1, Lofgren and others, 2013). The road is only open during daylight hours in the winter months, and was open continually after May 5, 2012, for the spring and summer. On sunny winter weekends, the Paradise parking lot can be filled by early morning, requiring visitors to turn around and travel back down the mountain. The road also may be closed for administrative reasons as happened during January 2012.

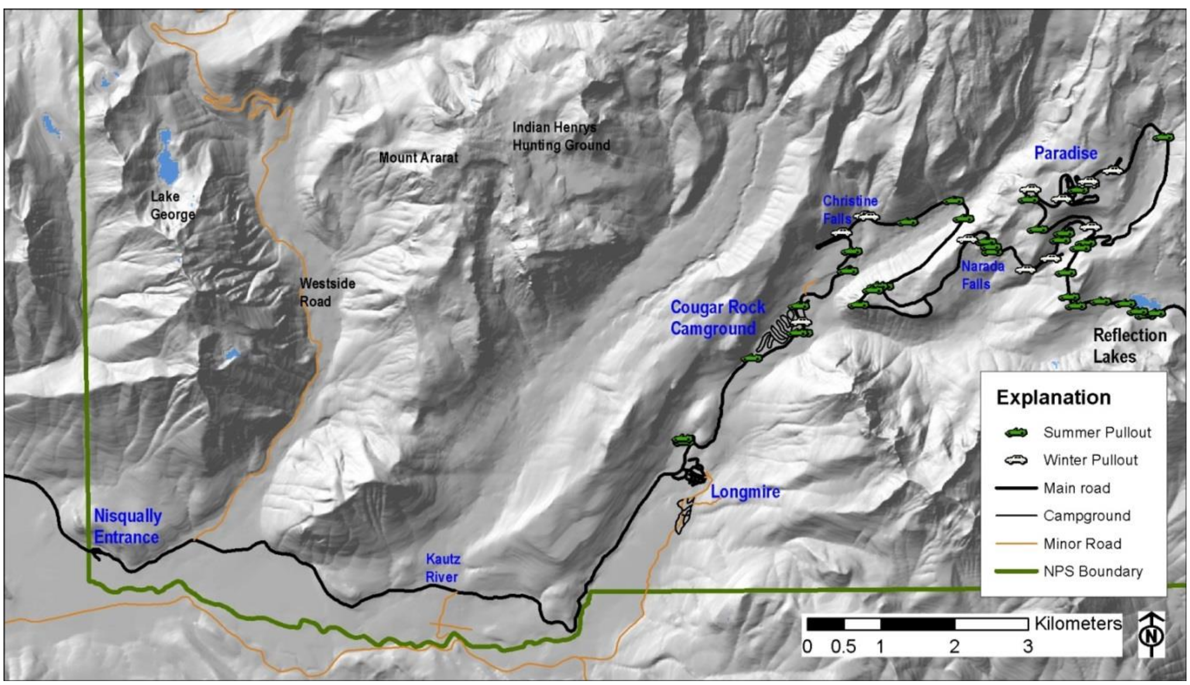

Figure 1. Cascade red fox study area in the southwestern region of Mount Rainier National Park, Washington. Blue text indicates human use areas, and black text indicates other place names. Roadside vehicle pullouts between

Longmire and Paradise are colored white if they were plowed to stay open through the winter, or green if they are only available after snow has melted.

Methods

Capture and Telemetry

We intended to capture up to five Cascade red foxes along roads and developed areas in the area between Longmire and Paradise during winter and to fit them with GPS radio collars that record location data. We focused trapping effort along park roads to target individuals associated with park facilities during winter. We determined locations where Cascade red foxes were frequently seen by park staff and visitors. After a fox was observed frequenting an area, we set live traps in the specific area (Tomahawk Live Trap, LLC, Wisconsin), size 109.5 (15×15×42 in.). In two cases, we used a catch pole to restrain the fox once it was trapped, then covered the fox's muzzle and eyes, and constrained the feet with soft bandages. In one case, the attending vet (A. Case, DVM) immobilized the fox with dexamedetomidine/butorphanol/medazolam before handling. All capture and handling methods were approved by the Institutional Animal Care and Use Committee of the National Park Service (Protocol Approval Number: PWR_MORA_Reid_Cascade Fox_2012).

Each captured fox was equipped with an approximately 140 g GPS radio collar (Telemetry Solutions, Inc., Walnut Creek, California: model Quantum 4000-Mini). Each radio collar was programmed to attempt to determine the collar location over a 90-second interval every 3.5 hours. Location data were stored on the collar until they were downloaded using a two-way UHF communication feature. In addition to the GPS capabilities, each collar emitted a VHF radio signal that allowed us to locate the animal using standard VHF radio-telemetry. Foxes were located via VHF telemetry on approximately a weekly basis, and GPS data were downloaded each time.

Data received from the GPS collars included results of all attempted location fixes. This included unsuccessful attempts, two-dimensional (2D) fixes derived from data obtained from three orbiting GPS satellites, and three-dimensional (3D) fixes based on data from four or more satellites. Both 2D and 3D fixes included East and North UTM coordinates, whereas 3D fixes also included an estimate of elevation above sea level.

Data Analyses

Home Range and Utilization Distributions

We estimated home ranges and core areas used by GPS-collared foxes based on fixed-kernel utilization distributions. A utilization distribution (UD) is essentially a map of the intensity of spatial use by an individual animal (Worton, 1989). We estimated UDs for each GPS-collared fox based on the complete datasets consisting of 2D and 3D locations. We evaluated several methods that are commonly used to determine bandwidth, which controls the width of individual kernels and, therefore, also the amount of smoothing applied to the data. We subjectively chose the h_{ref} method because it produced the most realistic depiction of the foxes' space-use patterns. Other commonly used methods, particularly the least-squares cross validation method, generally undersmooth highly clustered data (Silverman, 1986; Amstrup and others, 2004), as was the case in the fox dataset. We used the Animal Space Use software (Horne and Garton, 2009) to estimate the h_{ref} smoothing parameter for each set of locations. We used the percent volume contour tool from Hawth's Tools (Beyer, 2004) in ArcGIS 9.3 to define polygons that enclosed 95 percent and 50 percent of the UD volumes, corresponding with the approximate home range and the core areas used by each fox. Initially, we had planned to examine differences in the UDs of each radicollared fox during times of day when the road was open rather than closed as another means of evaluating the effect of road traffic on fox distribution, but we eliminated that analysis because partitioning the dataset resulted in small sample sizes and unclear interpretations. The partitioned analyses are provided in appendix A for possible future reference.

Resource Selection Probability Functions

We developed a resource selection probability function (RSPF) that describes variation in the relative probability of use within the study area by the three GPS-collared foxes (Manly and others, 2002). We analyzed the pooled data rather than estimating a RSPF for each individual animal (that is, Design 1, Thomas and Taylor, 1990) due to the small sample of individual animals used in the analysis.

The RSPF model uses logistic regression to identify environmental characteristics that best distinguish locations used by foxes from characteristics assessed at an equal number of points available to the foxes. This analysis yields a relative probability of use because it is not possible to know whether the available points were used or unused (Manly and others, 2002). After developing the model, we applied it across the study area to map the estimated relative probability of use across the landscape.

To define the specific region presumed available to all three foxes, we generated the minimum convex polygon (MCP) that enclosed all of the observed fox locations (Jennrich and Turner, 1969). We increased the size of the resulting polygon by 350 m around the perimeter. The 350 m buffer reflected the median distances moved per 3.5 hours for both foxes F068 and M206 (354 m). Within this available area we used GIS to generate a random set of 10,000 points. Those 10,000 random points represented the set of potential locations that could be used by the collared foxes if use were random within the area (we call this the set of 'available' locations). From the 10,000 available points, we randomly selected a number equal to the number of fox location points for RSPF analysis. Before conducting the analysis, we hypothesized that one or more covariates measured at used and available locations were likely to influence the probability of use by the collared foxes. The spatial covariates that we considered included slope (in degrees), elevation (in meters above sea level), distance to the main road (in meters), and distance to a developed human use area (in meters). We developed eight competing logistic models, each structured with an intercept and selected covariates. We were uncertain whether fox use would be affected most by proximity to the main road, or by proximity to developed areas along the roads where human use was prevalent (that is, Nisqually Entrance, Longmire, Cougar Rock Campground, Christine Falls and Narada Falls, Paradise, and pullouts along the road that were plowed for winter use). Therefore, we structured competing models with one or the other of those distance measures, but none that included both distance measures, because they were correlated.

The logistic model included a logit of a linear combination of coefficients (each coefficient, *i,* is labeled with the Greek letter beta, β_i) and covariates (x_i) in the numerator, and the quantity 1 + the logit in the denominator. In each model, β_1 was an intercept. For example, a model with an intercept (β_1) and three covariates ($\boldsymbol{x_2}, \boldsymbol{x_3}, \boldsymbol{x_4}$) was in the form:

$$\text{Logistic model} = \frac{e^{(\beta_1+\beta_2*x_2+\beta_3*x_3+\beta_4*x_4)}}{1+\, e^{(\beta_1+\beta_2*x_2+\beta_3*x_3+\beta_4*x_4)}}$$

We determined the value for spatial covariates at each of the 2D and 3D fox locations and at the ‘available’ locations. At each point, we used ArcGIS to extract the slope, elevation, distance to the main road, and distance to a developed human use area. We fit the candidate suite of eight models to the data, and used Akaike’s Information Criterion (AIC) to rank model parsimony (Burnham and Anderson, 2002).

We mapped the RSPF in the study area in six classes of relative use. To do this, we created raster feature datasets for slope, elevation, and the two distance measures, all made on the same base raster feature, with 10 m pixel size. Then we applied the coefficients from the highest-ranked model to the rasterized values of slope, elevation, and distance. Across all pixels of the study area, we found the maximum expected value for the logit in the model (this is the same as the numerator of the logistic model). For any given mapped pixel, the RSPF was the logit of the model, divided by this maximum value for the logit. As a result of dividing by the maximum of the logit, the RSPF was scaled so that the maximum possible value was 1. We used the Map Algebra feature of ArcGIS to create a raster of the study area with the scaled value of the RSPF.

Proximity to Roads and Areas Developed for Human Use

We examined seasonal and diurnal patterns in the distances that the GPS-collared foxes were located from the main road and from developed areas along the road. We examined differences in the distances of collared foxes from roads between diurnal and nocturnal periods. We defined diurnal locations as locations obtained between sunrise and sunset, whereas nocturnal locations corresponded to the time between sunset and sunrise. We determined sunrise and sunset times for Paradise Visitor Center from data provided by the U.S. Naval Observatory (2013).

For the diurnal period up until May 5, 2012 (after which the road was essentially always open), we also compared distances of foxes from roads between days that the road was open compared to days that the road was closed for weather or administrative reasons. Given that the road was often closed in daytime hours due to heavy snowfall, we recognize that our contrasts of fox spatial use in the road-open and road-closed time periods could have been affected by weather-related fox behaviors, in addition to patterns of human use. To define each day's opening time, we referred to the park's Twitter account (*https://twitter.com/MountRainierNPS*), which contained a daily record of gate openings. We consulted the park's gate closing schedule for winter 2011–12 to determine the daily closure times. For statistical comparison of means, we used a two-tailed t-test with a type-I error rate of 0.10. For the comparison of fox locations from roads, we used only the more accurate 3D locations of the GPS-collared foxes.

Results

Global Positioning System Collar Performance

We captured three Cascade red foxes and equipped each with a GPS collar during winter and spring 2011 and 2012. One adult female fox (F068) was captured on December 9, 2011, and two male foxes (M006 adult, M206 subadult) were captured on December 9, 2011, and April 4, 2012, respectively. Information was gathered on fox F068 until she was found dead of natural causes on July 30, 2012. The GPS data on fox M006 could not be downloaded during the last visual location in August 31, 2012, suggesting that the UHF battery on the collar was drained or the collar failed. Despite continued efforts, fox M006 could not be located again. Fox M206 was last located on May 4, 2012, and could not be located again, presumably because the collar failed or the fox moved to remote areas. An aerial telemetry flight conducted on February 15, 2013, failed to pick up signals of foxes M006 or M206, suggesting that both collars were no longer functional.

The GPS collars were successful in recording UTM coordinates for the fox's location in 704 instances for female fox F068, 1,204 instances for male fox M006, and 99 instances for male fox M206 (table 1). Successful fixes (2D or 3D) for the three foxes represented 43, 72, and 46 percent of attempts, respectively. Fix success rate for each of two foxes that were monitored for at least 7 months (F068, M006) was lowest during winter and highest during summer (fig. 2).

Table 1. Number of attempted and successful Global Positioning System fixes for each collar, Mount Rainier National Park, Washington, 2011—2012.

