Habitat Use by Mountain Lions at Carnegie State Vehicular Recreation Area in Alameda and San Joaquin Counties, California

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Introduction

The mountain lion (*Puma concolor*) occupies the most extensive range of any New World terrestrial animal. As an apex predator, mountain lions occupy the highest trophic level and can be found as far north as the Yukon Territory in Canada and as far south as the Straights of Magellan in Chile. Mountain lions are highly adaptable and can be found in low-lying swamps and wetlands (Cox et al. 2006), arid deserts (Logan and Sweanor 2001), high-elevation coniferous forests (Cooley et al. 2009), and equatorial rainforests (Kelly et al. 2008), provided that adequate prey is available (Hansen 1992, Logan and Sweanor 2001). However, mountain lions typically do not reside in urban areas and tend to avoid direct contact with humans but will use ex-urban areas for travel and hunting, especially when such areas are adjacent to open space (Crooks 2002; Ordenana et al. 2010; Kertson et al. 2011b; Wilmers et al. 2013; Lewis et al. 2015; Wang et al. 2015; Benson et al. 2016).

Mountain lions are primarily solitary animals that roam through expansive home ranges and are generally most active at dusk and dawn. In California, the size of home ranges varies between 41 square kilometers (km^2) or 16 square miles (mi^2) and 723 km^2 (279 mi^2) depending on sex of the mountain lion, season, climate, and geographic area (Beier and Barrett 1993; Grigione et al. 2002; Riley et al. 2014; Zeller et al. 2017). Large ungulates, especially deer, are the preferred prey of mountain lions, making up about 70% of their diet (Currier 1983; Iriarte et al. 1990). However, mountain lions are opportunistic predators, and they have been documented eating a wide variety of other larger and smaller prey (Currier 1983; Iriarte et al. 1990). An average adult mountain lion consumes 860 to 1,300 kilograms (1,896 to 2,866 pounds) of large prey annually; and kill 35 to 81 ungulates per year, depending on the sex of the mountain lion, whether the female has cubs, and surrounding human land use (Anderson and Lindzey 2003; Cooley et al. 2008; Knopff et al. 2010; Smith et al. 2015).

In the San Francisco Bay Area, mountain lions occur in the Coast Ranges, including the Santa Cruz Mountains and the Diablo Range in the East Bay and are included in the Southern California/Central Coast Evolutionary Significant Unit (ESU) (Gustafson et al. 2018) In April 2020, the California Fish and Game Commission designated mountain lion within the Southern California/Central Coast ESU as a candidate species under the California Endangered Species Act (CESA). While large tracts of open space exist in the Sant Cruz Mountains and the Diablo Range, mountain lion populations in these areas have low genetic diversity and effective population sizes due to habitat loss and fragmentation, which makes these populations particularly vulnerable to an increased risk of extinction (Ernest et al. 2014; Riley et al. 2014; Vickers et al. 2015; Benson et al. 2016; Gustafson et al. 2018; Benson et al. 2019).

Because mountain lions in the Bay Area are vulnerable to extinction and mountain lion habitat and movement corridors are being increasingly affected by the expansion of human development and human activity, long-term ecological studies, including how ecosystem-level influences (e.g., prey abundance, climate, location) may influence how mountain lions use the landscape, are important to develop conservation and land use strategies to minimize conflicts between humans and mountain lions and preserve critical habitat. This is especially true in mixed-use open space areas managed by agencies that are simultaneously tasked with conservation of natural resources and expanding or managing human recreational activities, since the spread of human development or activity into nearby open space can alter population dynamics and lead to the extirpation of top predators (Hansen et al. 2005; Gehrt et al. 2010; Šálek et al., 2014).

Mountain lion ecology, including occupancy estimation and modeling, has been investigated across the western United States using data from motion-activated cameras, including research on the effects of urbanization (Lewis et al. 2015; Wang et al. 2015), response to non-motorized recreational activities (Reilly et al. 2016), food web dynamics (Leempoel et al. 2019; Coon et al. 2020), and habitat occupancy and distribution (Haynes et al. 2010; Bender et al. 2017; McClanahan et al. 2017). Occupancy is defined as the proportion of an area that is occupied by a species and occupancy models are used to analyze presence–absence data while accounting for imperfect detection (i.e., non-detection does not necessarily mean absence). Since mountain lions have large territories and are generally secretive, occupancy modelling is a useful tool to ecologists because it provides a flexible framework to investigate ecological questions, including exploring hypotheses about factors (e.g., land use, environmental conditions, habitat, etc.) that may influence the occupancy and distribution of mountain lions and their spatial and temporal variation in an area (MacKenzie et al. 2002, 2003, 2006). Thus, occupancy models are an important component in studying habitat use and distribution of mountain lions, which can inform conservation and land use strategies.

In this study, we used camera-traps to survey for mountain lions in Carnegie State Vehicular Recreation Area (SVRA), an off-highway vehicular area that is part of the California State Park system, to investigate how motorized recreational activities affect occupancy. Mountain lions within Carnegie SVRA are part of the Southern California/Central Coast ESU.

Study Area

This study was conducted in and adjacent to Carnegie SVRA, a unit of the California Department of Parks and Recreation, in southeast Alameda and southwest San Joaquin Counties, California, from 20-April 2017 to 04-January 2020. Carnegie SVRA is an off-highway recreation area that is open to primarily motorcycle and all-terrain vehicles (ATVs). Carnegie is situated in a rural area, approximately 24.14 kilometers (km) or 15 miles (mi) east of Livermore with a population of 90,000 and 9.65 km (6 mi) south of Tracy with a population of 82,000 (Figure 1). Surrounding land use is primarily open space ranch land used for cattle grazing; the 28.33 km^2 (10.94 mi^2) Lawrence Livermore National Laboratory Experimental Test Site to the north, which is mostly open space; and the 1.97 km^2 (0.76 mi^2) SRI International explosives testing facility to the southeast, which closed operations in 2020 and is also mostly open space. Prior to 1930, Carnegie was the site of a large cattle grazing operation and as early as the 1930s, the area was used for off-road motorcycle riding.

