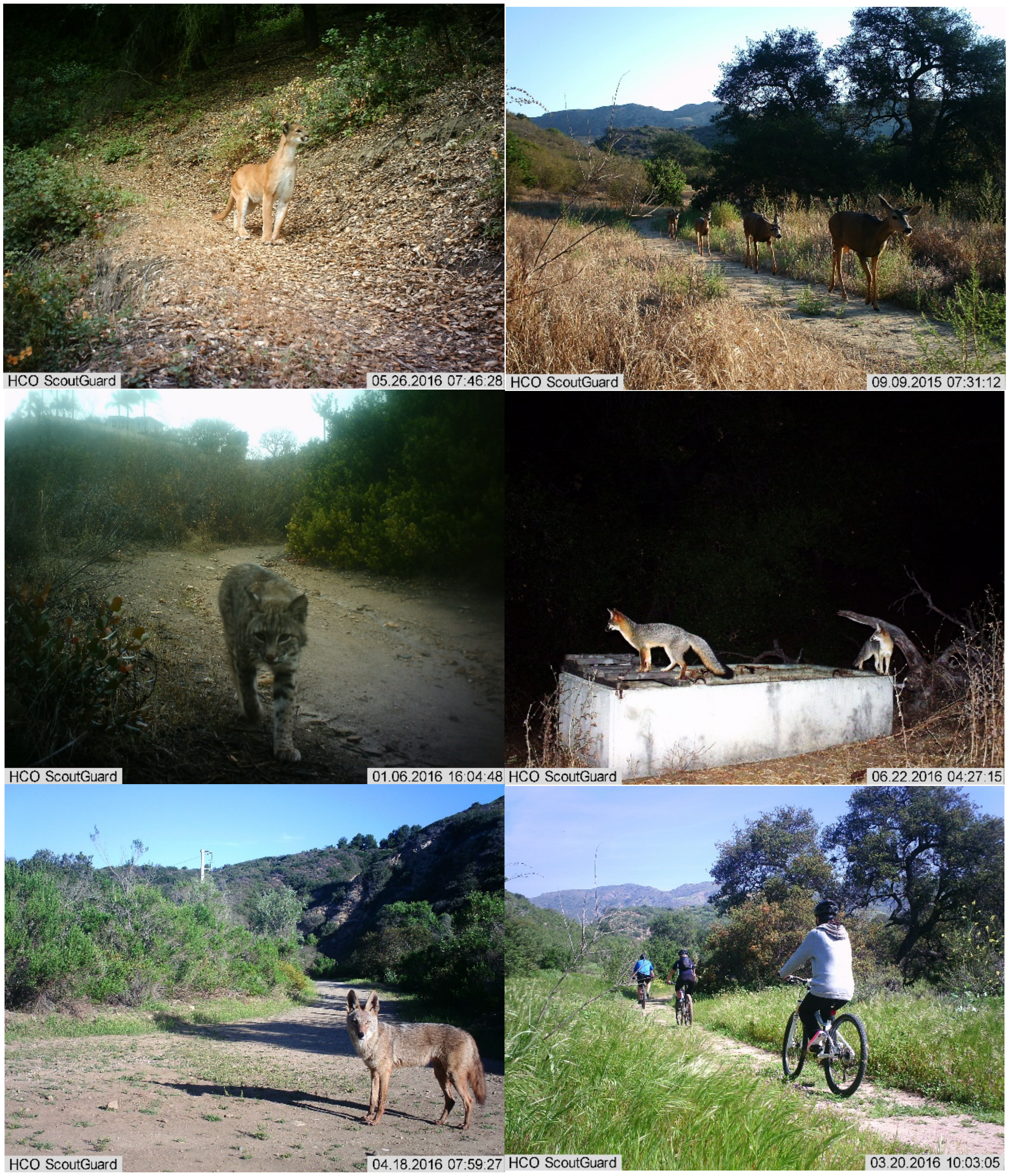
FINAL REPORT FOR California Department of Fish and Wildlife Local Assistance Grant #P1482109

Assessing Effectiveness of Adaptive Recreation Management Strategies and Evaluation of Core NCCP/HCP Habitat Areas



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for the
Natural Communities Coalition

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Cover Page Photos (left to right, top to bottom): Mountain Lion at DRSP (Limestone Canyon), Mule Deer at ROCA2 (Limestone Canyon), Gray Fox at WETR3 (Weir Canyon), Bobcat at BGBR (Buck Gully), Coyote at BGGC (Buck Gully), Mountain Bikers at ROCA2 (Limestone Canyon)

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Executive Summary

Recreation management is one of four key management elements of the County of Orange Central and Coastal Natural Community Conservation Plan/Habitat Conservation Plan (NCCP/HCP) Habitat Management Program. Objectives of program as they pertain to recreation include: (1) development of a network of observation systems for use in establishing a reliable baseline (and future measures) of human-use of NCCP/HCP-enrolled lands; (2) implementation of valuation studies of the public to help identify carrying capacities for individual parks and desired recreation and land management programs; (3) support of planning efforts and management activities contributing to design and maintenance of an authorized, compatible, and sustainable trail network within the NCCP/HCP Reserve; and (4) implementation of a recreation program consistent with the values of the public and long-term maintenance of biodiversity.

This Final Report to the California Department of Fish and Wildlife report summarizes the results of a Local Assistance Grant (LAG)-funded project (#P1482109) designed to address listed objectives by: (1) testing of recreation management hypotheses and recommendations rooted in analyses conducted under a prior LAG (#P0982014); (2) identifying high-value or core habitat areas within the NCCP/HCP Reserve to facilitate discussion among landowners and land managers about opportunities to reconfigure the current trail system to improve recreation opportunities while reducing impacts on wildlife; and (3) generating recommendations to revise and expand the human-use and wildlife monitoring system across the NCCP/HCP Reserve. The project focuses on assessment of temporal changes in activity of seven key mammal species, response to pulses of human activity, and seasonal patterns and associated changes in wildlife sensitivity. Specific questions about space use and anthropogenic effects with movement data on the bobcat, a medium-sized obligate carnivore strongly associated with natural habitat, are addressed. Subtler effects of adjacent urbanization are characterized by the measuring and modeling light pollution patterns across a portion of the NCCP/HCP Reserve.

In the present study, wildlife avoidance was evident regardless of species, type of human activity, and camera placement. The overall trend is sharply negative: as human activity increases, mammal activity decreases. Observed human-induced diel shifts by mule deer and coyote have important ramifications for predator–prey dynamics, as the marked shift by mule deer, a primary consumer, brought it into better temporal alignment with its chief predator (mountain lion) and the marked shift by the coyote, a secondary consumer, brought it into better temporal alignment with a chief source of prey (gray fox). All seven mammals exhibited short-term spatial shifts in response to large events. Across the seven focal species, mammal activity was shown to be markedly seasonal, with peak occurrence recorded in either spring (March) or summer (June) sample. No evidence was found suggesting mammal populations

have declined Reserve-wide between mid-2007 and mid-2016. Human activity, by contrast, was noisy with respect to season but has increased markedly across the study period. Bobcat space use assessed with resource selection functions supported prior research on this species and emphasized preference for natural habitat, with core “hot spots” in the center of large blocks of open space. In Limestone Canyon, acute changes in wildlife behavior in response to large events were clear, but chronic changes in behavior were not evident. The Coastal Reserve experiences a high level of light pollution, even under the best case scenario, due to skyglow and other sources of nighttime illumination.

Marked increase in human-use of wildlands over the last nine years coupled with observed temporal and spatial shifts by wildlife due to human presence highlights the importance of developing an over-arching, adaptive recreation management plan for the NCCP/HCP Reserve. Focal dimensions for recommended future work include: (1) determining current reserve-wide visitor-use levels and spatial and temporal distributions; (2) assessing biophysical resource conditions; (3) understanding visitor perceptions, values, and judgements, as well as their understanding of the genesis for the lands conserved under the NCCP; and (4) providing scientific expertise in park planning and management. New information on human-use and values, when complemented by the findings of the present study, is to advance planning tied to threshold management, core area designation, and trail design and use. Next steps involve determining thresholds of acceptability of key indicators of resource and social conditions, and assisting land managers in development of a range of possible management actions when conditions exceed these levels.

Specific management actions to be visited include the spatial and temporal separation of recreation uses, such as the separation of biking and hiking, equestrian, and vehicle use, and determination of acceptability to visitors for expanding the core area concept to define high, medium, and low intensity areas for the benefit of both the user’s experience and protection of natural resources. Distinct seasonal peaks of activity by wildlife recovered through time-series analysis of camera-trap data, suggest there are select times of the year when wildlife are most active and these times may present specific vulnerabilities to human presence (or disturbance). One management recommendation is to identify periods of the year when specific wildlife species may be most sensitive to increased human activity and block-out large events and/or limit the number of activities during these periods. Modeling efforts of bobcat space use highlight the need by female bobcats for contiguous quality habitat for home range placement. Female bobcats are strongly associated with natural areas, and resource selection models highlight the particular importance of the NCCP/HCP reserve habitat. Modeling efforts based on fine-scale selection highlight additional habitat areas outside of the NCCP/HCP Coastal Reserve that may be of real benefit to bobcats and likely other wildlife through the enhancement of functional connectivity. Given the limited amount of contiguous open space within the Coastal

Reserve and observed sensitivity of wildlife to human-presence, a cautionary approach to expanding human-activity beyond authorized trails and outside of already established sunrise to sunset activity envelopes is suggested.

Introduction

Recreation management is one of four key management elements of the County of Orange Central and Coastal Natural Community Conservation Plan/Habitat Conservation Plan (Central/Coastal NCCP/HCP) Habitat Management Program (Implementation Agreement, p. 54). Implementation of the Habitat Management Program is based on an adaptive management approach (Central/Coastal NCCP/HCP p. 11-290). The NCCP/HCP identifies specific policies and programs of the Habitat Management Program (Central/Coastal NCCP/HCP pp. 11-290 through 11-376), which provides general guidelines for development of a recreation management program within the NCCP/HCP Reserve (Central/Coastal NCCP/HCP pp. 11-343 through 11-354) but leaves the specific details of the program to be developed by the Natural Community Coalition (NCC), Wildlife Agencies (U.S. Fish and Wildlife Service, California Department of Fish and Wildlife), and participating landowners. Presently, NCC, together with the Wildlife Agencies, and partnering organizations are in the process of developing a 10-year plan for science and land management within the NCCP/HCP Reserve. Draft objectives under the 10-year plan as they pertain to recreation management include: (1) supporting development of a network of observation systems for use in establishing a reliable baseline (and future measures) of human-use of NCCP/HCP-enrolled lands; (2) supporting implementation of valuation studies of the public to help identify carrying capacities for individual parks and to identify recreation and land management programs that are desired by the public; (3) supporting planning efforts and management activities that contribute to the design and maintenance of an authorized, compatible, and sustainable trail network within the NCCP/HCP Reserve; and (4) supporting implementation of recreation programs consistent with the values of the public and long-term maintenance of biodiversity within the NCCP/HCP Reserve.

This report summarizes the results of a Local Assistance Grant (LAG)-funded project that addressed objectives 1, 3, and 4, of the 10-year plan, by advancing science and monitoring initiatives supporting assessment of the current trail network and identification of recreation management strategies within the NCCP/HCP Reserve designed to minimize potential impacts of human-use on natural resources.

Development of a sustainable recreation program consistent with the values of the public and long-term management of biodiversity within the NCCP/HCP Reserve is not only a requirement under the NCCP/HCP but is emerging as a top priority for owners and managers of the lands enrolled in the Central/Coastal NCCP/HCP. With more than 3,000,000 people living within a 30-minute drive of the NCCP/HCP Reserve, poorly managed human access has the potential to undermine the long-term biological and recreational value of the network of protected lands within central and coastal Orange County. Recognition of recreation as an emerging stressor of conserved lands aligns with the California State Wildlife Action Plan (CDFW 2015), which identifies human-use as a threat to wildlife within multiple areas of the State, including the South Coast Region.

The Irvine Ranch Natural Landmarks in Orange County, California, consists of 37,000 acres of protected land that comprises the NCCP/HCP Reserve. An additional 13,000 acres of designated open space is located adjacent to the NCCP/HCP Reserve with the majority protected by conservation easements dedicated to The Nature Conservancy and more recently the Orange County Parks Foundation. Public access in protected areas increases public appreciation of these areas but also carries its own negative impact on the land. Potential impacts include introduction of invasive species, indirect effects associated with trail use and maintenance, direct damage/impacts to native communities due to unauthorized off-trail use, and displacement of wildlife. These impacts are complex, with the potential for one change to ripple throughout an ecosystem. The complex and dynamic relationship between human activity, habitat quality, and wildlife use necessitates long-term monitoring and adaptive management rather than strict reliance on static cause-and-effect relationships.

Previous LAG funding (LAG #PO982014) was awarded to the Irvine Ranch Conservancy (IRC) in 2010, for development of an efficient monitoring framework and methods for adaptively managing human access on a subset of the NCCP/HCP Reserve lands (Fig. 1). The results of this project included a summary of recreation monitoring data collected from June 2007-June 2011, and vegetation and wildlife impacts associated with recreational uses. The study also quantified avoidance of human activity by wildlife, and developed testable recreation management hypotheses and monitoring strategies to assess human activity, wildlife activity, trail condition, and trailside vegetation. Since project completion, IRC has collected four years of additional camera-trap data and new methods have been developed (Tracey et al. 2013, 2014) supporting advanced visualization and estimation of animal location data. Together, the additional monitoring data and revised spatial analyses techniques will facilitate the advancement of science informing recreation management within the NCCP/HCP Reserve. The current LAG-funded project (#P1482109) builds off this study and was designed to: (1) test the management hypotheses and recommendations rooted in analyses conducted previously; (2) identify high-value or core habitat areas within the NCCP/HCP Reserve to facilitate discussion among landowners and land managers about opportunities to reconfigure the current trail system to improve recreation opportunities while reducing impacts on wildlife; and (3) generate recommendations to revise and expand the human-use and wildlife monitoring system across the NCCP/HCP Reserve as an essential component of the recreation management program that is in development.

Effects of human activity

A firm understanding of wildlife responses to human disturbance is essential to ensure that "passive recreation" (p.II-346), an allowable use in the NCCP/HCP Reserve is compatible with habitat protection and covered species' conservation, a primary goal of the Central/Coastal NCCP/HCP. Ongoing anthropogenic encroachment on habitats yields an inevitable increase in human–wildlife interaction, whether direct or indirect. Encroachment and interaction are guaranteed even in parks and reserves, which are, in many regions, increasingly embedded within a matrix of urban or suburban development that is often unsuitable for wildlife persistence (Gehrt et al. 2010). The proximity of reserves to development invariably increases human access and impact and can lead to myriad effects on wildlife, from habitat fragmentation (e.g., via disruption of dispersal corridors or home range needs) to alteration of food resources, introduction of disease vectors, competition from feral cats and dogs, poisoning through pest control, poaching, light pollution, and roadkill (Woodroffe et al. 2005, Smith-Patten and Patten 2008, White and Ward 2011, Barua et al. 2013). Moreover, population-level and demographic effects of human disturbance are poorly known, even if it is assumed that avoidance by wildlife leads to energetic costs that affects an animal's health and reproduction or may ultimately lead to a perceptual trap in which misleading cues cause an organism to avoid otherwise suitable habitat (Patten and Kelly 2010).

These problems are exacerbated in a region that has experienced extensive development for housing and infrastructure, such as in coastal southern California, where human population and associated habitat loss continues unabated. In this region the response of wildlife to human activity or encroachment is idiosyncratic. In general, medium- to large-bodied mammals such as coyote (*Canis latrans*), bobcat (*Lynx rufus*), and mule deer (*Odocoileus hemionus*) avoid areas of high human use in this area (George and Crooks 2006). However, meta-analyses of camera trap studies across a larger region revealed that detections of coyote and northern raccoon (*Procyon lotor*) increased with proximity and intensity of urbanization, whereas bobcat, gray fox (*Urocyon cinereoargenteus*), and mountain lion (*Puma concolor*) detections decreased (Riley et al. 2003, Ordeñana et al. 2010). In the NCCP/HCP Reserve, each of the species above plus the striped skunk (*Mephitis mephitis*) was found to avoid all types of human activities (Patten and Burger 2017). Furthermore, in areas of high human use relative to areas of low use, most mammal species are displaced temporally by shifting their activity toward night-time (Tigas et al. 2002, Riley et al. 2003, George and Crooks 2006). The generality of a negative response is unclear and needs more study.

Any negative response is predicated on how an animal uses space available to it or is restricted from use of space by anthropogenic activity. Because of their trophic position, large and medium-sized carnivores occur at low densities and have large home ranges relative to their body size. Such species may serve as indicators of landscape connectivity, isolation, and reserve system success (Woodroffe and Ginsberg 1998, Crooks 2002) and may act as “umbrella species” that protect other species with less constrained space or habitat needs (Lambeck 1997, Miller et al. 1998, Carroll et al. 1999). For example, tracking studies show that bobcat home ranges tend to be comprised of natural habitat (Riley et al. 2010, Jennings 2013), the species avoids developed areas and roads (Riley et al. 2003, Poessel et al. 2014), its occurrence decreases with increased proximity to urbanization (Ordeñana et al. 2010, Tracey et al. 2013), and individuals may more quickly traverse developed areas than natural habitat (Nogeire et al. 2015).

In this report, we reassess responses to human activity by key mammal species. We analyze temporal changes in mammal activity, response to pulses of human activity, and seasonal patterns and associated changes in wildlife sensitivity. We further address specific questions about space use and anthropogenic effects with movement data on the bobcat, a medium-sized obligate carnivore strongly associated with natural habitat (Tigas et al. 2002, Riley et al. 2003, Ordeñana et al. 2010), although it can persist in urban landscapes adjacent to wildland (Crooks 2002). Spatial analysis of bobcat movements allows for a detailed examination of how human disturbance and attendant urbanization may affect one of our focal species. Lastly, we characterize subtler effects of adjacent urbanization by measuring and modeling light pollution patterns across a portion of the NCCP/HCP Reserve.

Field methods

Fixed location digital wildlife cameras (Cuddeback Expert 3300, Non Typical, Inc., from 2007–2011; Scoutguard SG565F, HCO Outdoor Products, from 2012–2016) were installed to monitor human and wildlife activity concurrently on a long-term basis across the NCCP/HCP Reserve and adjacent conserved lands. Cuddeback cameras had a flash range of 18 m and were equipped with an instant trigger tripped by motion (6–30 m distance) and heat. Their detection angle is narrow, 2-m wide at 10-m distance, compared to other recent models. Scoutguard cameras had a flash range of 15 m and a motion/heat detector triggered at 10-m distance with a wider (52°) field of view. Camera sensitivity was adjusted to maximize detection but minimize extraneous photographs of moving vegetation or shadows. Each camera was set for a 1-minute delay between photographs to minimize duplicates of the same individual. Cameras were positioned along trails or roads where wildlife activity was likely, as well as by water troughs, future recreational trail locations, and established animal trails. Images were stamped with date and time on 1 Gb compact flash cards, which were collected every two weeks. Date, time, species, number of individuals, trap location, and notes were input to a relational biodiversity database Biota 2.04®.

Data collected from 56 camera traps deployed from June 2007–June 2016 were analyzed (Fig. 1), although not all cameras operated continuously over that period, so sometimes sample size is smaller. Thirty cameras were positioned along trails, six directly adjacent to water troughs or water sources, and the remainder off-trail. Twenty-eight cameras have operated continuously since June 2007. Each photograph was viewed by an IRC volunteer, intern, or staff member, who recorded the date, time, and species. We analyzed patterns for seven species: bobcat, mountain lion, gray fox, coyote, striped skunk, northern raccoon, and mule deer. If a human, bicycle, or vehicle was detected repeatedly within 1 hour then all such photos in that hour were summed as a single record. If a wildlife species occurred repeatedly within a 5-minute interval then photos were tallied as a single record. We did not estimate detection probability of the cameras because the number of repeated samples was so high that detection probability could be assumed to be more-or-less even and constant.

Field data on bobcats were collected in Orange County and adjacent portions of cismontane Riverside and San Bernardino Counties. Bobcats were affixed with a GPS collar and data logger by the U.S. Geological Survey (USGS) and Colorado State University. A total of 31 male and 20 female bobcats were tracked (for details see Tracey et al. 2013, Poessel et al. 2014, Nogeire et al. 2015). Tracking locations in Orange County included the North Irvine Ranch Open Space, December 2002–May 2004 (*n* = 16); the San Joaquin Hills from Newport Back Bay to Aliso and Woods Canyon Wilderness Park, May 2006–June 2007 (*n* = 17); and north of the Orange County Great Park (the former Marine Corps Air Station El Toro), February–December 2007 (*n* = 4). Additional tracking locations outside Orange County included Chino Hills (San Bernardino County), Prado Basin (Riverside County), and the Santa Ana Mountains at CA-71 and CA-91 (Riverside County), December 2008–July 2009 (*n* =14). Most collars collected GPS data for 3–4 months, but two collars collected data only for 1 week.

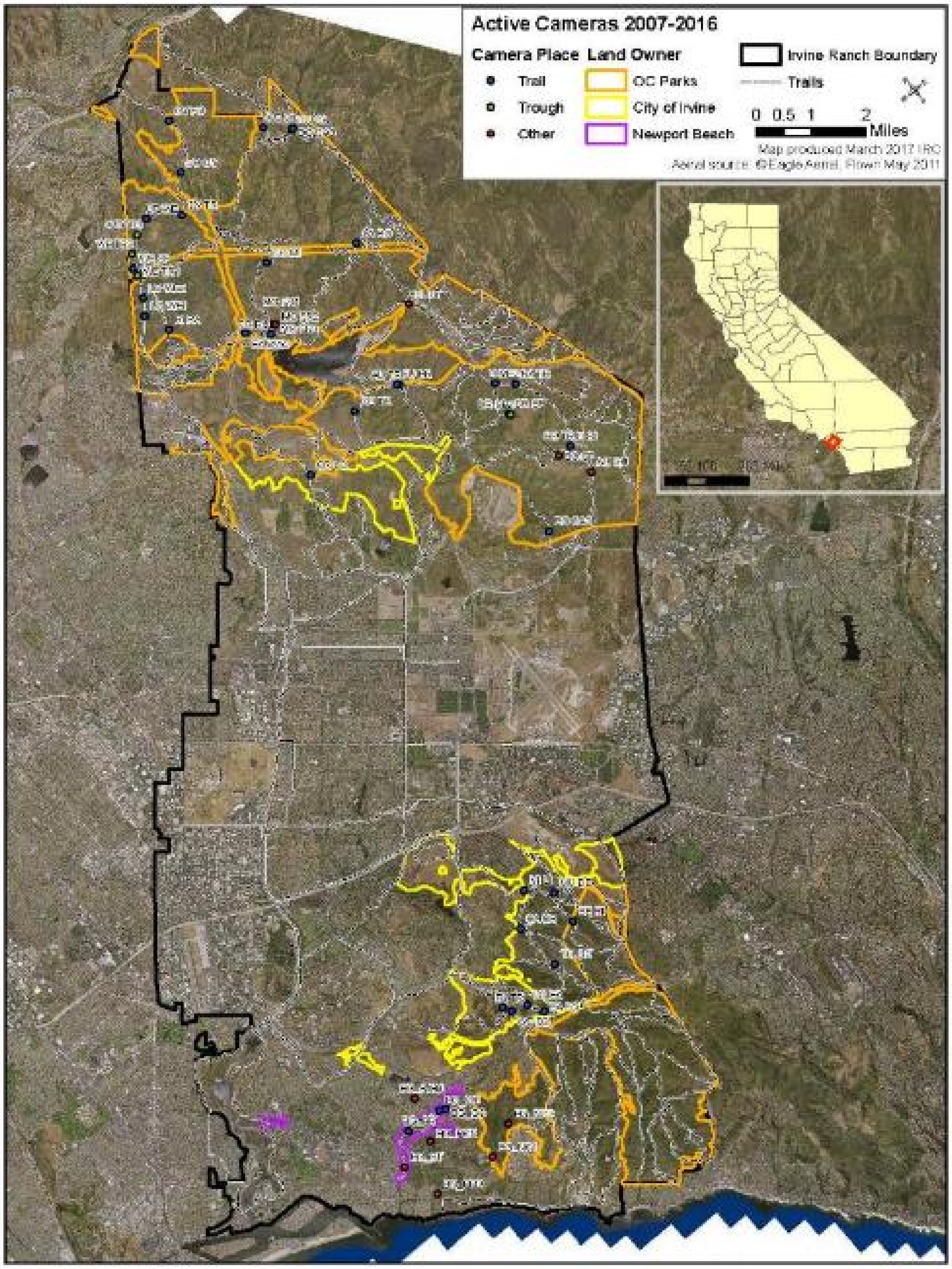


Figure 1. The study area in Orange County, California, showing the locations (the colored dots) of established camera traps.

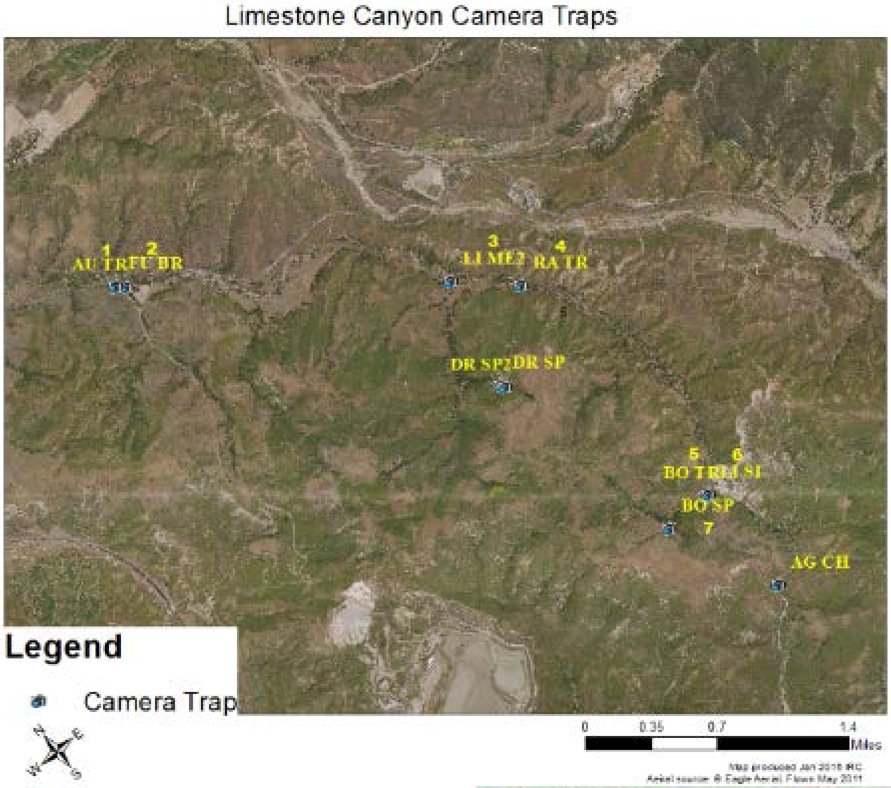
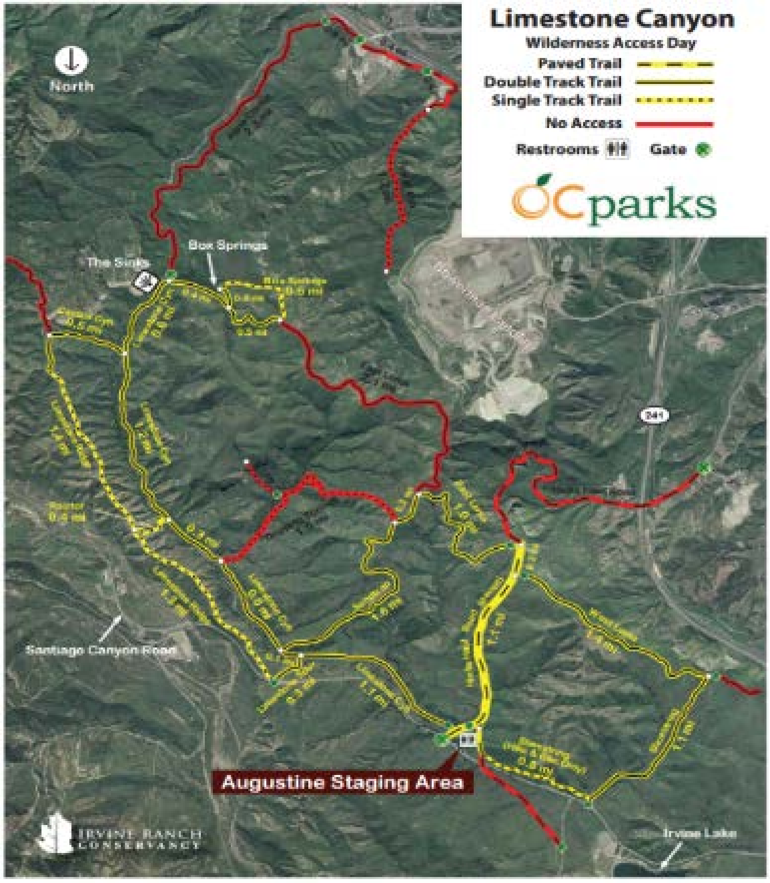


Figure 2. Numbered camera traps along Limestone Canyon (AU TR, FU BR, LI ME, RA TR, BO TR, LI SI, BO SP).

Figure 3. Limestone Canyon trail system used for analysis of large events.



We used data from a subset of seven cameras in Limestone Canyon (Fig. 2) to assess effects of large events on wildlife activity. Cameras were in an area accessible to the public only on wilderness access days and docent-guided tours (Figs. 2, 3). We gathered data for 16 wilderness access days that occurred from 2011–2015 that qualified as large events (> 100 visitors). We assessed images for five mammals with sufficient sample size (bobcat, mountain lion, gray fox, coyote, and mule deer) and four disturbance types (hikers, equestrians, bicyclists, and vehicles) for the event day and for five days before and after it. All independent (as defined on p. 10) captures were summed to create an activity metric, although the clock was reset if a different disturbance or species was recorded (e.g., if a vehicle triggered a camera and 5 minutes later a hiker was recorded, followed by the same vehicle, then the second occurrence was considered new even though it was less than 1 hour later because a different disturbance reset the clock).