[Successful fixes included both two-dimensional and three-dimensional fixes]

	F068	**M006**	**M206**
Start Date	12-10-11	12-10-11	4-5-12
End Date	7-30-12	8-10-12	5-4-12
Unsuccessful fixes	927	475	115
Two-dimensional fixes	106	117	22
Three-dimensional fixes	598	1,087	77
Successful fixes	704	1,204	99

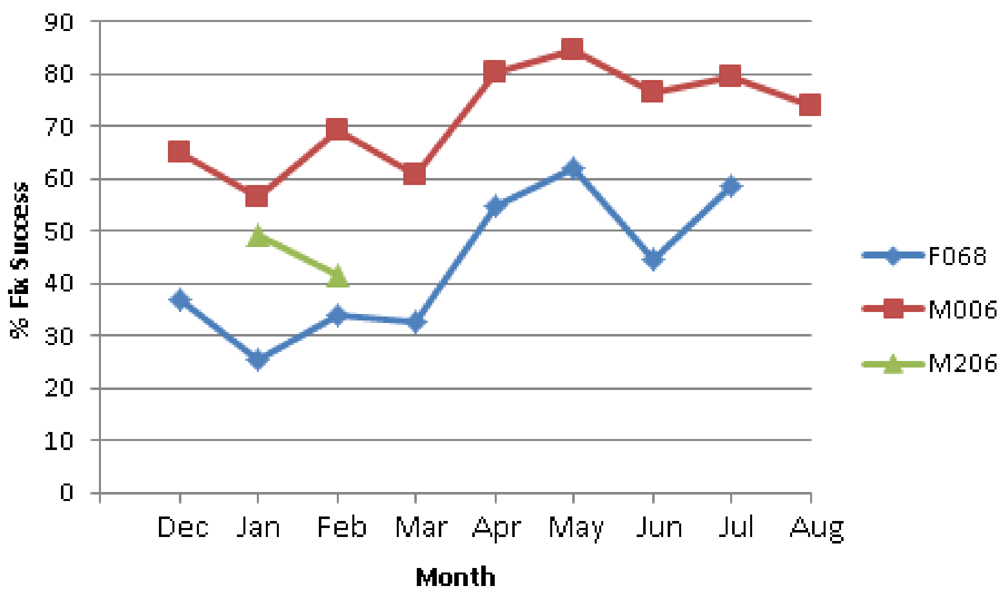

Figure 2. Monthly fix success rates (%) of Global Positioning System telemetry collars on Cascade red foxes at Mount Rainier National Park, Washington, December 2011–August 2012.

Utilization Distributions

The distribution of recorded points and 50 and 95 percent UD maps for each fox indicate that there was a close association between the GPS-collared foxes and developed areas along the Nisqually-Paradise Road. The association appeared strongest for fox F068 (fig. 3) and fox M006 (fig. 4), both of which were primarily located near Paradise and Longmire. Fox M206 had a nexus of activity away from the main road, but the Longmire area also was within the 50 percent UD for that fox (fig. 5).

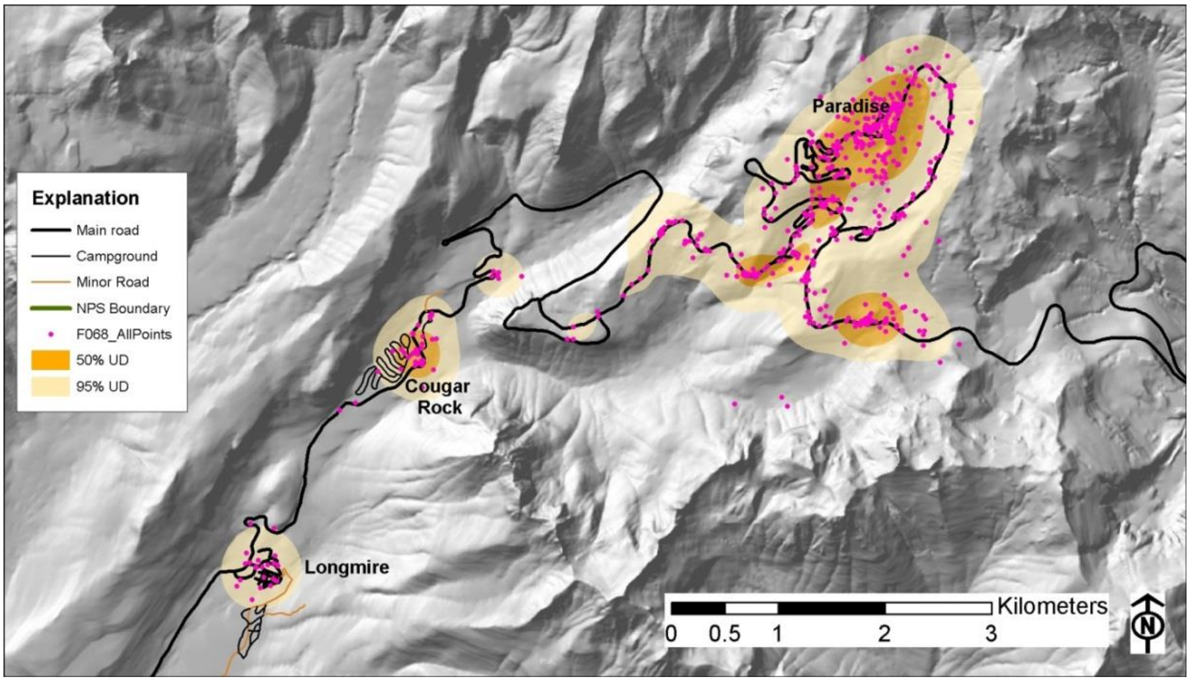

Figure 3. All Global Positioning System locations, and 50 and 95 percent utilization distributions (UD) for female Cascade red fox, F068, recorded from December 10, 2011, to July 30, 2012, Mount Rainier National Park, Washington.

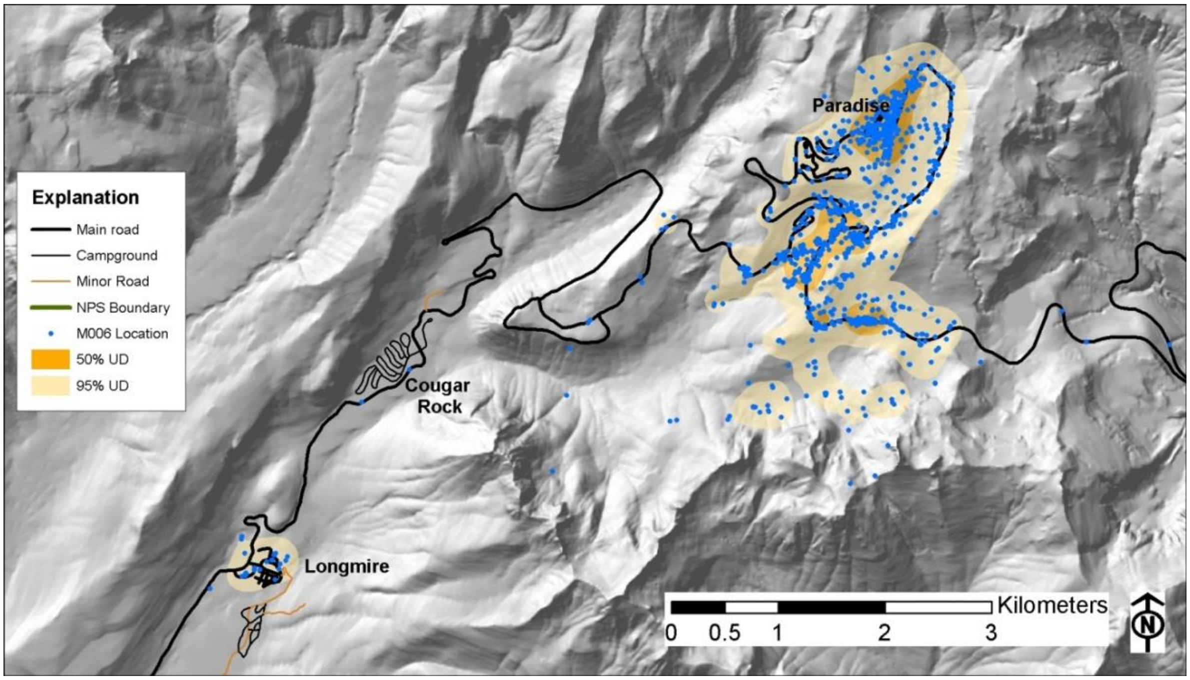

Figure 4. All Global Positioning System locations, and 50 and 95 percent utilization distributions (UD) for male Cascade red fox, M006, recorded from December 10, 2011, to August 10, 2012, Mount Rainier National Park, Washington.

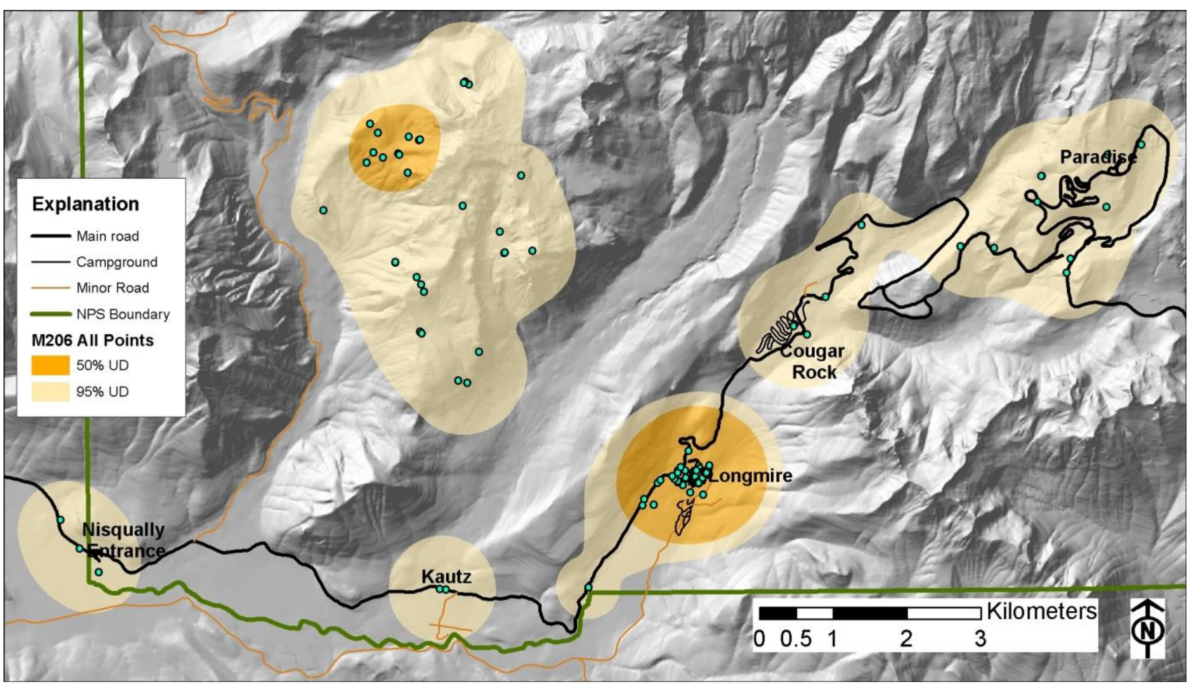

Figure 5. All Global Positioning System locations, and 50 and 95 percent utilization distributions (UD) for male Cascade red fox, M206, recorded from April 5, 2012, to May 4, 2012, Mount Rainier National Park, Washington.

Other than developed areas along the road, there was only one other area that fell within the 50 percent UDs for foxes F068 and M006. This was an area approximately 200–300 m west of Reflection Lakes (fig. 6). This focal area of use was on a south-facing slope near and above a rocky bluff above the road. Foxes F068 and M006 each were located only three times within 100 m of that focal area in the 61 days of March and April, but use of the area increased through the late spring and summer. Fox F068 was within 100 m of the focal point 25 times in July, and fox M006 was within 100 m of this focal point 21 times in July. The distance from the focal area to the nearest parking is approximately 300 m east.