The study area encompassed approximately 20.62 km^2 (7.96 mi^2), including the 20.25 km^2 (7.82 mi^2) Carnegie SVRA and the 0.37 km^2 (0.14 mi^2) Corral Hollow Ecological Preserve. The topography consists of rolling hills with some areas of extremely steep terrain and ranges in elevation from 183 to 671 meters (m) or 600 to 2200 feet (ft). Approximately 6.37 km^2 (2.46 mi^2) of Carnegie SVRA is open to off-highway vehicular use (mainly motorcycle and ATVs) with the remaining area closed to the public. The area closed to the public is accessible by a network of maintained dirt roads. Corral Hollow Creek, a semi-perennial creek, which drains a portion of the Diablo Range east of Livermore into the San Joaquin River basin of the Central Valley, flows through the study area. Also, there are numerous stock ponds throughout the study area (Figure 2).

The climate is Mediterranean, with most rain falling in the winter and spring. Mild cool temperatures are common in the winter. Hot to mild temperatures are common in the summer. The average daily maximum temperatures are 31.7 °C (89 °F) in summer and 3.3 °C (38 °F) in winter and mean annual precipitation is 32.3 centimeters (12.7 inches) (PRISM Climate Group 2020).

Habitats within Carnegie SVRA include blue oak (*Quercus douglasii*) woodland (709 hectares or 1,751 acres), California sagebrush-black sage (*Artemisia californica – Salvia mellifera*) scrub (223 hectares or 551 acres), Fremont cottonwood (*Populus fremontii*) forest (80 hectares or 198 acres), and wild oats and annual brome (*Avena* spp. – *Bromus* spp.) grassland (1,013 hectares or 2,503 acres). Habitats within the Corral Hollow Ecological Preserve include Fremont cottonwood forest and wild oats and annual brome grassland, as described above.

The most common large ungulate in the area is black-tailed deer (*Odocoileus hemionus*). Other ungulates included feral wild pigs (*Sus scrofa*), domestic cattle (*Bos taurus*), and tule elk (*Cervus canadensis nannodes*). Co-occurring carnivore species in the area included coyote (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*), and bobcat (*Lynx rufus).*

Camera-trapping Surveys

Mountain lions preferentially move through riparian corridors in xeric landscapes and are also known to use fire roads and trails (Beier 1995; Dickson et al. 2005). For this reason, cameras were deployed at 19 locations in riparian corridors throughout the study area. Riparian corridors included a semi-perennial creek (Corral Hollow Creek), as well as intermittent and ephemeral drainages. Within the riparian corridors, cameras were placed in flood plains and along game trails, as well as along riding trails and dirt access roads, where these features intersected the corridor (Figure 3). Several locations were previously known from felid sign (primarily scats, scrapes, marking sites, and kills) or in areas where mountain lions had been observed by SVRA staff or members of the public. Not all camera stations were deployed for the entire duration of the study (i.e., cameras were moved during the study), resulting in an average of 9.03 camera stations deployed within the study area at any given time during the study, and average camera density was approximately 0.44 cameras/km^2 (1.1 cameras/mi^2) (Table 1). The period that camera stations were deployed ranged from 3.5 months to 2.7 years (the length of the study period). One camera station was placed within the riparian corridor of Corral Hollow Creek in the Corral Hollow Ecological Reserve, approximately 4.2 km (2.6 mi) downstream of the study area and remained throughout the study period. This site was closed to the public and off-highway vehicular use. This site was included in the study to determine if mountain lions were using the Corral Hollow Creek riparian corridor outside of the SVRA. The camera brand used was the Reconyx XR6 Ultra-Fire (Reconyx, Holmen, Wisconsin), and cameras were set-up to record video. Cameras were operational 24 hours/day with a camera delay of 30 seconds (i.e., the time that the camera would be ready to take another video should another animal pass by) and video length of 5-20 seconds. Our sampling was passive in that we did not use attractants (i.e., sight, sound, scent) to lure animals to the camera location. We considered videos of mountain lions taken at a camera site to be a capture event if videos were obtained one hour apart. Kittens and dependent offspring (individuals typically of small body size and often accompanied by their mother in photographs) were not considered separate capture events and were excluded from analyses. We tallied the total number of capture events and calculated trap success as the number of mountain lion capture events per 100 trap days (Table 1). Additionally, a summary of camera locations, dates deployed, and rationale for site selection is included in Table 2 and depicted in Figure 3.

Table 1. Summary of date of survey, numbers of camera stations, trap days, and trap success.

Dates of Survey	No. of camera stations[1,2]	Average Camera Station Density	Survey length (days)	Total trap days[3]	Percent (%) mountain lion trap success[4]	Encounter Occasions[5]
20 April 2017 – 04 January 2020	19	0.44/km^2 (1.1/mi^2)	990 (2.71 years)	160,910	3.73	66

[1]18 cameras were placed within the boundary of the 20.25 km^2 Carnegie SVRA. One camera was placed outside the boundary of Carnegie SVRA. See text for details. An average of 9.03 camera stations were deployed within the study area at any given time during the study; [2]Not all camera stations were deployed for the entire duration of the study (i.e., cameras were moved during the study); [3]calculated as number of camera stations times number of trap days minus the number of days when stations were nonfunctional because of camera malfunctions; [4]calculated as capture events per 100 trap days. A total of 60 capture events; [5]number of trapping occasions used in program *PRESENCE* after collapsing the data into 66 15-day capture periods (single-season occupancy model).

Table 2. Summary of Camera Locations.