Data analysis

Avoidance behavior

Avoidance was addressed in the previous LAG (Burger 2012, Patten and Burger 2017), but methods and results are restated here for context, and some analyses were revised. We analyzed avoidance behavior by means of a randomization test. This test assessed whether the expected (E) joint probability of human and mammal occurrence differed from the observed (O) joint probability for data collected by 50 cameras June 2007–December 2011. We tested goodness of fit of O by means of 999 bootstrap resamples of the data to obtain a spread of E values, with a given *P*-value being the number of times $E \leq O / 1000$. Analyses were conducted with a program written in C. We performed tests across all cameras, by individual camera, for each individual species, and for disturbance type. We used beta regression (Ferrari and Cribari-Neto 2004), a technique akin to least-squares regression but with the response variable a probability or proportion, to examine how human disturbance is associated with the probability of mammal activity. We built a Bayesian model to estimate regression parameters (i.e., slope, β_1, and intercept, β_0). Our likelihood was $y_i \sim \text{beta}(\mu_i\phi, [1-\mu_i]\phi)$, with the line fit as $\text{logit}(\mu_i) = \beta_0 + \beta_1 x_i$. Priors were flat and set as $\beta_0 \sim N(0,0.000001)$, $\beta_1 \sim N(0,0.000001)$, and ϕ (the precision) ~ gamma(0.001,0.001). The Markov chain Monte Carlo algorithm to estimate β_0 and β_1 was run for 10,000 iterations in OpenBUGS 3.2.3 rev. 1012. A correlation coefficient between the probability of disturbance and probability of mammal activity was estimated as the square root of the approximate coefficient of determination (i.e., “pseudo-R^2") of the resultant equation.

Temporal shifts

We analyzed diel patterns of focal species in relation to human activity using data from June 2007–March 2015, over which 87,881 individual data points identifiable to species or activity were recorded. We excluded all records of non-focal species, and we considered all human activities, whether hiker, bicyclists, equestrian, vehicle, or domestic dog, to be examples of anthropogenic disturbance. We classified each focal mammal occurrence as either “disturbed” or “undisturbed,” the latter defined as human activity documented by the same camera less than 24 hours prior to when a focal mammal was photographed. We defined disturbance in either one of two other ways: human activity less than12 hours prior or between noon and sunrise the following morning. Results were consistent regardless of definition. We analyzed the paired data set using various circular statistics, the “circle” being a 24-hour clock. For each species, we used Rayleigh’s test to infer if activity peaked at a particular time (against a null expectation of random occurrence across the day). Circular analogs to ANOVA have restrictive assumptions (Batschelet 1981), assumptions our data generally could not meet; hence, we used a non-parametric rank sum test of difference in mean angle to compare peak activity of undisturbed vs. disturbed occurrences (Batschelet 1981:119). We assessed the extent of overlap between two species or between undisturbed vs. disturbed occurrences within species with both 95% confidence intervals (CI) around peak times and standard quantiles. The rank sum test was run in SAS Statistical Software 9.3; all others were run in package “circular” in R, for which some statistics were double-checked “by hand” in a Quattro Pro spreadsheet. We express differences between encounter rates of predator and prey as odds ratios of joint probability of disturbed vs. undisturbed occurrences binned at 15-minute intervals. (For these data an odds ratio is a measure of relative risk.) For a given species, the probability of occurrence in an interval is the quotient of the sum of occurrences in that interval and the total occurrences of that species. The joint probability of occurrence of predator and prey is the product of probabilities per interval, with overall joint probability the sum of all within-interval joint probabilities. From our joint probability for undisturbed (p_u) and disturbed (p_d), the odds ratio is $[p_d \cdot(1- p_u)]/[p_u \cdot(1- p_d)]$. We estimated 95% CIs for the odds ratios to assess whether the calculated odds ratio differed from 1.0, meaning no relative risk, by means of whether CIs overlapped 1.0 (Morris and Gardner 1988).

Seasonality and trends

Data trends were assessed with standard time-series analysis (Tabachnick and Fidell 2013), a technique used to (among other things) identify temporal patterns in a sequence of equally spaced observations that are correlated with themselves (i.e., autocorrelated) but offset (i.e., lagged) in time. Data were collapsed to rate of captures / camera-day by season (March, June, September, December) from June 2007 to June 2016 and analyzed using proc arima in SAS 9.3.

Bobcat space use

Resource selection functions (RSF; Manly et al 2002) estimate the probability of habitat selection by species of a suite of biological and physical resources on the landscape in a spatially explicit framework. Here RSFs were used to model bobcat space useand to help identify high-value habitat areas within the NCCP/HCP Reserve and adjacent conserved lands (Boydston and Tracey *in review)*. RSFs use regression models to relate each used (selected) resource unit (RU) to attributes of the collection of all RUs for a spatial variable. Each spatial data layer contained RU values of a predictor, whereas animal tracking data served as the response. Specific points from GPS collars on bobcats were one measure of their movement indicating selected RUs; an estimated home range, a continuous surface wherein all RUs were considered used, was another. Regardless of measure, for each individual bobcat attributes of used locations were compared to background values of the attribute within a defined area of resource availability to determine if resource units were used in proportion to their availability.

Spatial extent of resource availability was defined in two ways: the extent of the study region and the extent of an individual home range. These two ways, along with GPS points and the study region, yielded three sets of comparisons for a sample of used RUs to a sample from the available background (Fig. 4): A) GPS points relative to resource availability within home ranges, for which a sample of used RUs was compared to a background sample from each home range, similar to 3rd-order habitat selection (Johnson 1980) or Design III in Manly et al. (2002); B) home range relative to resource availability across the study region, for which a sample of used RUs from within the home range was compared to a background sample from the larger study area, similar to 2nd-order habitat selection (Johnson 1980) or Design II in Manly et al. (2002); and C) GPS point locations to resource availability across the study region, for which a sample of used RUs was compared to a background sample taken from the larger study area. This third comparison provided an alternative measure of 2nd-order selection (Johnson 1980) and Design II (Manly et al. 2002), which were developed prior to modern GPS collars.

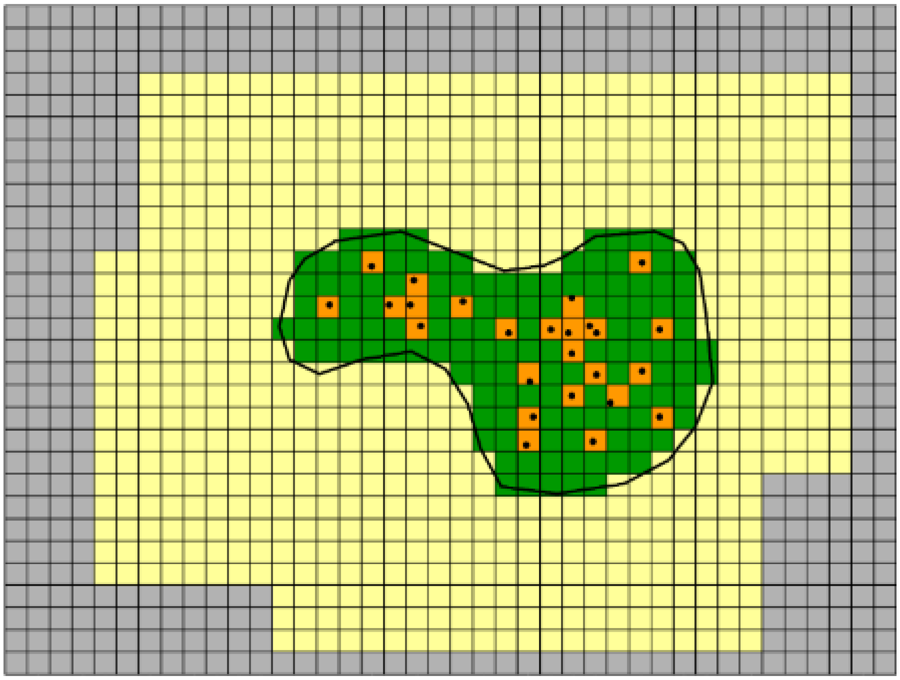


Figure 4. Schematic diagram of levels of habitat selection (from Boydston and Tracey *in review*). Dots represent GPS point locations for one collared bobcat. The black outline is an estimate of a home range (HR) for this bobcat, and the GPS points and HR outline are visualized over a raster layer representing a resource (the extent in yellow). For comparison A (3rd-order selection), selected RUs within the HR (orange cells) are compared to availability within the HR (green cells). For comparison B (2nd-order selection), all cells within the HR (green or orange cells) are classified as used RUs and are compared to the background of resource availability within a defined region (yellow cells). In comparison C (similar to 2nd-order selection), there is no assumption about the estimated HR, and selected RUs are those that align with GPS data (orange cells), which are compared to the background of the entire region of defined resource availability (green or yellow cells).

Resource use vs. availability (i.e., background) were assessed in all three comparisons, meaning RSFs estimated the probability that a random sample taken from an area was in the set of used samples; this is not the same as an estimate of the probability of presence, although the two estimates are related mathematically (Manly et al. 2002, Phillips et al. 2009). In other words, an estimate of the probability of a sample being used is proportional to the probability of presence, given the data (Phillips et al. 2009). Use vs. availability were compared separately for male and female bobcats because ecological requirements differ between the sexes. Female space use usually is associated closely with food and shelter needed for gestation, raising offspring, and survival, whereas male space use generally depends on the distribution of potential mates and mate competition (Clutton-Brock 1989). Among most felids, females occupy solitary home ranges or territories, and males, who do not contribute to parental care, have larger home ranges that both overlap home ranges of multiple females but avoid or exclude other males (Sandell 1989, Sunquist and Sunquist 1989).

Thus, we separated GPS movement data for the 30 male and 21 female bobcats (Fig. 5a, 5b). In the fragmented, developed southern California coastal landscape, we expected that RSF models based on GPS movement data for female bobcats would indicate greater selectivity for natural areas and avoidance of anthropogenic activity than male RSFs. The models with a fit value above a certain level were considered viable representations of bobcat habitat selection, and these were mapped to show the predicted resource selection across the study region.

For each bobcat, pixels in which its GPS locations occurred were identified as the used RUs (e.g., the orange cells in Fig. 4) for comparisons A and C. Each bobcat's home range was estimated using a kernel density estimator (Worton 1989) of the dispersion of GPS locations (Boydston and Tracey *in review*). The 99% kernel contour delineated the general area of use by each bobcat, and visual inspection confirmed that this contour yielded a good representation of home range for the GPS data (Fig. 5a, 5b, 5c). Pixels in kernel home ranges represented used RUs for comparison B. For each comparison, samples of used RUs were generated as input to RSF models indicating bobcat response to resource availability.

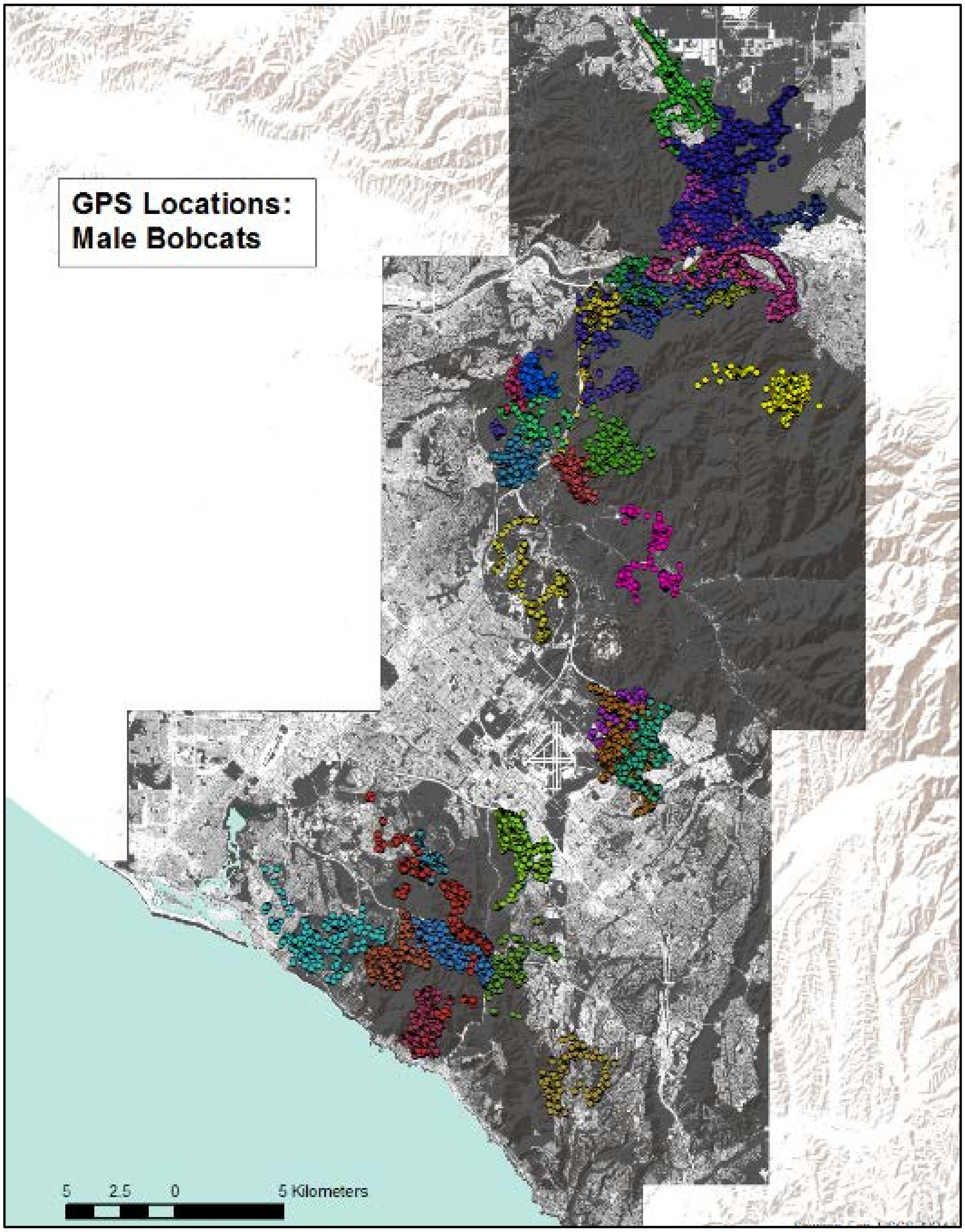


Figure 5a. GPS locations for 30 collared male bobcats; different colors represent GPS data for different individuals (from Boydston and Tracey *in revie*w). The grayscale layer represents urban land use (in white) for the study area and model prediction region, and is draped over a terrain layer.

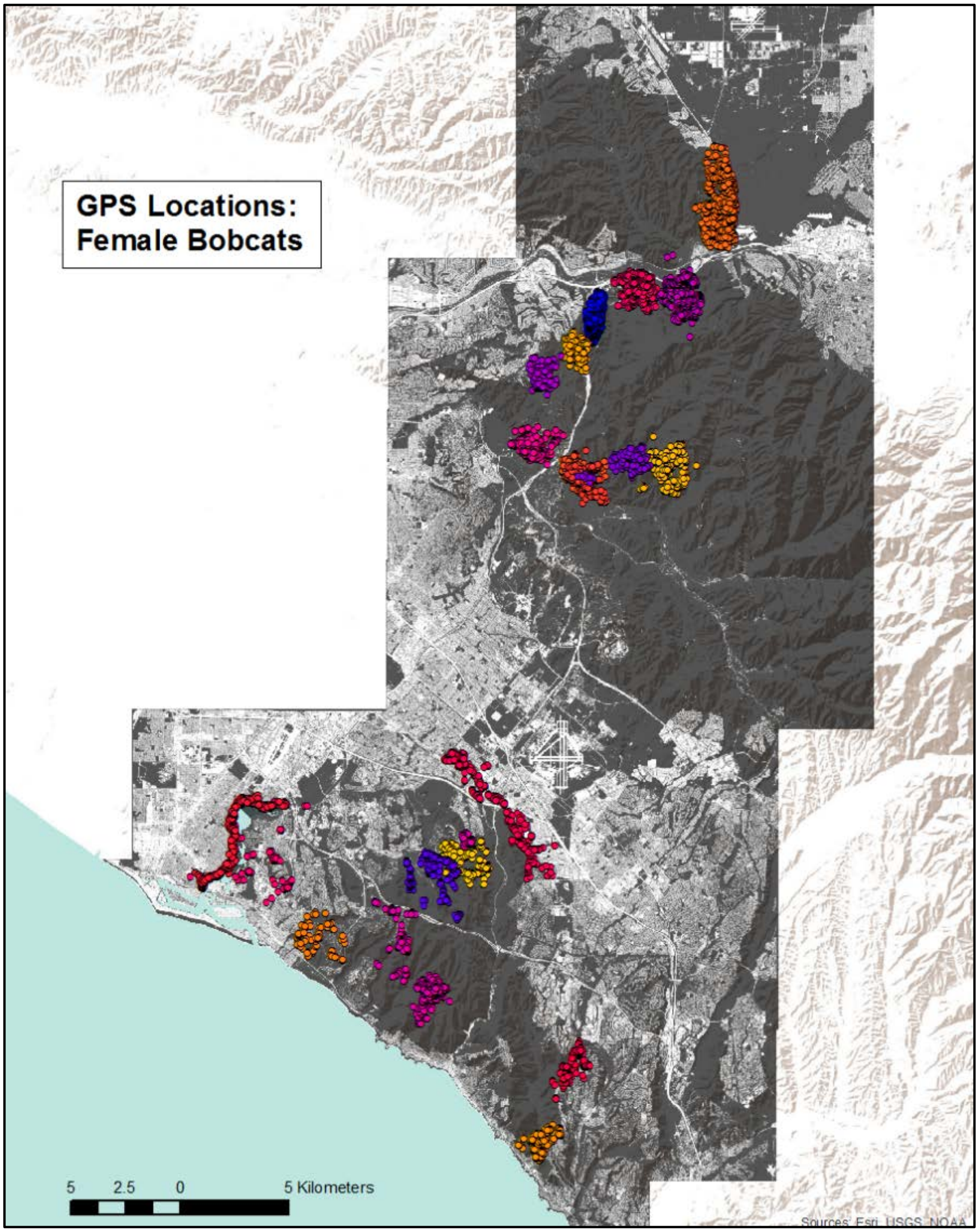


Figure 5b. GPS locations for 21 collared female bobcats; different colors represent GPS data for different individuals (from Boydston and Tracey *in review*). The grayscale layer represents urban land use (in white) for the study area and model prediction region, and is draped over a terrain layer.

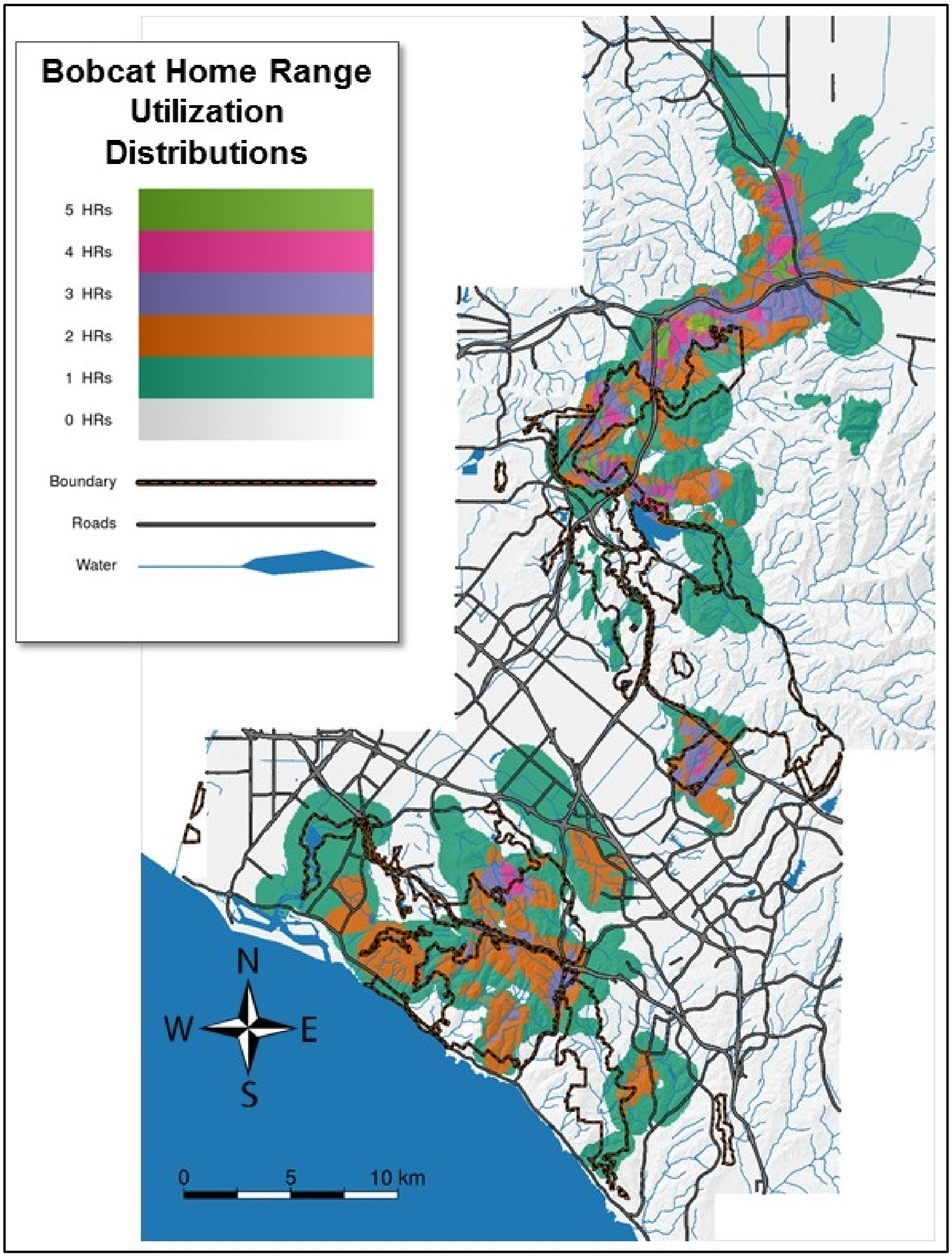


Figure 5c. Individual bobcat (*n* = 51, tracked 2002–2009) home range utilization distributions calculated via kernel density estimation, overlaid and intersected to show the geographic dispersion and how many overlapped spatially (although not necessarily temporally), which was up to five individual home ranges (from Boydston and Tracey *in review*).

On the basis of scientific literature, expert opinion, and previous USGS research, potential environmental determinants of bobcat habitat suitability, selection, and movement were identified for the RSFs. A broad range of environmental variables, biodiversity and other biotic factors, and anthropogenic features were considered. GIS maps for environmental inputs were created with a standard digital template to present each element as its own layer. The main categories of environmental variables considered were topography (e.g., elevation, slope), climate, primary productivity, certain linear features (e.g., streams, trails), and Land Use Land Cover (LULC). Details of these layers, including the primary data sources used, derivations and modifications employed, and sample figures, can be found in Boydston and Tracey (*in review*).

Generalized additive mixed-effects models (GAMMs) were used to build RSFs (Wood 2006). A mixed model was selected because GPS data is a natural type of repeated measures, in this case successive observations of each bobcat. Individual variation may be an important factor in space use and could account for as a random effect in the model (i.e., there is a different intercept term for each bobcat). The non-linear component in the models was a logit link, p(s|zi) = $\frac{e^{z_i}}{(1+e^{z_i})}$, with s = 1 if an observation was drawn from a used RU, s = 0 if it was drawn from a background RU, and zi = β0 + ∑ β1 yi, the equation for a line given data yi. Separate GAMMs were run for separate subsets of predictors. R was used to fit the gamm() function of the mgcv package and evaluate the prediction() and performance() functions of the ROCR package and to generate predictive maps. We evaluated model fit using the area under the curve (AUC) statistic (Bradley 1997), the curve being the receiver operating characteristic. AUC ranges from 0.5 to 1.0, with a greater value indicating better fit and AUC = 0.75 a minimum threshold for a good model (Elith 2002).

The initial set of predictors was large, so a two-stage approach was used, an exploratory phase, in which models were fit and evaluated to identify informative predictors, and an exploitation phase, in which 128 alternative models identified in the exploratory phase were fit. Models were grouped by number of predictors and from each group, the model with the highest AUC was selected (excluding those with AUC < 0.75). Then GIS layers of means were created, the predicted selection of the landscape by males or females averaged across the best models for each comparison, and standard deviations, where the best models differed (Boydston and Tracey *in review*).

Large events

We analyzed large event data with a variety of techniques. To avoid falsely attributing animal activity on early mornings prior to human access on event days, we considered a day to be 06:00 am to 05:59 am the following day. This adjustment added a half-day (Day -6), and Day +5 became a half-day. We organized data by day (-6 through +5), event (16 events), and camera (7 cameras) but deleted first and last days because they represented only partial samples. Days were then aggregated into pre, during, and post large event. There were many zeroes, so we transformed the data as $\log_{10}(y+1)$ (Lentner and Bishop 1986). We used one-way ANOVA (with Tukey's HSD post hoc) to determine if wildlife activity, collectively and by species, differed among the pre, during, and post event. We conducted a two-way ANOVA to explore whether a water source (present at three cameras) affected activity. We quantified the relationship between wildlife activity and human disturbance with two multivariate techniques, a canonical correlation analysis with associated redundancy analysis (Rotenberry et al. 1996) and a Mantel test. Each test calculates a correlation between two sets of data, but the first is a parametric test that correlates linear combinations of the raw variables whereas the second is a non-parametric regression of two distance matrices calculated from the raw data. For each test one set contained data on four species with sufficient sample size, the bobcat, mountain lion, coyote, and mule deer, and the other set contained data on four types of human disturbance, hiker, bicyclist, vehicle, and equestrian. Datasets were populated with activity by day (-6 through +5), event (16 events), and camera (7 cameras). The canonical correlation was run in R Studio. Our distance measure was the Mantel test was Euclidean and significance was assessed with a standard randomization (PC-ORD, ver. 4). For full details see Appendix A.

Anthropogenic light

Preliminary observations along reserve edges within the coastal region of the Central/Coastal NCCP/HCP suggested that incident direct and indirect nighttime illumination from development may affect animal behavior and habitat use. To test this hypothesis, we used nighttime illumination data from two sources for remotely sensed satellite imagery, VIIRS DNB (low resolution) and ISS (medium resolution), to construct a model of light pollution across the NCCP/HCP Coastal Reserve. The model was built from a high-resolution airborne light detection and ranging (LiDAR) layer for Orange County obtained from USGS, and using streetlight locations obtained from Southern California Edison through the City of Irvine's Department of Public Works. Streetlight intensity ranged from 5,800 to 30,000 lumens. Streetlight locations were loaded into ArcGIS 10.3, with streetlights greater than 50 m from the habitat edge removed (Bennie et al. 2014). Moonlight, car headlights, light reflection off surfaces, skyglow, residence lights, and other sources of artificial lighting were not considered (modeling skyglow is data and labor intensive; Chalkias et al. 2006). Each street light was assumed to be 8 m tall, spherical, and emit light uniformly in all directions. Light intensity (i) was assumed to decrease with distance (d) according to the inverse square law, $\frac{i}{4\pi d^2}$. Total lux for a cell was the sum of lux values from each individual light. The point shapefile of streetlights was parsed into 299 individual shapefiles using the *split by attribute* tool (Fox 2015). For each point a distance and intensity could be estimated. Raster values for each sample location were correlated with field-truthed data that were gathered 1–5 August 2016 between 20:00 p.m. and 12:30 a.m. using an ExTech LT300® Light Meter, and a *t*-test was performed to assess differences between light pollution by edge type. Statistics and graphing were done in R Studio v.3.3.1, Microsoft Excel 2007, or JMP Statistical Software. We integrated light model estimates and field measurements into a single entity, which we could adjust results by regression against the field observations for the area and buffering at eight intervals: 2 m, 5 m, 10 m, 25 m, 50 m, 100 m, 200 m, 400 m.

Results

Avoidance behavior

Wildlife activity was negatively associated with human disturbance on a camera-by-camera basis, in that there were significant departures from expectations of independence for 92% (45 of 49; one camera had human data only) of cameras (Table 1). Null-model probability distributions calculated for mammals co-occurring on the same day as humans, under the H_0 of no association between the number of days that mammals co-occur with humans (Fig. 6), consistently showed that the observed number of days on which both mammals and humans occurred was significantly less than expected (Table 1). Each of the seven large and medium-sized mammals detected on the study site responded negatively to human disturbance (Table 2). Parsing human disturbance into its five constituent types—pedestrians, bicycles, motorized vehicles, horses, and domestic dogs—revealed that avoidance behavior was markedly higher of pedestrians, bicycles, and vehicles than of dogs and horses (Table 3). Across sites, the probability of mammal detection was correlated strongly and negatively ($r \approx -0.91$) with the probability of human presence (Fig. 7). The back-transformed (from logit) slope of the relationship is $\beta_1 \approx -0.0148$, a drop in activity from about 2.46/day on days with few humans (p_d near 0) to 0.62/day with high human disturbance (p_d near 1).