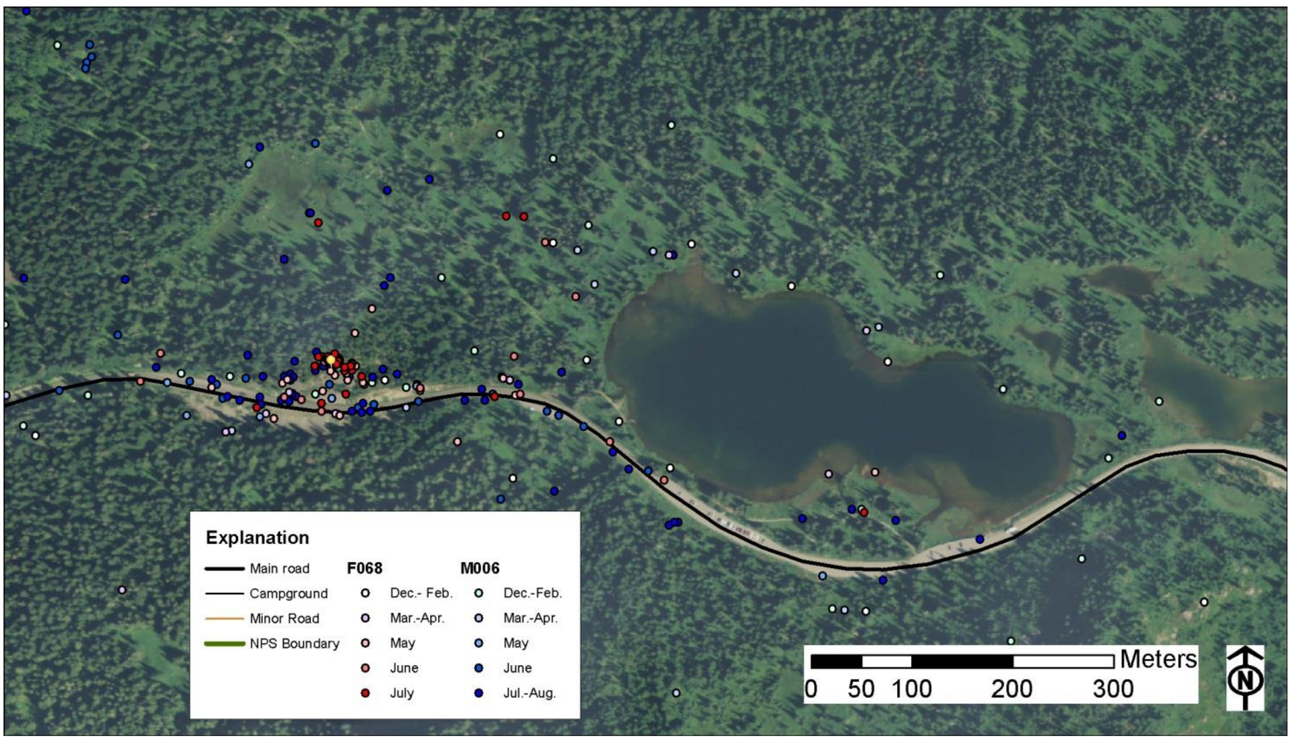

Figure 6. Cascade red fox locations centered on an area of the park that is not specifically developed for high human use, Mount Rainier National Park, Washington. Cascade red fox locations are indicated in shades of red (F068) and blue (M006) corresponding to different months. The focal area of activity is a south-facing shrubby area indicated by a yellow marker on the map. The rocky area along the road close to the focal area is a road cut.

Resource Selection Probability Function

The eight logistic models comparing used points to an equal number of available points led to only one model having appreciable support (table 2). The AIC weight, which represents the relative likelihood of each model, given the data and the set of models considered, was nearly 1 for the top-ranked model. The most parsimonious of the models was Model 2, which included distance to developed areas, elevation, and slope.

Table 2. List of candidate logistic models fit to the used (Cascade red fox locations) and available (random points) dataset, Mount Rainier National Park, Washington, 2011–2012.

[Models are ranked here by AIC score, with the highest-ranked models being those with the lowest score. AIC weight (w_{AIC}) for each model is shown at right]

Model	**AIC**	**w_{AIC}**
2. Distance to Developed Area + Elevation + Slope	2619.5	1
1. Distance to Main Road + Elevation + Slope	2708.1	6×10^{-20}
6. Distance to Developed Area + Elevation	2725.6	0
3. Distance to Main Road + Elevation	2818.1	0
5. Distance to Developed Area	3210.5	0
4. Distance to Main Road + Slope	3279.2	0
7. Distance to Developed Area + Slope	3195.0	0
8. Distance to Main Road	3292.7	0

The logit for the highest-ranked logistic model can be expressed as:

logit = $e^{(\beta 1+ \beta 2 * Distance\ to\ developed+ \beta 3 * Elevation+ \beta 4 * Slope)}$

The coefficient estimates for the highest-ranked model are presented in table 3.

Table 3. Coefficient estimates for the top-ranked RSPF model, which included an intercept applied to all locations, and effects of the distance in meters to a developed human use area, elevation in meters, and slope in degrees, Mount Rainier National Park, Washington, 2011–2012.

[The Greek letter beta (β) signifies the coefficients in the model. The standard error (SE) for each estimate is also listed]

Coefficient	Covariate	Estimate	SE
β1	Intercept	-2.884884674	0.2383171
β2	Distance to developed human use area (m)	-0.002013486	7.593652×10^{-5}
β3	Elevation above sea level (m)	0.004064464	1.900199×10^{-4}
β4	Slope (degrees)	-0.041070008	4.036970×10^{-3}

Given the range of elevations, slopes, and distances to the high use developed areas within the study areas, the maximum expected value of the logit for model 2 was 39.6898. We divided by this value when we rescaled all the expected logit values to calculate the scaled RSPF.

$$RSPF = \frac{e^{(\beta 1+ \beta 2 * Distance\ to\ developed + \beta 3 * Elevation + \beta 4 * Slope)}}{39.6898}$$

Based on this RSPF, the expected relative proability of an area's use by foxes declines as a function of distance to a developed area, and declines as slope increases (fig. 7). The function shown in fig. 7 corresponds with model predictions assessed at the median elevation within the study area (1525 m) although the relative probability of use is predicted to increase as elevation increases. Mapped across the landscape (fig. 8), the model leads to a high level of predicted use at Paradise.

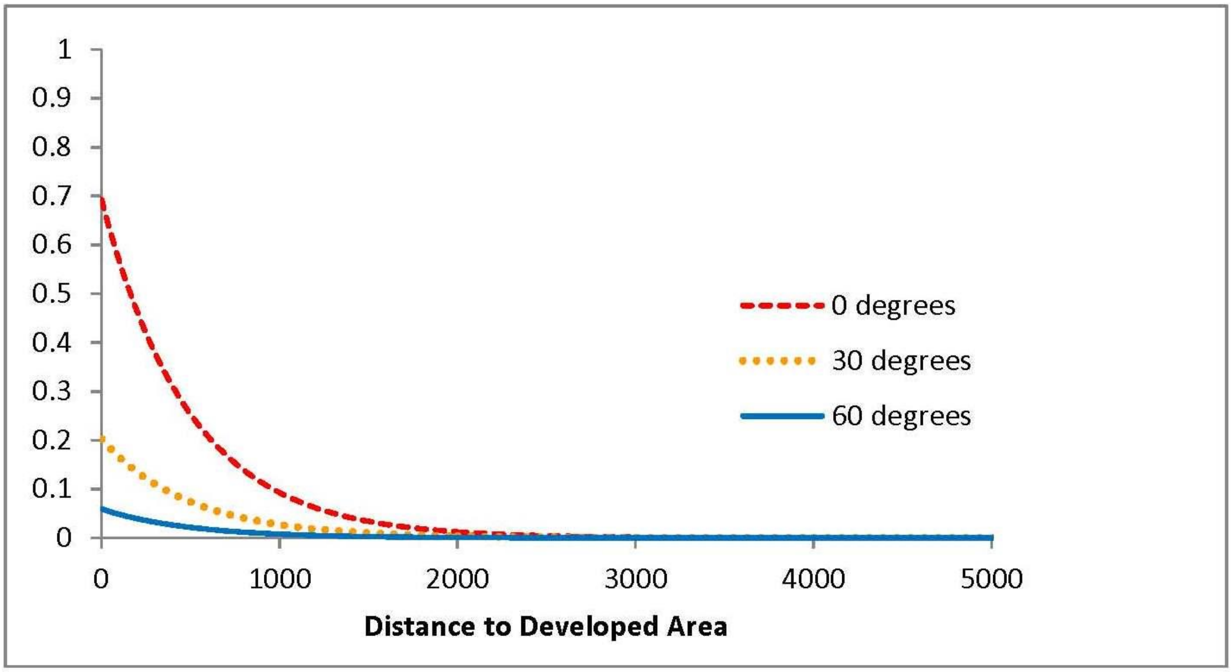

Figure 7. Expected relative probability of Cascade red fox use, as a function of distance to a developed human use area (parking lot, visitor center, administrative center, winter pullout) and slope, Mount Rainier National Park, Washington. The results here are shown for an elevation of 1,525 m, which was the median value in the study area.

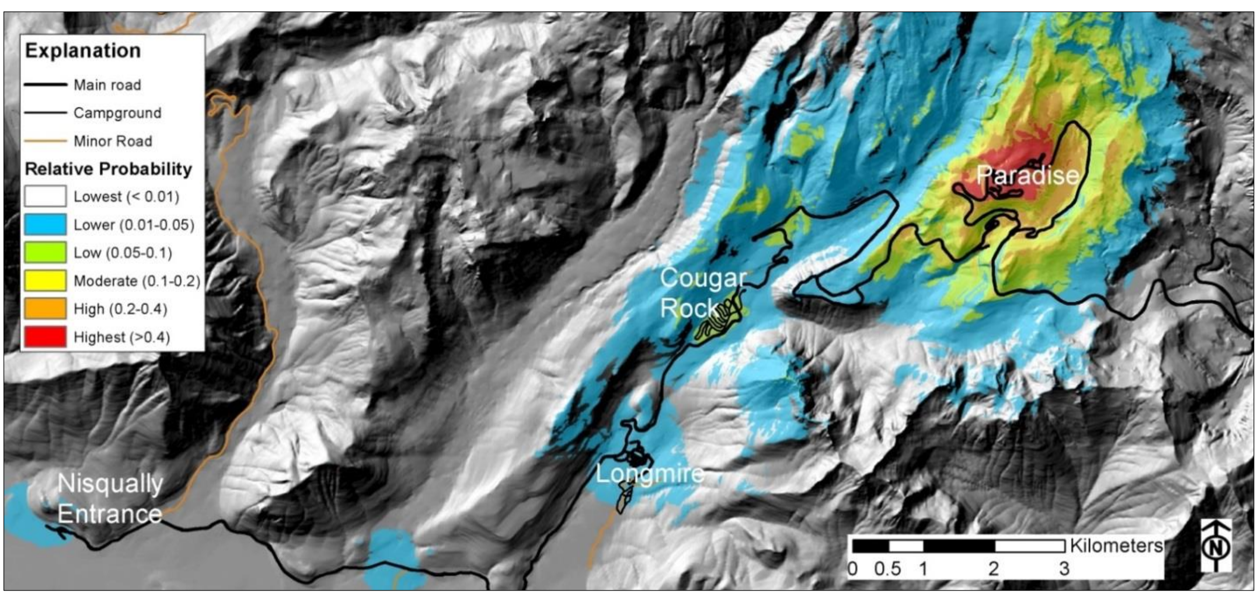

Figure 8. Expected relative probability of Cascade red fox use, in the study area of Mount Rainier National Park, Washington.

Distances to the Main Road and to Developed Areas

On average, fox F068 was located less than 100 m from the road, regardless of the time of day, or whether the road was open or closed (table 4). The average distance to a road was slightly greater for fox M006, and was much greater for fox M206 (table 4). On average, foxes F068 and M006 were both located closer to a road during the day than they were at night (two-sided t-test; fox F068 difference=21.0 m, P=0.0032; fox M006 difference =32.1 m, P=0.0038). Fox M206 was not discernibly closer to a road during the day than at night.

Among the diurnal locations, there was some variation in the average proximity to the road, depending on whether the road was open or closed (table 4). On average, fox M006 was located closer to the road during days when it was open than when it was closed (M006 average difference=75.2 m, P=0.04). There was no difference in the distances that foxes F068 and M206 were found from the road during days that were open rather than closed to human use (fox F068 average difference=16.5 m, P=0.19; fox M206 average difference=1258.9 m, P=0.11).

Table 4. Mean distances between Global Positioning System-collared foxes and the Nisqually-Paradise Road, presented for all three-dimensional telemetry locations combined (All locations), three-dimensional locations between sunrise and sunset (Day), locations between sunset and sunrise (Night), locations at times up through May 5, 2012 when the road up from Longmire to Paradise was open (Open), and locations at times when the road from Longmire to Paradise was closed (Closed), Mount Rainier National Park, Washington.

[For each value, the standard error is given in parentheses]

	F068	**M006**	**M206**
All locations	55.1 (3.4)	92.4 (6.1)	1,545.5 (244.5)
Day	47.9 (3.2)	78.5 (5.9)	1,590.4 (319.3)
Night	68.9 (7.8)	110.6 (11.7)	1,469.5 (382.5)
Open, daytime	59.9 (5.8)	80.4 (9.7)	1,282.1 (353.3)
Closed, daytime	43.4 (10.9)	155.6 (35.4)	2,541.0 (669.8)

Although foxes F068 and M006 made frequent use of the road, their average distances to an area developed for high human use was greater on average, at 276 and 359 m, respectively (table 5). The average distance to developed areas was much greater for fox M206, 1,640 m. The average distance to a developed human use area was less in the day than at night for fox M006 (difference= 91.0, *P* =0.001). The average distance from fox F068 to developed areas also tended to be closer in the daytime than at night, but this difference was not significant (*P*=0.14). Any differences in the average distances that the foxes were located from developed areas in the daytime when the road was open, compared to in the daytime when the road was closed were not statistically significant.