Site	OHV or Non-OHV	Distance from Tesla Road	Dates Active	Deployed for the Entire Study	Rationale for Site Selection
1	OHV	0.16 km (0.10 mi)	4/20/2017 to 8/24/2017 (4.2 months)	No	Placed within woodland along the streambed/floodplain of Corral Hollow Creek. Mountain lion sign observed in area.
2	OHV	1.61 km (1.00 mi)	4/20/2017 to 1/4/2020 (2.7 years)	Yes	Placed along a maintained dirt road/trail where it crosses an ephemeral drainage. Mountain lion sign observed in area.
3	OHV	0.16 km (0.10 mi)	4/20/2017 to 12/7/2018 (1.6 years)	No	Placed within the streambed/floodplain of Corral Hollow Creek in an open area.
4	Non-OHV	0.19 km (0.12 mi)	4/20/2017 to12/19/2017 (8 months)	No	Placed within the streambed/floodplain of Corral Hollow Creek in open area. Mountain lion sign observed in area.
5	Non-OHV	1.79 km (1.11 mi)	4/20/2017 to 8/30/2018 (1.4 years)	No	Placed along maintained access road on the top of bank of Mitchell Ravine.
6	Non-OHV	3.30 km (2.05 mi)	4/20/2017 to1/4/2020 (2.7 years)	Yes	Placed in woodland along maintained dirt road where it crosses Corral Hollow Creek. Mountain lion previously observed in area.
7	Non-OHV	1.08 km (0.67 mi)	4/20/2017 to 1/4/2020 (2.7 years)	Yes	Placed in the streambed/floodplain of Corral Hollow Creek in an open area. Mountain lion sign observed in area.
8	Non-OHV	0.11 km (0.07 mi)	4/20/2017 to 1/4/2020 (2.7 years)	Yes	Placed in woodland along game trail adjacent to Corral Hollow Creek in Corral Hollow Ecological Reserve.
9	Non-OHV	1.67 km (1.04 mi)	4/20/2017 to 1/4/2020 (2.7 years)	Yes	Placed in woodland at the entrance of a 60" culvert that conveys an ephemeral drainage under a maintained dirt access road.
10	OHV	1.32 km (0.82 mi)	12/19/2017 to 9/24/2019 (1.8 years)	No	Placed along a maintained dirt road/trail where it crosses an ephemeral drainage in chaparral.
11	OHV	1.09 km (0.68 mi)	3/20/2018 to 1/4/2020 (1.8 years)	No	Placed within woodland along an OHV trail where it crosses an ephemeral drainage.
12	Non-OHV	0.03 km (0.02 mi)	3/30/2018 to 9/24/2019 (1.5 years)	No	Placed in woodland at the confluence of a culvert that conveys an ephemeral drainage under Tesla Road and a game trail that crosses over a maintained dirt access road and continues into another ephemeral drainage.
13	Non-OHV	1.01 km (0.63 mi)	8/20/2018 to 9/24/2019 (1.1 years)	No	Placed within the streambed/floodplain of Mitchell Ravine in an open area.
14	OHV	0.43 km (0.27 mi)	12/12/2018 to 1/4/2020 (1.1 years)	No	Placed in an intermittent drainage used as an OHV trail.
15	OHV	0.87 km (0.54 mi)	9/24/2019 to1/4/2020 (3.4 months)	No	Placed along a game trail in an intermittent drainage.
16	OHV	0.89 km (0.55 mi)	9/24/2019 to1/4/2020 (3.4 months)	No	Placed within woodland along an OHV trail where it crosses an ephemeral drainage.
17	OHV	1.54 km (0.96 mi)	9/24/2019 to 1/4/2020 (3.4 months)	No	Placed within chaparral along a maintained dirt road/trail where it crosses an ephemeral drainage.
18	Non-OHV	1.01 km (0.63 mi)	9/24/2019 to 1/4/2020 (3.4 months)	No	Placed along a game trail in woodland adjacent to Mitchell Ravine. Upstream 15 meters (50 feet) of Site 13. Replaced site 13.
19	Non-OHV	0.03 km (0.02 mi)	9/24/2019 to 1/4/2020 (3.4 months)	No	Placed along a game trial in an ephemeral drainage in a grassland adjacent to a maintained dirt access road. Downstream 20 meters (65 feet) of site 12. Replaced site 12.

Site Covariates

We characterized each camera location by whether it was in an area open (OHV) or closed to off-highway vehicular use (Non-OHV) and distance from the 2-lane rural Corral Hollow and Tesla Roads. We used two categories for distance of sites from Corral Hollow and Tesla Roads: less than 1 km (<1 km) or greater than 1 km (>1 km). Corral Hollow Road extends from the City of Tracy in the east to Carnegie SVRA and then continues as Tesla Road at the Alameda County line to the west into the City of Livermore (Figure 1). Corral Hollow/Tesla Road runs along the northern border of Carnegie SVRA and is used as an alternate commuter route to I-580 between Tracy and Livermore. A 2012 traffic study reported traffic volumes at 2,400 weekday vehicles (Monday to Friday) and 900 vehicles on the weekend (Saturday and Sunday) (KD Anderson & Associates, Inc. 2012). The majority of weekday traffic volume occurs during peak commute times of early morning and late afternoon. We included these site covariates in our occupancy models to investigate the influence of off-highway vehicle (OHV) recreation and distance from a commuter traffic corridor on mountain lion occupancy.

Occupancy Modeling

Single-season occupancy models were used to analyze the mountain lion data set, grouped by encounter occasions (MacKenzie et al. 2002). We used the program *PRESENCE* ver. 2.12.43 to develop and analyze the models (Hines 2006). The program *PRESENCE* uses the maximum likelihood approach for site occupancy models with the models generating simultaneous estimates for the probability of the site being occupied by a mountain lion (ψ) and the probability of detecting a mountain lion during an encounter occasion (p). Occupancy models generated in *PRESENCE* also allow the inclusion of covariates that can affect occupancy and detection probability.