Table 1. Avoidance behavior of large and medium-sized mammals relative to human activity at each of the 50 camera traps. Legend: n = sample size (number of days); p_d = probability of human disturbance (i.e., number of human detections at a camera trap divided by n); p_m = probability of a mammal "capture"; p_j = joint probability of human disturbance and mammal capture *under the H_0 of they are independent of each other* (in which case $p_j = p_d \times p_m$); EXP = *expected* number of captures of both humans and mammals under the H_0 of independence; OBS = *observed* number of captures of both humans and mammals on the same day; P = probability of OBS against a null distribution from bootstrap randomization of the data. Note that OBS consistently is lower than EXP and that cameras with high human disturbance have low mammal captures and vice versa. No mammals were detected at camera EA FO, so statistical analyses could not be conducted for it, yet human disturbance there was present every day, so the general pattern held at that camera trap, too.

camera	n	p_d	p_m	p_j	EXP	OBS	P
AG CH	119	0.185	0.933	0.172	21	14	0.055
AU TR	484	0.074	0.959	0.071	35	16	0.0001
BG_GC	402	0.888	0.239	0.212	85	51	0.0001
BG_NC1	20	0.550	0.550	0.303	6	2	0.0001
BG_NC2	21	0.333	0.714	0.238	5	1	0.006
BG_PCN	377	0.332	0.793	0.263	99	47	0.0001
BG_PPD	206	0.204	0.864	0.176	36	14	0.0001

BG_SJH1	296	0.324	0.784	0.254	75	32	0.0001
BG_ST	94	0.245	0.819	0.200	19	6	0.0001
BG_WE	262	0.515	0.676	0.348	91	50	0.0001
BL ST	154	0.455	0.604	0.274	42	9	0.0001
BO SP	384	0.091	0.930	0.085	33	8	0.0001
BO TR	526	0.492	0.705	0.347	183	104	0.0001
CO MI	609	0.898	0.223	0.201	122	74	0.0001
CO TR	479	0.380	0.789	0.300	144	81	0.0001
DO CA	154	0.539	0.552	0.297	46	14	0.0001
DO CA2	51	0.196	0.843	0.165	8	2	0.0001
DR SP	400	0.647	0.482	0.312	125	52	0.0001
DR SP2	72	0.750	0.306	0.229	17	4	0.0001
EA FO	162	1.000	0.000	0.000	0	0	
EA MW	739	0.706	0.594	0.420	310	222	0.0001
FR RO	162	0.593	0.728	0.432	70	52	0.0001
FU BR	941	0.913	0.601	0.549	517	484	0.009
FU TR(BC)	280	0.204	0.857	0.174	49	17	0.0001
GY FO	179	0.341	0.883	0.301	54	40	0.006
LA RO	480	0.594	0.544	0.323	155	66	0.0001
LI ME	599	0.910	0.182	0.166	99	55	0.0001
LO EA	70	0.714	0.443	0.316	22	11	0.0001
LO WE1	574	0.927	0.213	0.197	113	80	0.0001
LO WE2	882	0.765	0.732	0.561	494	439	0.0001
MI LI	831	0.996	0.043	0.043	36	33	0.319
MO FR1	200	0.265	0.785	0.208	42	10	0.0001
MO FR2	32	1.000	0.031	0.031	1	1	0.997
MO FR3	191	0.644	0.419	0.270	52	12	0.0001
MU DE	912	0.798	0.822	0.656	599	566	0.002
OR LO	158	0.576	0.475	0.273	43	8	0.0001
OV TR	352	0.108	0.932	0.101	35	14	0.0001
RA TR	83	0.916	0.181	0.165	14	8	0.024
RI RA	425	0.922	0.144	0.132	56	28	0.0001
RO CA	237	0.662	0.409	0.271	64	17	0.0001
SE RI	843	0.986	0.197	0.194	164	154	0.194
SO GY	409	0.421	0.702	0.295	121	50	0.0001
TH SI	330	0.918	0.100	0.092	30	6	0.0001
UP WE	618	0.921	0.217	0.200	123	85	0.0001
WE FO	370	0.959	0.103	0.099	36	23	0.003
WE SP	330	0.155	0.891	0.138	45	15	0.0001
WE TR1	606	0.380	0.817	0.310	188	119	0.0001
WE TR2	479	0.113	0.939	0.106	51	25	0.0001
WE TR3	102	0.078	0.941	0.074	8	2	0.014
WE WI	327	0.688	0.385	0.265	87	24	0.0001

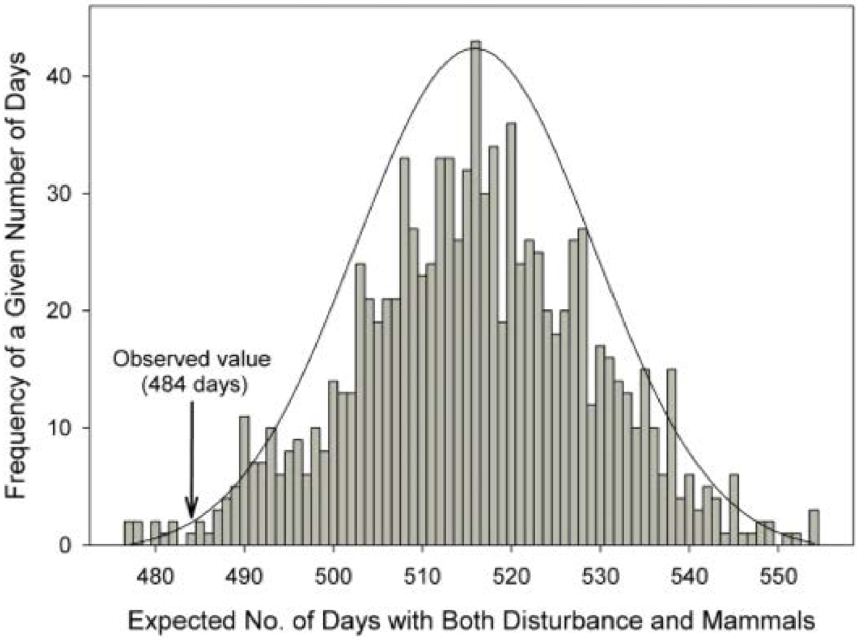


Figure 6. An example of a probability distribution of expected number of days that both mammals and humans would co-occur if humans had no effect on mammals, with the observed number of days that both occurred. In this case the observed number of days of co-occurrence was substantially lower than expected under the H_0 of no effect.

Table 2. Avoidance behavior of each of seven large and medium-sized mammal species across all types of human activity. Legend: r_s = Spearman rank correlation between mammal "capture" and human presence; see Table 1 for definitions of other headings. Note that for each species the observed number of join detections was far less than the expected number under the H_0 of independence (i.e., no relationship between the presence of humans and presence of mammals). All statistical tests of observed vs. expected rejected the H_0 at $P < 0.0001$.

species	*n*	r_s	pDist	pMamm	pBoth	exp	obs
Canis latrans	11133	-0.372	0.865	0.268	0.232	2581	1480
Urocyon cinereoargenteus	8981	-0.362	0.937	0.093	0.087	780	266
Lynx rufus	9939	-0.390	0.893	0.180	0.161	1600	729
Puma concolor	8518	-0.259	0.970	0.043	0.042	359	117
Mephitis mephitis	8455	-0.202	0.978	0.036	0.036	300	120
Procyon lotor	8518	-0.314	0.963	0.043	0.042	356	54
Odocoileus hemionus	13016	-0.660	0.722	0.374	0.270	3516	1254

Table 3. Avoidance behavior across seven large and medium-sized mammal species relative to type of human activity. See Tables 1 and 2 for definitions of headings. Note that for each species the observed number of joint detections was far less than the expected number under the H_0 of independence (i.e., no relationship between the presence of humans and presence of mammals). All statistical tests of observed vs. expected rejected the H_0 at $P < 0.0001$.

disturbance type	n	r_s	pDist	pMamm	pBoth	exp	obs
pedestrian	11769	-0.646	0.449	0.667	0.299	3523	1362
bicycle	8611	-0.594	0.247	0.812	0.200	1724	503
motorized vehicle	14032	-0.579	0.538	0.626	0.337	4726	2302
domestic dog	6828	-0.326	0.050	0.962	0.048	328	82
horse	6826	-0.253	0.050	0.967	0.048	328	112

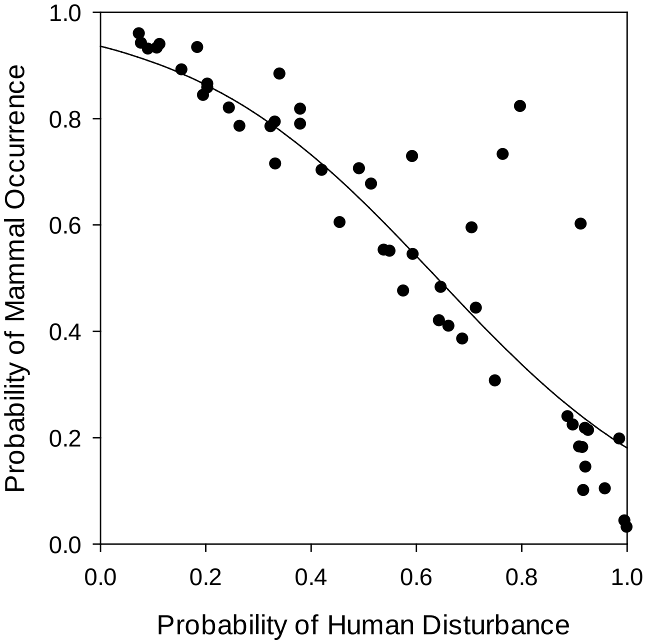


Figure 7. The probability of mammal occurrence against the probability of human disturbance (data are from the third and fourth columns of Table 2). The fitted line is from a beta regression with parameters generated via Bayesian estimation (see text). The approximate correlation, from the pseudo-coefficient of determination of the regression, is $r = -0.91$.

Temporal shifts

Four of the seven mammal species shifted their peak activity in response to human presence (Table 4). Shifts were particularly striking for coyote, which switched use from shortly before dawn to shortly before midnight (Fig. 8), and mule deer, which shifted use from near sunrise to after sunset (Fig. 9). Marked diel shifts in these two species created substantial overlap with their respective interactors in predator–prey dynamics, the gray fox and the mountain lion (Figs. 8,9), neither of which shifted peak activity (Table 4). These diel shifts significantly increased the relative risk of predation of both the gray fox (odds ratio [95% CIs]: 1.39 [1.13, 1.43]) and the mule deer (1.31 [1.06, 1.34]).

Table 4. Peak activity across undisturbed and disturbed days for seven mammal species in coastal Orange County, California. All peaks (from angle θ, with it and 95% confidence intervals, CI, converted to time of day, on a 24-h clock) differed significantly (Rayleigh test: $P < 0.0001$) from a random distribution of occurrences around the clock. Statistic r, which varies from 0 to 1, is a standardized measure of peak strength. At the right, results are presented as a rank sum test of peak shift between undisturbed vs. disturbed occurrences.

	undisturbed			disturbed				
species	peak time	r	n	peak time	r	n	Z	P
Lynx rufus	00:23:56	0.20	2140	22:43:47	0.42	992	-3.53	0.0004
Puma concolor	00:14:45	0.40	514	22:57:40	0.59	157	-1.36	0.17
Urocyon cinereoargenteus	00:34:23	0.60	971	23:10:05	0.70	268	-1.42	0.16
Canis latrans	04:03:54	0.26	3671	23:07:53	0.40	2440	-9.04	<0.0001
Mephitis mephitis	01:30:27	0.61	280	00:52:35	0.74	108	-2.06	0.04
Procyon lotor	00:23:29	0.55	599	23:58:54	0.62	91	-1.65	0.10
Odocoileus hemionus	06:44:19	0.15	15689	20:56:41	0.24	2471	-16.48	<0.0001

Seasonality and trends

A flat trend (Fig. 10, upper left panel) across the 37 seasons sampled (4 seasons annually from June 2007–June 2016) suggests neither an increase nor decrease in mammal captures (i.e., mammal captures are equal across the 37 seasons). Conversely, a plot of the autocorrelation function (ACF) for the mammal data shows a pattern of spikes at lags of 4 (e.g., $r = 0.576$) and 8 (and perhaps at 2), a pattern supported by the spikes at lag 4 (one full year) in both the partial ACF and, especially, inverse ACF (Fig. 10). The probability of white noise (shown below) is high, indicating autocorrelation in the data. This pattern is classic for seasonal cycles across a year.

Autocorrelation Check for White Noise

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	27.80	6	0.0001	-0.041	-0.407	0.132	0.576	-0.071	-0.342

As expected, adding lag = 4 to the analysis removed statistically significant autocorrelations from the data; for example, $r = -0.323$ for lag 4, a spike that no longer extended beyond confidence limits, and the probability of white noise became trivial ($P = 0.41$), meaning there were no evident lag effects remaining in the data. The conclusion is that mammals have a distinct seasonality but have been encountered at the same frequency across the study period.

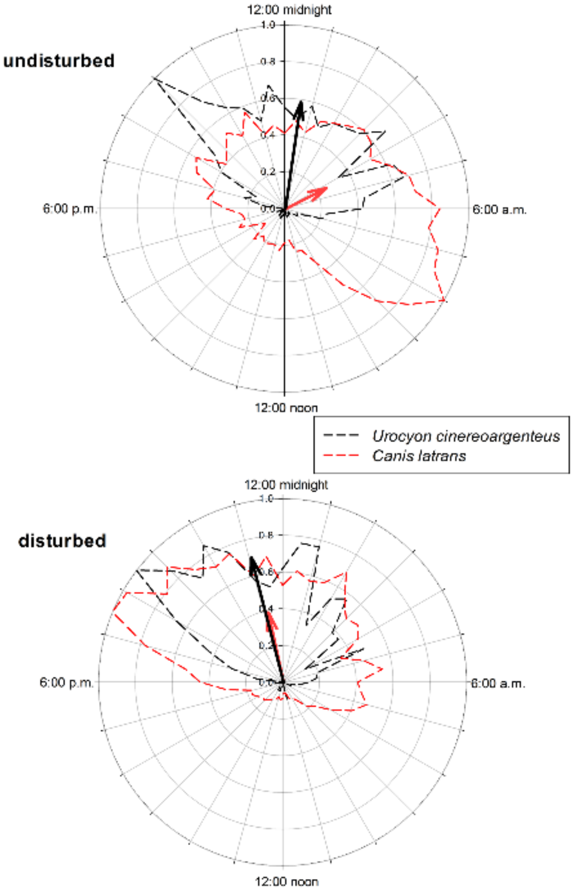
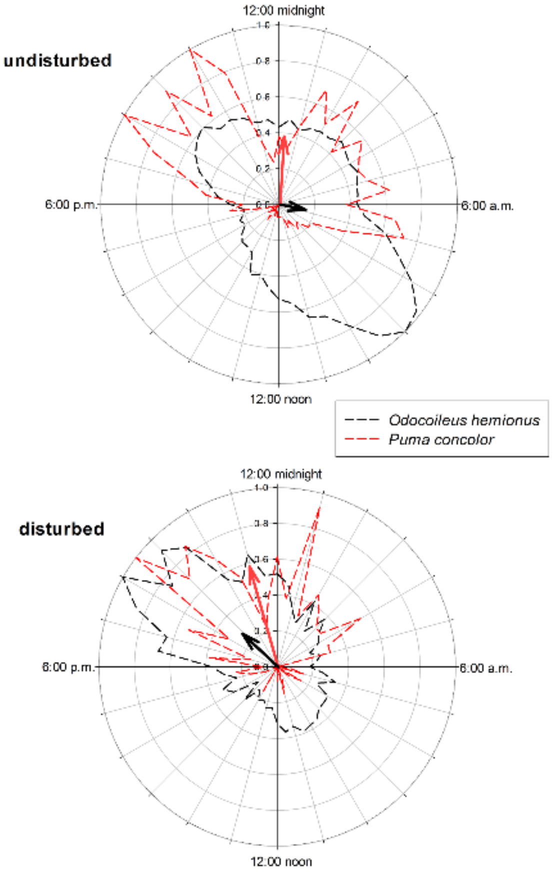


Figure 8. Diel activity of gray fox (*Urocyon cinereoargenteus*) and coyote (*Canis latrans*) across days in which there was or was not human disturbance. Arrows indicate the time and proportional magnitude at peak activity. Note the coyote's nightward shift when disturbance was present.

Figure 9. Diel activity of mule deer (*Odocoileus hemionus*) and mountain lion (*Puma concolor*) across days in which there was or was not human disturbance. Arrows indicate the time and proportional magnitude at peak activity. Note the mule deer's nightward shift when disturbance was present.



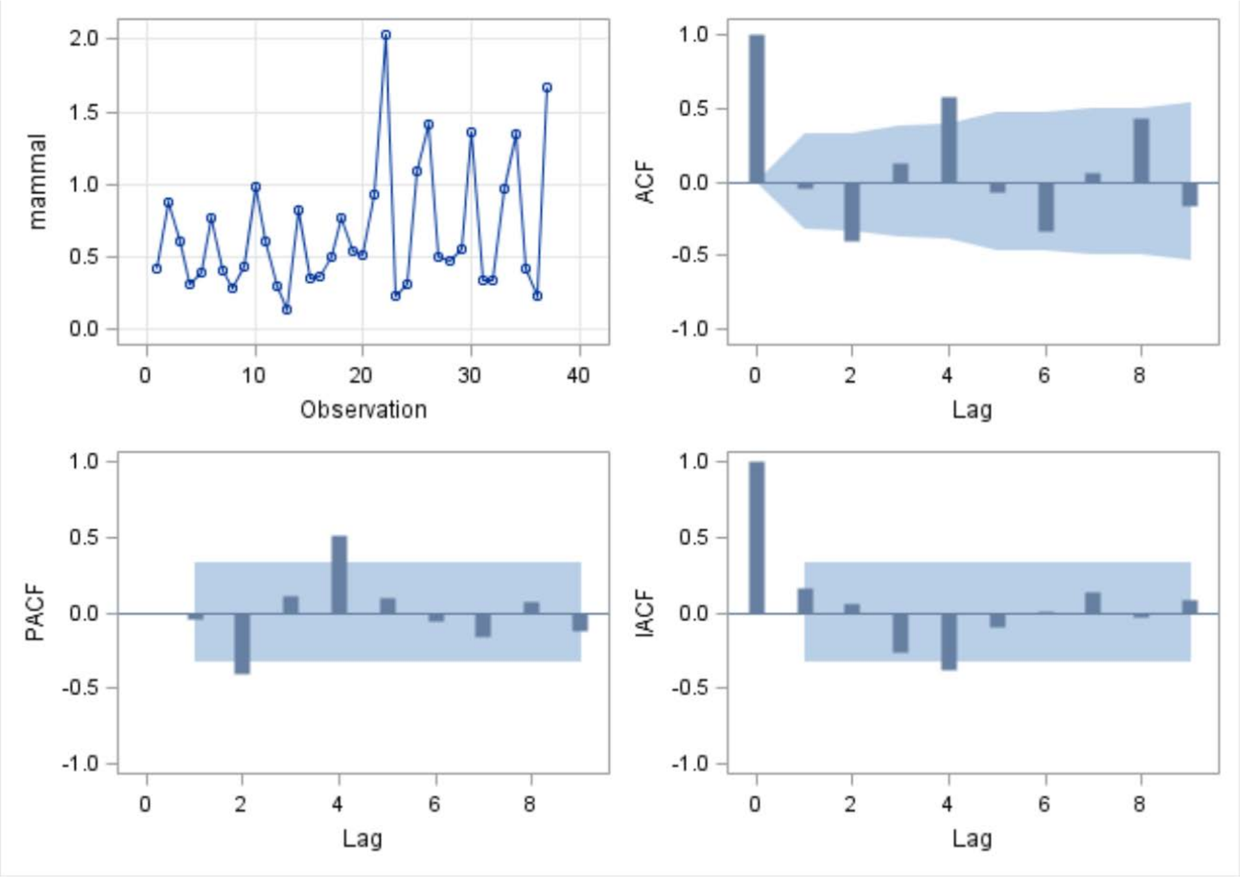


Figure 10. Trend (upper left) and autocorrelation plots for mammals recorded at camera traps in Orange County, California, June 2007–June 2016. There is no linear trend of increase, but there is a pattern of seasonal variation across annual cycles, evident in the significant (extending beyond the shaded confidence interval) lag at 4, a full year later (e.g., March to March or December to December).

The long-term pattern of human activity differed strikingly from that of mammal activity, in that there is clear evidence of autocorrelation but in this case the ACF plot portrays the classic stair-step pattern—note the high positive correlations at each step, regardless of lag—typical of a trend in the data (Fig. 11, upper left panel; compare this figure with the comparable one for the mammal data, for which no trend is evident).

Autocorrelation Check for White Noise

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	52.24	6	0.0001	0.564	0.535	0.498	0.461	0.351	0.223

Such a trend needs to be removed before any seasonal patterns might be evident. Once this trend was removed (i.e., lag = 1), there was no evidence of seasonality in human occurrence, although there remained inexplicable autocorrelation in the data (white noise *P* = 0.03), perhaps suggesting human activity may be somewhat seasonal.

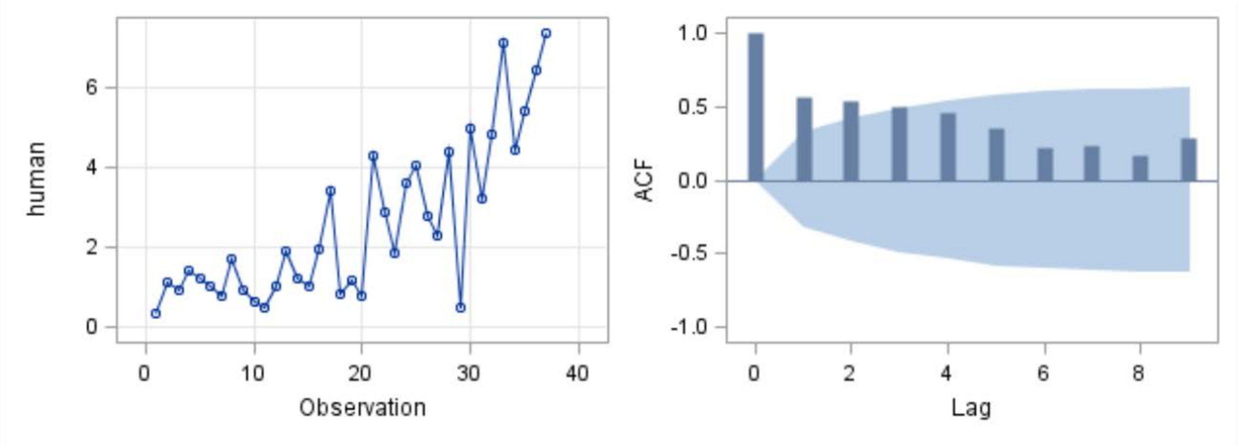


Figure 11. Trend (left) and autocorrelation plot (right) for humans recorded at camera traps in Orange County, California, June 2007–June 2016. There is distinct increasing trend, evident in the "stair-step" pattern of in the lags. By contrast, after accounting for the trend, there is no pattern of seasonal variation across annual cycles.

A perusal of the raw data (in terms of captures per camera per season) suggests that human activity most often (6 of 10) peaks in summer (June), but in some years (3 of 10) activity peaks in spring (March). Such a pattern may be related to interannual variation in weather, with earlier springs or subsequent hotter summer associated with earlier peaks in recreational use.

Putting the mammal and human data together in a cross-correlation analysis (Fig. 12), we find that the two are correlated negatively (r = -0.244) after accounting for respective trends. The magnitude of this cross correlation is not high, but on the basis of the figure (note the extension outside the 2SE bounds), it is statistically significant.

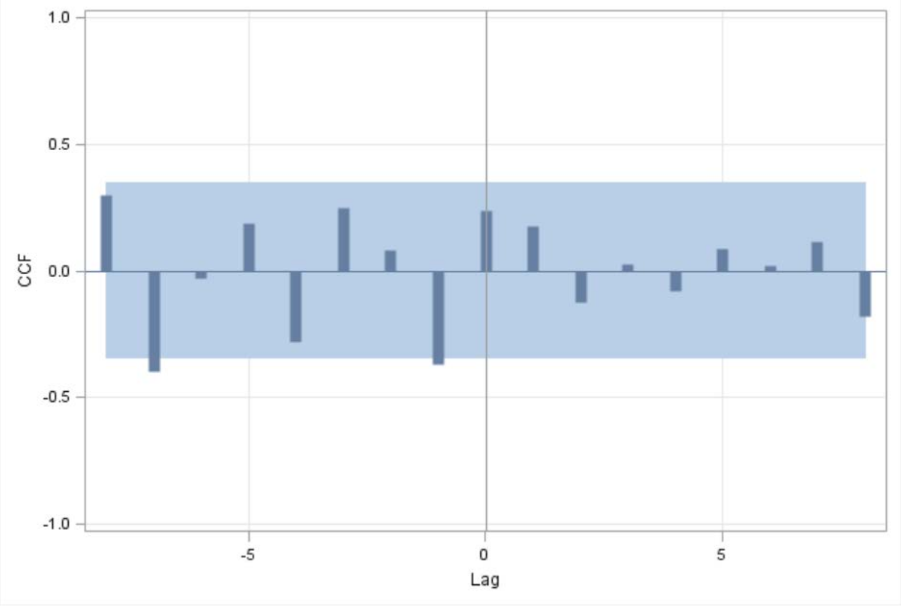


Figure 12. Cross-correlation of mammal and human data with seasonal oscillations and linear trends removed. The shaded area signifies two standard errors from r = 0.0. The y-axis is the correlation. The x-axis is the range of lags tested. Negative lags, as with lows here at lag -1, -4, and -7, indicate a negative association at those steps (i.e., mammals respond negatively in the wake of human disturbance but also seasonally).

Bobcat space use

For Comparisons A, B, and C, we fit 128 models that had 2 to 8 predictors each for male and female bobcats. AUC values were generally distinctly clustered by comparison type and by sex of bobcats (Fig. 13). Comparison C (GPS location vs. study area) performed the best of the three comparison groups, with AUC per model of 0.76–0.84 for males and 0.79–0.86 for females (Fig. 13; see also Boydston and Tracey *in review*).

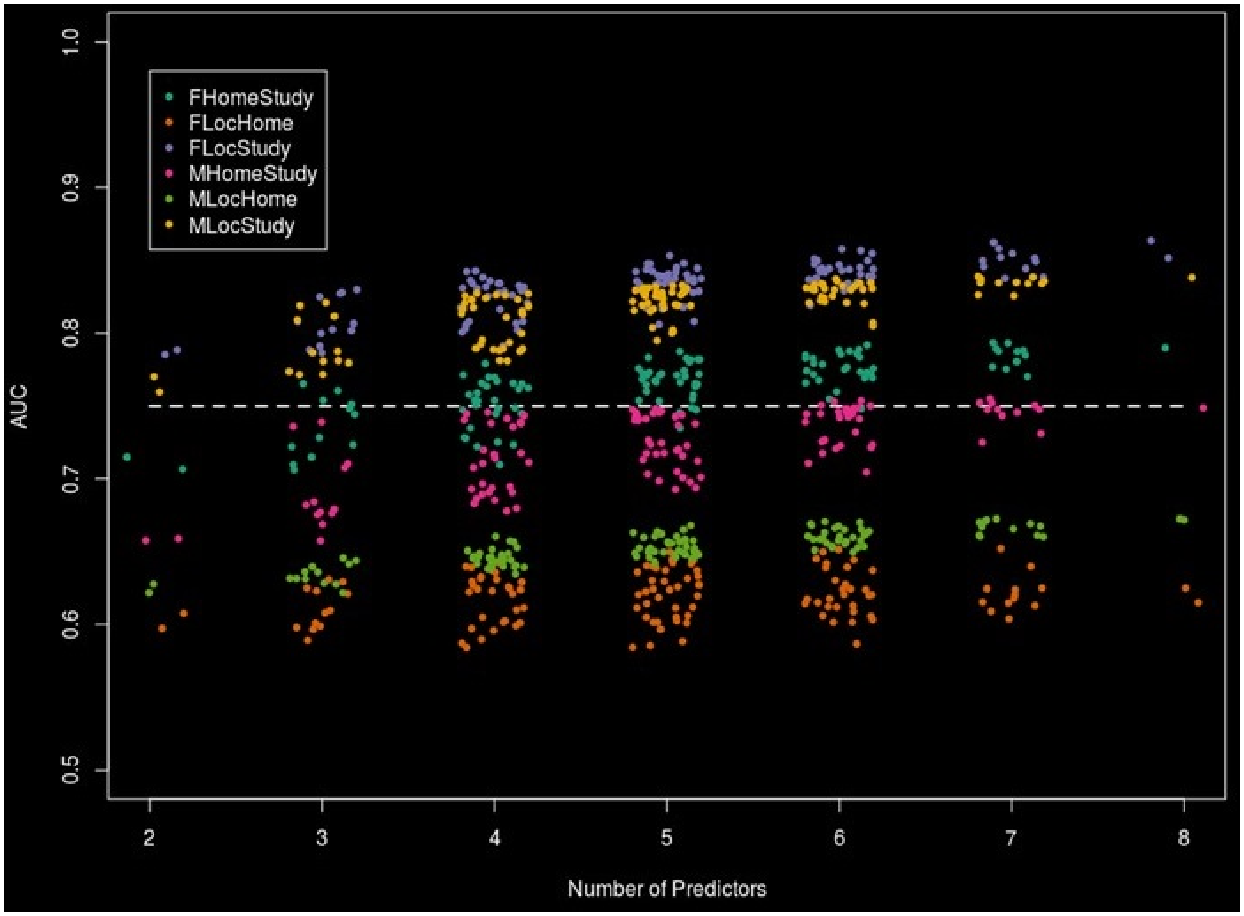


Figure 13. Scatterplot of AUC values vs. the number of predictors for each of three model comparisons by male (leading M) and female (leading F). Legend: HomeStudy = home range vs. study area (comparison B); LocHome = locations vs. home range (comparison A); LocStudy = locations vs. study area (comparison C). The dashed line marks AUC = 0.75, the minimum acceptable threshold for a good model. See Table 1 for descriptive statistics and Boydston and Tracey (*in review*).

By contrast, Comparison A (locations vs. home range) models performed poorly in all cases (AUC << 0.75). With number of predictors held constant, mean AUC decreased as: Comparison C for females, Comparison C for males (Fig. 14), Comparison B for females, Comparison B for males, Comparison A for males, and Comparison A for females (Fig. 13). AUC values increased with number of predictors included, which is expected with fitting models given the tradeoff between adding more predictors and the power to explain areas beyond the data (eventually a high number of predictors leads to overfitting and losing predictive power of the model). Models of resource selection within individual bobcat home ranges (Comparison A) did not yield robust RSFs, implying that selection occurs at a higher level (i.e., home range within study area). Understanding selection within bobcat home ranges may require higher resolution spatial data and or GPS data spanning multiple seasons. On the other hand, the quantity of data yielded by GPS collars allowed home range estimates that did not include large unused areas typically seen in VHF and some GPS studies. Further, given that bobcats have little concurrent overlap among home ranges within the sexes, results of RSF models for locations compared to the study region may offer the best combination of accuracy and precision, at an appropriate scale for resource management planning.