Table 5. Mean distances between Global Positioning System-collared foxes and areas that are maintained during winter for human use (parking lots, visitor centers, administrative areas and pullouts along the road), presented for all three-dimensional telemetry locations combined (All locations), three-dimensional locations between sunrise and sunset (Day), locations between sunset and sunrise (Night), locations at times up through May 5, 2012 when the road from Longmire to Paradise was open (Open), and locations at times when the road from Longmire to Paradise was closed (Closed), Mount Rainier National Park, Washington.

[For each value, the standard error is given in parentheses]

	F068	**M006**	**M206**
All locations	276.3 (14.2)	359.5 (13.1)	1,639.9 (248.7)
Day	260.7 (16.8)	320.1 (14.0)	1,643.2 (327.9)
Night	306.1 (25.8)	411.1 (23.8)	1,634.4 (382.1)
Open, daytime	183.5 (23.2)	210.3 (21.4)	1,312.3 (358.4)
Closed, daytime	162.3(34.8)	301.2 (49.8)	2,663.4 (702.6)

Boxplots graphically illustrate seasonal and diurnal variation of the two GPS-collared foxes most closely aligned with developed areas within the study area (foxes M006 and F068) (fig. 9, appendix B; boxplots of distances to roads are shown in appendix C for comparison). Each vertical box represents the statistical distribution of distances that an individual fox was found from a developed area within successive 2-hour intervals each month. The horizontal line within the box represents the median distance, and the upper and lower extents of the box represent the 25th and 75th percentile of the distribution (the 'interquartile range'). In most cases, the dashed lines extend to the maximum and minimum distances that a collared fox was located from a park developed area. In cases where the maximum or minimum value is further from the median than 1.5 times the interquartile range, the dashed lines extend only 1.5 times the interquartile range from the median, and outliers are shown with an asterisk. We defined outliers as locations that were more than 1.5 times the interquartile distance from the upper or lower quartile.

Patterns in the distance of foxes M006 and F068 from park developed areas were variable between months and times of day (fig. 9). There also was a high degree of variation between individual foxes (appendix B). Both of the GPS collared foxes tended to be close to park developed areas during early to late morning hours, particularly during December–April. In those months, the distances from those GPS-collared foxes to developed areas tended to be greater in the afternoon and evening. Both of the foxes also were frequently close to park developed areas throughout the remaining months, but diurnal patterns were more variable. The GPS-collared foxes tended to be least associated with park developed areas during July.

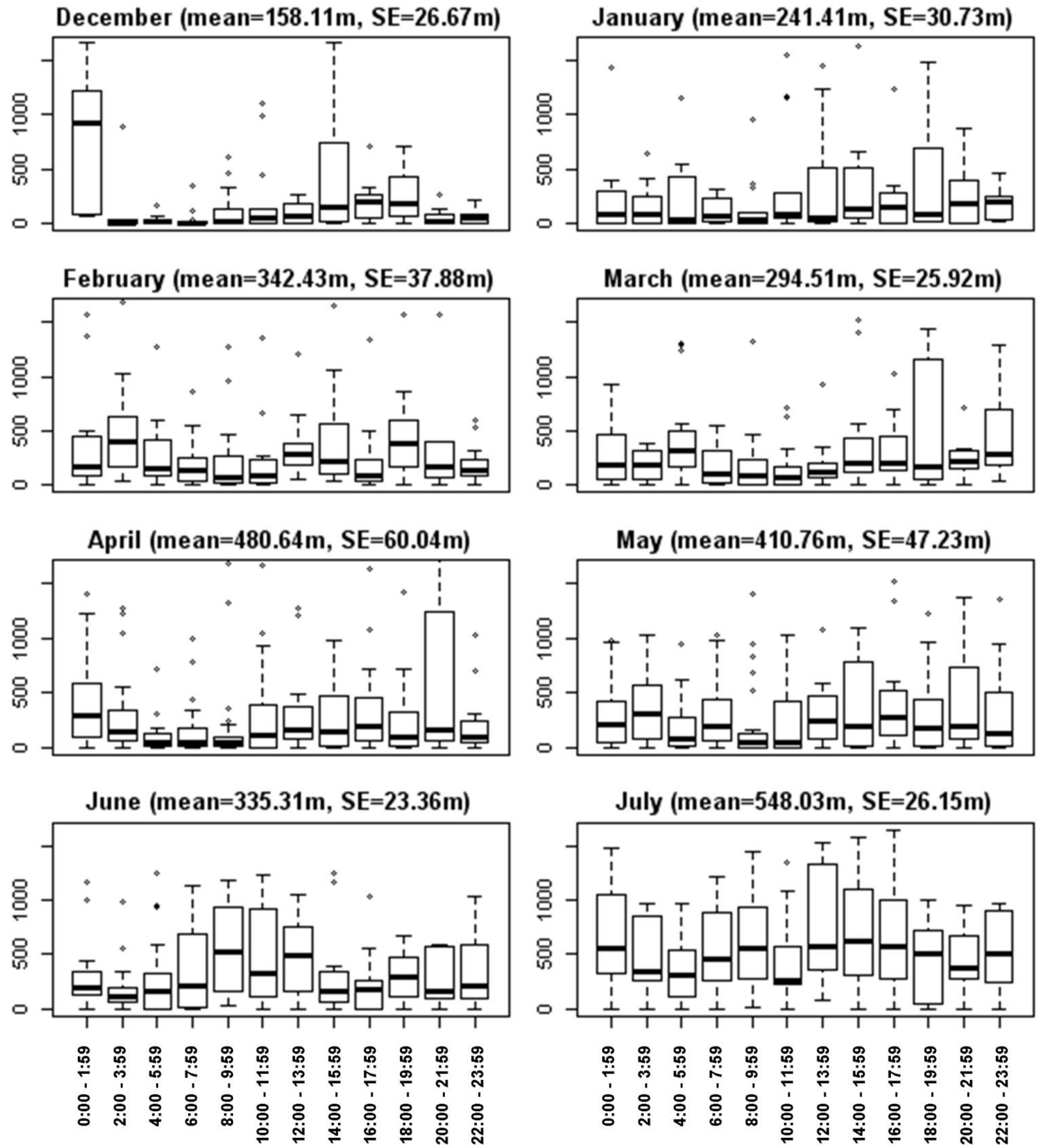

Figure 9. Distribution of distances between Global Positioning System-collared red foxes F068 and M006 and park developed areas, plotted by month and 2-hour interval, Mount Rainier National Park, Washington. Each box shows the lower 25th and upper 75th percentile of the distribution and the median within that range. Mean distances to

developed areas, and standard errors of those means, are based on all available locations each month. See text for a description of outliers and dashed lines representing minima and maxima.

Discussion

We identified two foxes that were closely associated with human use areas of the park (F068, M006), a pattern expected of food-conditioned animals that are habituated to human presence, and one fox that was less clearly tied to human activity centers (M206). The utilization density of both foxes F068 and M006 was strongly clustered around the Paradise parking area, visitor center, and lodge, with other centers of high human use around Longmire administrative area, Cougar Rock campground, and the roadside pullouts near Narada Falls. The resource selection probability model corroborated the expectation that developed areas of the park may be primary centers of resources for food-conditioned foxes. Foxes were most closely aligned with park developed areas during winter and early-spring mornings, but foxes also were associated with developed areas during late spring and early summer.

We examined the associations of GPS-collared red foxes to plowed parking areas (that is, associated with lodges, visitor centers, and pullouts) and to roads independently, but not to both simultaneously because parking areas were obviously associated with roads. Resource selection by red foxes was more closely aligned with parking areas during winter than to roads, although the two foxes most closely associated with park developed areas were also closely associated with roads throughout winter. We surmise that foxes may use plowed roads for ease of travel, but they concentrate activity around places where humans stop the car and congregate, presumably where they have most reliably obtained food from humans.

We identified only one area of high use by GPS-collared foxes (defined in this context as areas within the 50 percent utilization density) that was not clearly associated with an area that was maintained for human use during winter. Two foxes were located there primarily during late spring and early summer but we found no evidence the pair used this area for breeding. Another potential explanation for the frequent use of this area is that its southern exposure causes early snow melt and may provide favorable thermal characteristics and hunting opportunities.

Fix acquisition rates were variable among the three foxes studied, but generally were comparable to other studies in steep mountainous terrain in the Pacific Northwest. Wells and others (2011) and Jenkins and others (2011), for example, both reported similar low rates of GPS fix success in studies of mountain goats during winter in the Washington Cascade Range. We did not investigate the causes of seasonal variations in fix success rates observed in the GPS-collared foxes, but an extensive literature highlights the complex interactions of slope, aspect, elevation, forest canopy, and topographic obstruction, as well as the effects of animal activity and behavior on fix acquisition rates in

GPS collars (see comprehensive review by Friar and others, 2010). We surmise that seasonal variations we observed in fix success rates of collars on foxes were likely related to seasonal behavioral changes related to the use of dense vegetation or topographic cover during winter. Although we are unaware of any previous studies that examined the effect of snow on GPS fix success rates, we hypothesize that heavy snow, particularly in tree canopies or rocky cover, might enhance the signal obstruction characteristics of both features during winter. Loss of data resulting from GPS signal obstruction could have biased our results in favor of more open environments, which may have enhanced our conclusions about spatial associations between GPS-collared foxes and roads and other open areas. This is an area of study that will require greater focus in the future if we extend our work, as is currently proposed, to more comprehensively examine the spatial distributions of the Cascade red fox in Mount Rainier National Park.

Currently the NPS is planning to implement a more consistent program of hazing food-conditioned foxes in an effort to promote more natural behavior patterns. The ongoing effort to educate the public about the negative effects of feeding wildlife, and the use of aversive conditioning on foxes will continue during 2014 and into the future. Results from this preliminary study suggest several possibilities for monitoring changes in the distribution of Cascade red foxes associated with public education and law enforcement activities or aversive conditioning of foxes. The simplest indicator, which does not require ongoing telemetry studies, would be to monitor changes in the frequency of foxes observed by park staff along roadways and in park developed areas. Frequency indicators are highly influenced by variations in survey and reporting effort (that is, the number of observers reporting and emphasis placed on reporting), so the most repeatable index would be produced from standardized surveys conducted throughout the winter. Preliminary indications from this report suggest that surveys conducted during daylight hours in December and January are likely to produce the greatest number of sightings. Extension of surveys to cover the entire winter (for example, November–March), however, would permit a more comprehensive analysis of seasonal patterns of fox-human interactions.

Ongoing use of GPS-telemetry would allow for a more comprehensive analysis of changes in fox distribution in response to increased visitor education or aversive conditioning of foxes. If movements of foxes were monitored before and after an aversive conditioning program was implemented, for example, the simplest indicator of the effectiveness of aversive conditioning would be an increase in the post-treatment distance between individual foxes and areas developed for human use. Aversive conditioning could be considered successful if a Cascade red fox that before treatment had a UD like foxes F068 or M006 were to shift its UD more to remote areas away from human activity centers.

Our preliminary work suggests that resource selection modeling provides a useful suite of tools for assessing the effectiveness of future management practices aimed at promoting more natural behaviors in red foxes. Specifically, the coefficient in any RSPF that relates probability of use to distance to road or winter-use area is an index of association. Because model coeeficients in a RSPF vary in response to all other variables in the model and their correlation structures, the most interpretable measure of association between foxes and human-use areas may result from using a univariate model that contains only the one variable associated with distance of foxes to roads or facilities. RSPF's modelled for individual foxes could be averaged to provide a population-level index of the fox-human interactions and monitored over time. As an alternative to the RSPF modeling approach, other researchers also have assessed wildlife habitat utilization functions, which are based on measuring correlations between the utilization densities within the home ranges of individual animals and environmental variables (Millspaugh and others, 2006). These and similar resource selection modeling approaches have been used effectively in previous analyses of wildlife distributions relative to diverse sorts of human activities or facilities, for example roads (Cooper and Millspaugh, 1999), campgrounds (Neatherlin and Marzluff, 2004), and oil drilling pads (Sawyer and others, 2006).

This preliminary study provided only a glimpse into the spatial ecology of a small sample of Cascade red foxes in Mount Rainier. Additional studies of fox spatial distribution and behavior before, during, and after aversive conditioning practices would permit a more comprehensive assessment of the effects of human use and facilities on the spatial ecology of the Cascade red fox in Mount Rainier. The case studies we examined demonstrate the utility of GPS-based telemetry for assessing changes in distribution patterns and behaviors of Cascade red foxes relative to visitor facilities and in relation to NPS management practices that aim to reduce wildlife dependency on human foods. Future research, however, will need to include a description of the effects of potential fix acquisition bias on the estimated spatial patterns of foxes during winter.