Because camera stations run continuously and mountain lions can move approximately 5 km (3.1 mi) per day (Ager et al. 2003), the same individual mountain lion may pass by a camera station several times over the course of hours to days. If each capture event is treated as an independent event, estimates of occupancy will be likely be biased upwards. Therefore, we constructed a capture history for mountain lions by collapsing all capture events at a camera site within a 15-day period as one encounter occasion. All camera sites were used to construct encounter occasions. Other occupancy studies of mountain lions have used 1- to 22-day periods for the encounter occasion with study durations from two to four months (Kelly et al. 2008; Townsend et al. 2013; Lewis et al. 2015; Fort 2016). However, we found occupancy estimates to be insensitive to period of collapse after seven days.

Additionally, not all camera sites had the same number of 15-day occasions, but missing observations (occasions when a site was not surveyed, e.g., a non-operational camera or a camera moved to another location) are accommodated by *PRESENCE*. These capture-recapture histories were then analyzed in the program *PRESENCE* using a single-season model (Hines 2006). The assumptions of this model are: (1) the sites remain occupied during the study period and are considered “closed”, i.e., no extinction, emigration, or colonization occurs at the camera sites, (2) the probability of occupancy across all sites is equal, or differences in occupancy probability are modeled using covariates, (3) the detection probability is greater than zero, and (4) the detection of a species in a site is not influenced by the detection at other sites.

We assumed the camera sites experienced a constant state of occupancy throughout the study period since occupancy at the camera sites did not vary throughout the study (Table 3). Therefore, no variables were used to predict colonization or extinction because we assumed little variation in overall distribution dynamics over the study period. Additionally, for these models we are considering ‘occupancy’ as ‘habitat use’ as suggested by Burton et al. (2012) which permits non-closed sites.

We developed a set of candidate models that included site covariates hypothesized to affect habitat choice (Table 4): camera location (OHV or Non-OHV) and distance from road (<1km or >1km). We evaluated the candidate models using the Akaike Information Criterion (AIC), which provides a relative measure of fit. The model with the smallest AIC provides the best fit to the data, e.g., the model with an AIC of zero is the best fit model relative to the other candidate models. As a rule of thumb, a delta AIC >2 suggests a lack of support for the model relative to the other candidate models. The candidate models were also evaluated using the AIC weight, which can be interpreted as the probability that a model is the best model given the data and a set of candidate models. Models that did not converge were not evaluated as candidate models.

We predicted that occupancy would follow patterns to those described for occupancy in relation to human disturbance and development. (Beier 1995; Dickson and Beier 2002; Dickson et al. 2005; Ordeñana et al. 2010; Kertson et al. 2011; Lewis et al. 2015; Wang et al. 2015; Benson et al. 2016; Zeller et al. 2017; Wang et al. 2017). Therefore, we hypothesized that mountain lions would be more likely to frequent areas with little or no human disturbance and thus exhibit higher estimates of occupancy at these sites, and that mountain lions would use areas with greater human disturbance or development with less frequency and thus demonstrate lower estimates of occupancy at such sites. Since we did not expect detection to be influenced by camera location or distance from Tesla Road, we did not include them as covariates for detection probability.

Table 3. Summary of Capture Events by Camera Site.

Site	OHV or Non-OHV	Site Description	Distance from Tesla Road	Number of Capture Events per Period (% of Total for Period)			
				4/20/2017 to 4/14/2018	4/15/2018 to 4/9/2019	4/10/2019 to 1/4/2020	Total Capture Events by Site (% of Total Capture Events)
2	OHV	Southern boundary of SVRA along maintained dirt road/trail	1.61 kilometers (1 mile)	9 (32%)	3 (17%)[1]	1 (8%)	**13** (22%)
5	Non-OHV	Mitchell Ravine along maintained dirt road	1.79 kilometers (1.11 miles)	3 (11%)	0 (0%)[2]	NA[3]	**3** (5%)
6	Non-OHV	Corral Hollow Creek at maintained dirt road crossing	3.30 kilometers (2.05 miles)	12 (43%)	9 (50%)	3 (23%)[4]	**24** (41%)
7	Non-OHV	Corral Hollow Creek	1.08 kilometers (0.671 mile)	2 (7%)	1(5%)	3 (23%)	**6** (10%)
9	Non-OHV	60" Culvert under maintained dirt road	1.67 kilometers (1.04 miles)	2 (7%)	5 (28%)[5]	6 (46%)	**13** (22%)
Total Capture Events for Each Period				**28**	**18**	**13**	**59 (100%)**

[1]camera was non-operational from 6/17-6/20; [2]camera was non-operational from 3/30-5/3 and 5/13-6/20; [2]camera removed on 8/30; [3]camera removed 8/30/2018; [4]camera was non-operational from 1/11-2/22 and 5/26-7/17; [5]camera was non-operational from 5/15-6/19 and 6/21-7/18.

Results

A summary of capture events by camera sites is presented in Table 3 and shown in Figure 4. During the study period, five camera sites had capture events, four in the non-OHV area and one in the OHV area. All sites were greater than 1 km (0.62 mi) from Corral Hollow/Tesla Road. Approximately 78% of all capture events occurred in the non-OHV area and 22% at one OHV site. Within the non-OHV area, approximately 51% of capture events occurred within the riparian corridor of Corral Hollow Creek. The OHV site was positioned along the boundary of the SVRA and SRI International test site and was adjacent to a maintained dirt road /trail in an ephemeral drainage. All sites remained occupied during the study period except for site 5. However, the camera was removed from this site in August 2018.

A summary of candidate models generated in program *PRESENCE* is presented in Table 4. The model that best fitted the data supported OHV/Non-OHV sites and distance from Corral

Hollow/Tesla Road as key predictors of habitat use (candidate model 1 with a delta AIC value of zero and AIC weight of 0.59). With a delta AIC value less than two, candidate model 2 could be an important model, but it does not support the data as well as candidate model 1 since it has a smaller AIC weight (0.31). Candidate models that did not include distance from Corral Hollow/Tesla Road as a covariate were not supported (models 3 and 4) with delta AIC values of 4.87 and 6.75, respectively.