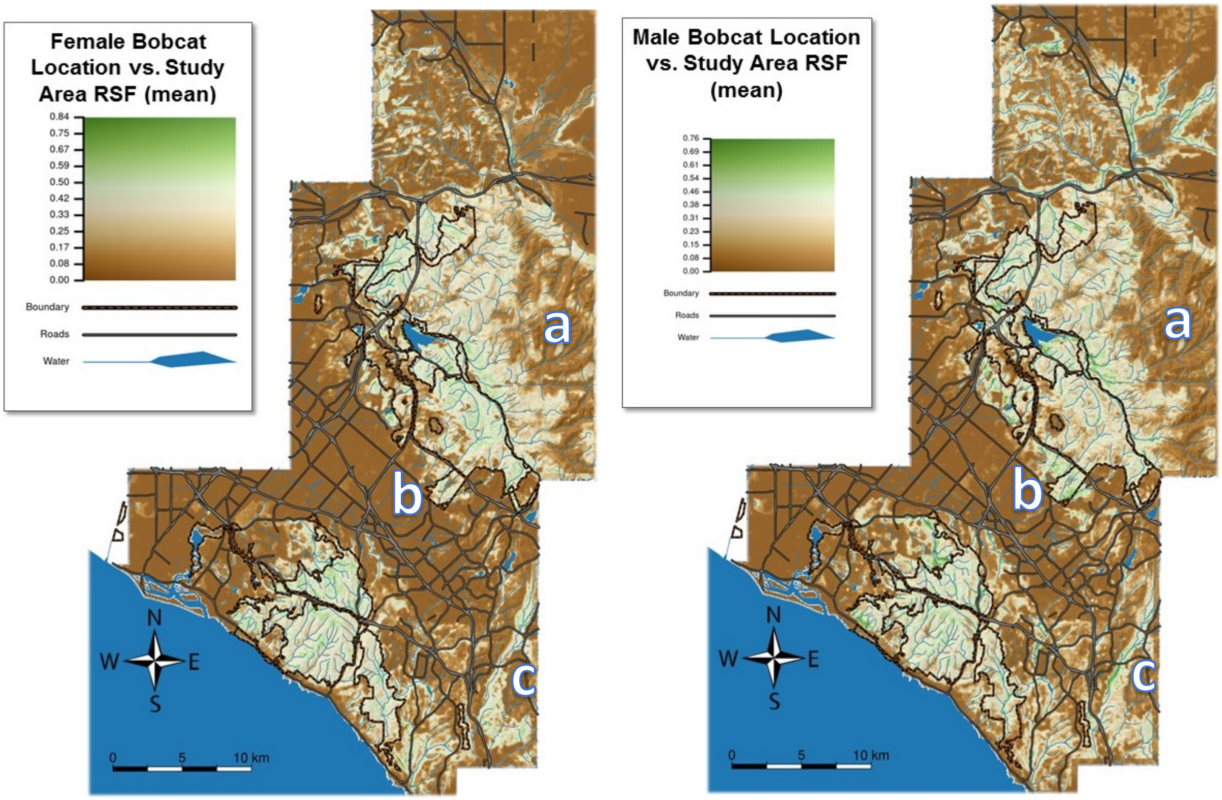


Figure 14. Mean of the best resource selection function (RSF) models for female (left) and male (right) bobcats on the basis of GPS locations vs. study area (Comparison C), in Orange County, California, at 28 m resolution and with NCCHCP Reserve boundaries and major roads shown (from Boydston and Tracey *in review*). Areas labeled with lower case letters are a) a region for which the models may not have performed well, b) sits in an area with very low prediction for bobcats and is adjacent to an area which was predicted for both males and females but for which only data from males was available (Fig. 5a, 5b), and c) suggests possible connection route between Coast and Central Reserves; these are discussed further in the text.

Female and male RSF mapped results were similar to each other; the expected differences that males would show less selectivity were subtle (Fig. 14; Boydston and Tracey *in review*). The areas predicted for bobcats were generally the same but the strength of the prediction varied within them.

The mountainous region on the eastern edge of the study area (label a, Fig. 14) showed mixed results across models but generally low RSF values. The environmental characteristics of this region of the Santa Ana Mountains are not represented elsewhere in the study area; elevations are highest here, and in many other measures, conditions are the most extreme in this relatively remote area (see figures in Boydston and Tracey *in review*). However, no bobcat tracking work was conducted here and no GPS data for these conditions, resulting in poor predictive ability of the models in this area. In the center of the study region (label b, Fig. 14), there were no GPS data for female bobcats immediately on the south side of Toll Road 241, but both male and female RSF results predicted bobcat occurrence here at the base of the Santa Ana Mountains. This was true for other parts of the study area with similar predictions for males and females despite the differences in spatial coverage in GPS data for them, providing confidence in the RSF results. For both sexes, models predicted bobcat selection along a corridor to the southeast of the Reserve (label c, Fig. 14). While roads intersect the possible route, the models suggest conditions existed at least in 2009 (the year of imagery used for Land Use Land Cover) to form a movement corridor between the Central and Coastal Reserves, if permeability exists across the roads.

Detailed movement data such as the bobcat GPS locations were not available for other species, but other types of data for smaller vertebrates were used to develop species distribution models (Boydston and Tracey *in review*). While the predictive ability of these models depends on data inputs, the estimates for certain birds, reptiles, and amphibians suggests where common and varying needs for species occur. Thus while bobcat RSFs indicate areas of high-value to this species and potentially many other species, some taxa differ greatly in their resource selection, leading to different spatial requirements. One approach to identifying areas of special value to particular species or Reserve characteristics that may support particular components of biodiversity is a step-wise filter that combines selected spatial layers to identify areas for management considerations. The inputs can come from the many spatial layers generated here for environmental characteristics, habitat configurations, and distribution models for numerous vertebrates. Boydston and Tracey (*in review*) suggest a filter process and provide examples of results of different combinations of abiotic and biotic characteristics mapped for the NCCP/HCP Coastal Reserve.

Large events

Wildlife activity did not differ across days (Fig. 15). Analyses for individual mammal species likewise failed to reject the null hypothesis of no difference across the event period ($P > 0.2$ in all cases), yet for three of the four species with sufficient sample size the mean number of detections was lowest during large events (Table 5).

Table 5. Average activity by species relative to wilderness access days.

	coyote	mountain lion	mule deer	bobcat
pre	0.245	0.023	1.252	0.038
during	0.220	0.070	1.170	0.030
post	0.254	0.026	1.246	0.046

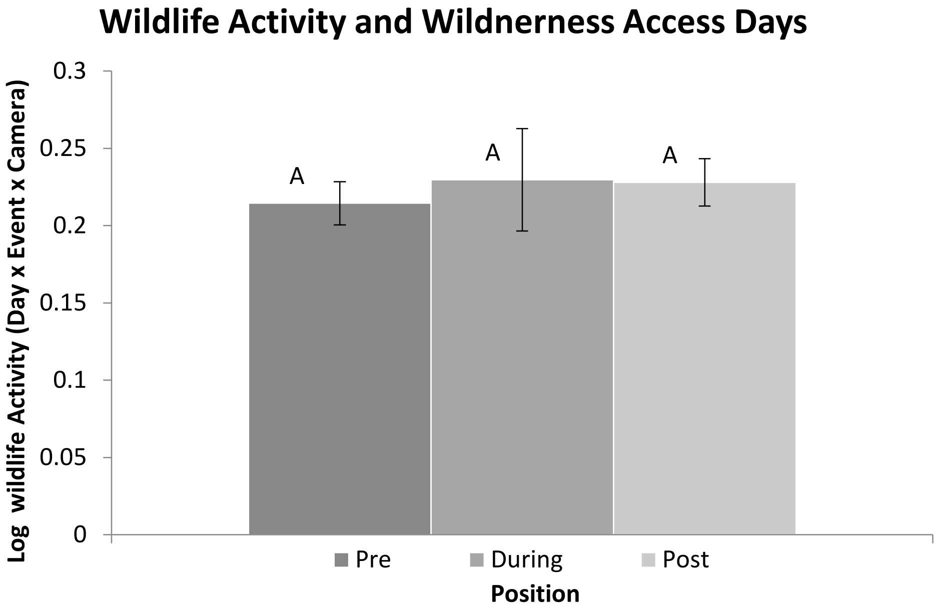


Figure 15. Mean wildlife activity (±SE) around wilderness access days. A one-way ANOVA failed to reject the null hypothesis of no difference [$F_{2,1196} = 0.023$; $P = 0.98$].

By contrast, the mean number of captures of hikers, bicyclists, equestrians, and vehicles was higher on event days (Table 6), with the increase in the first three disturbances significantly higher (hiker: $F_{2,1196} = 52.91$, $P < 0.001$; equestrian: $F_{2,1196} = 101.6$, $P < 0.001$; bicyclist: $F_{2,1196} = 360.3$, $P < 0.001$).

Table 6. Average human activity relative to Wilderness Access days.

	bicyclist	equestrian	vehicle	hiker
pre	0.07	0.07	0.54	0.76

during	8.77	1.08	2.62	48.79
post	0.20	0.03	0.46	0.88

Current management institutes a three-day rest period on program activities following large events, although regularly scheduled programs on the Sunday after wilderness access days are allowed. In terms of hikers alone, activity decreased markedly immediately after an event day (Fig. 16). Overall, human activity and wildlife activity were correlated along two multivariate dimensions (axis 1: $r_c = 0.22$, $P < 0.001$; axis 2: $r_c = 0.14$, $P = 0.001$). Loadings (correlations between raw variables and linear combinations) implied the first dimension reflected a negative association between equestrians and occurrence of both bobcat and mountain lion, whereas the second reflected a negative association between vehicles and coyote (Fig. 17), although a redundancy analysis indicated that, overall, only about 2% of the variation in wildlife activity was accounted for by human disturbance, likely because data were coarse, sample sizes small, and numerous other factors affect wildlife occurrence during these brief large events.

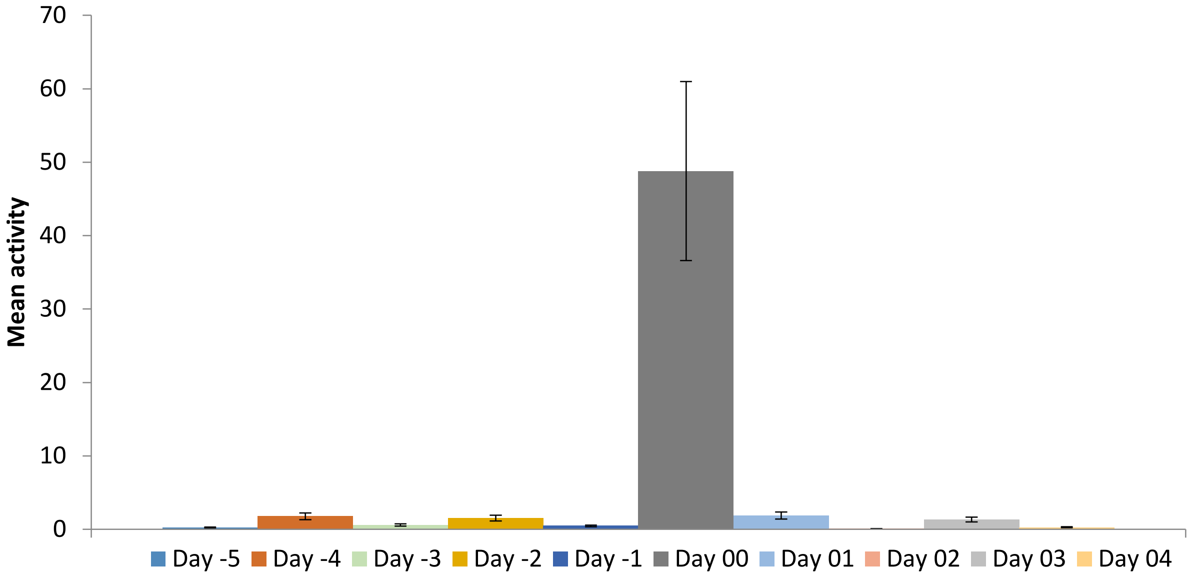


Figure 16. Mean activity (day by event by camera) of hikers in relation to Wilderness Access days ($n = 16$).

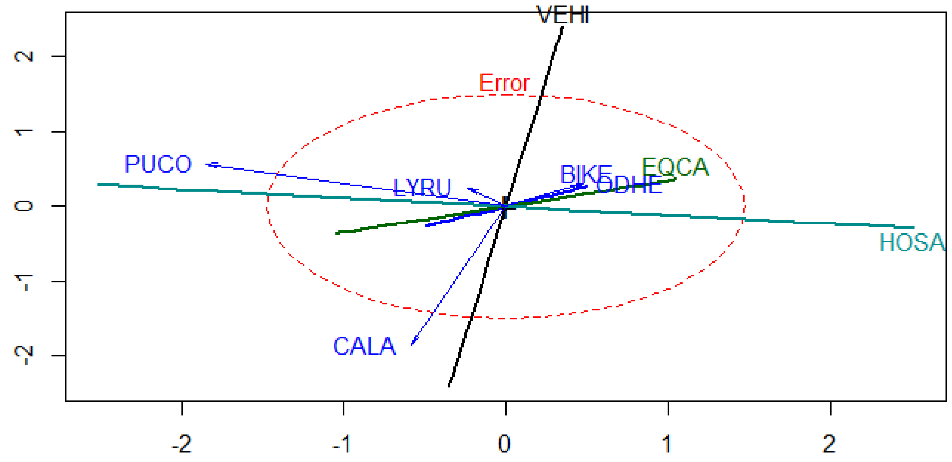


Figure 17. Species and disturbances correlations and effect size (vector length) in relation to canonical axes. Note the negative associations between humans (HOSA) and the cats (PUCO, LYRU) and vehicles and coyotes (CALA).

Spatial correlation was low (Mantel test), yet there was a temporal effect, in that there was a shift away from diurnal activity toward nocturnal activity beginning the night of an event day (Fig. 18). Across species, the proportion of day-to-night activity differed between events both before and after events ($G_2 = 30.8$, $P < 0.001$). The bobcat ($G_2 = 7.5$, $P = 0.02$) and mule deer ($G_2 = 21.6$, $P < 0.001$) shifted significantly toward nocturnal activity, and the coyote ($G_2 = 4.6$, $P = 0.10$) and mountain lion ($G_2 = 5.7$, $P = 0.06$) may have as well. Joint probability analysis indicated avoidance of roads, where human activity was more pronounced. We found neither an effect of a water source on mammal activity (2-way ANOVA: $P = 0.007$) nor a no water × time interaction, meaning activity was no higher at water sources, regardless of human activity.

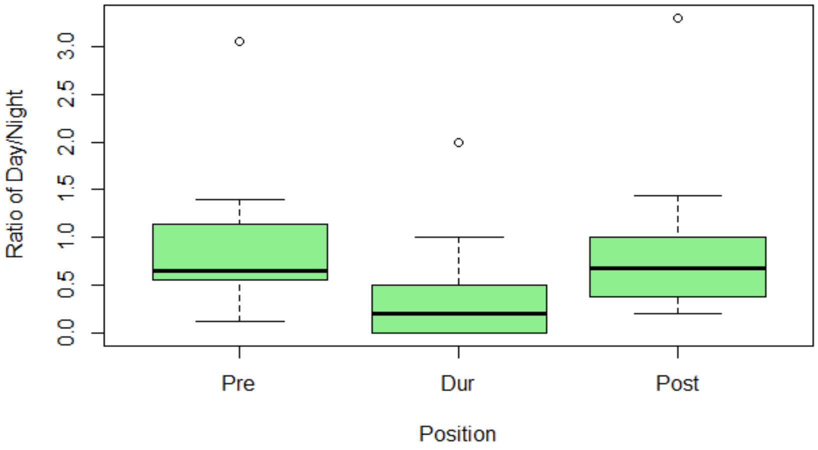


Figure 18. Diurnal vs. nocturnal activity of wildlife pre, during, and post large events, plotted as a ratio of diurnal to nocturnal activity across 14 events, all days, and 7 cameras.

Anthropogenic light

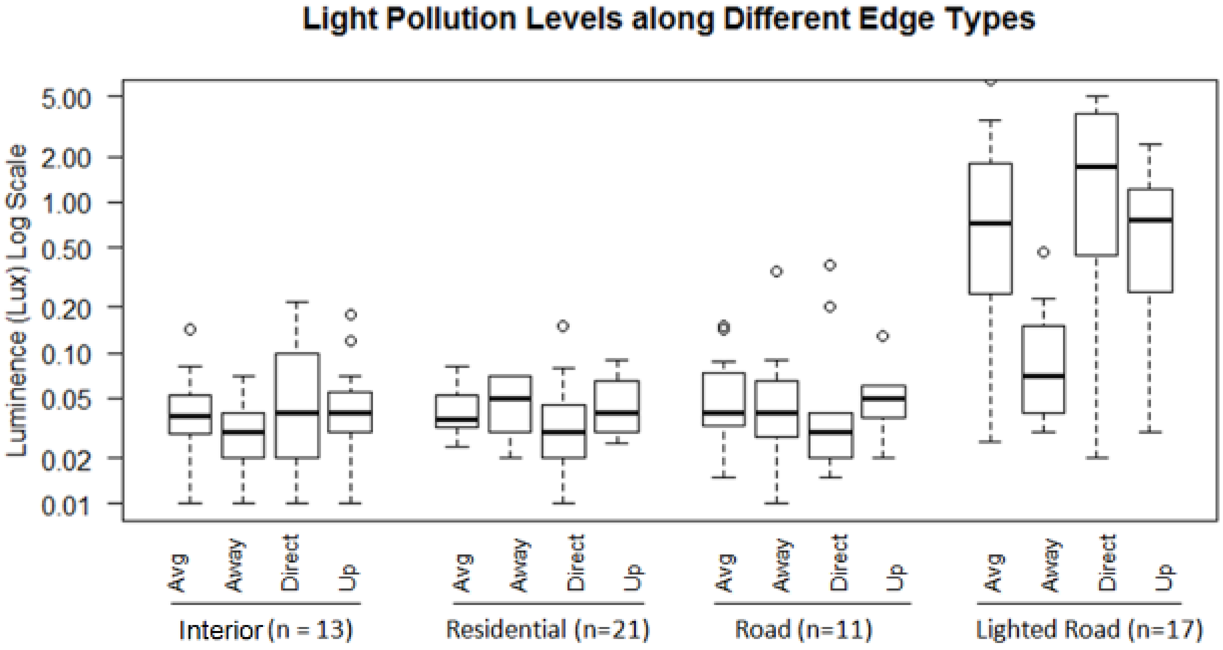


Figure 19. Light pollution readings (Lux) 5 meters from the edge, for different edge types and directions. The dark line is the median value, the edges are the first and third quantiles. Circles represent outliers. Not pictured are several outliers for the lighted road.

The largest source of light pollution along the urban–wildland interface occurs at streetlight locations (Fig. 19), consistent with results from other spatial studies (Kuechly et al. 2012). Greater light intensity along the edge corresponds with farther light penetration into the NCCP/HCP Coastal Reserve (Fig. 20). Perhaps more surprisingly, our field data revealed that nearly the entire Reserve exhibits illuminance of at least 0.01 lux during the new moon, which is the amount of illuminance under a quarter moon with natural conditions. The only locations that reach below 0.01 lux are densely vegetated willow groves and riparian areas. This is the neighboring urban area's skyglow and prevents any part of the Reserve from reaching natural new moon illuminance levels. Based on our readings, the marine layer plays a significant impact on skyglow effect. Skyglow values range from 0.01 (no marine layer) to 0.22 (heavy marine layer, reading taken along Quail Hill), which is why the integrated model has both a best case and worst case scenario. For the worst case scenario, a skyglow value of 0.06 lux was used because that was the highest illuminance reading from an interior location receiving no direct illumination. Many light studies ignore the marine layer, but our findings demonstrate that this layer is an important feature of light pollution in the Coastal Reserve.

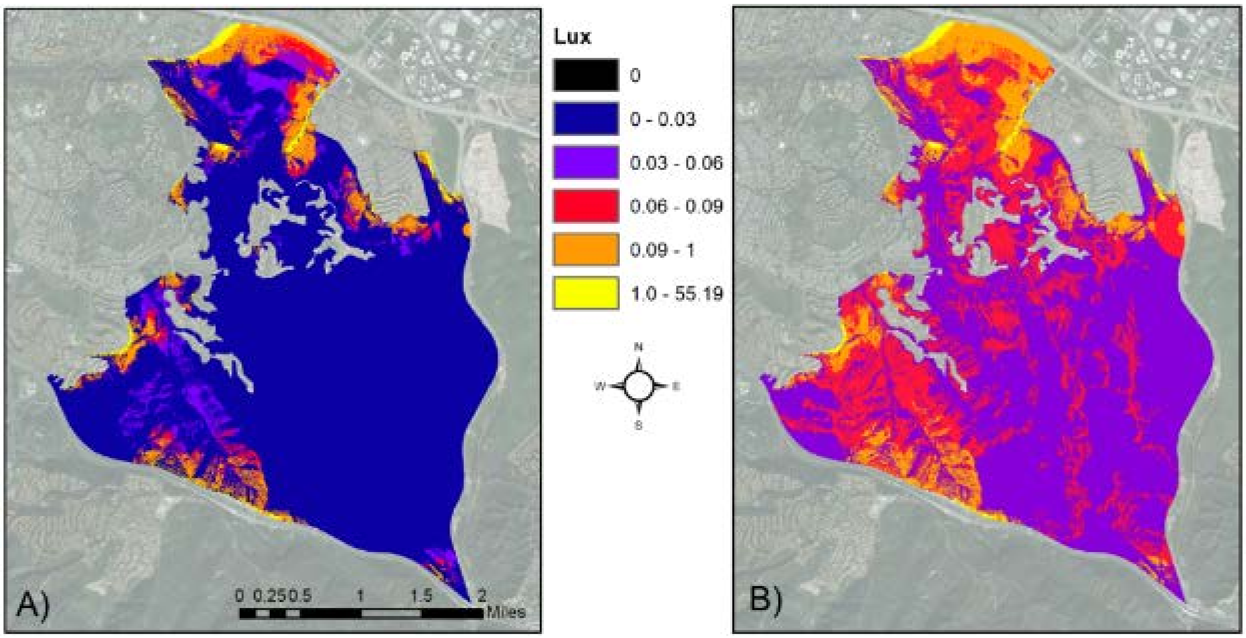


Figure 20. Best case (A) and worst case (B) scenarios of the integrated model. The integrated models include the original model, I-405 buffering, Laguna Canyon Road-Lake Forest Drive intersection buffering, and a skyglow assumption of 0.01 (A) and 0.06 (B). For reference, quarter moon is 0.01 lux and full moon is 0.1 lux.

Summary

We reported earlier (Burger 2012) on a strong signal of avoidance behavior of human activity by a range of mammal species. The current study supports these earlier findings and showed that avoidance was evident regardless of species, regardless of the type of human activity, and regardless of camera placement. The overall trend is sharply negative: as human activity increases, mammal activity decreases. An open question about the original findings concerned mechanism. Did increased human disturbance cause mammals to shift spatially or temporally? The current study showed that two mammals, over the long term, have shifted temporally and all seven mammals exhibited short-term spatial shifts in response to large events.

Our finding that relative risk of predation increases after human-induced diel shifts has important ramifications for predator–prey dynamics. Crucially, shifts were not solely of species in one trophic level (e.g., secondary consumers); instead, we uncovered evidence for a marked shift in a primary consumer that brought it into better temporal alignment with its chief predator (mule deer and mountain lion) and for a marked shift in a secondary consumer that brought it into better temporal alignment with a chief source of prey (coyote and gray fox). In either case the post-shift increase in relative risk was seemingly small (albeit statistically significant), but even a small increase in encounter rate (C) can have a large decrease in prey populations because “the number of surviving prey declines exponentially” as a function of the encounter (Abrams and Ginzburg 2000:339), and the number of prey consumed per predator also is a function of the encounter rate. Simple estimates using equations in Abrams and Ginzburg (2000) suggest a potential for broad effects: if we assume there are 100 individual predators and 1000 individual prey that have a non-predation mortality rate of 0.1, then the seemingly modest change in encounter rate we detected translates to an increase in one individual prey taken per predator, a rate that sums to about 10% of the prey population under our simple assumptions. We suggest that such losses in prey populations are unsustainable in light of additional stressors these populations face, which range from continued loss of habitat to avoidance of humans in protected areas (Crooks 2002, George and Crooks 2006, Ordeñana et al. 2010, Patten et al. 2016). It is possible that some prey find refuge when humans are numerous (Muhly et al. 2011), but we found no evidence to support this finding; in our system, human presence was as strongly negatively associated with the spatial and temporal activities of the mule deer as it was for any of the carnivores (Patten et al. 2016). This effect was stark regardless of how “human” activity was measured, in that the pattern was the same whether it was humans on foot or on bicycles, humans in vehicles or on horseback, or humans accompanied by dogs, a finding in line with other work (e.g., Reed and Merenlender 2011).

Across the seven focal species, mammal activity is markedly seasonal, with peak occurrence recorded in either our spring (March) or summer (June) sample. We found no evidence that mammal populations have declined Reserve-wide between mid-2007 and mid-2016. Human activity, by contrast, was noisy with respect to season but has increased markedly across the study period. Given avoidance behavior and temporal shifts of the various mammal species, any further increase in human disturbance may yet drive mammal populations downward.

Bobcat space use assessed with resource selection functions supported prior research on this species and emphasized preference for natural habitat, with core “hot spots” in the center of large blocks of open space.

In Limestone Canyon, acute changes in wildlife behavior in response to large events were clear, but chronic changes in behavior were not evident. This lack of a consistent long-term change in wildlife response activity in response to large events may indicate a level of habituation (*sensu* Whittaker and Knight 1998). The ability to habituate to recurring or predictable human perturbations may be crucial for animals to thrive in the urban–wildland interface (George and Crooks 2006). Even so, the more nuanced joint probability analysis indicates a degree of avoidance of humans, especially in locations near major roads. The threshold or mechanism of avoidance behavior is not understood fully. George and Crooks (2006) found similar results in which coyotes and bobcats had negative associations with human disturbances, and they found decreasing presence of mule deer with increasing recreational activity. In this canyon, the high ratio of nocturnal activity returned to pre-event levels within a few days, a fast recovery time for animal behavior, although the deeper negative associations found through joint probability analysis and the strong diel shift provide evidence of strong effects on wildlife when human activity spikes during wilderness access days.

The Coastal Reserve experiences a high level of light pollution, even under the best case scenario. Skyglow in particular accounted for a great deal of nighttime illumination within the Reserve. The effects of skyglow and other anthropogenic light on wildlife activity requires further study.

Recommendations

The marked increase in human-use of wildlands over the last nine years coupled with the observed temporal and spatial shifts by wildlife due to human presence highlights the importance of developing an over-arching, robust, and adaptive recreation management plan for the NCCP/HCP -Reserve and adjoining conservation lands. Resource management planning and implementation strategies in natural areas are often more successful when informed by interdisciplinary research that combines both ecological and social science approaches. A multi-year research and monitoring effort to address ecological aspects, human benefits and values, and contemporary management approaches tied to recreation within the region is strongly recommended to advance the present work.

Specifically, we recommend four focal dimensions for future work: (1) determining current reserve-wide visitor-use levels and spatial and temporal distributions; (2) assessing biophysical resource conditions; (3) understanding visitor perceptions, values, and judgements, as well as their understanding of the genesis for the lands conserved under the NCCP; and (4) providing scientific expertise in park planning and management. Associated fieldwork would include (1) an assessment of both authorized and unauthorized trail locations and conditions, popular destination sites, and other areas of visitor use, (2) a determination of the spatial-temporal distribution of use, and (3) an assessment of visitor attributes and preferences, including demographics, motivations, values, and judgements of resource and social conditions.

New information on human-use and values, when complemented by the findings of the present study will advance planning tied to threshold management, core area designation, and trail design and use, both for long-term sustainability purposes and wildlife and sensitive resource protection. Next steps involve determining thresholds of acceptability of key indicators of resource and social conditions, and assisting land managers in development of a range of possible management actions when conditions exceed these levels. Secondly, the expansion of the core area concept, first explored by the present study, should be advanced via an interdisciplinary process informed by biophysical assessments, thresholds of acceptability, and desired future conditions. Specific management actions to be visited include the spatial and temporal separation of recreation uses, such as the separation of biking and hiking, equestrian, and vehicle use, and the determination of acceptability to visitors for expanding the core area concept to define high, medium, and low intensity areas for the benefit of both the user's experience and protection of natural resources.

The strong observed short-term negative association between human and wildlife activity, the temporal shifts toward nighttime activity associated with recreation, as well as the use of non-reserve habitat by bobcats, cautions land managers of the need for a sound management plan under scenarios of continued increases in reserve use and nearby land use. Managers can manage or mitigate for these vulnerabilities by one or more of a number of methods, including: (1) managing use directly through numeric and/or spatial controls, (2) adjusting trail configurations to minimize overlap with high wildlife use areas, (3) restoring trail-sides to screen wildlife from trail activity, (4) avoiding nighttime recreation activity in areas with high daytime use, 5) adjusting large events seasonally based on seasonal vulnerabilities of wildlife and other resources, (6) protecting and enhancing regional connectivity, and (7) managing lands as large landscapes in the context of the surrounding urban environment and changes thereto.

The distinct seasonal peaks of activity by wildlife recovered through time-series analysis of camera-trap data, suggest there are select times of the year when wildlife are most active and these times may present specific vulnerabilities to human presence (or disturbance). One management recommendation, to be considered in short-order, is to identify periods of the year when specific wildlife species may be most sensitive to increased human activity and block-out large events and/or limit the number of activities during these periods. Block-out periods focused on minimizing the overlap of events with the height of activity by wildlife may be most effective.

Seasonal wildlife activity as indicated by numbers of detections may indicate particularly important life phases. However, identifying the behaviors leading to changes in detection frequency may further help understand how human activity can affect behavior. Similarly, animal movements, such as those of bobcats collected via GPS collars, can suggest behavior, which may be difficult to validate on cryptic, hard to observe species. Linking movements or detections of wildlife to when and where specific behaviors occur, such as hunting or breeding, can further help understand how to meet spatial and temporal needs of wildlife in areas accessed by people.