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Appendix A. Utilization Distributions for Daytime, Nighttime, Road-Open Periods, and Road-Closed Periods

This appendix presents the utilization distributions (UDs) for subsets of Cascade red fox locations corresponding to all 2D and 3D locations. Figures A1–A3 compare distributions of individual Global Positioning System-collared foxes between daytime and nighttime periods. Figures A4–A6 compare distributions of individual Global Positioning System-collared foxes between daytime periods when the Nisqually-Paradise road was open and days that the road was closed due to heavy snow. Kernel bandwidth (h_{ref}) estimates for each of these subsets of locations are in table A1. In that table, the h_{ref} values derived from all points contributed to the UDs mapped in figures 2, 3, and 4 of the main body of this report. We did not estimate h_{ref} for F068 or M206 daytime road closed locations because in each case there were less than 30 points in those subsets. For those subsets, we did not prepare UDs; rather we plotted the recorded locations.

Table A1. Kernel-based estimated bandwidth (h_{ref}) values for three Cascade red foxes, Mount Rainier National Park, Washington, 2011–2012.

[The listed h_{ref} values are specific to the set of points including all locations, locations between sunrise and sunset (‘day’), locations between sunset and sunrise (‘night’), daytime locations at times when the Nisqually-Paradise Road was closed (‘closed’) above Longmire, and daytime locations at times up through May 5, 2012, when the road remained open (‘open’). The ‘n/a’ placeholders here indicate that we did not estimate h_{ref} values or prepare a utilization distribution for categories of locations with a sample size less than 30]

	F068	**M006**	**M206**
All	441.6	289.6	1161.5
Day	506.1	293.3	1118.5
Night	439.3	362.4	1630.5
Open, daytime	463.0	411.1	1151.4
Closed, daytime	n/a	606.0	n/a

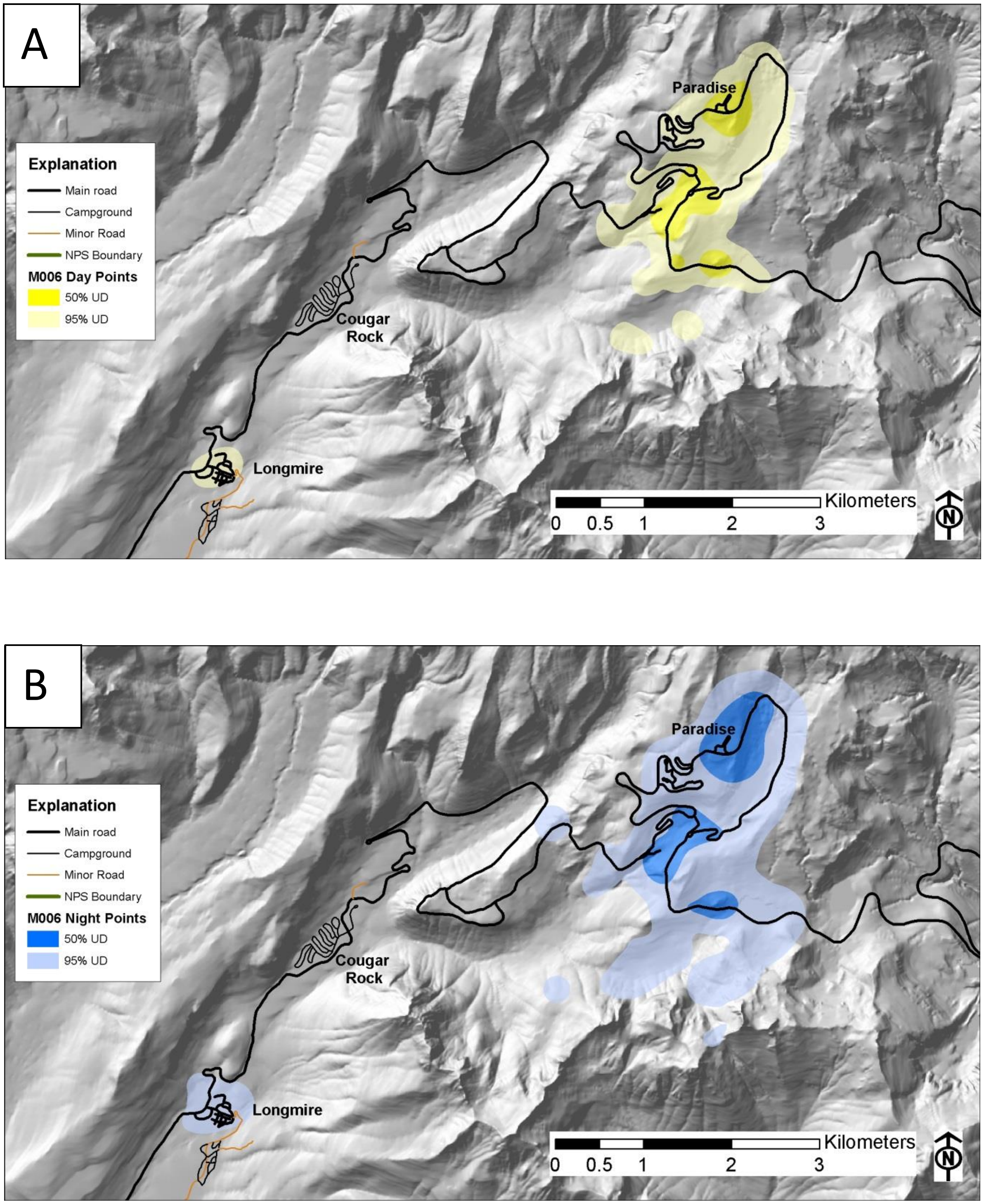


Figure A1. Contrasting sets of utilization distribution (UD) maps for male Cascade red fox M006 locations recorded in the daytime (A) or nighttime (B) , Mount Rainier National Park, Washington.

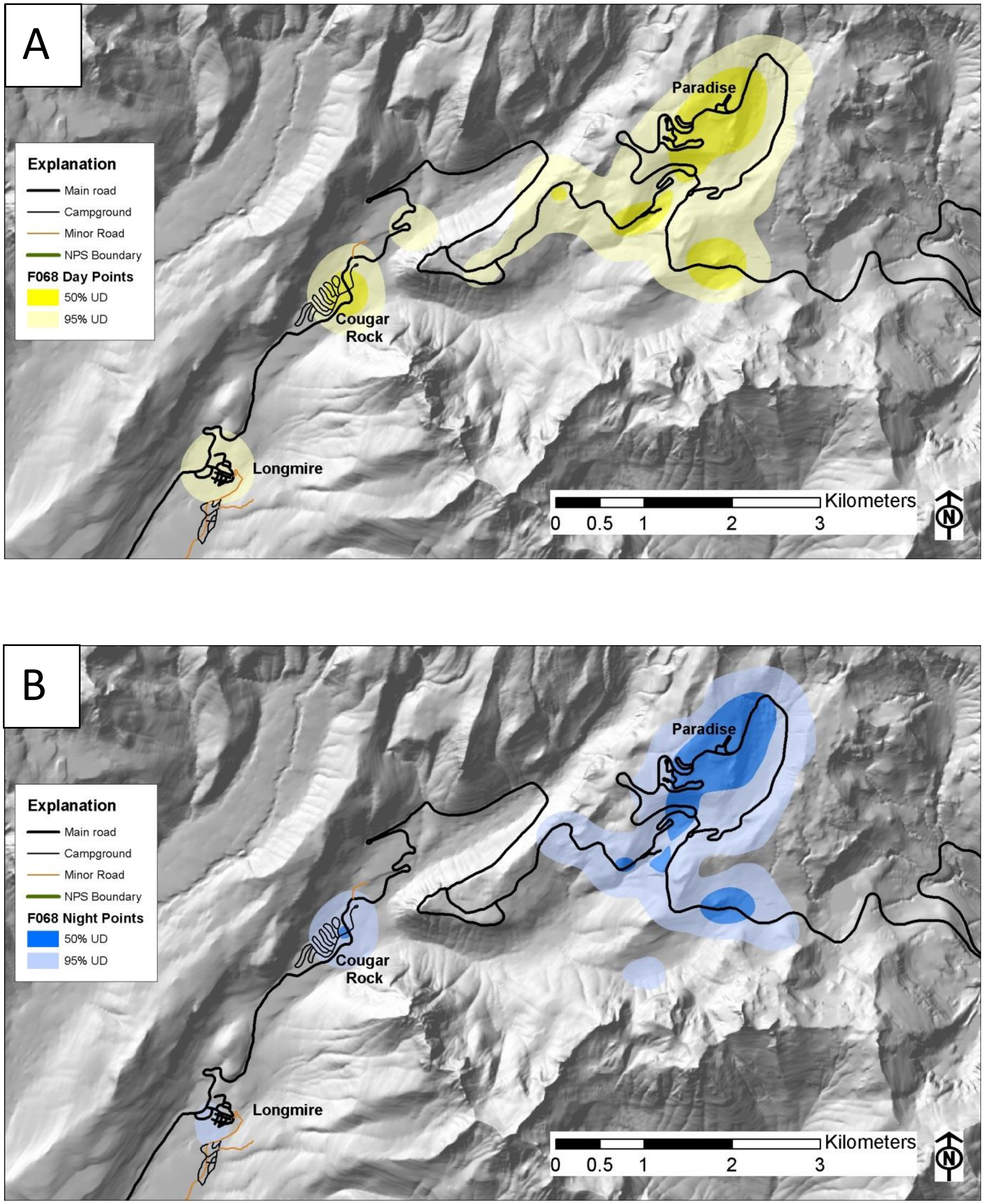


Figure A2. Contrasting sets of utilization distribution (UD) maps for female Cascade red fox F068 locations recorded in the daytime (A) or nighttime (B) , Mount Rainier National Park, Washington.