Table 4. List of single-season occupancy candidate models generated in *PRESENCE*.

Candidate Model	Hypothesis Tested	Rationale for Candidate Model	Occupancy Estimate (ψ) and Standard Error (SE)[1,2]								Detection Probability (p) and Standard Error (SE)	Delta AIC (AIC weight)
			OHV	Non-OHV	All Sites <1km	All Sites >1km	OHV & <1km	OHV & >1km	Non-OHV & <1km	Non-OHV & >1km		
1	Occupancy is different between OHV and non-OHV depending on distance from Tesla Road. Detection probability is the same at all camera sites.	A model that includes the site covariates OHV/Non-OHV and distance from Tesla Road as predictors of habitat use.					0.00	0.18 ± 0.17	0.00	0.73 ± 0.20	0.21 ± 0.03	0.00 (0.59)
2	Occupancy is different between sites that are greater than 1km and less than 1km from Tesla Road. Detection probability is the same at all camera sites.	A model that includes the site covariate distance from Tesla Road as a predictor of habitat use.			0.00	0.45 ± 0.15					0.21 ± 0.03	1.33 (0.31)
3	Occupancy is different between the OHV and Non-OHV sites. Detection probability is the same at all camera sites.	A model that includes the site covariate OHV/Non-OHV as a predictor of habitat use.	0.12 ± 0.11	0.43 ± 0.17							0.21 ± 0.03	4.87 (0.05)
4	Occupancy and detection probability are the same at all camera sites.	A model that does not include site covariates as predictors of habitat use.					0.29 ± 0.11				0.21 ± 0.03	4.93 (0.05)

[1] OHV: the area of Carnegie SVRA that is open to off-highway vehicle use; Non-OHV: the area of Carnegie SVRA closed to off-highway vehicle use; [2] distance from the 2-lane rural Corral Hollow and Tesla Roads treated as a categorical variable with two categories, greater than 1 km or less than 1km

Discussion

Occupancy Modeling

Since mountain lions have home ranges larger than our study area, the results of our occupancy modelling should be interpreted as the probability of a mountain lion using the area in the vicinity of the site as opposed to actual occupancy at the site (e.g., a mountain lion may be passing through the site en route to other areas). However, patterns in habitat use by mountain lions at the landscape level can still be reliably estimated with occupancy modeling.

In our study, proximity to a rural 2-lane paved road with a 55 miles per hour speed limit that is used as a commuter corridor along with camera location (OHV or Non-OHV) appear to influence mountain lion occupancy. In fact, no mountain lions were detected at camera sites within 1 km of Corral Hollow/Tesla Road. Even though mountain lions used a site that was regularly disturbed by ATVs and motorcycles, estimates of occupancy were smaller for OHV sites (ψ = 0.18) than Non-OHV sites (ψ = 0.73).

Our findings are consistent with other studies that found mountain lions generally avoid areas with regular human disturbance, including regularly used roads (Crooks 2002; Dickson and Beier 2002; Dickson et al. 2005; Wilmers et al. 2013; Wang et al. 2015). Paved roadways, particularly roadways with regular traffic travelling at high speeds, result in the direct mortality of mountain lions by vehicle collisions and are a significant threat to the persistence of mountain lion populations in the Bay Area (Center for Biological Diversity and the Mountain Lion Foundation 2019). For mountain lions, regularly used paved roads, particularly highways and interstates reduce landscape permeability, or the degree to which wildlife is able to move across a landscape; and increase habitat fragmentation (Bennett 2011). However, mountain lions will use moderately disturbed areas as they travel and hunt (Wilmers et al. 2013; Gray et al. 2016), but occupancy is lower in developed areas, and they are more likely to use developed areas if they border open spaces (Wang et al. 2015).

Indeed, the one OHV site regularly used by mountain lions was along the border of the SVRA and adjacent to open space, which could potentially mitigate the impacts of human disturbance. Thus, the level of human disturbance at or near other camera sites in the OHV area could have potentially been a factor affecting occupancy within the OHV area. Although distance from Corral Hollow/Tesla Road was a significant factor influencing occupancy in our study, mountain lions were detected at mores sites in the non-OHV area, further suggesting that habitat at the non-OHV sites is preferred by mountain lions and that human disturbance associated with off-highway vehicular recreation may be potentially a factor in habitat selection by mountain lions.

However, it has been found that non-motorized human recreation, including hiking, biking, and equestrian use, does not negatively affect occupancy in open space areas, suggesting that the presence of humans in itself does not affect occupancy (Reilly et al. 2016). However, mountain lions shift their diel activity patterns in the presence of humans and become more active at night (Wang et al. 2015). We observed a similar pattern in our study since mountain lions were only captured at camera sites during the day in the non-OHV area. In addition, all camera sites were occupied by black-tailed deer, an important mountain lion prey, suggesting that occupancy estimates were not substantially altered by availability of this prey within the study area. It has been found that mountain lions preferentially occupy habitats that facilitate their stalk and ambush hunting strategy rather and not necessarily habitats with abundant deer (Coon et. al 2020). A full list of mammalian species detected at the camera sites during the study is included in Appendix A.

Our study found that avoidance of areas close to Corral Hollow/Tesla Road was a significant factor in mountain lion habitat use in the and that they may be preferentially using Non-OHV areas, suggesting that disturbance from off-highway vehicular may potentially influence habitat use in the study area.