Modeling efforts of bobcat space use based on employing home range as a continuous surface highlight the need by female bobcats for contiguous quality habitat for home range placement. Female bobcats are strongly associated with natural areas, and resource selection models highlight the particular importance of the NCCP/HCP reserve habitat to them. Male bobcats appeared less specifically dependent on NCCP/HCP lands as expected based on their wider movements in general, but they were still strongly associated with undeveloped areas including the NCCP/HCP Reserve and adjacent lands. Results indicate the NCCP/HCP –Coastal Reserve is critically important to bobcats as contiguous, high-quality open space in a highly urbanized region adjacent to the ocean, whereas the Central Reserve still neighbors other large undeveloped areas that may help support movements and home ranges that span across management boundaries.

Modeling efforts based on fine-scale selection from point locations across a landscape highlight additional habitat areas outside of the NCCP/HCP Coastal Reserve that may be of real benefit to bobcats (and likely other wildlife). Models suggest there may be small areas near the Reserve that could provide additional suitable home range or movement areas for bobcats, potentially through restoration, connectivity, or reduced edge effects. While fine-scale selection of key elements within a bobcat range was not apparent in the resource selection modeling, the management scale for this species appears to be at the level of home ranges and areas for dispersal. An area of missing information is trends in bobcat numbers. Source-sink dynamics across this landscape, such as due to roads between areas accessed by bobcats, may play an important role in population trends. Future effort focusing on local connectivity and the potential benefits of additional habitat through restoration or improved movement pathways, calibrated against population trends, may indicate specific areas for management actions.

The first level of assessment of high-value habitat areas highlights the limited amount of contiguous habitat available to bobcats along the coast, and thus the importance of the entire Coastal NCCP/HCP Reserve as a core-habitat area. With implementation of appropriate protection measures within the Coastal Reserve and adjacent open space lands, an opportunity exists to cobble together marginal habitats (identified through fine-scale selection modelling effort) by recognizing the importance of enhancing functional connectivity to natural lands protected under the Southern Orange HCP to the south and to expand the resource base for the population of bobcats in the South Coast Wilderness, and potentially supporting a larger population than what is otherwise present today.

The NCCP/HCP recognizes the importance of other areas that support significant natural lands but are located outside the Reserve. These additional areas, called supplemental non-reserve habitat areas, consist of Special Linkages and are recognized for contributing to connectivity between Reserve areas (NCCP/HCP pp. II-203-215). The modeling work only reinforces their importance and encourages local jurisdictions to work with land managers and researchers to consider more robust ways to minimize incidental road mortality in these areas.

Within the foothills and canyons of the Santa Ana Mountains (that is, the Central Reserve and adjacent Easement lands), the results highlight the importance of the conservation measures taken following the signing of the NCCP/HCP. The conservation easements held by The Nature Conservancy and the Orange County Parks Foundation have protected an additional 12,500 acres of land, without which the NCCP/HCP Reserve, by itself, would be challenged to ensure persistence of bobcats and other wildlife, such as mountain lions. Existing and potential roadway underpasses along and within the canyons considered to be most valuable to enhancing functional connectivity should be revisited and longer-term plans for maintaining the ecological connectivity and minimizing incidental mortality on roads in these areas reviewed and revisited.

Given the limited amount of contiguous open space within the Coastal Reserve and observed sensitivity of wildlife to human-presence, a cautionary approach to expanding human-activity beyond authorized trails and outside of already established sunrise to sunset activity envelopes should be taken. The importance of this recommendation is only highlighted by the observed night-time illumination of the NCCP/HCP Coastal Reserve by skyglow and lighting along roads. Together, greater illumination is likely to lead to shifts in predator-prey dynamics during the nocturnal hours. Increasing human activity within a limited area, like the coast, during these times only further complicates an increasing complicated situation for wildlife, as humans present a new challenge to wildlife already affected by daytime activities and increased nighttime illumination.

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IRVINE RANCH CONSERVANCY

Wildlife Response to Wilderness Access Days

Impacts on Abundance and Behavior

Nico Alegria

9/18/2015

An in depth analysis for wildlife activity response to Wilderness Access Days, both spatially and behaviorally, in Limestone Canyon.

Executive Summary

Wilderness access days in Limestone Canyon allow local communities to explore landscapes within Irvine Ranch Open Space (owned by Orange County Parks) that are otherwise limited to the public. These large events generate a pulse of human disturbances by allowing hundreds of bodies onto the Irvine Ranch Open Space. This influx creates the potential for conflict between wildlife and recreationalists. Data from 16 events (2011-2015) were collected from seven cameras along Limestone Canyon for four disturbance agents (bicyclists, pedestrians, equestrian riders, and vehicles) as well as five target mammals (deer, coyote, mountain lion, bobcat and fox). Effects of human disturbance on wildlife were not significant using one-way ANOVA and Mantel tests. Evaluation of probability of expected joint occurrence between wildlife and human disturbance found observed values to be less than expected value across all seven cameras indicating a degree of avoidance by wildlife. G-Tests yielded significant results on the proportion of night to daytime activity, highlighting the notable nocturnal behavioral shift in wildlife on event days. Management recommendations range from potentially shortening the duration of access days or regulating the number of large events to improved security on nighttime trespassing after the day of an event. Further analysis should work to place these results in the context of long-term population trends throughout the ranch.

Background and Motivation

The Irvine Ranch Conservancy (IRC) takes part in management of nearly 40,000 acres of wildlands and parks throughout the historic Irvine Ranch. The core pillars of Conservancy's mission are to protect the land's natural resources for future generations and to connect people to the land in a manner that encourages their appreciation and understanding of it. From 2011 to 2012, access days were held monthly and from 2013 onward, they occurred every other month. The pulse of human bodies can range from roughly 150 on lighter days to well over 600 bodies on the land during popular events. Activities welcomed during these days include; horseback riding, mountain biking, hiking, and heightened trail monitoring by Orange County (OC) park vehicles. Event activity occurs throughout Limestone canyon, which itself is part of the greater Limestone Canyon Wilderness Preserve owned by OC Parks and managed jointly by IRC and OC Parks. From 2012 onward, guidelines for wilderness access days recommended three days of rest, with no scheduled recreation programs, following each weekend that had a wilderness access day.

Human-animal conflict is no novel condition in the wildland-urban interface and while these access days provide a great opportunity to connect local communities to the land, it should not come at a cost to sustainable management. Urban mammals can be seen as dignified and welcomed, or as a nuisance and danger to domestic animals and people (Gerht et al. 2010). For wildlife, disturbance from recreation can lead to long-term and short-term effects (Taylor and Knight 2003). Avoidance behavior or fleeing can cause unneeded stress on energy expenditure. Reduced foraging time or alteration of metabolic rate can have critical impacts on growth, reproduction, and survival (Geist 1978, Taylor and Knight 2003). As sustainable stewardship is a foundation of the IRC, proper evaluation of these access days is vital to meet this objective, culminating in the guiding question: what are the impacts on wildlife of these wilderness access days and how should management proceed?

Data Collection

The Irvine Ranch Conservancy operates an extensive camera trapping program using Scoutguard SG-565F cameras that is monitored with the help of diligent volunteers and wildlife technicians. These cameras capture images of humans and wildlife alike and will be the basis for this analysis. Cameras are generally positioned 45 degrees towards the trail or given target (i.e. trough). Seven camera traps were monitored along Limestone Canyon (Figure 1) in areas only accessible to the general public on wilderness access days and docent guided tours (Figure 2). Three cameras, Bolero trough, Augustine trough and Bolero springs were oriented towards water sources. Information was gathered for 16 events ranging from 2011 to 2015. Images were recorded for five days prior to the event, the day of the event, and five days after event. The 11-day periods bridging the access days aimed to catch possible activity responses or delayed recuperation. Data from images collected were input into a Biota® database system. The five wildlife species monitored were: Coyote, deer, mountain lion, bobcat, and fox. The disturbance agents recorded were: pedestrian hikers, horseback riders, mountain bicyclists, and vehicles. If a horseback rider or bicyclist dismounted, they would then be recorded as a pedestrian. A given specimen would have records of Time, Abundance, Duplicate Images, Date, and Species Code. Data entry procedures were consistent with the Irvine Ranch Conservancy data entry guidelines. Several subtle, nevertheless, vital nuances should be noted regarding these guidelines. Every unique individual within an image would count towards the total "Abundance" tally for that image. If within one hour of initial image capture, a human disturbance of the same type is recorded, then that image would be labeled as a "Duplicate". The abundances of these duplicate images would then be summed for that specimen and added to the total "Abundance" tally. For wildlife, the same procedure is followed, except the elapsed time period is only five minutes for a duplicate image. For all specimens, the time clock is reset for every new species to enter the camera frame. This means that if a vehicle was to trigger the camera and five minutes later a hiker followed by a new vehicle re-triggered the camera, that vehicle would be a new specimen entry. Activity levels (number of distinct photographs per day) do not accurately represent absolute abundance because of one-minute trigger delays. They provide a measure of activity and an index for relative abundance.

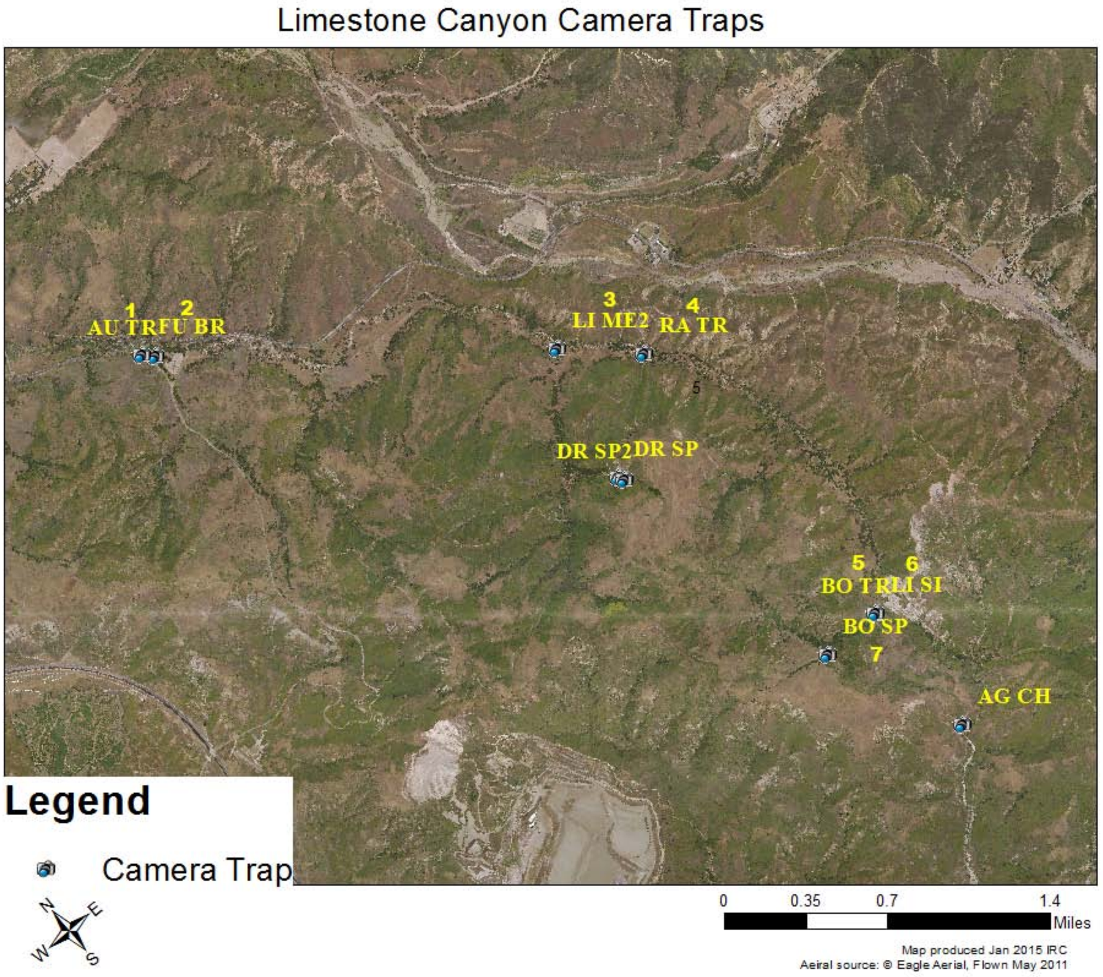

Figure 1. Limestone Camera Traps. Numbered camera traps along Limestone Canyon that can potentially capture impacts during Wilderness Access Days (AU TR, FU BR, LI ME, RA TR, BO TR, LI SI, BO SP).

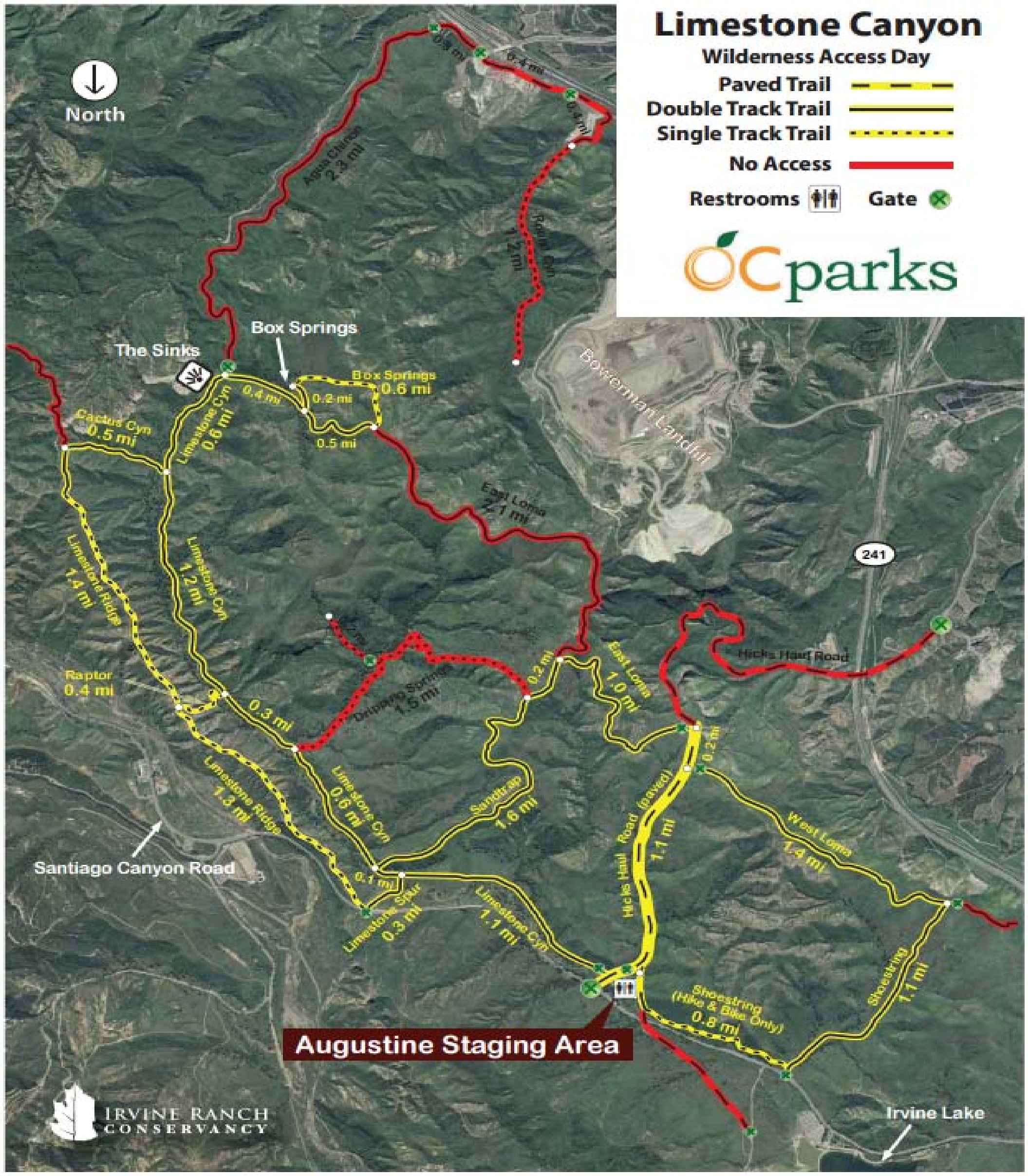

Figure 2. Limestone Canyon Trail Access. Area of interest begins at Augustine Staging Area and follows Limestone Canyon trail through Box springs.

Statistical Analysis

Activity over Time

In order to avoid falsely attributing animal activity on early mornings prior to human access on event days, a time shift was conducted , adjusting days to span 06:00 am to 05:59 am on the following day. An extra half-day was thus added (Day -6) and Day +5 became a half-day. Data were then organized by day (-6 through +5), event (16 events), and camera (7 cameras). First and last days were eliminated for the analysis because they represent only partial samples. Days were then aggregated into "Pre, "During" and "Post" event. Data were transformed using a *log(y+1)* transformation due to the high number of zero values (Lentner and Bishop 1986). One-way ANOVAs were performed on transformed wildlife activity across "Pre" "During" and "Post" periods, to see if the means were significantly different due to open access day disturbance. Species specific tests were run for each species and individual disturbance agents as well. Tests were conducted using R-Studio Open Source Edition, version 0.99.467. Three cameras were associated with water sources for wildlife, Augustine Trough (AU TR), Bolero trough (BO TR), and Bolero Springs (BO SP). A Two-way ANOVA was conducted to explore the relationship of water with abundance and day. Once again, total wildlife was transformed using the same log operation as with the previous ANOVA tests.

Spatial Associations over Time

In order to test spatial associations between animal activity and human disturbance presence, Mantel Tests were conducted in PC ORD, version 4. Average abundance of species (either human disturbances or wildlife) by camera (7 cameras) for each day (-5 through +4) across events were put into two matrices to measure spatial relationship on human and wildlife (see Appendices, A1 for matrices). A Mantel test was conducted to calculate a multivariate correlation across factors (r) using Euclidean distance measures. P-values were found through both Mantel's asymptotic approximation method and randomization (Monte Carlo) test.

Relationships between Wildlife and Human Activity

Canonical correlation measures associations between two sets of variables simultaneously and was used to measure the relationship between human disturbance variables and wildlife species variables (Rotenberry et al. 1996). Calculations were made for matrices of four wildlife species (bobcat, coyote, deer, mountain lion) against a matrix of the four human disturbance agents along with redundancy analysis, a means to assess how much variation in one set is explained by another. Fox were eliminated from the analysis because of lack of sufficient data. Matrices were populated with activity by day (-6 through +5), event (16 events), and camera (7 cameras). Analysis was done in R-Studio Open Source Edition, version 0.99.467 utilizing the "Candisc" package (Michael Friendly [aut, cre], John Fox [aut]).

Expected Joint Probability

The expected joint probability of aggregated wildlife activity and human activity was calculated based on the actual number of wildlife and human occurrences and compared to the observed number of days both occurred together for each camera. A simple binominal goodness of fit test was used to assess the difference of expected and observed days of joint occurrence for each camera location. The difference in these values would suggest avoidance of wildlife given human presence, merging both time and spatial components into the analysis.

Behavior

Specimens were organized into diurnal and nocturnal activity based on sunrise and sunset data from 2010 for Irvine Ranch (Zone: 8h West of Greenwich) to test for temporal displacement of wildlife by human activity. Initially, ratios of day to night activity by “Pre” “During” and “Post” events were studied to assess notable trends. Next, G-tests were run in R-Studio Open Source Edition, version 0.99.467, to assess statistical significance of the different proportion of day to night activity by “Pre,” “During” and “Post” categories. G-tests were run for total aggregated wildlife, and by species for: bobcat, mountain lion, deer, and coyote. These tests were meant to assess direct behavioral shifts in diurnal activity due to the pulse of human activity during event days.

Results

Activity over Time

All wildlife activity was not significantly different across days (Figure 3) while all disturbance agents except vehicles were significantly different during event days.

Wildlife

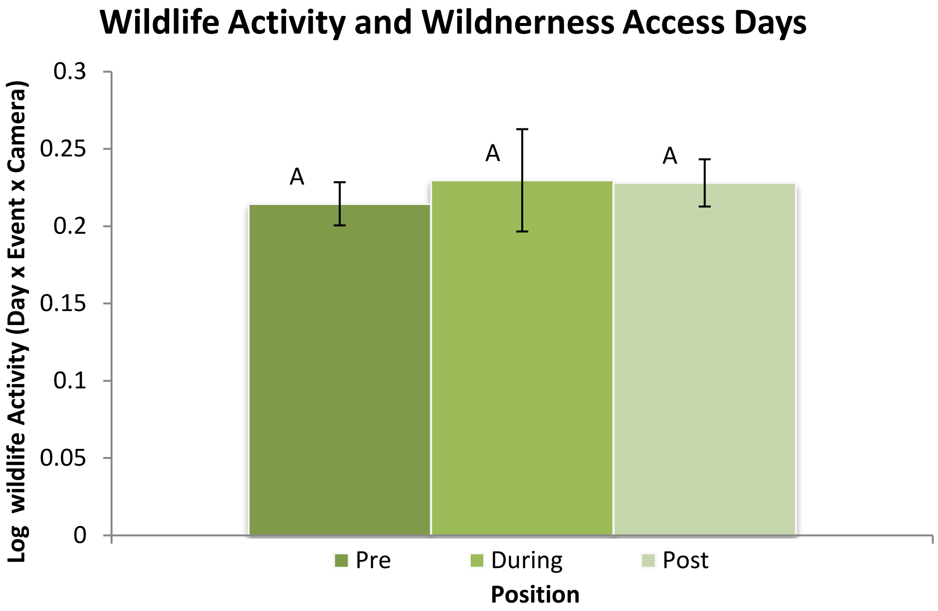

Figure 3. Wildlife Activity and Wilderness Access Days. A log(y+1) transformation of wildlife activity before, during, and after open access days with standard error bars. A one-way ANOVA was performed to show no significant difference between means [*F*(2,1196) = 0.023; P = 0.978].

A one-way ANOVA was performed to assess activity of coyotes, bobcats, mountain lions, foxes and deer. There was no significant effect of access days on average abundance at a significance level of α = 0.05 for the aggregated five species [*F*(2,1196) = 0.023; P = 0.978]. Individual ANOVAs were performed for four individual wildlife species, none of which returned a significant result. For coyote [*F*(2,1196) = 0.366; P = 0.694], deer [*F*(2,1196) = 0.01; P = 0.99], bobcat [*F*(2,1196) = 0.166; P = 0.847] and mountain lion [*F*(2,1196) = 1.502; P = 0.223] there was no observed impact. Table 1 illustrates average activity by time period for individual species of wildlife,

Table1. Average activity by species relative to wilderness access days.

	Coyote	Cougar	Deer	Bobcat
Pre	0.245	0.023	1.252	0.038
During	0.220	0.070	1.170	0.030
Post	0.254	0.026	1.246	0.046

Disturbance Agent

A one-way ANOVA was performed to assess how activity of pedestrians, mountain bicyclists, equestrians, and vehicles changed before, during and after access days. There was a significant effect of access days on abundance at α = 0.05 for each of the disturbance agents except vehicles. A post hoc Tukey test was performed to verify, that the "During" position was in fact significantly different than the other two time periods for impact on activity. Pedestrian [*F*(2,1196) = 52.91; P = <0.001, Figure 4], equestrian [*F*(2,1196) = 101.6; P = <0.001], mountain bike [*F*(2,1196) = 360.3 ; P = <0.001] were all significant but vehicle [*F*(2,1196) = 0.489; P = 0.613] was not significant. Table 1 illustrates average activity by time period for individual disturbance agents.

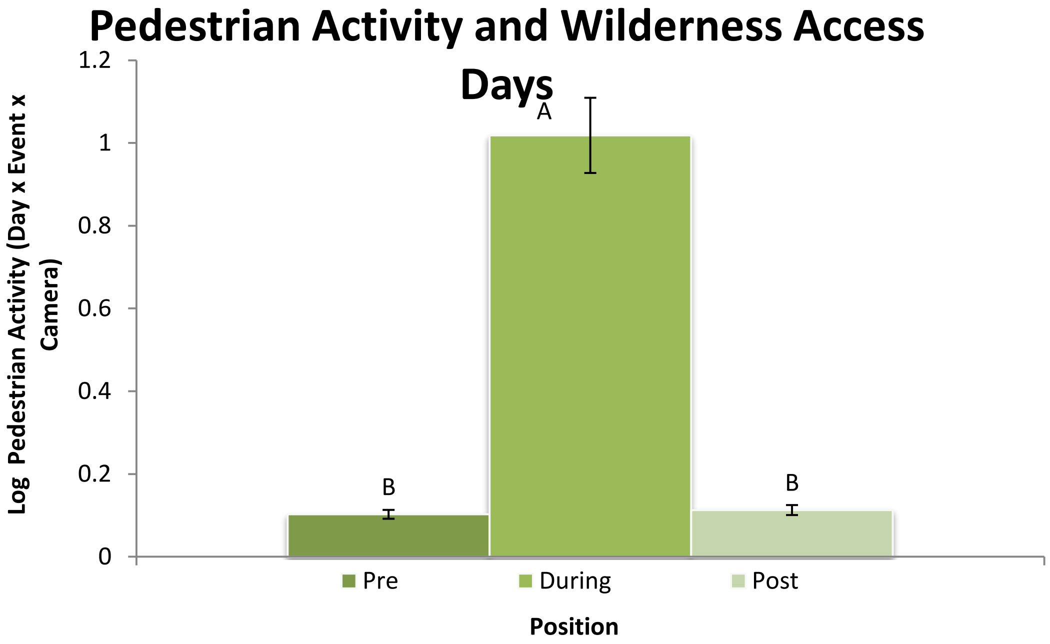

Figure 4. Pedestrian Activity and Wilderness Access Days. Log transformation of pedestrian activity before, during and after access days with standard error bars. There was significantly more pedestrian activity during access days than before or after [*F*(2,1196) = 52.91; p = <0.001].

Table2. Average activity by disturbance agent relative to wilderness access days.

	Bike	**Equestrian**	**Vehicle**	**Pedestrian**
Pre	0.07179	0.0717863	0.540902	0.761269
During	8.77	1.08	2.62	48.79
Post	0.2	0.034	0.46	0.884

Effect of Three Days of Rest

There is a three day pause on program activity after event days but regular scheduled program activity the Sunday after access days is allowed. Day 1 (Sunday) pedestrian activity seemed similar to other non access day levels however (Figure 5). Day two, the start of the rest period, did have a noticeable decrease in pedestrian activity. Day three and four had similar activity levels relative to pre-event days. This could be due to activity at staging areas which could catch pedestrian activity on camera FU BR or to normal IRC operations (See Appendix A2, Table 1 for Average Pedestrian Activity by Day). Either way, there is minimal evidence of decreased pedestrian activity due to the rest period.

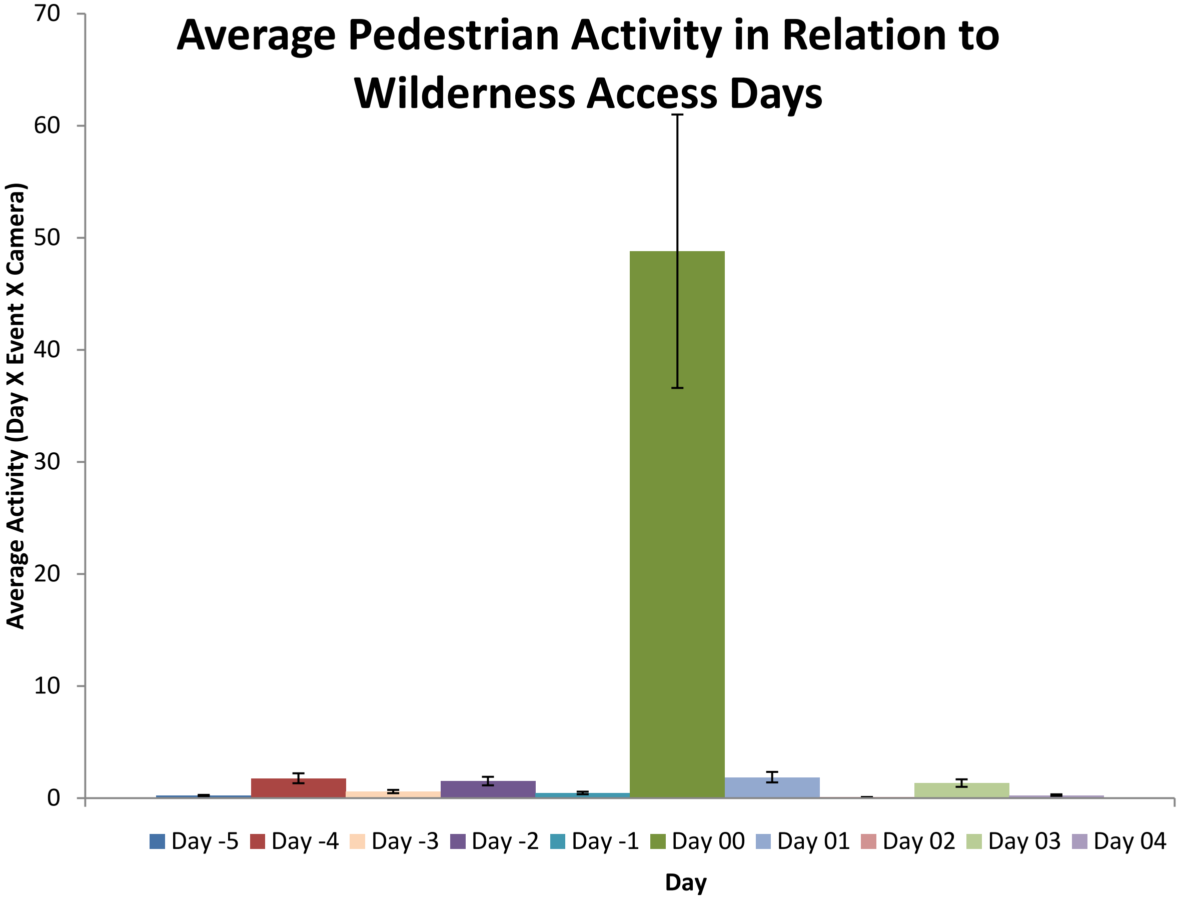

Figure 5. Average Pedestrian Activity in Relation to Wilderness Access Days (n=16).