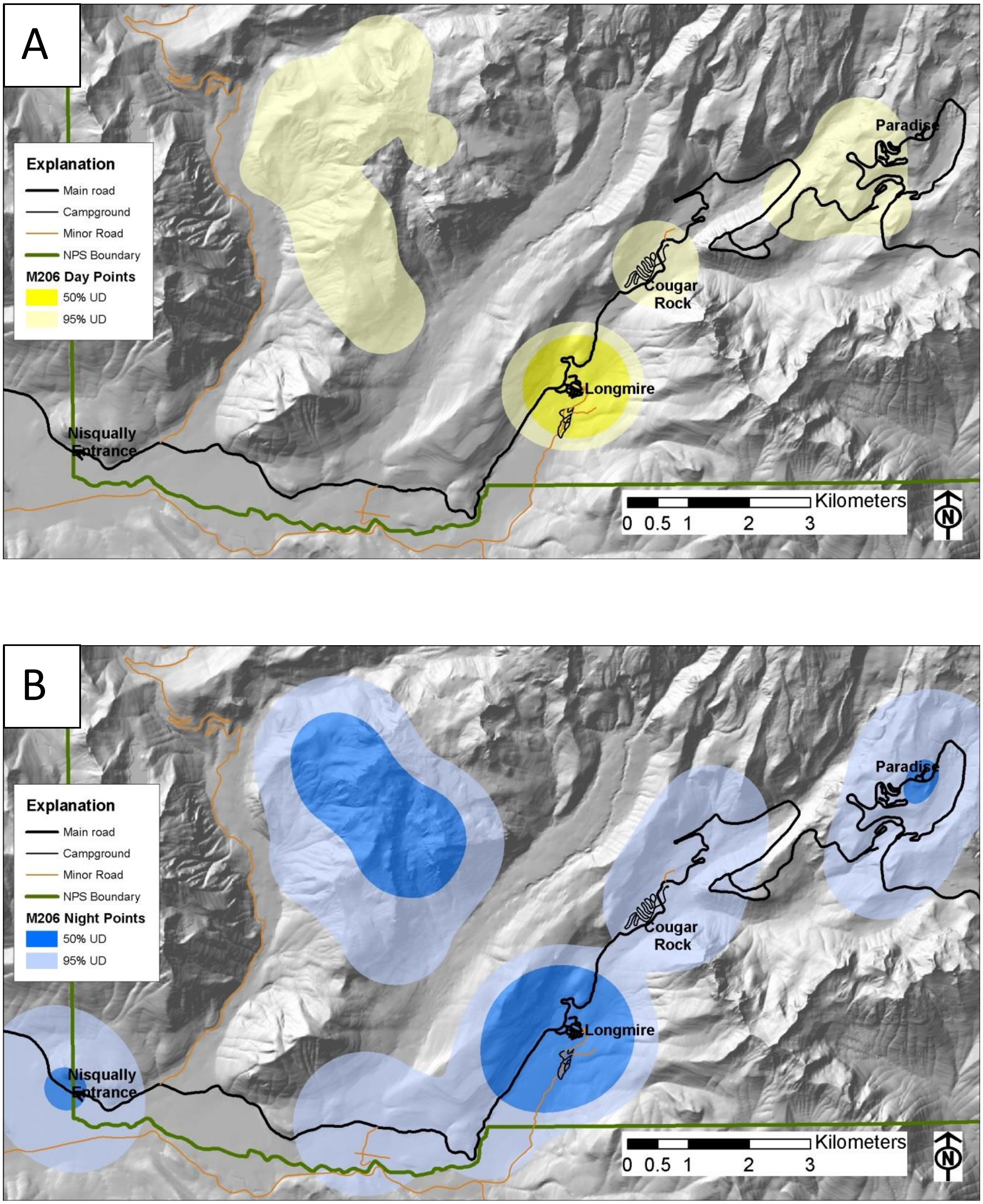
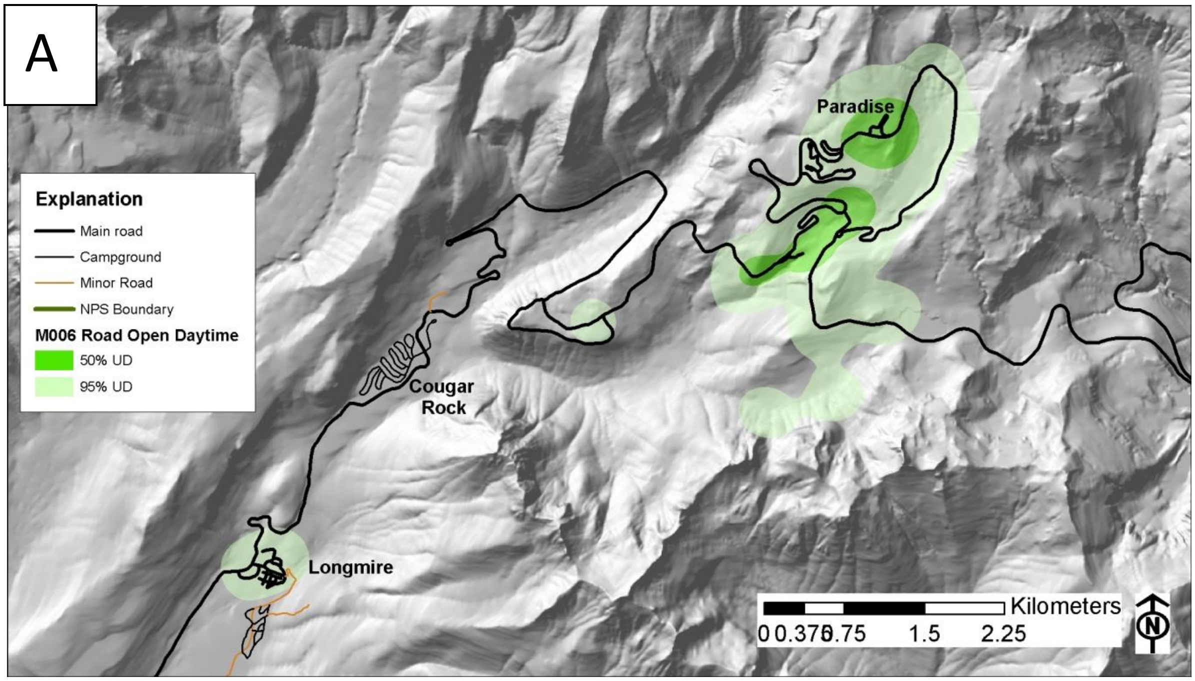


Figure A3. Contrasting sets of utilization distribution (UD) maps for male Cascade red fox M206 locations recorded in the daytime (A) or nighttime (B) , Mount Rainier National Park, Washington.



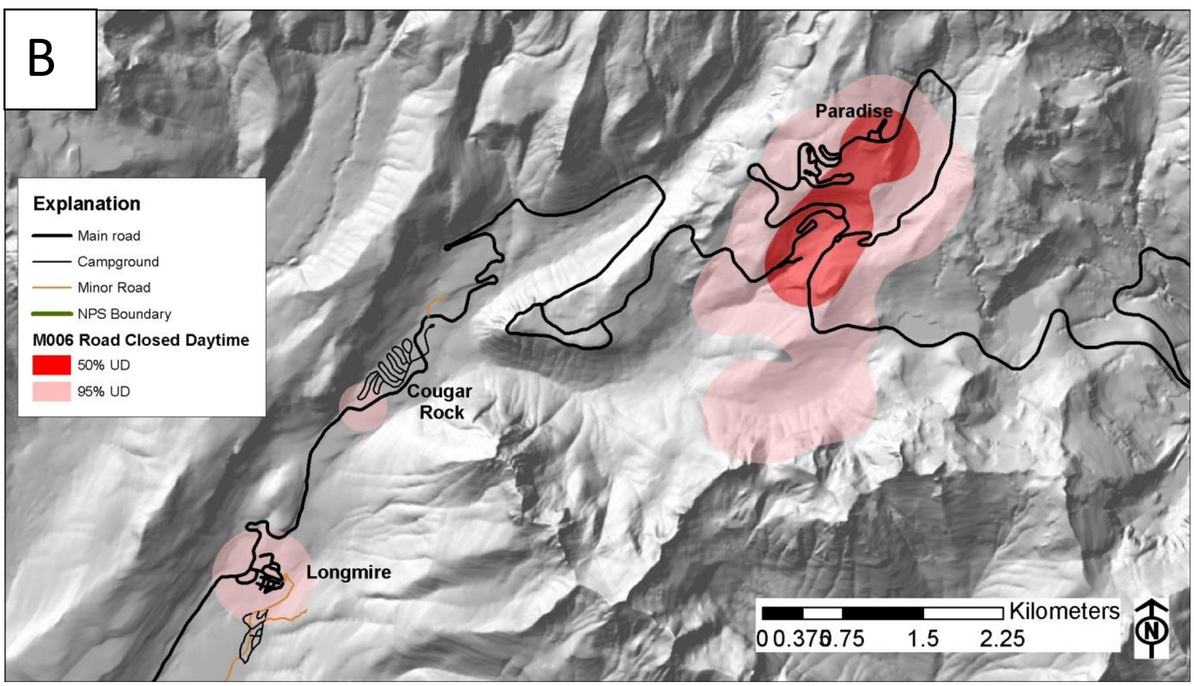
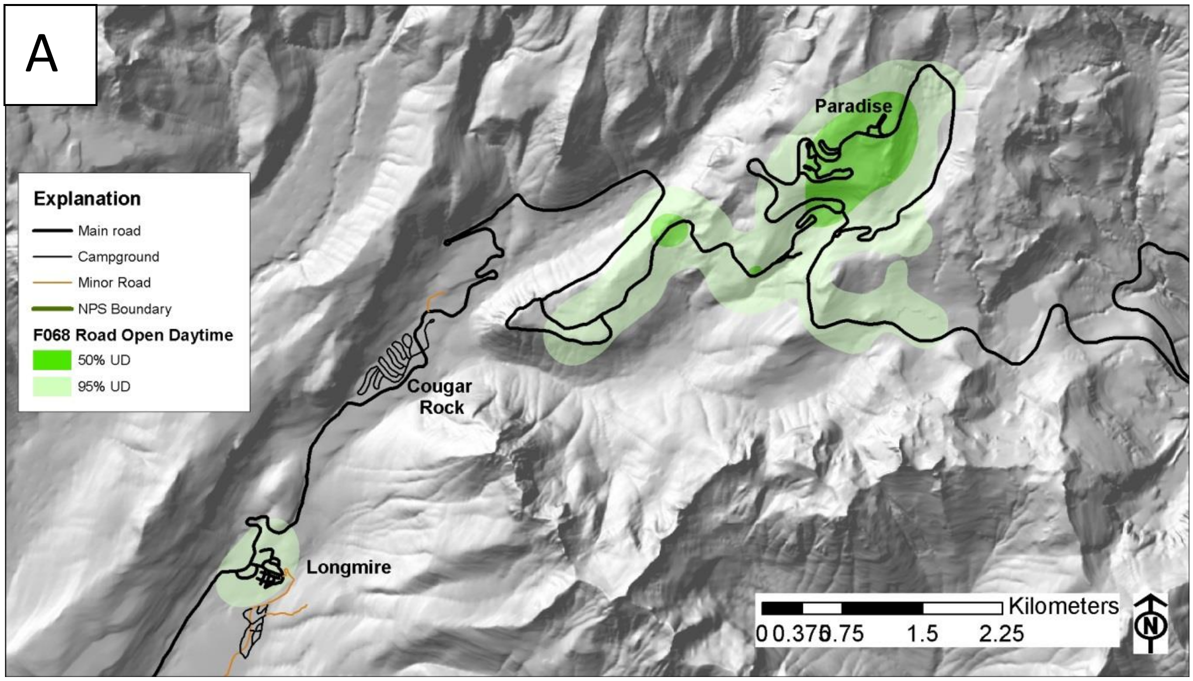


Figure A4. Contrasting sets of utilization distribution (UD) maps for male Cascade red fox M006 locations recorded in the daytime when the road was open (A) or in the daytime when the road was closed (B), Mount Rainier National Park, Washington. The data contributing to these UD estimates were limited to dates up to May 5, 2012, when the road remained open.



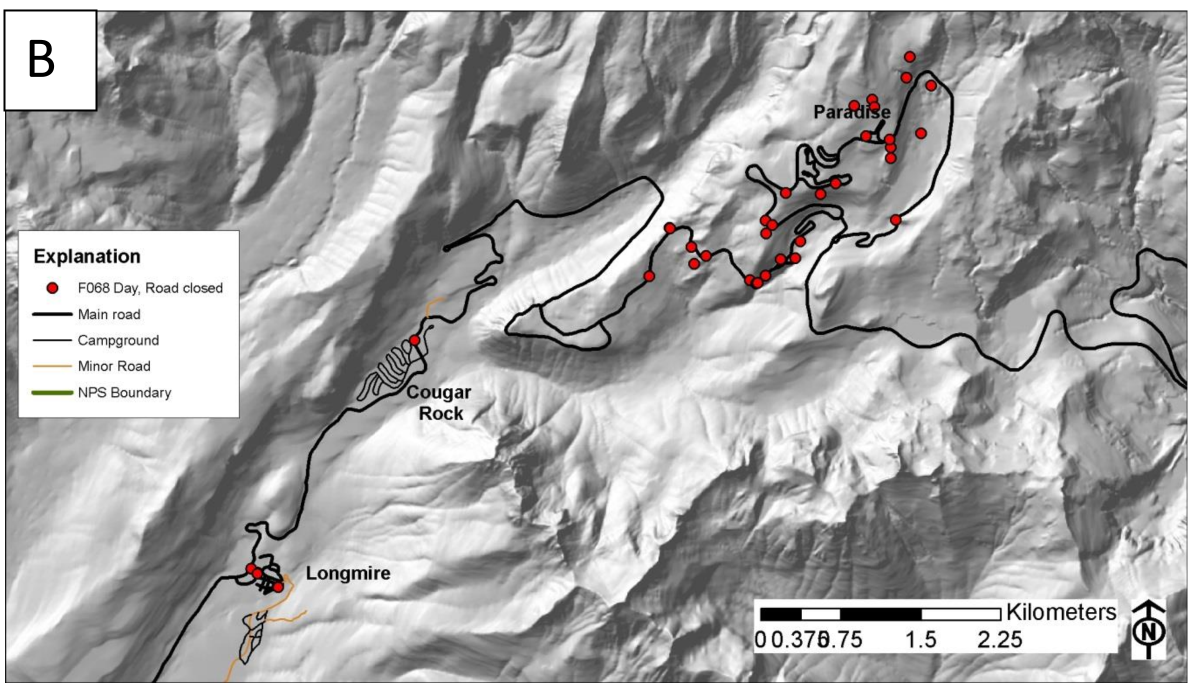
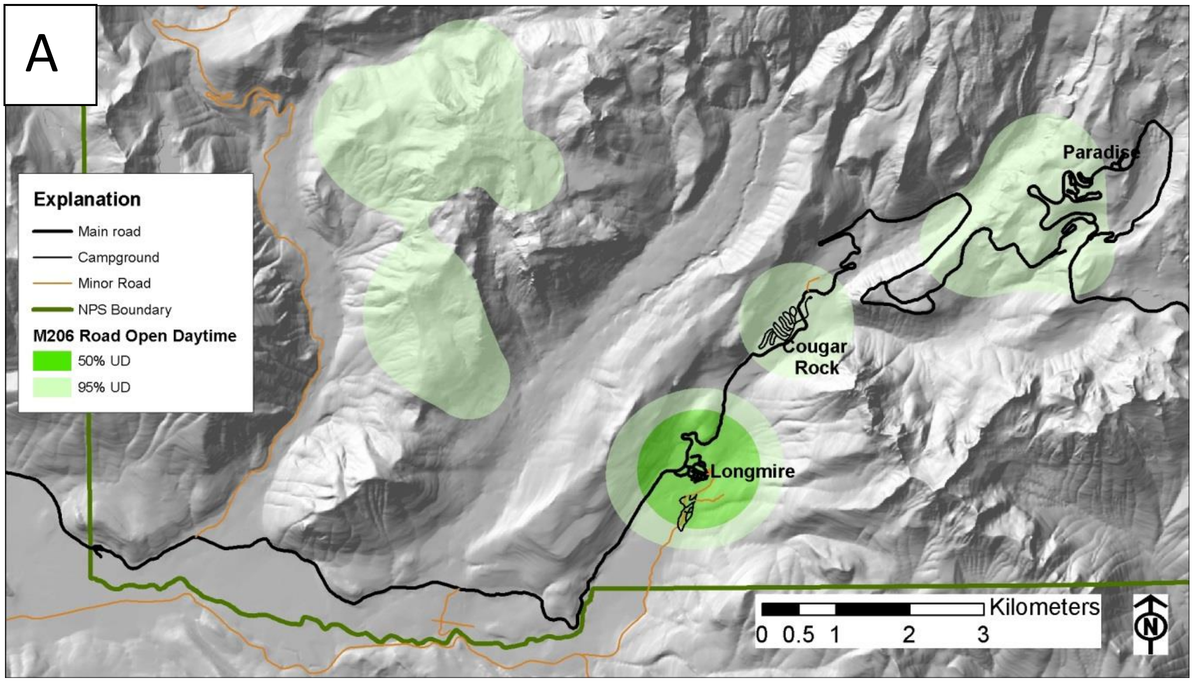


Figure A5. Utilization distribution (UD) map for female Cascade red fox F068 locations recorded in the daytime when the road was open (A), and mapped distribution of locations for that fox from the daytime when the road was closed (B), Mount Rainier National Park. The data contributing to these UD estimates were limited to dates up toMay 5, 2012, when the road remained open.