Wildlife Corridors

The Critical Linkages Project identified the western portion of Carnegie SVRA as part of a wildlife corridor that provides a critical linkage for the movement of mountain lions in the Diablo Range, allowing for gene flow and habitat connectivity within the CC-N genetically distinct mountain lion population (Penrod et al. 2013) (Figure 5). Carnegie SVRA is likely used as a habitat corridor since our study demonstrated that mountain lions regularly occupy both the OHV and non-OHV areas within Carnegie SVRA. At a regional landscape scale, Carnegie SVRA is part of a contiguous open space landscape that connects to protected open space areas, including the Ohlone and Sunol Regional Wilderness areas to the west, and the Blue Oak Ranch Reserve and Henry W. Coe State Park to the south.

Mountain lions were not detected at the camera site placed in the Corral Hollow Ecological Reserve, within the riparian corridor of Corral Hollow Creek, approximately 4.2 km (2.6 mi) downstream of the SVRA. The site was approximately 116 m (381 ft) from Corral Hollow/Tesla Road. Based on our conclusions, mountain lions are not likely using the site because of the site's proximity to the road. In contrast, 50% of all capture events during the study occurred at two sites along Corral Hollow Creek in the non-OHV area. These findings suggest the importance of maintaining wildlife corridors, particularly riparian corridors, in open space areas that are far from roads actively used by commuter traffic.

Management Implications

Since mountain lion populations in Alameda and western San Joaquin Counties were included in a petition for listing under the California Endangered Species Act, conservation measures to protect and preserve existing populations will likely need to be incorporated into future land management planning processes. The non-OHV sites used by mountain lions during our study are in areas proposed for future development, including OHV trails, picnic areas, and camping areas (Carnegie SVRA 2015). Even though our study found that proximity to Corral Hollow/Tesla Road is the primary factor influencing mountain lion occupancy in the study area, we cannot exclude the possibility that mountain lions are avoiding OHV areas due to human disturbance. Therefore, development of visitor facilities and associated human disturbance from off-highway vehicular use could negatively affect occupancy and hinder the movement of mountain lions through the non-OHV areas relative to current conditions. Given the short duration of our study and since mountain lions have only been identified at one site in the OHV area, our study does not provide sufficient data to address management actions that could improve or expand habitat use in the areas of the park currently used for off-highway vehicle use.

At the regional level, Carnegie SVRA is part of larger open space area that is core habitat for mountain lions. At the landscape scale, our study has demonstrated that mountain lions regularly occupy four sites within the non-OHV areas. When designing a trail system, it is important to include measures that protect these sites along with buffers to create movement corridors that allow mountain lions to move among these sites and the larger, adjacent open space area.

Riparian corridors were actively used by mountain lions during our study and are generally favored movement routes in xeric landscapes (Beier 1995; Dickson et al. 2005). One approach to conserving habitat connectivity could be to buffer the lengths of Corral Hollow Creek (location of camera sites 6 and 7) and Mitchell Ravine (location of camera site 5), and the drainage that connects camera site 9 with Mitchell Ravine. At the landscape scale, corridors should be at a minimum 100 m (328 ft) wide when the length of the corridor is less than 800 m (2,625 ft), and a minimum of 400 m (1,312 ft) wide for corridors that are 1-7 km (0.62-4.35 mi) in length (Beier 1995) (Figure 6).

Future Work

Long-term ecological studies are extremely valuable for making ecologically informed decisions on land use management. Our study demonstrated that occupancy estimates for mountain lions can be reliably estimated through remote camera surveys, and such estimates are extremely valuable for allowing land managers to balance species conservation and land use. Since mountain lions are secretive and rarely seen, camera traps are one of the few methods to obtain population parameters, like range and patterns in habitat use.

Since the open space areas of Carnegie SVRA likely provides critical habitat for mountain lions in the densely populated Bay Area and mountain lions are a focal species for conservation planning due to their critical role as a top-down ecosystem regulator, we recommend that camera monitoring continue at Carnegie SVRA to collect additional data on habitat use of mountains lions (Beier 2010). More specifically, we recommend continuing to move cameras to other riparian sites throughout the study area, especially sites closer to Tesla Road in both the OHV and Non-OHV areas. We also recommend sampling more diverse habitats, particularly woodland and chaparral in non-riparian areas since these habitats comprise over 45% of the land cover within the SVRA.

Literature Cited

Ager, A.A., B.K. Johnson, J.W. Kern, and J.G. Kie. 2003. Daily and seasonal movements and habitat use by female Rocky Mountain elk and mule deer. Journal of Mammalogy 84(3): 1076-1088.

Anderson, Jr., C.R. and F.G. Lindzey. 2003. Estimating Cougar Predation Rates from GPS Location Clusters. The Journal of Wildlife Management 67(2): 307-316.

Beier, P. 1995. Dispersal of Juvenile Cougars in Fragmented Habitat. The Journal of Wildlife Management 59(2), 228-237.

Beier, P. and R.H. Barrett. 1993. The cougar in the Santa Ana Mountain Range, California. Final report. Orange County Cooperative Mountain Lion Study, Department of Forestry and Resource Management. University of California, Berkeley, USA.

Beier, P., D. Choate, and R.H. Barrett. 1995. Movement patterns of mountain lions during different behaviors. Journal of Mammalogy 76(4): 1056-1070.

Beier, P. 2010. A focal species for conservation planning. In Cougar: ecology and conservation, editor. M. Hornocker and S. Negri, University of Chicago Press.

Bender, L.C., O.C. Rosas-Rosas, and M.E. Weisenberger. 2017. Seasonal occupancy of sympatric larger carnivores in the southern San Andres Mountains, south-central New Mexico, USA. Mammal Research 62: 323-329.

Bennett, V.J., W.P. Smith, and M.G. Betts. 2011. Toward understanding the ecological impact of transportation corridors. Genera. Technical Report. PNW-GTR-846. Portland, OR: U.S Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Benson, J.F., P.J. Mahoney, J.A. Sikich, L.E.K. Serieys, J.P. Pollinger, H.B. Ernest, and S.P.D. Riley. 2016. Interactions between demography, genetics, and landscape connectivity increase extinction probability for a small population of large carnivores in a major metropolitan area. Proceedings of the Royal Society B: Biological Sciences 283(1837): 20160957.