Available Water Source

Two-way ANOVA revealed a significant main effect of water [F(1) = 7.3, P = 0.007] on animal activity but insignificant effect of time relative to access day [F(2) = 0.57, P = 0.566] and no significant interaction between the two factors [F(2) = 0.314, P = 0.72]. Cameras adjacent to water sources captured more wildlife activity regardless of human activity

Spatial Impact

Results for Mantel Tests showed no significant associations between wildlife and human matrices for both combined disturbances and pedestrian disturbance under both methods of p-value approximation (Table 3). The low Mantel r (0.02) and high P-values indicate a minimal association between wildlife activity and human activity when data from all events were averaged.

Table 3. Mantel Test results yielded no significant findings (α = 0.05).

	Monte Carlo	T-Test Statistic	Mantel R
Pedestrians v Wildlife	0.388 = P	0.919 = P	0.024038 = r
All Human v Wildlife	0.378 = P	0.926 = P	0.021804 = r

Relationships between Wildlife and Human Activity

Results from the canonical correlation found a weak but significant association for two axes in canonical space [R= 0.22, F(16,3639)=5.68 P= <0.001] and [R=0.14, F(16,2901)=3.04, P= 0.001]. Based on canonical coefficients, Equestrian (0.33) had the most influential weight on bobcat (-0.51) and mountain lion (-4.1) for the first canonical variate pair. The second showed vehicle (-0.56) weighted heavily, with coyote (-1.10) having a strong negative association in the second canonical variate pair. Redundancy analysis concluded that only ~ 2% of variation in wildlife species activity (Y) could be explained by human disturbance (X), highlighting that this test had statistical significance but a low biological signal. Moreover, the strong equestrian coefficient could be explained by the fact that wilderness access days are generally the only day in the dataset used that there is any notable horse activity on the landscape, and could reflect the overall effect of access days on wildlife rather than equestrians. Graphical representation adds further complexity to the result (Figure 6). A variable term can be seen as notable if it reaches outside the error ellipsoid and the orientation of that term relative to the Y Canonical Axes explains what dimension that X variate corresponds to (R “Candisc” package, Michael Friendly [aut, cre], John Fox [aut]). Relative lengths relate to the proportion of variance that is accounted for in the Y canonical dimensions and the angles between the variable terms and the canonical axes show the correlations of Y variables with the canonical dimensions (R “Candisc” package, Michael Friendly [aut, cre], John Fox [aut]). Essentially, the effect of equestrian (EQCA) does not break the error ellipsoid and while bobcat (LYRU) has a negative association with the X variables, it does not pierce the error either. Mountain lion (PUCO), however, is shown to have a strong negative relationship with the x variables. On the second Axes, vehicle (VEHI) has a significant influence in the system and coyote (CALA) has a clear negative association. To conclude, vehicles may impact coyotes and there is some negative association of mountain lions and bobcats with human activity.

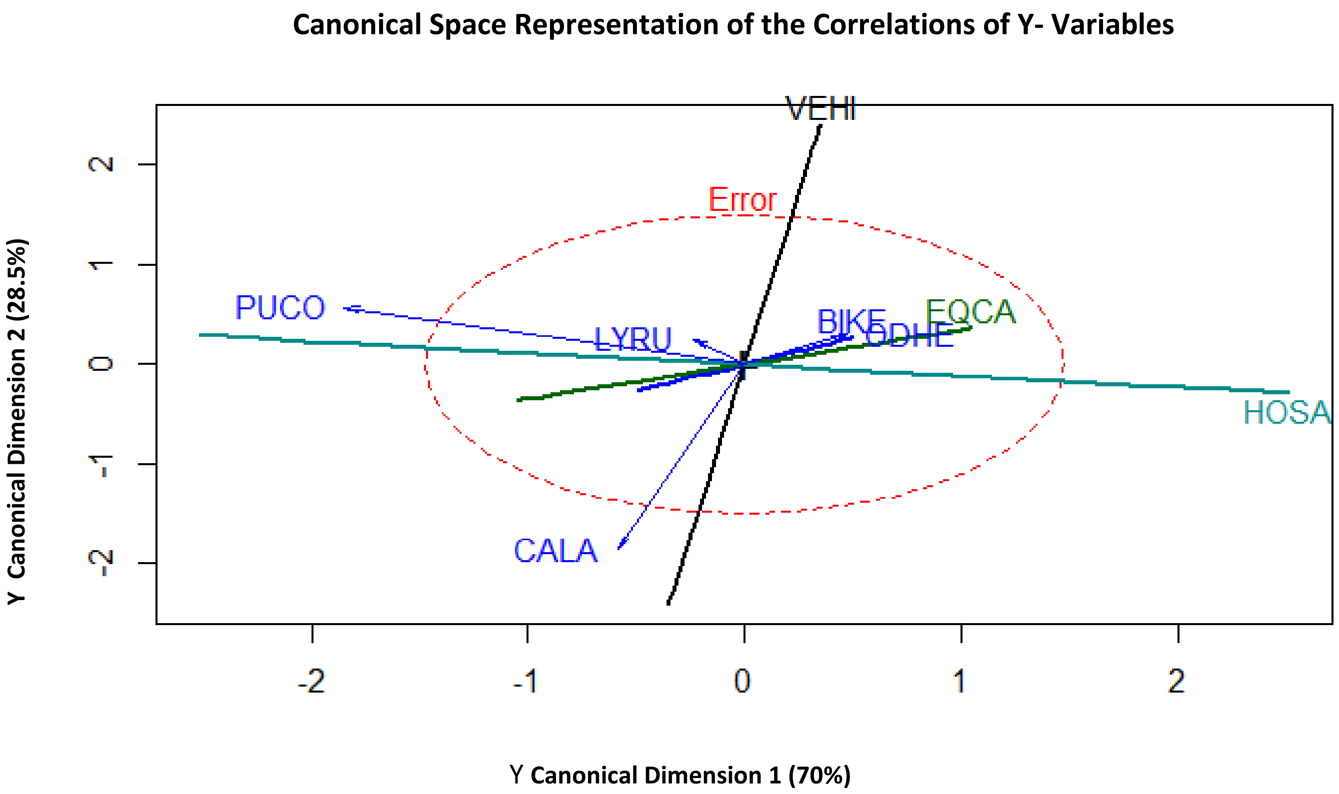

Figure 6. Canonical Space Representation of the Correlations of Y-Variables. Species and disturbances correlations and strength of effect are displayed as vectors in relation to canonical axes.

Expected Joint Probability

Probabilities for mammal occurrence, disturbance occurrence (combined human activity) and joint occurrence were calculated (Table 5). For every camera location, observed days of joint occurrence was less than calculated expected number of days (Figure 9). A simple binomial goodness of fit test was performed for each camera location to determine significance. Three camera locations LIME (P= 0.020), BOTR (P= 0.055) and FUBR (P=0.06), were significant or nearly significant at α = 0.05. While BOSP at α = 0.10 was found to be close to significance as well (P=0.105). Probabilities of joint occurrence for two cameras AUTR (P=0.5) and RATR (P=0.244) were not significantly different from expected probabilities.

Table 5. Reference table for wildlife and disturbance probabilities with corresponding expected and observed values for joint occurrence.

	n	pMam	pDist	pBoth	EV	OV
AUTR	78	0.961538	0.153846	0.147929	11.53846	9
BOSP	87	0.91954	0.172414	0.158541	13.7931	8
BOTR	120	0.741667	0.65	0.482083	57.85	47
FUBR	150	0.606667	0.813333	0.493422	74.01333	63
LIME	139	0.467098	0.861199	0.402265	60.33969	42
LISI	45	0.8	0.755556	0.604444	27.2	25
RATR	112	0.125	0.955357	0.11942	13.375	9

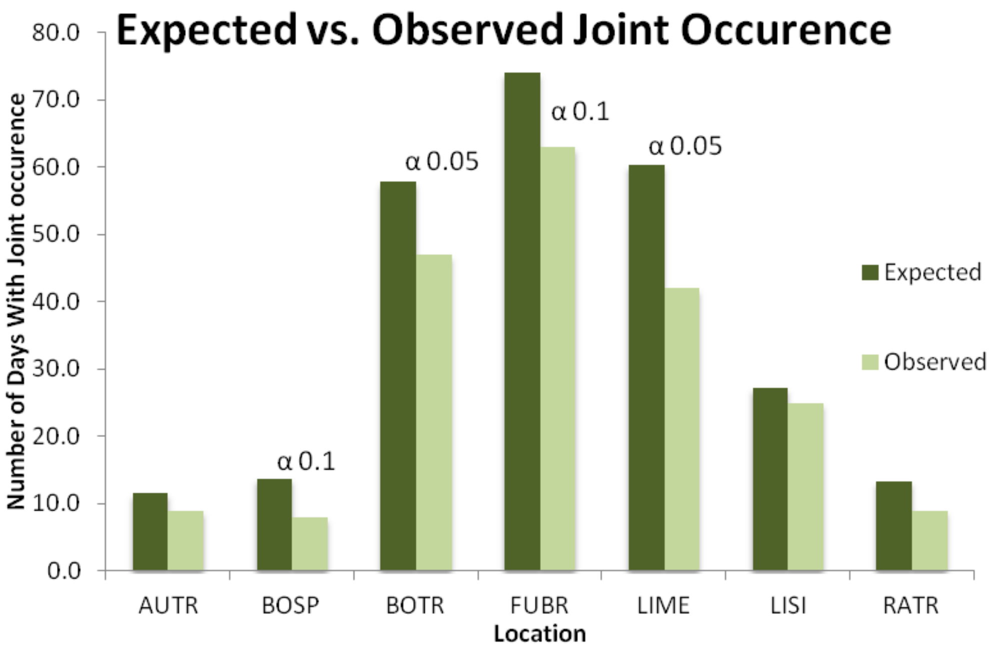

Figure 9. Expected vs. Observed Joint Occurrence. Expected (dark) in relation to observed (light) days of joint occurrence. Observed was ~significantly different for expected in BOSP, BOTR, FUBR, LIME camera locations.

Behavioral Shift

There was a notable shift away from daytime activity to nocturnal behavior on the night of an event day (Figure 7). G-tests were performed to assess significance for this shift (Table 2). Proportion of day to night activity for aggregated wildlife was significantly different during events compared to before and after events (G = 30.8309, Df = 2, P = <0.001). Proportions were significantly different (α = 0.05) for two of the four species assessed. While coyote (G = 4.5598, Df = 2, P = 0.102) and mountain lion (G = 5.7145, Df = 2, P= 0.057) were nearly significant, bobcat (G = 7.527, Df = 2, P= 0.0232) and deer (G = 21.604, Df = 2, P = <0.001) were significant. Individual species G-Test tables can be found in Appendices A3. The ratio of wildlife activity returned to pre-wilderness access day by the following day (Figure 8).

Table 4. G-test for total day and night wildlife activity relative to wilderness access days.
G Test: G = 30.8309, Df = 2, P = <0.001

	Pre	**During**	**Post**
Day	**434**	**40**	**402**
Night	**505**	**112**	**397**

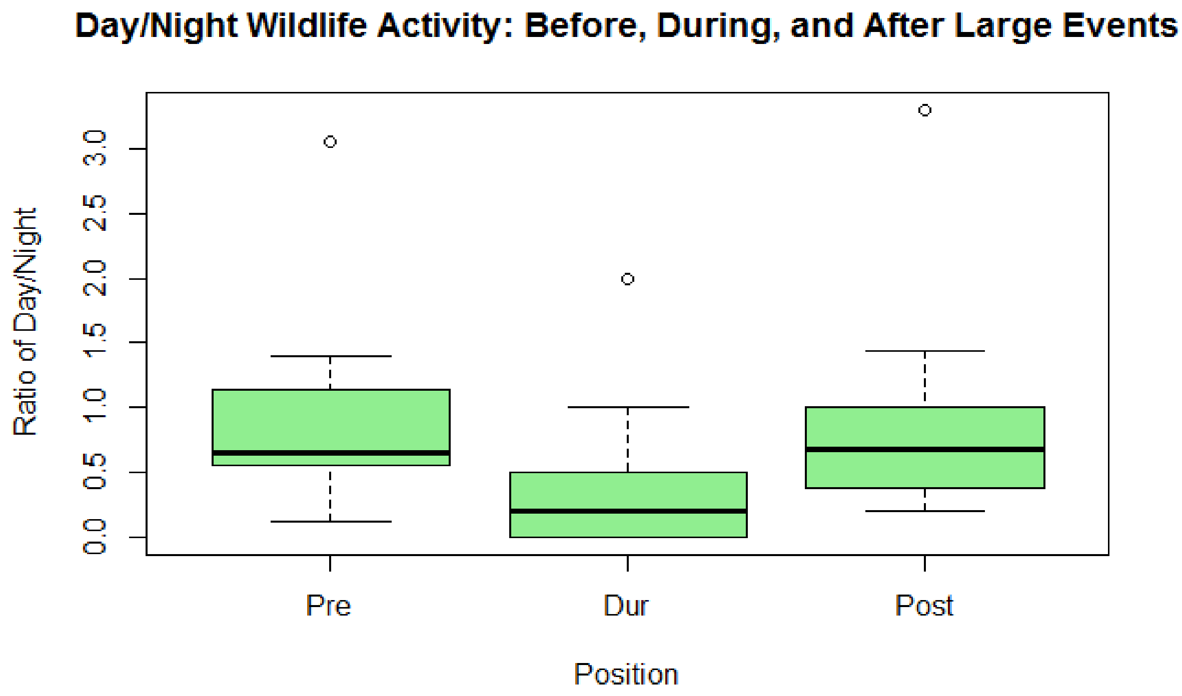

Figure 7. Day/Night Wildlife Activity: Before, During, and After large Events. The ratio of day to nighttime activity for wildlife relative to access days. Plots represent average activity across 14 events, all days, and 7 cameras.

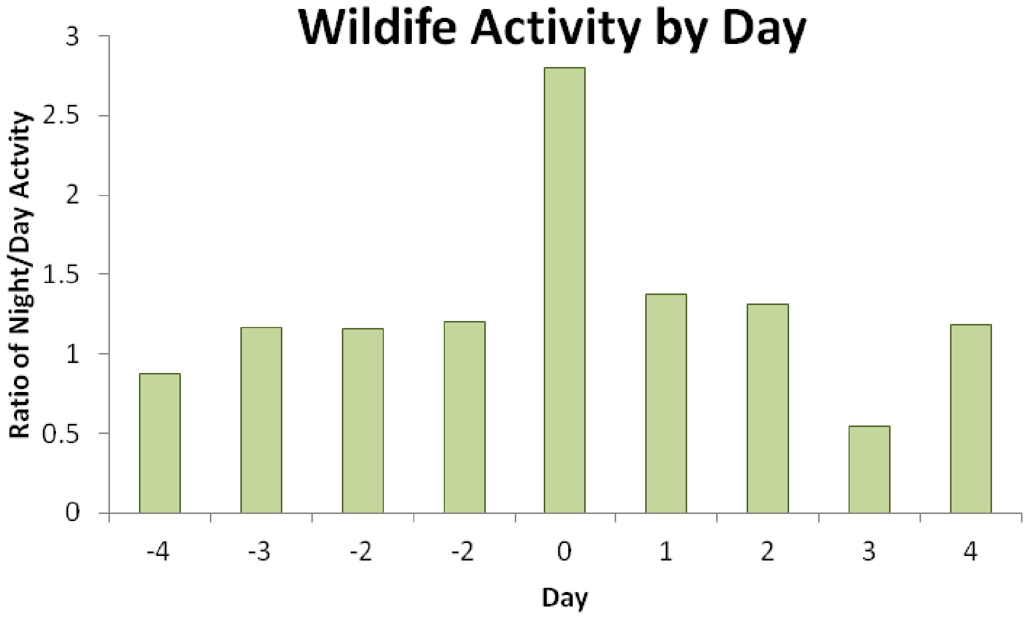

Figure 8. Wildlife Activity by Day. Average night/day wildlife activity by day relative to access days, Day 0 represents day of event. Columns represent summed activity across 16 events for each day

Discussion

Overall, the lack of wildlife response from the ANOVA tests and lack of association with the Mantel tests suggest either a level of habituation or that the effect of variability in activity across wilderness access days (which span several seasons and weather conditions) is greater than any wildlife response to human activity by wildlife in the reserve. Habituation defined by Whittaker and Knight (1998) is essentially that repeated stimuli lead to reduced responses. The ability to habituate to recurring or predictable human perturbations may be crucial for animals to thrive in the wildland-urban interface (George and Crooks 2006). These tests look at relationships on an average or aggregated level but the joint probability analysis assesses the full suite of data. It provides evidence that animals are being observed less frequently than expected on days that humans occur. This more nuanced analysis indicates there is clear degree of avoidance or fleeing occurring especially in locations near major roads, LIME and FUBR. It should be noted that there was also avoidance near water sources, BOSP and BOTR, which could have potentially detrimental impacts on wildlife health. The threshold or magnitude of this avoidance is not yet fully understood through this analysis. Georges and Crooks (2006) found similar results in which coyotes and bobcats had negative associations with human disturbances. Moreover, they found decreasing presence of deer with increasing recreational activity. In terms of the nocturnal shift, numerous studies have found urban wildlife such as coyote often have higher rates of nocturnal activity in an urban setting (Gehrt et al. 2010). This shift could impact forging, prey availability for carnivores and cause other metabolic stresses. It should be noted that the high ratio of nighttime activity returned to pre-wilderness day levels after the event, which indicates a fast recovery time for animal behavior which is a positive note. Nonetheless, the deeper associations found through joint probability analysis and nocturnal shift provide evidence of legitimate impacts on wildlife due to the dramatic increase of human activity during wilderness access days. On a specific species level, Deer seemed to have a more severe nocturnal shift. The canonical correlation expressed some negative association of wilderness days (through equestrian activity) on bobcat and mountain lion activity and vehicles on coyote activity.

Moving Forward

Due to the variety of stakeholders and contributors to the management of these lands, management necessitates a fine level of discretion and finesse. The notable nocturnal shift of wildlife on the night of events requires keen attention to trespassing and night time security as to insure no further disturbance. Another potential option is shortening the duration in which recreationalist are on the land. Similarly, managers should caution against extending the duration of activities into the late afternoon, evening or the pre-dawn period. Potential future evaluations could explore associations between duration of disturbance and wildlife behavior. It is clear that cameras near water access have higher rates of activity. Perhaps if a rotation was set up to avoid all locations being open at once for recreation, impacts could be reduced. Fortunately, animal activity and behavior post event seems to remain at similar levels as pre-event, which bodes well for the resilience of the reserve's wildlife. Although animals show no significant decrease in activity after events, it does not mean that increasing wilderness access days or allowing more people on the land will not lead to more severe impacts. Likewise, the three day rest period should be revisited for effectiveness. While the scope of these tests explore the immediate days before and after events, they do not necessarily reflect long term trends in wildlife population and behavior on the ranch. These results should be placed in context with overall trends of nocturnal activity and population abundances. The threshold for wildlife avoidance is still unclear, and the unique nature of the Irvine Ranch National Landmark commands respect for wildlife and habitat.

Acknowledgments

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Appendix A1

Table 1. Mantel wildlife matrix populated with average abundances for days across 16 wilderness access events. Day 00 represents the wilderness access day

	Day-5	Day-4	Day-3	Day-2	Day-1	Day00	Day01	Day02	Day03	Day04
AU TR	2.5	3.3125	3.4	2.875	2.3125	2.125	3.188	2.875	1.9375	1.875
BO SP	1.3125	1.0625	1.4375	1.5625	1.9375	0.875	1.4	0.8125	1	1.5625
BO TR	4.875	4.1875	3.75	5.1875	3	3.9375	4	5.125	4.125	3.125
FU BR	0.75	1.125	1.625	1.5625	1.125	0.6875	1.563	1.3125	1.1875	1.3125
LI ME	0.875	0.5625	0.3125	0.4375	0.875	0.5625	0.938	0.3125	0.4375	1.0625
LI SI	2.25	3.5	5	2.5	2.75	4.5	4.5	3	3.5	2.5
RA TR	0	0.125	0.625	0.125	0.125	0.1875	0.063	0.0625	0	0

Table 2. Mantel pedestrian matrix populated with average abundances for days across 16 wilderness access events. Day 00 represents the wilderness access day

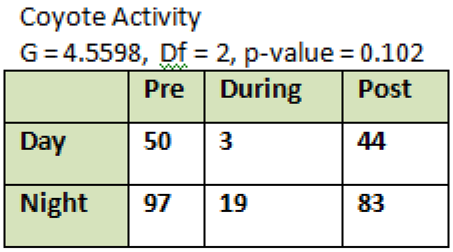
	Day-5	Day-4	Day-3	Day-2	Day-1	Day00	Day01	Day02	Day03	Day04
AU TR	0	0	0	0.5625	0	0.125	0	0	0	0
BO SP	0	0	0	0.4375	0	0	0	0	0	0
BO TR	0.0625	0.313	0.375	1.3125	0.625	12.063	0.375	0.063	0.3125	0.125
FU BR	0.625	10.13	0.375	1.25	0.875	47.688	6.125	0	7.4375	0.0625
LI ME	0.625	0	0.125	2.0625	0.563	122.06	2.6875	0	0.1875	0.75
LI SI	0	0.5	3.5	5	0.75	185.5	0.75	0	0	0.75
RA TR	0.125	0.5	1.875	2.625	0.625	76.625	2.3125	0.438	0.4375	0.5625

Appendix A2

Table1. Average Pedestrian Activity by Day

Day-5	Day-4	Day-3	Day-2	Day-1	Day00	Day01	Day02	Day03	Day04
0.23	**1.77**	**0.585859**	**1.52**	**0.46**	**48.79**	**1.87**	**0.08**	**1.34**	**0.27**

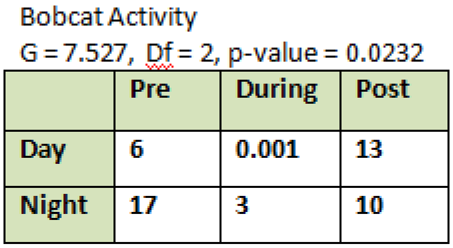
Appendix A3



Coyote Activity

G = 4.5598, Df = 2, p-value = 0.102

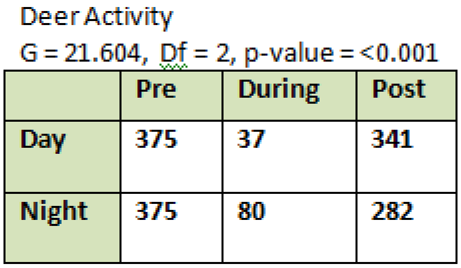
	Pre	During	Post
Day	**50**	**3**	**44**
Night	**97**	**19**	**83**



Bobcat Activity

G = 7.527, Df = 2, p-value = 0.0232

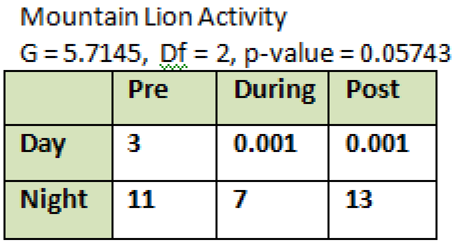
	Pre	During	Post
Day	**6**	**0.001**	**13**
Night	**17**	**3**	**10**



Deer Activity

G = 21.604, Df = 2, p-value = <0.001

	Pre	During	Post
Day	**375**	**37**	**341**
Night	**375**	**80**	**282**



Mountain Lion Activity

G = 5.7145, Df = 2, p-value = 0.05743

	Pre	During	Post
Day	**3**	**0.001**	**0.001**
Night	**11**	**7**	**13**

The Urban Edge: Ecological Light Pollution within the City of Irvine Open Space Preserve

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Summary

The urban edge and light pollution can play a major roll affecting animal behavior within natural preserves. The open spaces within coastal Orange County are an excellent location to study this interaction. We examined remote sensing, light modeling, and field measurements as a way to create spatial light pollution data. We found that lighted roads are the most significant source of light pollution and that streetlight penetration models are superior to satellite imagery in creating a spatial layer. Skyglow and the marine layer play a big part in elevating illumination farther from the edge. Lastly, we created a raster file that uniquely incorporated street light p enetration modeling, topography, vegetation cover, and skyglow from field measurements. This information can be used in association with wildlife movement patterns and raptor nesting behavior to better understand how light pollution effects animal behavior from a spatial perspective.

Introduction and Background

Human development encroaches on many of nature's open spaces, creating an edge along the urban-wildland interface. Edge conditions along this interface, such as degraded habitat, noise, and urban runoff, play a big role governing the behavior of organisms that live along the edge (Fagan et al 1999). Another effect of human development related to the edge is artificial light pollution through the increasing use of high-powered electric lights.

Artificial light permeates nearly everywhere mankind can be found (Cinzano et al 2001). Most often, light pollution refers to a diminished ability to observe the cosmos (Reigel 1973). However, there is a growing field of literature that reveals how light pollution affects animal behavior and has been dubbed ecological light pollution (Longcore & Rich 2004). Well known examples of animal behavior affected by light pollution include sea turtle hatchlings becoming disoriented by beachfront lighting (Salmon et al 1995), and moths being attracted to lights (Frank 1988). Furthermore, ecological light pollution can be split into two categories: glare and ambient light. Glare constitutes a point of light that doesn't necessarily increase the brightness around an organism, but is recognizable, such as lighted structures attracting migrating birds (Ogden 1996). Ambient light is the light of organisms' surroundings and can alter behavior such as frog mating patterns (Rand et al 1997) and rodent foraging behavior (Lima 1998). In this study, we will refer to light pollution as artificial ambient ecological light pollution. Even minimal levels of light pollution are able to have a drastic effect on animal behavior. The lunar cycle plays an important role in governing much animal behavior (Zimecki 2006), indicating that many animals are sensitive to illuminance fluxes between 0.01 (quarter moon) and 1.0 lux (full moon). For reference, a sunny day exceeds 10,000 lux. Among open spaces neighboring human development, light pollution is one important component of edge effects and as such, presents its own challenging characteristics. Urban open spaces are important because they provide refuge amongst shrinking habitats for nocturnal animals (Gaston et al 2015) and serve as wildlife corridors (Bennie et al 2014).

Most ecological light pollution studies rely on highly controlled environments rather than on measuring natural or artificial light levels out in the field; however, there are several studies that have examined spatial light pollution from other sources. These can be separated into studies that have utilized remotely sensed satellite imagery or created light distribution models. There are three main sources for remotely sensed satellite data: The Defense Meteorological Satellite Program's Operational Linean System (DMSP-OLS), the Suomi National Polar-orbiting Partnership's Visible Infrared Imaging Radiometer Suite (VIIRS), and the International Space Station (ISS).

Satellite Imagery

The DMSP is operated by the Department of Defense and monitors earth-systems. The OLS instrument collects relative data ranging from 0-63 rather than absolute values and must be converted to radiance (Elvidge et al 1997). The resolution is 0.9km, contains cloud-free images, and is made available by NOAA's Earth Observation Group (EOG). The DSMP-OLS has been used in studies including nightlight dynamics and distribution in national parkland (Gillespie 2016) and marine ecosystem health (Aubrecht et al 2009, Aubrecht et al 2010). The VIIRS provides radiance data based on visible and infrared radiometric measurements. The EOG provides a VIIRS DNB Cloud-Free Composite with a resolution of 742 meters. VIIRS data is considered superior to DMSP data because it has higher spatial detail, superior range, and reduced urban saturation (Elvidge et al 2013), and has been used in studies such as estimating Earth's albedo (Wang et al 2013). ISS imagery has been made easier with the implementation of the European Space Agency's Nightpod camera mount, which is able to account for the satellites orbital velocity when taking long exposure night pictures. ISS images have no units; rather each pixel has an accompanying digital number. Resolution is approximately 50 meters. Images are available through the Gateway to Astronaut Photography project and have been used to correlate nighttime lights with socio-economic trends (Levin & Duke 2012) as well as sea turtle nesting concentrations (Mazor et al 2014). Additionally, there is a fourth source that can be utilized: EROS-B high resolution night time imagery, whose resolution can be below 1 meter. This is derived from a commercial satellite and is not available to the public (Levin et al 2014).

Modeling

While convenient, remotely sensed satellite imagery is not high resolution and captures light that is directed skyward. Light modeling is therefore another possible approach to measuring ecological light pollution. Light models utilize a DEM or DSM constructed from LiDAR data and designated light sources to simulate how light moves through study area. A key component of light modeling is the inverse square law which explains that light intensity decreases by the square of the distance from the emitting source. Light modeling studies often have to make simplifying assumptions, such as only examining streetlights (Bennie et al 2014), so therefore need to be validated with field measurements. However, the high resolution of the

Bennie et al 2014 model allowed the authors to apply their study to ecological processes by simulating the potential migration patterns of photophobic bats.

Simple light models have a difficult time incorporating varying sources of light that are very relevant in the urban-open space interface including motor vehicle lights, dynamic light schedules, and skyglow. Skyglow refers to the scattering of urban light in the atmosphere back to the surface. It can play a big role in elevating illuminance levels far from the urban edge, and cloud cover can play a big role in amplifying these effects (Kyba et al 2011). Attempts to model skyglow have been made, although the process is quite difficult (Chalkiaas et al 2006, Duriscoe et al 2014).

Here, we focus on a wildland surrounded by human development and explore light pollution along the urban edge. We compare remotely sensed data (VIIRS low resolution and ISS high resolution) and a light model against field data to examine correlations. Then we assemble a spatial light pollution layer that integrates these aspects. This layer could be used in future studies with spatial animal data, such as USGS data on bobcat home ranges.

Materials and Methods

Study Area

The Cities of Irvine and Newport Beach in Orange County, California both contain designated nature reserves surrounded by urban development. The study area includes two natural areas in Newport Beach: Big Canyon and Buck Gully. The study area also includes the Irvine Open Space Preserve Southern portion, which constitutes Bommer Canyon, Shady Canyon, and Quail Hill (fig 1). All aforementioned areas are managed by the Irvine Ranch Conservancy for science and recreation purposes. Bordering Shady Canyon is a segment of the Laguna Canyon Wilderness Park, which is managed by Orange County Parks. The study area consists of a Mediterranean climate, an active marine layer, rugged hills, and a variety of vegetation regimes including grasslands, chaparral, sage scrub, riparian woodlands, and hilly complexes. These areas are surrounded by either residential development or roadways. Of note, Buck Gully, Bommer Canyon, Shady Canyon, and the Laguna Canyon Wilderness Park are part of the Natural Community Conservation Planning (NCCP) for Orange County and contain a variety of fauna including bobcats and coyotes. The interplay between open space and development make this area an ideal location to study.