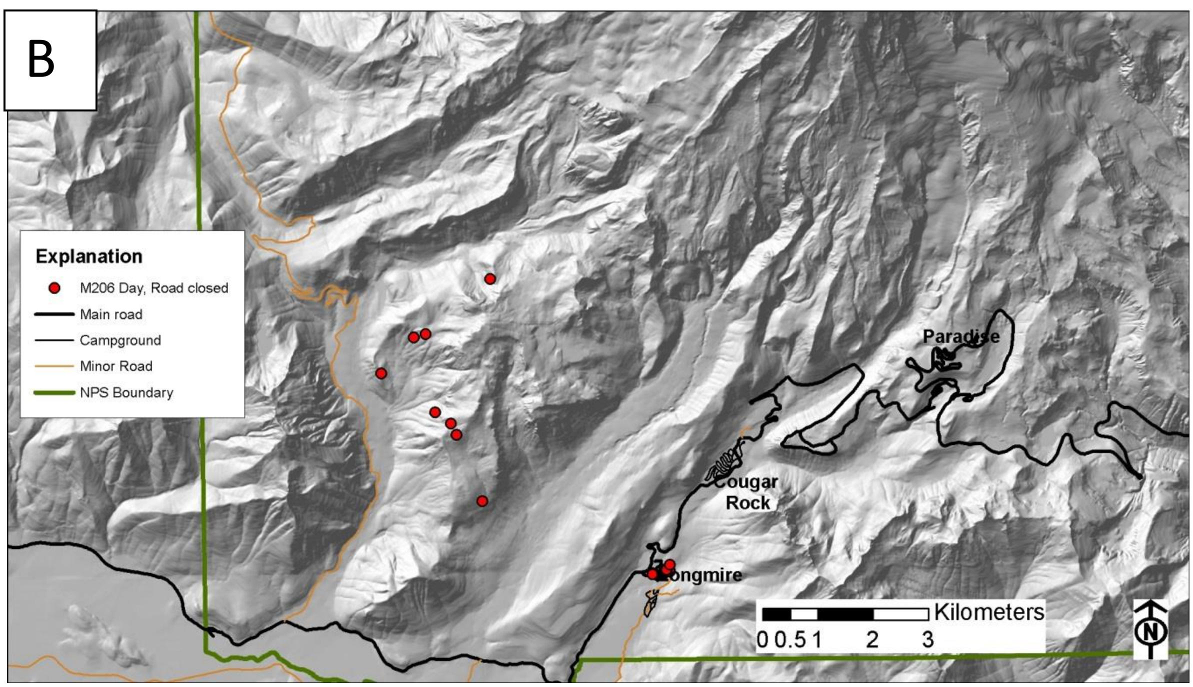


Figure A6. Utilization distribution (UD) map for male Cascade red fox M206 locations recorded in the daytime when the road was open (A), and mapped distribution of locations for that fox from the daytime when the road was closed (B), Mount Rainier National Park, Washington.

Appendix B. Distances of Individual Global Positioning System-Collared Cascade Red Foxes From Developed Areas

This appendix contains boxplots that graphically illustrate seasonal and diurnal variation in the proximity of Global Positioning System-collared foxes to developed areas (figs. B1, B2, B3). Each vertical box represents the statistical distribution of distances that an individual fox was found from developed areas within successive 2-hour intervals each month. The horizontal line within the box represents the median distance, and the upper and lower extents of the box represent the 25th and 75th percentile of the distribution (the ‘interquartile range’). In most cases, the dashed lines extend to the maximum and minimum distances that a collared fox was located from the road. In cases where the maximum or minimum value is farther from the median than 1.5 times the interquartile range, the dashed lines extend only 1.5 times the interquartile range from the median, and outliers are shown with an asterisk. We defined outliers as locations that were more than 1.5 times the interquartile distance from the upper or lower quartile.

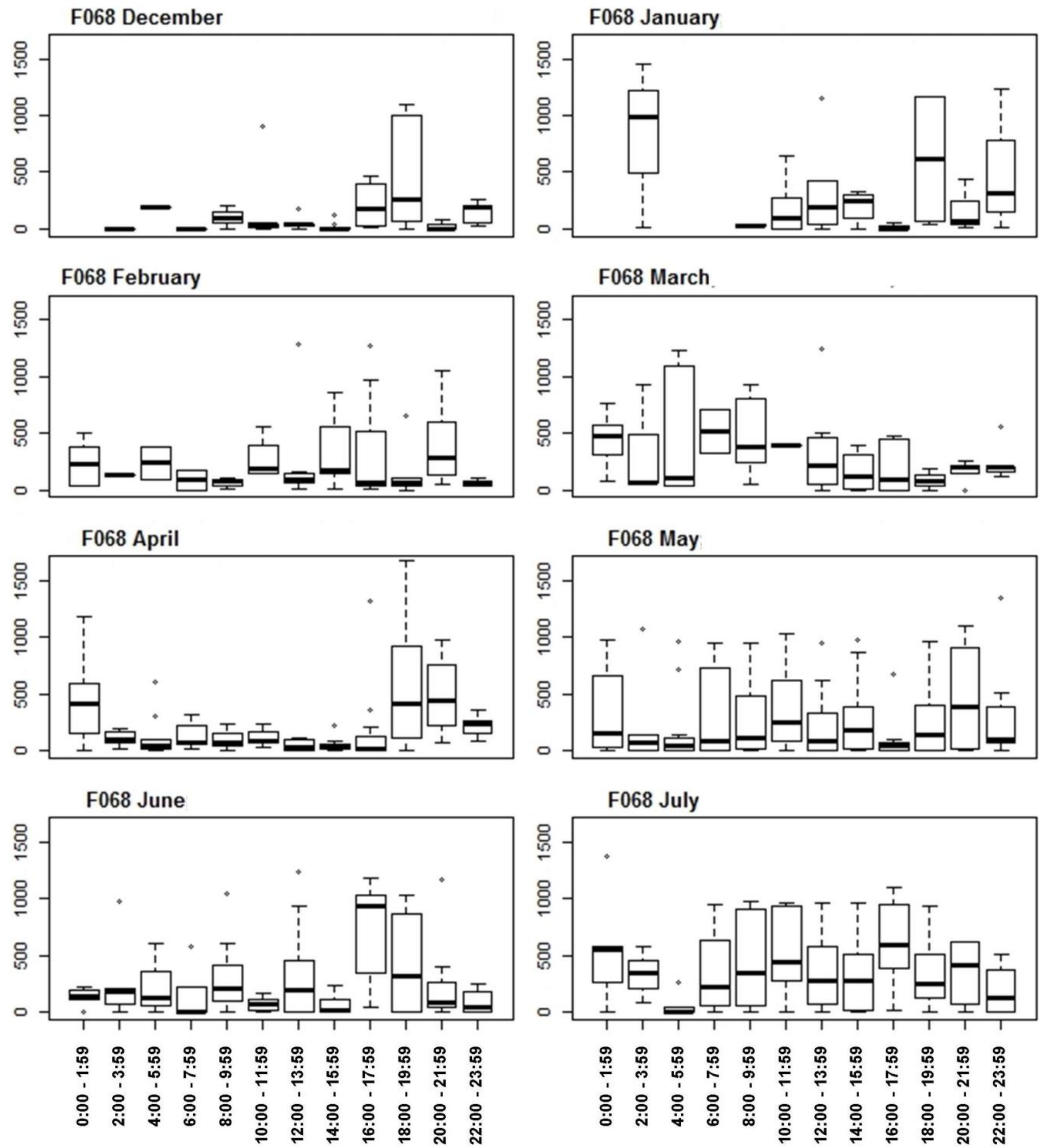


Figure B1. Distribution of distances between female Cascade red fox F068 and park developed areas by month and 2-hour interval, Mount Rainier National Park, Washington. Each box shows the lower 25th and upper 75th percentile of the distribution and the median within that range. See text for a description of outliers and dashed lines representing minima and maxima.

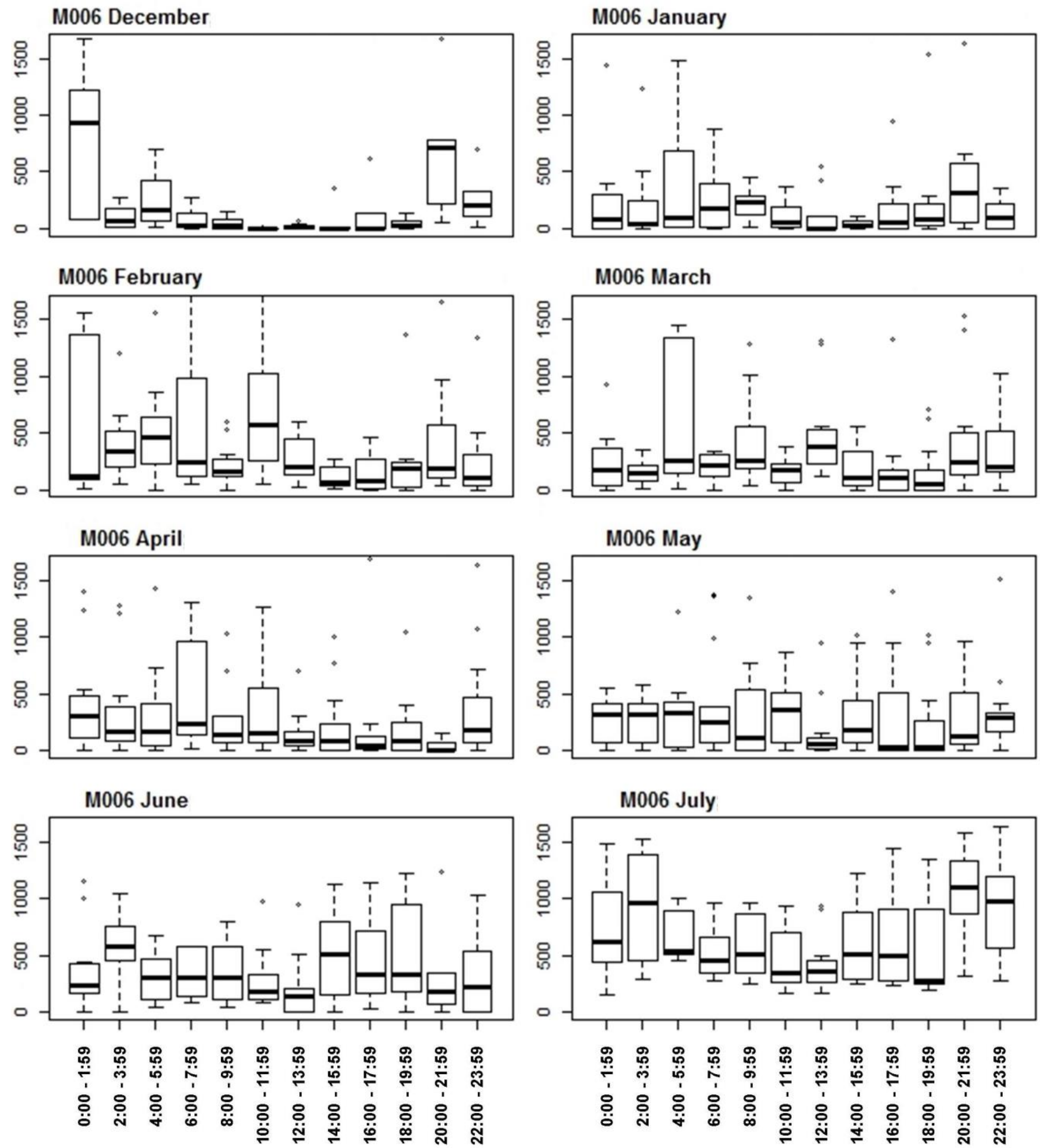


Figure B2. Distribution of distances between male Cascade red fox M006 and park developed areas by month and 2-hour interval, Mount Rainier National Park, Washington. Each box shows the lower 25th and upper 75th percentile of the distribution and the median within that range. See text for a description of outliers and dashed lines representing minima and maxima.