Benson, J.F., P.J. Mahoney, T.W. Vickers, J.A. Sikich, P. Beier, S.P.D. Riley, H.B. Ernest, and W.M. Boyce. 2019. Extinction vortex dynamics of top predators isolated by urbanization. Papers in Natural Resources 1033.

Burton A.C, M.K. Sam, C. Balangtaa, and J.S. Brashares. 2012. Hierarchical Multi-Species Modeling of Carnivore Responses to Hunting, Habitat and Prey in a West African Protected Area. PLoS ONE 7(5): e38007.

Carnegie SVRA. 2015. Carnegie State Vehicular Recreation Area General Plan Revision, Preliminary General Plan. California State Parks Off-highway Motor Vehicle Recreation Division, April 2015.

Center for Biological Diversity and the Mountain Lion Foundation. 2019. A Petition to List the Southern California/Central Coast Evolutionarily Significant Unit (ESU) of Mountain Lions as Threatened under the California Endangered Species Act (CESA).

Cooley, H.S., H.S. Robinson, R.B. Wielgus, and C.S. Lambert. 2008. Cougar prey selection in a white-tailed deer and mule deer community. Journal of Wildlife Management 72(1): 99-106.

Cooley, H.S., R.B. Wielgus, G.M. Koehler, H.S. Robinson, and B.T. Maletzke. 2009. Does hunting regulate cougar populations? A test of the compensatory mortality hypothesis. Ecology 90: 2913–2921.

Coon, C.A.C, P.J. Mahoney, E. Edelblutte, Z. McDonald, and D.C. Stoner. 2020. Predictors of puma occupancy indicate prey vulnerability is more important than prey availability in a highly fragmented landscape. Wildlife Biology 2020 (1).

Cox, J.J., D.S. Maehr, and J.L. Larkin. 2006. Florida panther habitat use: new approach to an old problem. Journal of Wildlife Management 70: 1778-1785.

Crooks, K.R., 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. Conservation Biology 16: 488-502.

Currier, M.J. 1983. *Felis concolor*. Mammalian Species 200: 1-7.

Dickson, B.G., and P. Beier. 2002. Home-range and habitat selection by adult cougars in Southern California. The Journal of Wildlife Management 66(4): 1235-1245.

Dickson, B. G., J.S. Jennes, and P. Beier. 2005. Influence of Vegetation, Topography, and Roads on Cougar Movement in Southern California. Journal of Wildlife Management 69(1): 264-276.

Ernest, H.B., T.W. Vickers, S.A. Morrison, M.R. Buchalski, and W.M. Boyce. 2014. Fractured genetic connectivity threatens a Southern California puma (*Puma concolor*) population. PLoS ONE 9(10).

Fort, J.L. 2016. Large Carnivore Occupancy and Human – Wildlife Conflict in Panama. Master's Thesis. Department of Forestry in the Graduate School, Southern Illinois University Carbondale.

Gehrt, S.D., S.P.D. Riley, and B.L. Cypher. 2010. Urban carnivores: ecology, conflict, and conservation, editors. 2010. John Hopkins University Press, USA.

Gray, M., C.C. Wilmers, S.E. Reed, and A.M. Merenlender. 2016. Landscape feature-based permeability models relate to puma occurrence. Landscape and Urban Planning 147: 50-58.

Grigione, M. M., P. Beier, R.A. Hopkins, D. Neal, W.D. Padley, C.M. Schonewald, and M.L. Johnson. 2002. Ecological and allometric determinants of home-range size for mountain lions (*Puma concolor*). Animal Conservation 5: 317-324.

Gustafson, K. D., R.B. Gagne, T.W. Vickers, S.P.D. Riley, C.C. Wilmers, V.C. Bleich…, and H.B. Ernest. 2018. Genetic source–sink dynamics among naturally structured and anthropogenically fragmented puma populations. Conservation Genetics 20(2): 215-227.

Hansen, K. 1992. Cougar: the American lion. Northland Publications.

Hansen, A.J., R.L. Knight, J.M. Marzluff, S. Powell, K. Brown, P.H. Gude, and A. Jones. 2005. Effects of exurban development on biodiversity: patterns, mechanisms, and research needs. Ecological Applications 15, 1893–1905.

Haynes, L., J. Lamberton, C. Craddock, S. Prendergast, C. Prendergast, M. Colvin, B. Isaacs, E. Isaacs, R. Maxwell, S. Bless, D. Siegel, T Dee, M. Culver, and J. Koprowski. 2010. Mountain Lions and Bobcats of the Tucson Mountains: Monitoring Population Status and Landscape Connectivity, Final Report—June 2010. University of Arizona Wild Cat Research and Conservation, School of Natural Resources and Environment, University of Arizona. Tucson, Arizona.

Hines, J.E. 2006. PRESENCE- Software to estimate patch occupancy and related parameters. USGS-PWRC. http://www.mbr-pwrc.usgs.gov/software/presence.html.

Iriarte, J.A., W.L. Franklin, W.E. Johnson, and K.H. Redford. 1990. Biogeographic variation of food habits and body size of the America puma. Oecologia 85: 185-190.

KD Anderson & Associates, Inc. 2012. Existing Traffic Conditions Report for the Carnegie GP and EIR. Prepared for AECOM.

Kelly, M.J., A.J. Noss, M.S. Di Bitetti, L. Maffei, R.L. Arispe, A. Paviolo, C.D. De Angelo, and Y.E. Di Blanco. 2008. Estimating Puma Densities from Camera Trapping Across Three Study Sites: Bolivia, Argentina, and Belize. Journal of Mammalogy 89(2): 408-418.

Kertson, B.N., R.D. Spencer, J.M. Marzluff, J. Hepinstall-Cymerman, and C.E. Grue. 2011. Cougar space use and movements in the wildland – urban landscape of western Washington. Ecological Applications 21(8): 2866-2881.