Satellite Imagery and Model Data Sources

We used two sources for remotely sensed satellite imagery: VIIRS DNB (low resolution) and ISS (medium resolution). The VIIRS DNB cloud free composite data was downloaded through NOAA's Earth Observation Group from http://ngdc.noaa.gov/eog/viirs/download_monthly.html for March 2016. In Orange County, pixel values ranged from 0.32 (Cleveland National Forest) to 244.22 (Disneyland) in radiance. The spatial resolution was 750 meters, and the image was already georeferenced. The ISS image (ISS030-E-63284 was taken on January 30, 2012 at 07:50:37 GMT (00:50:37 Local Time) by astronauts with a Nikon D3S camera. It was acquired through the NASA Johnson Space Center's Earth Science and Remote Sensing Unit at https://eol.jsc.nasa.gov/. In Orange County, the image consists of digital numbers ranging from 0 to 255 with a spatial resolution of approximately 68 meters (fig 2).

For the model, a high resolution airborne light detection and ranging (LiDAR) layer for Orange County was obtained from the U.S. Geological Survey. The data were collected by Dewberry corporation from December 17, 2011 to February 9, 2012. The LiDAR was converted into a detailed surface model (DSM) in ArcGIS with a resolution of 1 meter. DSM maps landscape surface at the height of existing vegetation.

Streetlight data were obtained from Southern California Edison through the City of Irvine's Department of Public Works. This dataset included street light GPS coordinates for each streetlight as well as light intensity information, which ranged from 5,8000 lumens to 30,000 lumens. These locations were loaded into ArcGIS, and street lights farther than 50 meters from the edge were clipped and removed. Height information was unavailable, so it was assumed each light was at 8 meters. The data set did not include data from the 73 toll road, the I-405 bike path alongside Quail Hill, and the residential communities of Turtle Ridge and Shady Canyon. Streetlights for these locations were designated using an aerial provided by NearMap® with a resolution of 7.5 cm and were assigned light intensity values based on similar light sources from the City of Irvine data.

Model Description

Preliminary observations along the edge and within the interior of the City of Irvine Open Space indicated two primary light sources affecting the reserve: 1) street lights along roads and 2) skyglow. Lights from residential units played limited role in increasing illuminance, although residential lights were recognizable as glare.

These initial observations informed the creation of the light penetration model in ArcGIS v10.3. Several assumptions were made. First, only streetlight locations within 50 meters of the edge were considered as light sources, which is similar to comparable light penetration studies (Bennie et al 2014). Moonlight, car headlights, light reflection off surfaces, skyglow, residence lights, and other sources of artificial lighting were not considered. Other studies have attempted to model the skyglow (Chalkias et al 2006), but this study lacked the resources. Each street light was assumed to be 8 meters in height, spherical, and emit light uniformly in all directions. The intensity of the light was assumed to decrease with distance according to the inverse square law— therefore, at location d meters from the light source of intensity i lumens, the modeled lux values from an individual light would be $\frac{i}{4\pi d^2}$. The total lux value of that cell would be the sum of the lux values from each individual light. The DSM informed the surface locations where direct light contacted. Vegetation height informed the direct light contact, but was not further factored into the model as an attenuator of light. A vegetation multiplier coefficient could further be applied based on the data available to the Irvine Ranch Conservancy to simulate reduced illumination levels in areas of dense vegetation.

Model Workflow in ArcGIS

In ArcGIS v10.3, the point shapefile of streetlights was parsed into 299 individual point shapefiles using the U.S. Geological Survey's *split by attribute* tool (Fox 2015). In ArcGIS' model builder, each of these points was fed into the light distribution using the *feature iterator* tool. For each point, two rasters were calculated. The first was a viewshed from that point using the DSM. The *viewshed* tool returns values of 1 (visible from point) and 0 (not visible from point). This raster was multiplied by the Lumens field via the *get values* tool. The second was a raster containing the distance from the light source to each raster cell. Distance along a flat plane was calculated using the *Euclidean distance* tool. Each streetlight was assumed to be 8 meters tall, so this value was added to distance using the *sum* tool.

Both of these two rasters were clipped to the edge boundary for the Irvine Open Space. Because the streetlights were assumed to emit light uniformly in all directions and the light intensity was assumed to decrease according to the inverse-square law, the overall lightshed intensity of each street light was calculated using the Math Toolbox to be:

$$\frac{viewshed\ raster}{4\pi(distance\ raster)^2}$$

A lightshed raster was calculated for all 299 light sources, and then summed together using the *cell statistics* tool to obtain the overall modeled light pollution layer for the Irvine Open Space (fig. 3 & fig. 17)

Field Measurements

Night light surveys were conducted in order to validate the satellite imagery and light model. Point measurements were taken with the ExTech LT300® Light Meter (range: 40.00 lux, 400.0 lux, 4000 lux, 40.00klux, 400.0klux, for sensitivity see fig. 5), with a resolution of 0.01 lux. Measurement locations were determined using the *random point generator* in ArcGIS. The number of measurements per edge type (residential vs road) is proportional to the length of the edge type. Measurements were taken in Big Canyon, Buck Gully, and the City of Irvine Open Space Preserve. Measurements were taken 5 m from the edge and were gathered 45 cm above the ground to simulate the height of a bobcat's eyes. Measurements were taken in five directions: toward the lighted edge, away from the lighted edge, to the left, to the right, and up towards the zenith. In select lighted areas, we performed transect sampling, and moved set intervals into the preserves to examine how light decayed with distance. Cloud cover was noted for each sample. In areas of vegetation, samples were collected above and within the vegetation. Surveying took place from August 1, 2016 to August 5, 2016 from 10:00pm to 12:30am local time and corresponded with the new moon and no moon cycles to avoid moonlight effects. Additionally, light sensor loggers were set up in multiple locations to examine how the light levels change throughout the night. These loggers use the ISL29033® light sensor (for sensitivity see fig. 6) that ranges from 0.0019 to 8,000 lux. At each location, the two loggers are set up in different directions to gauge directional differences in illumination. Supplementing the loggers are trial DSLR images that pick up light levels and glare with different exposure times (Duriscoe et al 2015). This technique is not used in our analysis because the camera needs to be calibrated first.

A total of 62 point samples, 20 transect samples, and 3 logger samples were gathered.

Units of Measurement

The VIIRS data, ISS image, and model each output different units of light measurement. The VIIRS data's units are radiance ($W \cdot sr^{-1} \cdot m^{-2}$). The ISS image's unit is the digital number which describes the pixel value without any calibration. The model's units are lux, which is the SI unit for illuminance- illuminance is equal to the amount of lumens (luminous flux) per square meter. Converting between lux and other digital numbers or radiance is impossible without the specific spectrum, and converting between digital numbers and radiance relies on the equation described in Elvidge et al 1997. Here, the values are analyzed on a relative scale.

Statistical Analysis and Spatial Correlation

The coordinates of each sample location were uploaded into ArcGIS. For each location, the raster values of the VIIRS image (radiance), the ISS image (digital numbers), and the light model layer (lux) were extracted and then exported. The correlation between the field measurements and each layer were evaluated using Pearson's r and Spearman's rank correlation. The lux values from the logger sensors were graphed to visualize change throughout the night. Boxplots were constructed to visualize the differences between lux sensor directions and edge type. A t-test was performed to look at significant difference between light pollution by edge type.

All statistics and graphing were done in R Studio v.3.3.1, Microsoft Excel 2007, or JMP Statistical Software.

Integration

The light model plus the field measurements will be integrated into one entity. There are two main categories of flaws in the light model based on the preliminary observations of street lighting being the primary source of light pollution into the reserves: 1) lights that are unaccounted for in the model and 2) sky glow. There are two places where lighting information was inaccurate: along I-405 where there is a significant amount of ambient light due to car traffic despite an absence of freeway lights, and at the intersection of Route 133 and Lake Forest Drive on the eastern boundary where a flaw in the DSM (discussed later) prevents light penetration simulation through the *viewshed* tool. These were corrected in the integration by: 1) running a regression against the field observations for the area, 2) performing a buffering sequence at different intervals (2 meters, 5 m, 10 m, 25 m, 50 m, 100 m, 200 m, 400 m) from the light source based on field data, and 3) applying the values from the regression to each interval. This process does not take into account the DSM. Skyglow was also incorporated into the integration via field measurements. Skyglow is ubiquitous yet highly variable, and so best case scenario (no marine layer) and worst case scenario (dense marine layer) were presented based on field observations. The best case scenario was created by adding 0.01 to each pixel of the layer, based on the lowest lux reading achieved at an interior location on a non-marine layer night. The worst case scenario was created by adding 0.06 to each pixel of the layer, based on the highest lux reading achieved at an interior location on a thick marine layer night (fig. 11). Important note: all statistic analyses were performed on the modeled light pollution layer, and not on the integrated light pollution layer.

Results

Field Data

Upon initial examination of the field data, there was an obvious trend towards lighted roadways being the largest contributor to light pollution along the wild land's edge (fig 7). When the direct lux readings from along the lighted roadways (n = 17) was compared with the direct lux readings from along the residential edge (n = 21), there was a significantly greater amount of light penetration along the lighted roadways (t = -2.26, p = 0.038. While no significant differences existed between middle of the preserve, residential, or unlighted road readings, nor between the direct, up, or away readings, there was a noticeable trend that the direct light readings towards the residential and the non-lighted roads are actually lower than the away light readings. Street light penetration affected the reserves at magnitudes of 10 lux, while the skyglow affected the reserves at magnitudes of 0.1 lux. Additionally, the transect data shows how light decays farther into the reserve (fig. 12).

Modeled Light Pollution Raster

The light pollution model took 34 hours to run and created a raster file with 1 meter resolution (fig 9). Values range from 0 to 55.13 and correspond to lux. This light model only examined areas lighted by street lights; subsequently, the highest lux values fall along the edges where street lights occur. At the top of the image the area along I-405 remains dark in the model despite car presence, and the area beside the western most survey position is dark despite the presence of bright LED lights due to a flaw in the DSM. Along Route 133 at Forest Road Dr., the LiDAR that was used to create the DSM picked up high elevation electric wires; thus, the DSM simulated a barrier along the area and prevented simulated light penetration. These two issues are addressed in the model integration.

Correlations between Remote Sensing and Model

Using a linear correlation, statistically significant trends were found only between the observed values and the modeled value (Pearson's r = 0.607, p < 0.001), while no trends were found between the ISS digital numbers and the observed values (Pearson's r = -0.096, p = 0.43) nor the VIIRS radiance and the observed values (Pearson'r r = -0.096, p = 0.44). Using

Spearman’s rank correlation, statistically significant trends were found between all three variables and the observed data. The ISS data (Spearman’s rho = 0.533, $p < 0.001$) and the VIIRS data (Spearman’s rho = 0.417, $p < 0.001$) exhibited moderate correlations to the observed data, while the modeled data exhibited a strong correlation to the observed data (Spearman’s rho = 0.855, $p < 0.001$). These comparisons are visualized through scatter plots (fig. 9.)

Light Sensor Loggers and Digital Photography

The light sensor loggers clearly show changes in lux levels throughout the night as well as increases in light pollution when the marine layer rolls in (fig. 10). They also show that different angles of the sky have different illumination levels, which is reflected in the DSLR photography (fig. 16)

Model Integration

The integrated model’s light pollution edge layer is essentially the same as the light pollution layer, but with higher baseline lux values (no zero values) and increased light along I-405 and the Route 133-Lake Forest Dr. intersection (fig. 11).

Discussion

Edge effects and light pollution are important aspects of the urban wildland interface (Fagan et al 1999, Longcore & Rich 2004) and are important for land managers to consider. Our field data clearly indicates that the largest source of light pollution along the wild land edge occurs at streetlight locations, similar to what other spatial studies have found (Kuechly et al 2012). Greater light intensity along the edge corresponds with farther light penetration into the preserve (fig. 12). Furthermore and perhaps more surprisingly, our field data reveals that nearly the entire preserve exhibits illuminance of at least 0.01 lux during the new moon, which is the amount of illuminance under a quarter moon with natural conditions (fig. 13). The only locations that reach below 0.01 lux are densely vegetated willow groves and riparian areas. This is the result of the neighboring urban area's skyglow and prevents any part of the preserve from reaching natural new moon illuminance levels. Based on readings from Bommer Canyon, Shady Canyon, and the Lux Loggers, the marine layer plays a significant impact on skyglow effect (figures 10.). Skyglow values range from 0.01 (no marine layer) to 0.22 (heavy marine layer, reading taken along Quail Hill) (fig. 14), which is why the integrated model has both a best case and worst case scenario. For the worst case scenario, a skyglow value of 0.06 lux was used because that was the highest illuminance reading from an interior location receiving no direct illumination. While many light studies ignore the marine layer, these findings indicate that it is an important feature of light pollution in coastal systems.

Interestingly, the readings from our Lux meter pointed directly at the residential edge indicated slightly lower illuminance levels than pointing the Lux meter away. The most likely reason for this is that the away readings are gathering sky glow measurements, while the residential houses: A) have minimal lighting along their backside and B) are blocking the sky glow effect in the direct measurements. This trend has been noted in previous studies on sea turtles (Salmon et al 1995) and suggests that the current management strategy to reduce light penetration along residential edges is effective at reducing light pollution. Management methods could include encouraging responsible residential lighting and increasing light barriers along the edge (such as with walls or vegetation).

Buck Gully and Big Canyon were not used in the spatial analysis but were included in the edge type comparison. Data from these locations gave additional insights. Both locations had several singular lights within residencies that illuminated a large area; these light sources actually illuminated areas farther from the edge than closer to the edge because of the steep canyon walls of both areas. Yet, the trend of lower light levels facing towards residential houses held true. Separately, Big Canyon was sampled on the only night with 0% marine layer. For an area with high urban density, the readings were relatively low because of the marine layer absence. Still, lux levels from the horizon across Newport Bay provided the highest readings due to skyglow.

From a spatial perspective, our tests show the light model layer is a much more effective method to analyze spatial data than satellite imagery. The light model is imperfect for a variety of reasons, the biggest of which is that it does not take into account skyglow, which has been modeled in previous studies (Chalkiaas et al 2006). This discrepancy can be noticed in the analysis. In the correlation between the observed values and the modeled values (fig. 9), there are a large number of values at the bottom of the graph that do not correlate well. This cluster of 0.01 values for the modeled lux values correspond to a range of 0.08 to 0.15 observed sum lux values, and show that the model breaks down when the observed values get below 0.1 lux. This is because the biggest contributor to illuminance in these locations (no direct light source) is skyglow. This is significant because these differences in illumination (0.01 to 0.1) are important to many animal behaviors (Zimecki 2006). Incorporating sky glow into the model would alleviate this discrepancy, and here is done during the model integration (see below). The model still does a stellar job simulating high levels of light pollution along the edge that could affect both diurnal and nocturnal animal behavior.

Additionally, the model only examines streetlight data while ignoring other types of point light sources such as car lights (such as the continuous stream of car lights along I-405) and sporting structures. Furthermore, specifically for the City of Irvine Open Space Preserve, the DSM used to perform the viewshed analysis was flawed along Route 133 at Forest Road Dr. The LiDAR that was used to create the DSM picked up high elevation electric wires; thus, the DSM simulated a barrier along the area and prevented simulated light penetration. Fortunately, this only affected one light source. Additionally the *Euclidean distance* tool is imperfect because it traces distance along a flat plane. In reality, the landscape is dynamic, and decay of light depends on the elevation and the Pythagorean Theorem. Finally, most light sources do not emit light equally in all directions, but rather emit light in a downwards direction. Southern California Edison did not provide this information.

Despite these flaws, the light model performed considerably better in predicting observed lux values than the remotely sensed images. The light model had a moderate correlation with the observed values using Pearson's product-moment correlation and a high correlation using Spearman's rank correlation. The ISS image and the VIIRS data had no correlation with Pearson's product-moment correlation and a low correlation using Spearman's rank correlation. There are two major reasons for these results. First, the light model has a much higher resolution (1 meter) compared to the ISS (68 meters) and the VIIRS (750 meters) which allows the values to be more precise. Secondly, the remotely sensed data only indicates upwardly directed light and does a poorer job at representing spatial illuminance. These results question the effectiveness of using satellite imagery when studying fine-scale spatial animal behavior.

The integrated model addresses the skyglow and missing light issues to create a more accurate light pollution layer. This layer is important because it can be used in future spatial studies. In the Irvine Open Space Preserve, bobcats (*L. rufus*) and coyotes (*C. latrans*) are important mesopredators. Previous studies have found that both animals' behavior depends on lighting levels, as bobcats move and coyotes howl at higher frequencies at specific lunar illumination levels (Bender et al 1997, Rockhill et al 2012). Future studies could utilize the light pollution edge layer in a spatial analysis that analyzes bobcat and coyote behavior in areas with different lighting regimes (fig. 15) or examine wildlife corridor effectiveness (Benny et al 2014).

Such studies would especially be valuable if they could, for example, help inform the City of Irvine's impending construction of a wildlife corridor along the southern portion of the great park. Furthermore, the Irvine Ranch Conservancy has spatial raptor nest data that could be overlaid on the light pollution layer to examine raptor nesting preferences.

Future edge studies could examine many aspects, but two useful ones could be: 1) to see how sound, which has a larger effect along roadways, contributes to the edge effect, 2) utilize the DSLR cameras (fig. 16) to better incorporate skyglow into the integrated model.

Management Implications

The results of this study also indicate an important distinction between urban wildland management and rural wildland management. Along the urban interface, the biggest source of artificial light is direct streetlight illumination. However, in wilderness areas such as the Grand Canyon, the biggest source of artificial light is indirect sky glow from distant human development (Duriscoe et al 2015). In urban wildlands, unshielded light sources can influence animals by increasing both illuminance and glare. Solutions could be barriers of some sort, such as walls or vegetation. Also, implementing bulbs with lower power could prevent light from penetrating as far into the preserve. Reduced lighting on the edge could increase the amount of habitat available to the native nocturnal species. Additionally, light pollution levels could be an interesting parameter to help guide restoration strategy locations.

Acknowledgements

Special thanks to my internal advisors Jutta Burger and Yi-Chin Fang, my external advisors Travis Longcore, Erin Boydston, and Michael Patten, and my field crew Daniel Vise and Maegan Blansett.

Figures

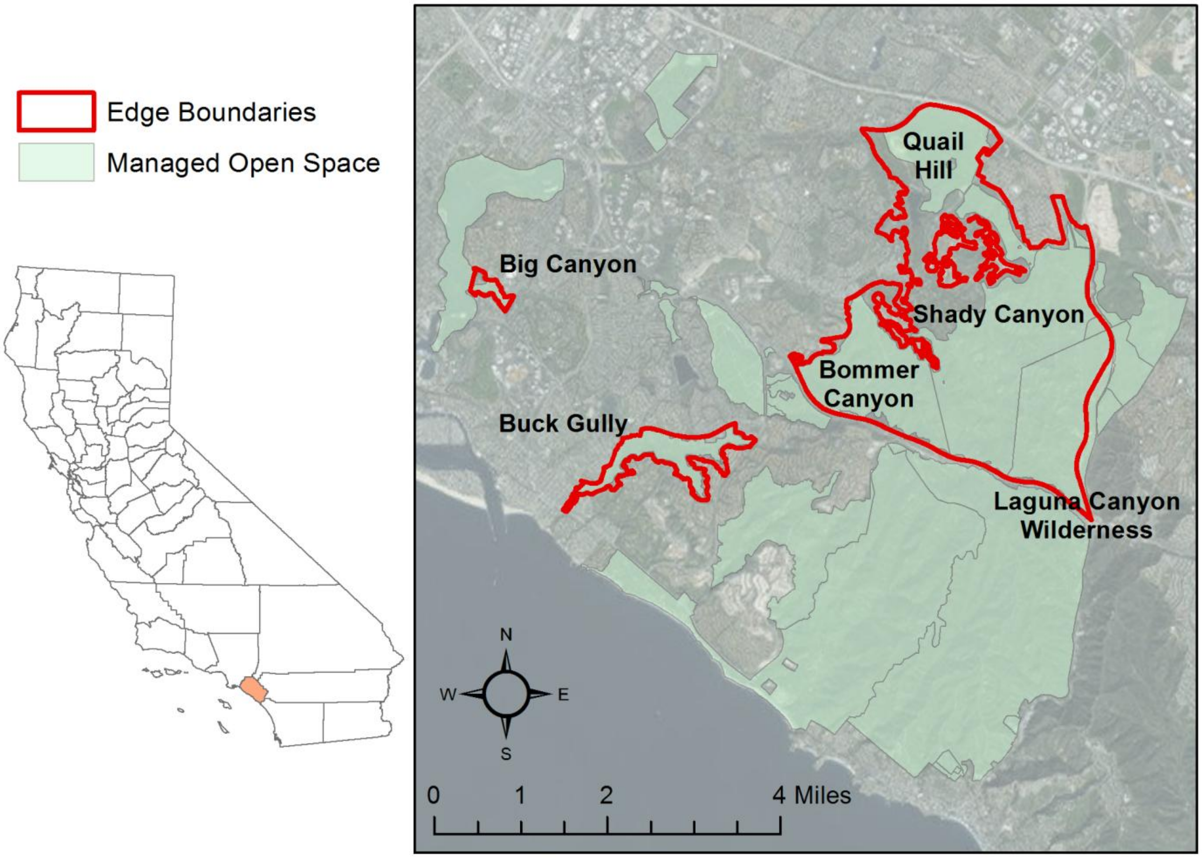


Figure 1. Study Area within Orange County, CA. Field sampling occurred in Big Canyon, Buck Gully, Quail Hill, Shady Canyon, and Bommer Canyon. The model included all areas bordered in red.

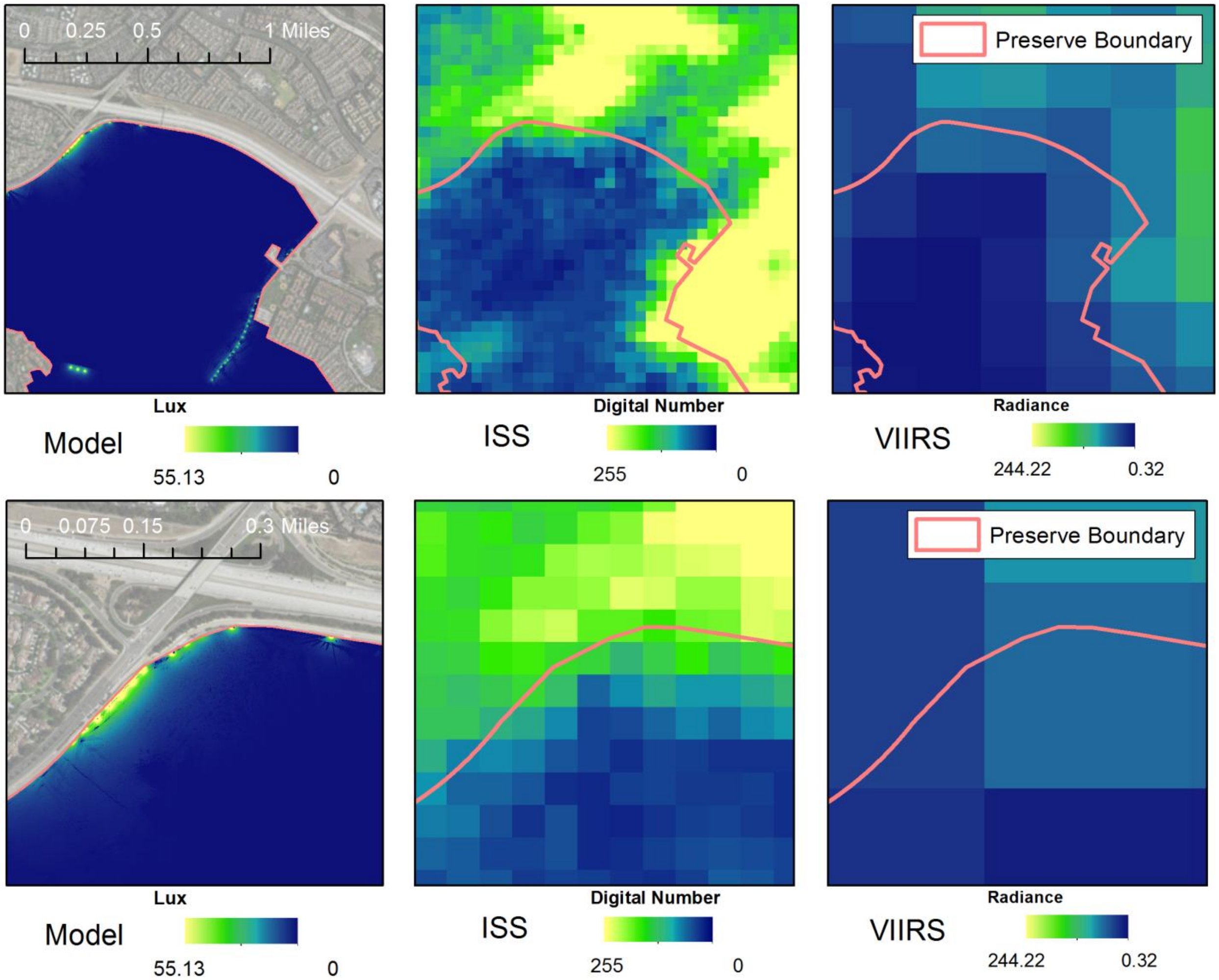


Figure 2. Resolution comparison between model output, ISS, and VIIRS at Quail Hill zoomed at two different levels. The model output has a resolution of 1 meter, the ISS image has a resolution of about 68 meters, and the VIIRS data has a resolution of approximately 750 meters.

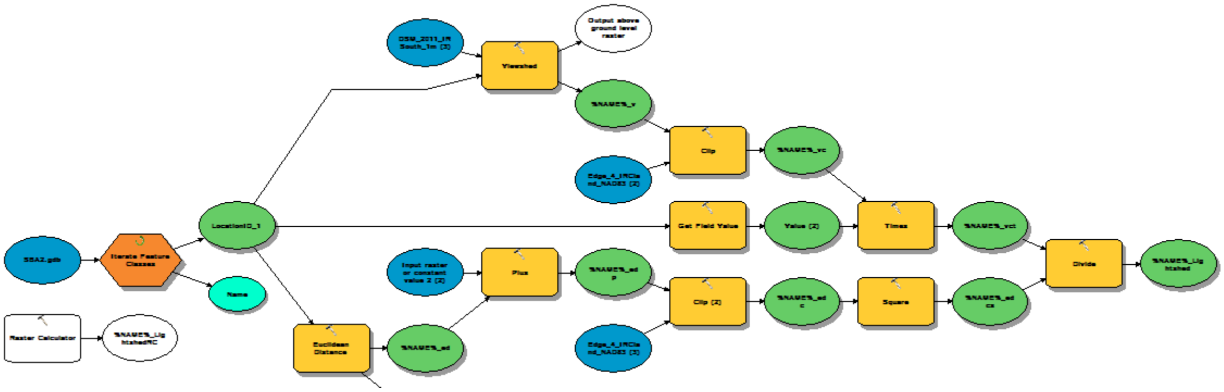


Figure 3. Example of the model workflow in ArcGIS' Model Builder. The actual model is available on IRC's database.

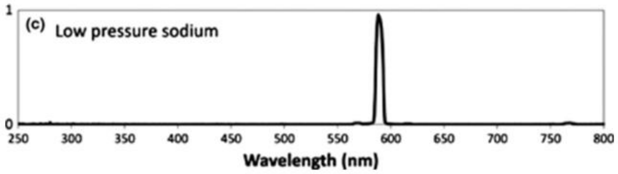


Figure 4. Light spectrum of low pressure sodium streetlights, most common in the study area.

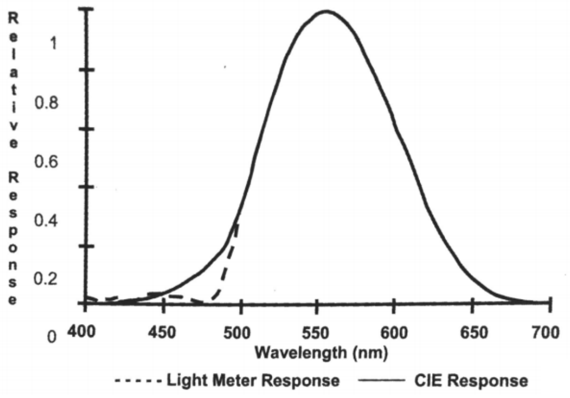


Figure 5. Spectral sensitivity of the ExTech LT300® compared to the luminosity function (spectral sensitivity of the human eye) as established by the International Commission on Illumination (CIE).

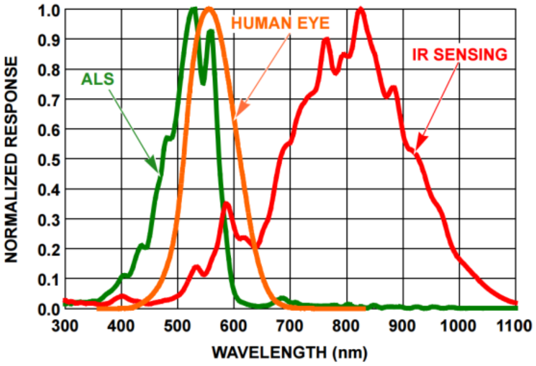


Figure 6. Spectral sensitivity of the ISL29033® light sensor (ALS) compared to the luminosity function.