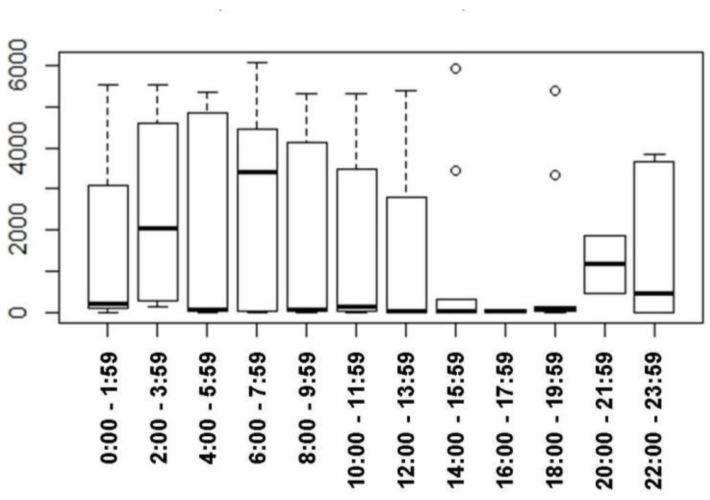


Figure B3. Distribution of distances between male Cascade red fox M206 and park developed areas by 2-hour interval, Mount Rainier National Park, Washington. This plot shows all available data for fox M206, including locations from April and May 2012. Each box shows the lower 25th and upper 75th percentile of the distribution and the median within that range. See text for a description of outliers and dashed lines representing minima and maxima.

Appendix C. Distances of Global Positioning System-Collared Cascade Red Foxes from the Nisqually-Paradise Road

This appendix contains boxplots that graphically illustrate seasonal and diurnal variation in the proximity of Global Positioning System-collared foxes to the Nisqually-Paradise Road (figs. C1, C2, C3). Each vertical box represents the statistical distribution of distances that an individual fox was found from the road within successive 2-hour intervals each month. The horizontal line within the box represents the median distance, and the upper and lower extents of the box represent the 25th and 75th percentile of the distribution (the 'interquartile range'). In most cases, the dashed lines extend to the maximum and minimum distances that a collared fox was located from the road. In cases where the maximum or minimum value is farther from the median than 1.5 times the interquartile range, the dashed lines extend only 1.5 times the interquartile range from the median, and outliers are shown with an asterisk. We defined outliers as locations that were more than 1.5 times the interquartile distance from the upper or lower quartile.

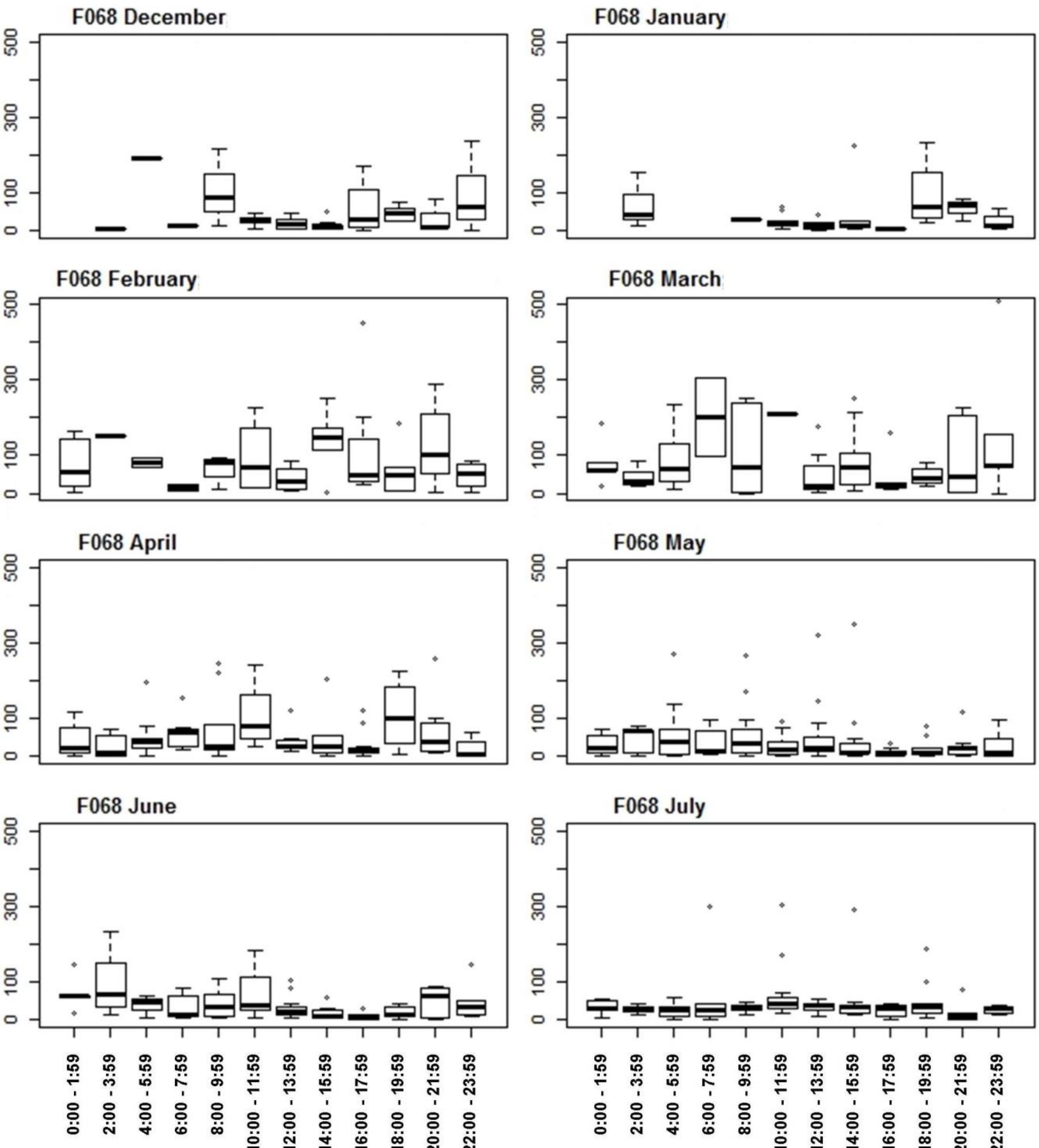


Figure C1. Distribution of distances between female Cascade red fox F068 and the Nisqually-Paradise Road, by month and 2-hour interval, Mount Rainier National Park, Washington. Each box shows the lower 25th and upper 75th percentile of the distribution and the median within that range. See text for a description of outliers and dashed lines representing minima and maxima.

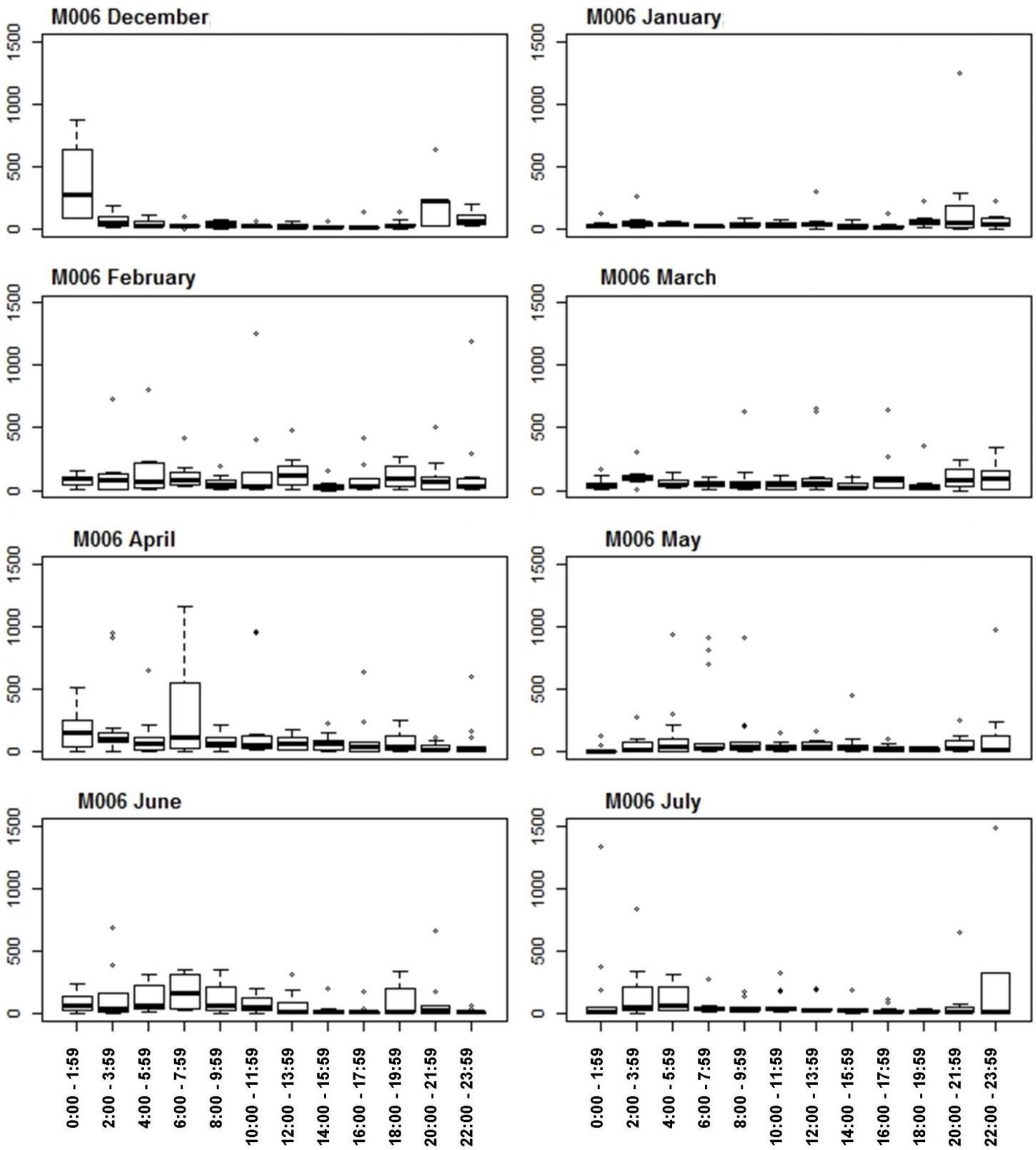


Figure C2. Distribution of distances between male Cascade red fox M006 and the Nisqually-Paradise Road, by month and 2-hour interval, Mount Rainier National Park, Washington. Each box shows the lower 25th and upper 75th percentile of the distribution and the median within that range. See text for a description of outliers and dashed lines representing minima and maxima. Note the differences in scale of the Y axis between figures B1 and B2.

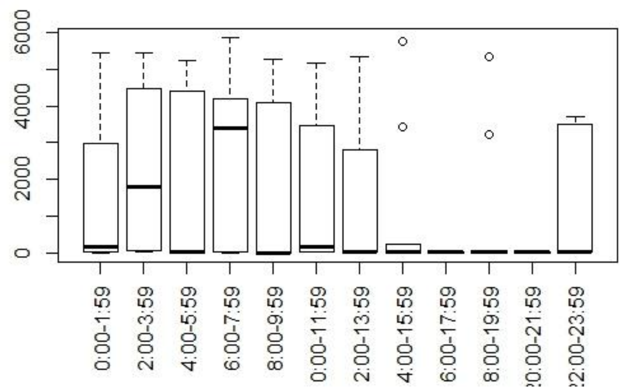


Figure C3. Distribution of distances between male Cascade red fox M206 the Nisqually-Paradise road, by 2-hour interval, Mount Rainier National Park, Washington. This plot shows all available data for fox M206, including locations from April and May 2012. Each box shows the lower 25th and upper 75th percentile of the distribution and the median within that range. See text for a description of outliers and dashed lines representing minima and maxima.