Knopff, K.H., A.A. Knopff, A. Kortello, and M.S. Boyce. 2010. Cougar kill rate and prey composition in a multiprey system. Journal of Wildlife Management 74(7): 1435-1447.

Leempoel, K., J. Meyer, T. Hebert, N. Nova, and E.A. Hadly. Return of an apex predator to a suburban preserve triggers a rapid trophic cascade. bioRxiv 564294; doi: https://doi.org/10.1101/564294.

Lewis, J.S., K.A. Logan, M.W. Alldredge, L.L. Bailey, S. Vandewoude, and K. R. Crooks. 2015. The effects of urbanization on population density, occupancy, and detection probability of wild felids. Ecological Applications 25 (7): 1880-1895.

Logan, K.A., and L.L. Sweanor. 2001. Desert Puma: Evolutionary Ecology and Conservation of an Enduring Carnivore. Island Press, Washington.

MacKenzie, D.I., J.D. Nichols, G.B. Lachman, S. Droege, J.A. Royle, and C.A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83: 2248-2255.

MacKenzie, D.I., J.D. Nichols, J.E. Hines, M.G. Knutson, and A.B. Franklin. 2003. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. Ecology 84: 2200-2207.

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey, and J.E. Hines. 2006. Occupancy Estimation and Modeling, 1st Edition. Elsevier, Burlington.

McClanahan, K.A., B.N. Duplisea, J.A. Dellinger, and M.W Kenyon. 2017. Documentation of mountain lion occurrence and reproduction in the Sacramento Valley of California. California Fish and Game 103: 7-14.

Ordeñana, M.A., K. R. Crooks, E.E. Boydston, R.N. Fisher, L.M. Lyren, S. Siudyla, C.D. Haas, S. Harris, S.A. Hathaway, G.M. Turschak, A.K. Miles, and D.H. Van Vuren, 2010. Effects of urbanization on carnivore species distribution and richness, Journal of Mammalogy 91 (6): 1322–1331.

Penrod, K., P.E. Garding, C. Paulman, P. Beier, S. Weiss, N. Schaefer, R. Branciforte, and K. Gaffney. 2013. Critical Linkages: Bay Area & Beyond. Produced by Science & Collaboration for Connected Wildlands, Fair Oaks, CA www.scwildlands.org in collaboration with the Bay Area Open Space Council's Conservation Lands Network www.BayAreaLands.org.

PRISM Climate Group. 2020. Online PRISM Data Explorer. Oregon State University, Corvallis, Oregon. Accessed March 2020 from http://www.prism.oregonstate.edu/.

Reilly, M.L., M.W. Tobler, D.L. Sonderegger, and P. Beier. 2016. Spatial and temporal response of wildlife to recreational activities in the San Francisco Bay ecoregion. Biological Conservation 207: 117-126.

Riley, S.P.D., L.E.K. Serieys, J.P. Pollinger, J.A. Sikich, L. Dalbeck, R.K. Wayne, and H.B. Ernest. 2014. Individual behaviors dominate the dynamics of an urban mountain lion population isolated by roads. Current Biology 24(17): 1989-1994.

Šálek, M., L. Drahníková, and E. Tkadlec. 2014. Changes in home range sizes and population densities of carnivore species along the natural to urban habitat gradient. Mammal Review. http://dx.doi.org/10.1111/mam.12027.

Smith, J.A., Y. Wang, and C.C. Wilmers. 2015. Top carnivores increase their kill rates on prey as a response to human-induced fear. Proceedings of the Royal Society B: Biological Sciences 282(1802).

Townsend, S., M. Halbur, and L. Micheli. 2013. Wildlife Camera Studies at Pepperwood, 2011-2013. A technical report of Pepperwood's Dwight Center for Conservation Science prepared for the Sonoma County Agricultural and Open Space District. Santa Rosa, CA. 20 pp.

Wang, Y., M.L. Allen, and C.C. Wilmers. 2015. Mesopredator spatial and temporal response to large predators and human development in the Santa Cruz Mountains of California. Biological Conservation 190: 23–33.

Wang Y., J.A. Smith, and C.C. Wilmers. 2017. Residential development alters behavior, movement, and energetics in an apex predator, the puma. PLoS ONE 12(10).

Wilmers, C.C., Y. Wang, B. Nickel, P. Houghtaling, Y. Shakeri, M.L. Allen, J. Kermish-Wells, V. Yovovich, and T. Williams. 2013. Scale dependent behavioral responses to human development by a large predator, the puma. PLoS ONE 8(4).

Zeller, K.A., T.W. Vickers, H.B. Ernest, and W.M. Boyce. 2017. Multi-level, multi-scale resource selection functions and resistance surfaces for conservation planning: Pumas as a case study. PLoS ONE 12(6).

Appendix A. Summary of Mammalian Species Observed During the Study

Species	Detected in OHV Area	Detected in Non-OHV Area
Black-tailed Deer (*Odocoileus hemionus columbianus*)	Yes	Yes
Black-tailed Jackrabbit (*Lepus californicus*)	Yes	Yes
Bobcat (*Lynx rufus*)	Yes	Yes
Coyote (*Canis latrans*)	Yes	Yes
Desert Cottontail (*Sylvilagus audubonii*)	Yes	Yes
Gray Fox (*Urocyon cinereoargenteus*)	Yes	Yes
Ground Squirrel (*Otospermophilus beecheyi*)	Yes	Yes
Racoon (*Procyon lotor*)	Yes	Yes
Striped Skunk (*Mephitis mephitis*)	Yes	Yes
Tule Elk (*Cervus canadensis nannodes*)	No	Yes
Virginia Opossum (*Didelphis virginiana*)	No	Yes
Western Gray Squirrel (*Sciurus griseus*)	No	Yes
Wild Boar (*Sus scrofa*)	Yes	Yes