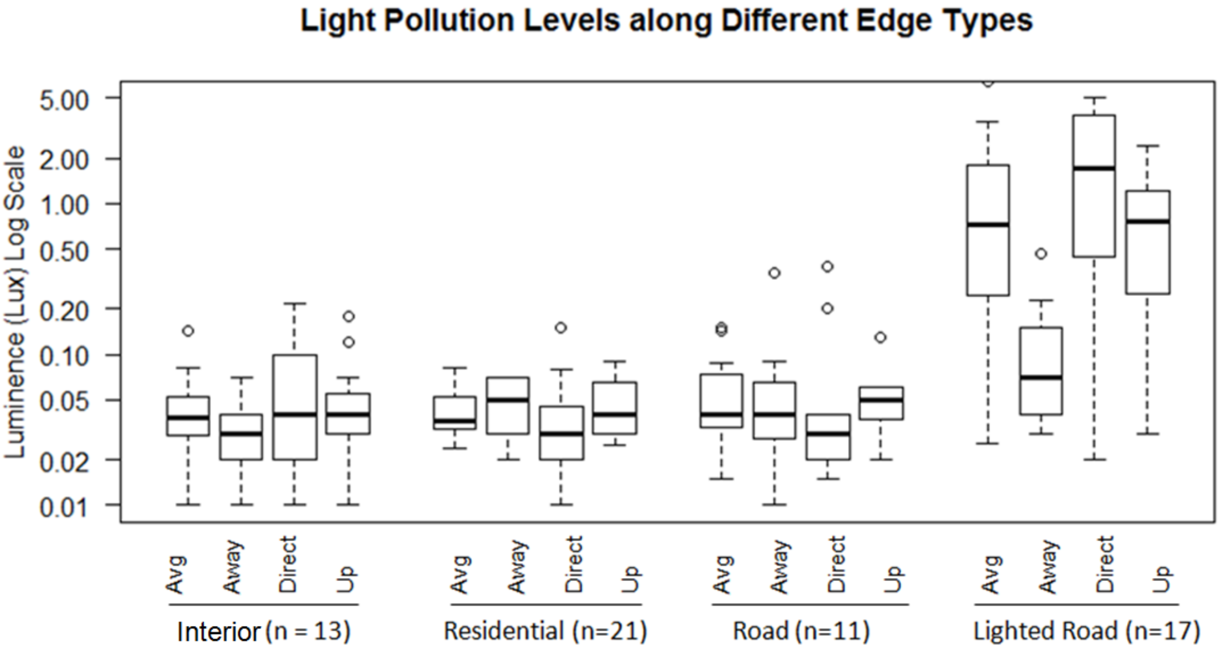


Figure 7. Light pollution readings (Lux) 5 meters from the edge, for different edge types and directions. The dark line is the median value, the edges are the first and third quantiles. Circles represent outliers. Not pictured are several outliers for the lighted road.

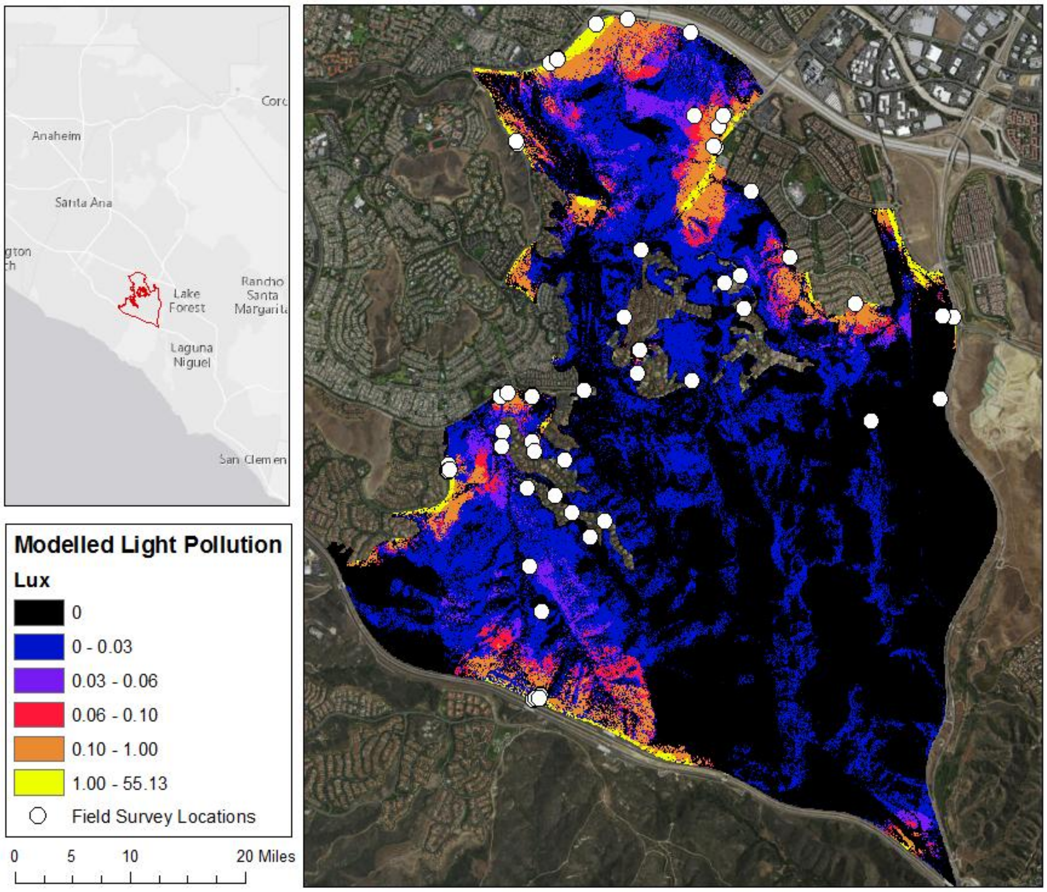


Figure 8. Results of light pollution modeling based on streetlights for the City of Irvine Open Space preserve incorporating Bommer Canyon, Shady Canyon, Quail Hill, and a portion of Laguna Coast Wilderness Park.

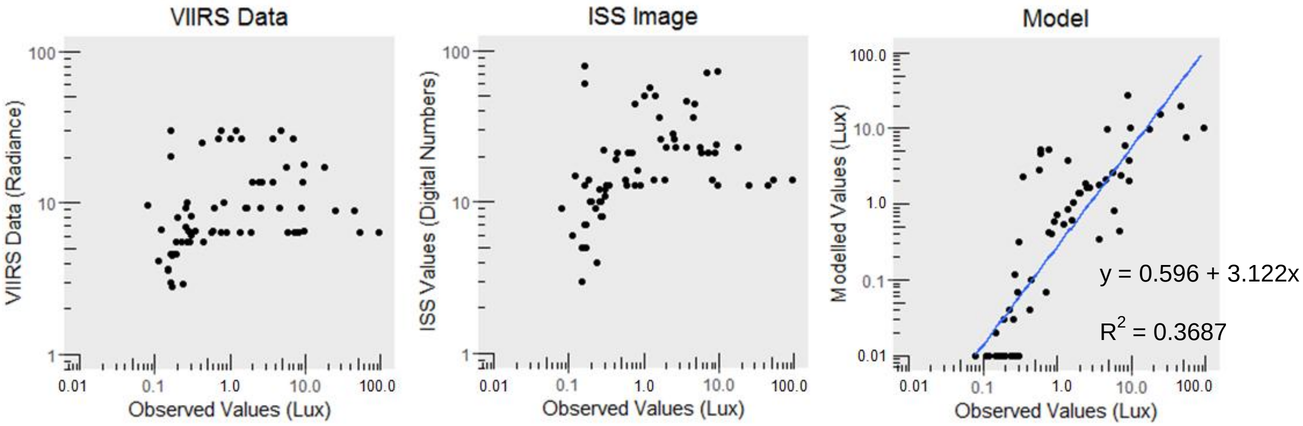
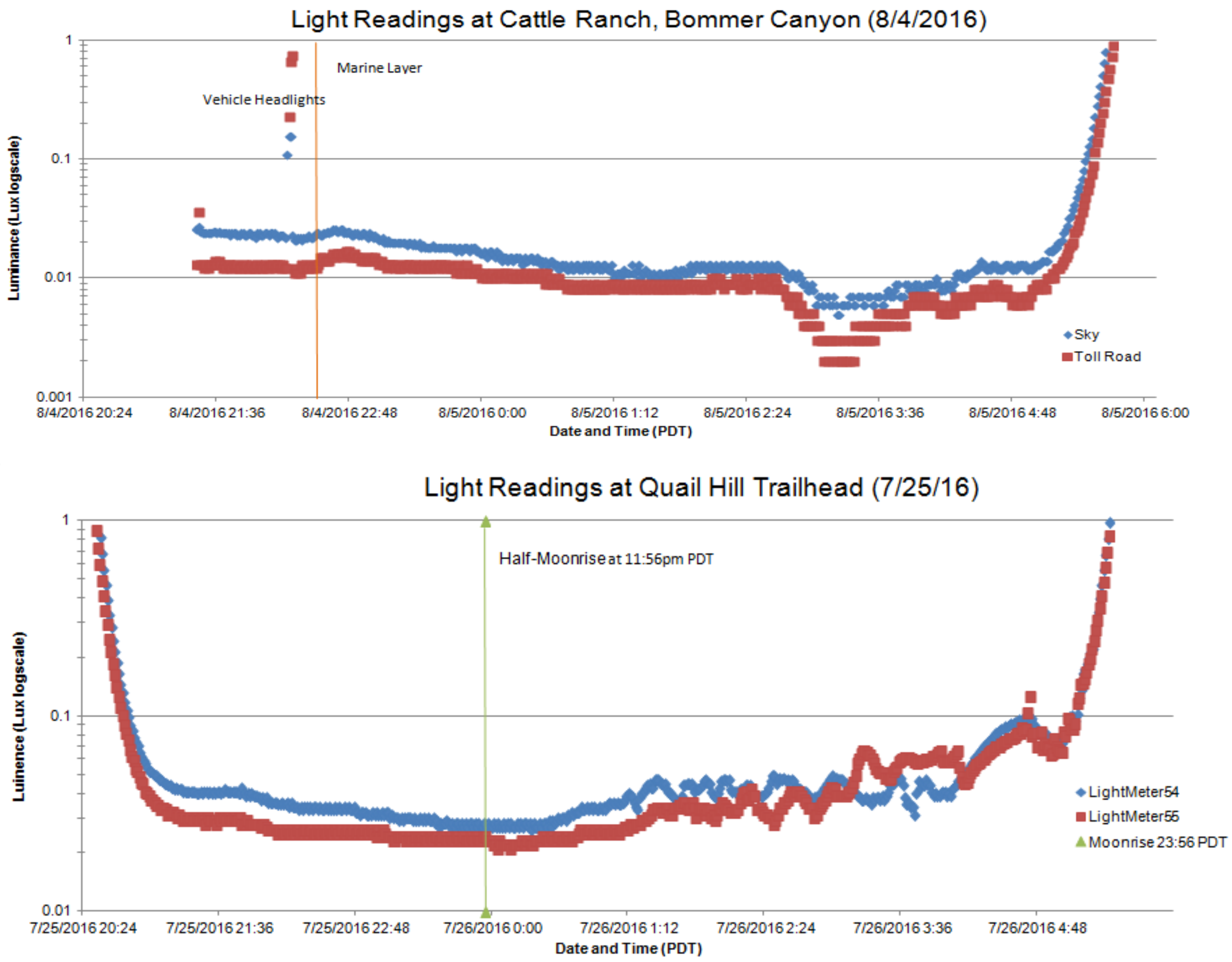


Figure 9. Comparissons between observed values and: VIIRS data, ISS imagery, and modeled data. Intercept standard error = 3.04.



Light Readings at Cattle Ranch, Bommer Canyon (8/4/2016)

Light Readings at Quail Hill Trailhead (7/25/16)

Figure 10. Continuous light readings from the overnight lux sensor loggers. At Bommer Canyon, the blue line is looking at the zenith and the red line is looking at the 73 toll road in the distance; and the marine layer bumps illuminance by 0.01 lux. At Quail Hill, the blue line is looking at a 45̊ out of the reserve and the red line is looking at a 45̊ angle into the reserve. We hypothesize the erratic behavior around 1:15 am is caused by fluctuations in the marine layer.

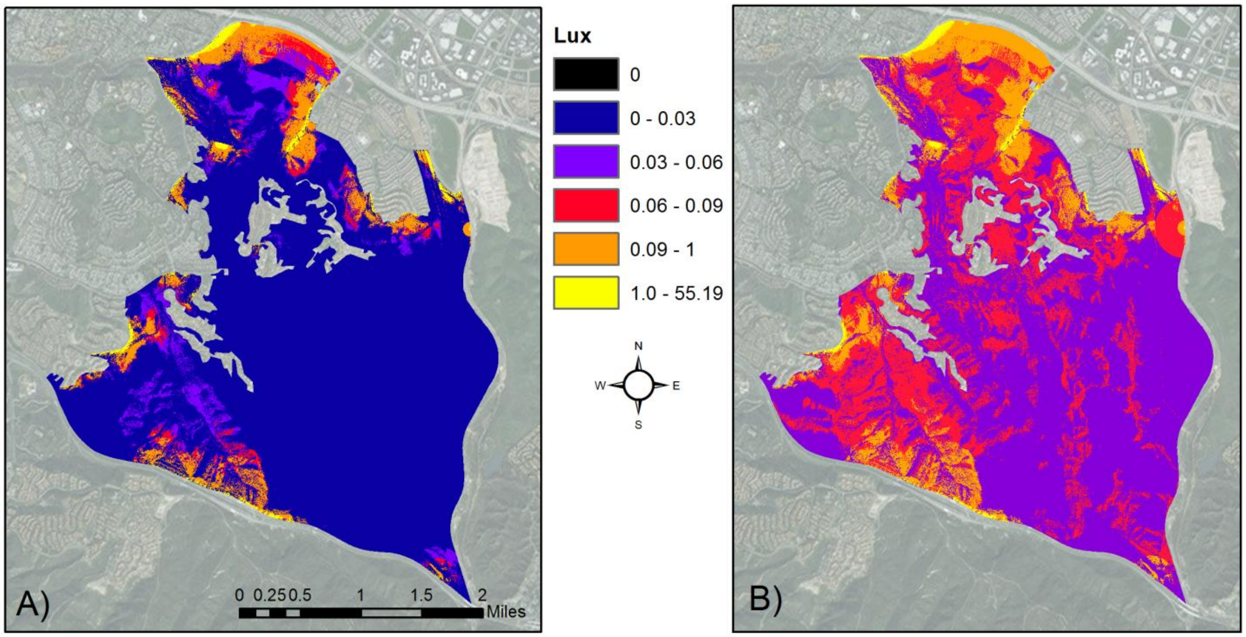


Figure 11. Best case (A) and worst case (B) scenarios of the integrated model. The integrated models includes the original model, I-405 buffering, Laguna Canyon Rd.-Lake Forest Dr. intersection buffering, and a skyglow assumption of 0.01 (A) and 0.06 (B). For reference, quarter moon is 0.01 lux and full moon is 0.1 lux.

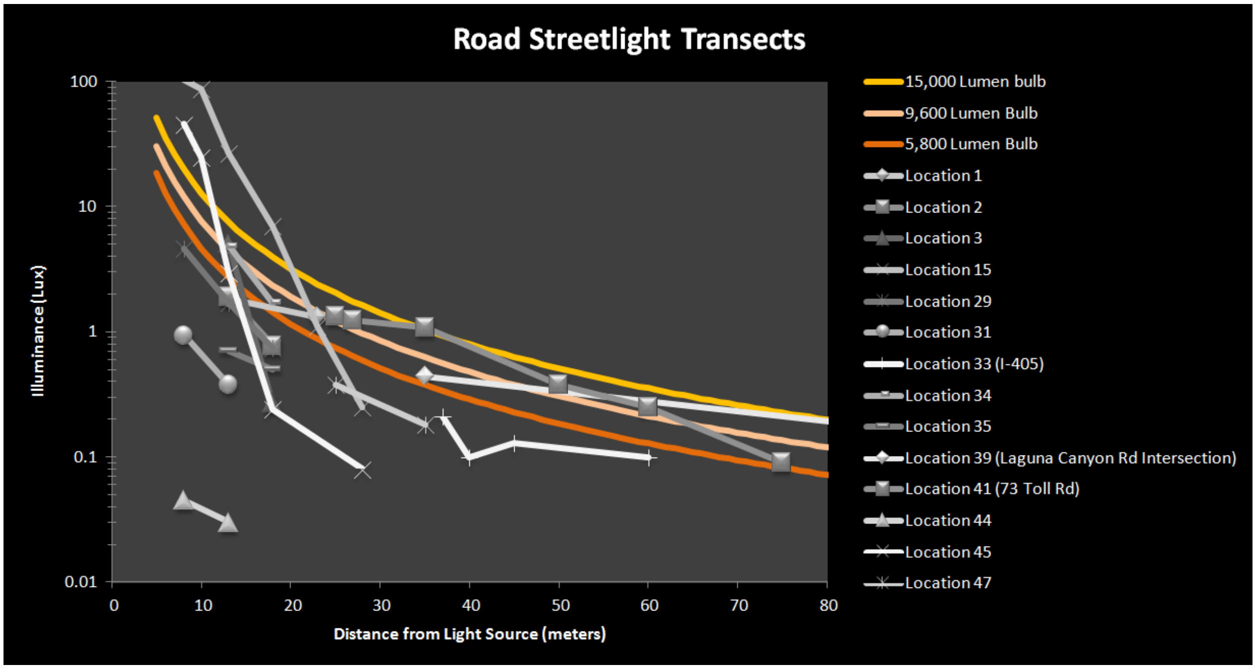


Figure 12. Transects graphs from each point, demonstrating the decay of light with distance. The orange and yellow lines indicate the ideal decay from certain light bulb intensities.

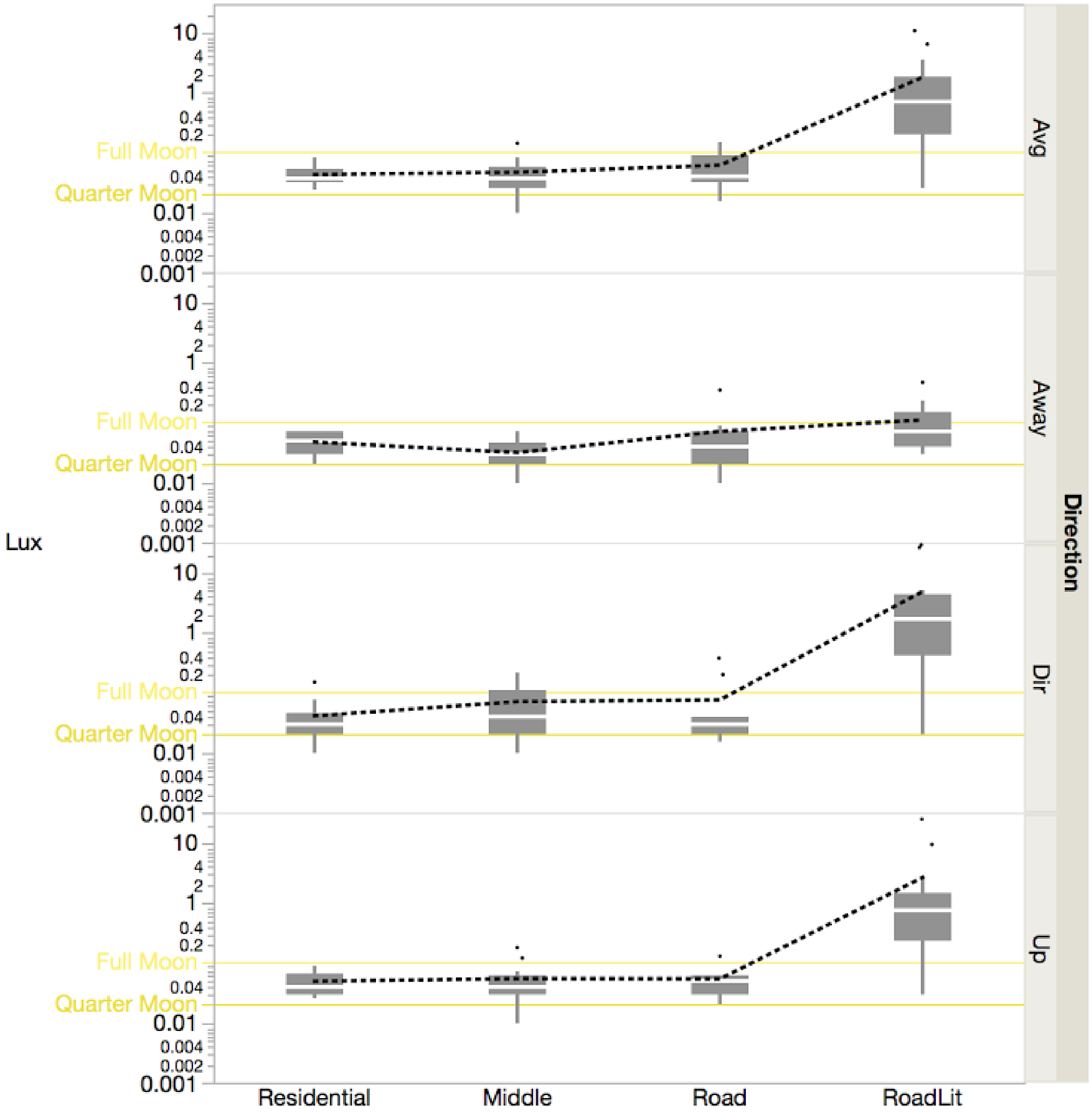


Figure 13. Boxplots demonstrating the difference between the different edge types parsed by directional measurements. The figure also includes full moon illuminance (0.1) and quarter moon illuminance (0.015). Figure courtesy of Travis Longcore.

Figure 14. View from hill in Shady Canyon. Lux reading near this location in this direction was 0.06.

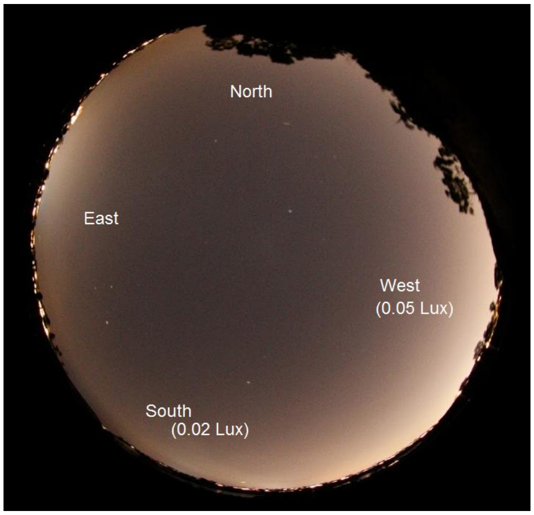


Figure 16. DSLR image from Big Canyon . The brightest spots correspond with skyglow, not residential edge, and the lux values are from the lux meter.

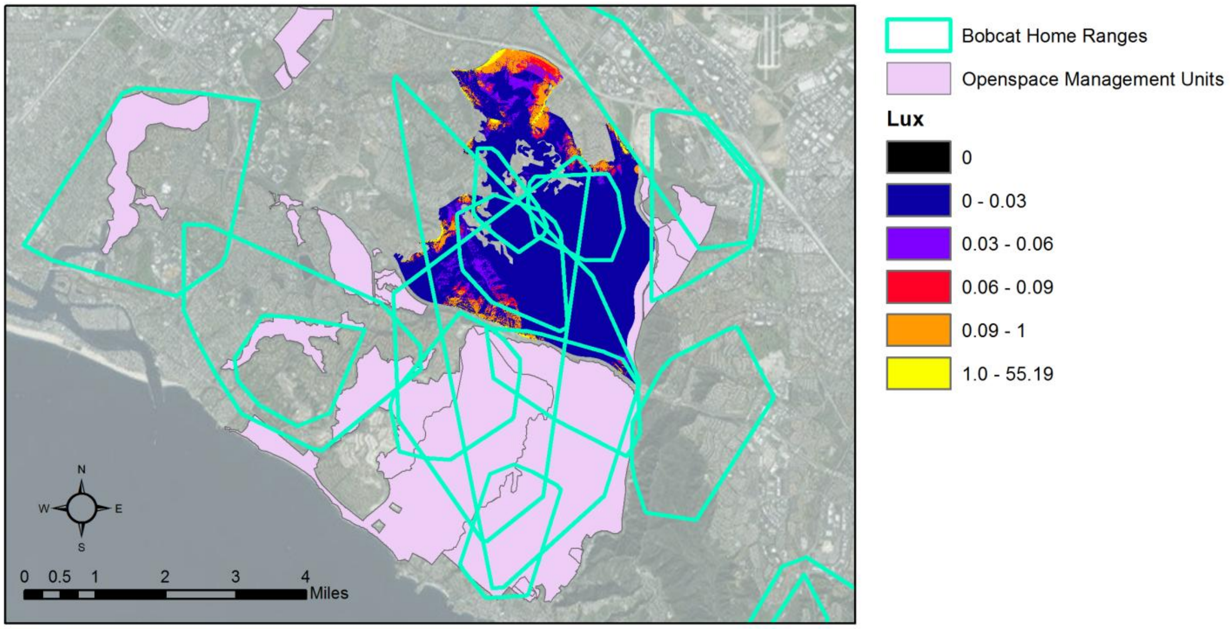


Figure 15. Bobcat home range (USGS data) overlay onto best case scenario integrated model. Data also exists for raptor nesting for future potential studies.

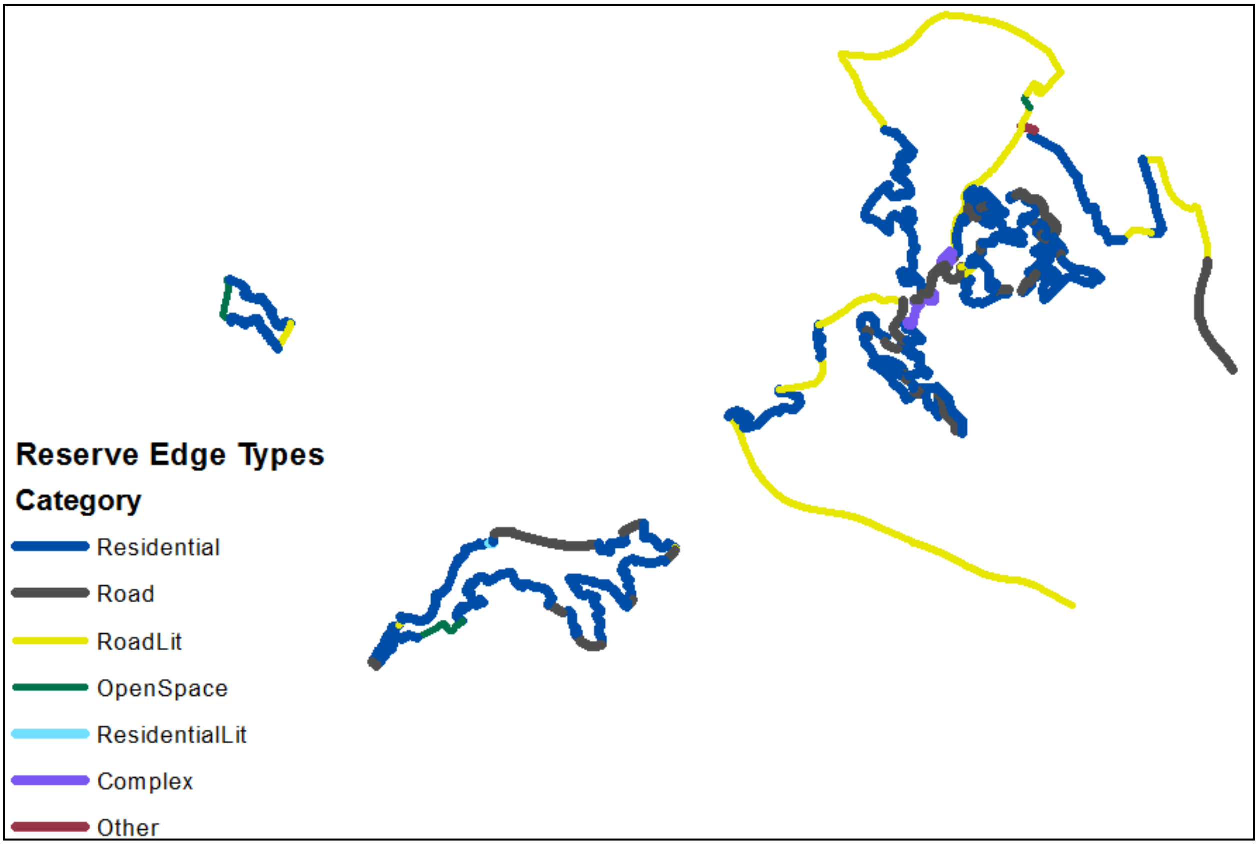


Figure 16. Edge type of the study area. There are four main categories: Residential, Road, Lighted Road, and Openspace. Intended to be directly compared with figures 1, 8, and 11. Light penetration occurs along the lighted roadways.

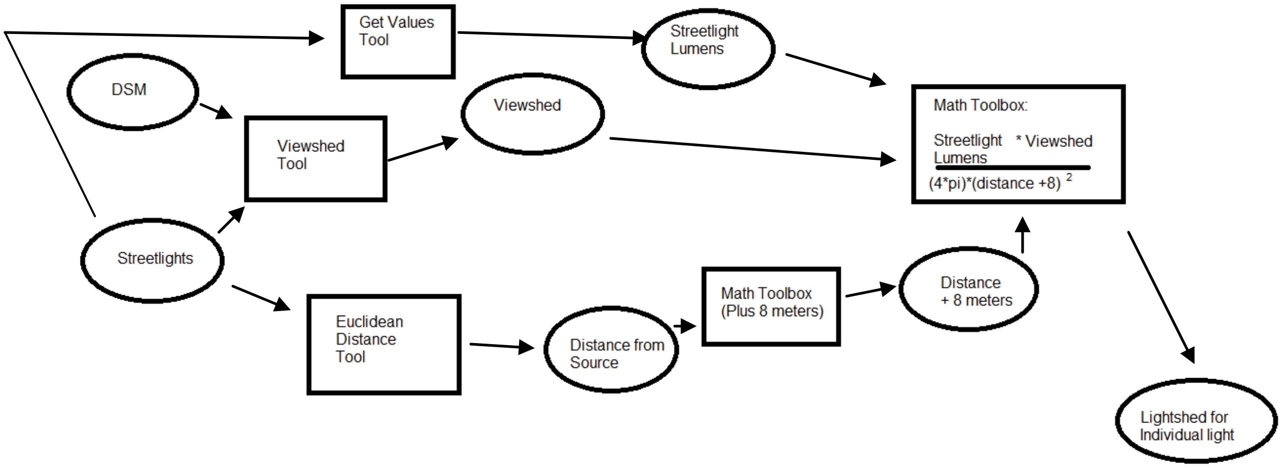


Figure 17. Simplified model workflow in ArcGIS.

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