Spring 2013

Effects of Landscape Covariates on the Distribution and Detection Probabilities of Mammalian Carnivores on the Former Fort Ord, California

Bartholomew Lukas Kowalski
California State University, Monterey Bay

EFFECTS OF LANDSCAPE COVARIATES ON THE DISTRIBUTION AND DETECTION PROBABILITIES OF MAMMALIAN CARNIVORES ON THE FORMER FORT ORD, CALIFORNIA

A Thesis

Presented to the

Faculty of the

Division of Science and Environmental Policy

California State University Monterey Bay

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in

Coastal and Watershed Science and Policy

---

by

Bartholomew Lukas Kowalski

Spring 2013

CALIFORNIA STATE UNIVERSITY MONTEREY BAY

The Undersigned Faculty Committee Approves the

Thesis of Bartholomew Lukas Kowalski:

EFFECTS OF LANDSCAPE COVARIATES ON THE DISTRIBUTION AND
DETECTION PROBABILITIES OF MAMMALIAN CARNIVORES
ON FORMER FORT ORD, CALIFORNIA

Fred Watson, Committee Chair
Division of Science and Environmental Policy, CSUMB

Corey Garza
Division of Science and Environmental Policy, CSUMB

Bruce Delgado
Bureau of Land Management, Fort Ord National Monument

Marsha Moroh, Dean
College of Science, Media Arts, and Technology

May 24, 2013
Approval Date

Formatted for submission to the Landscape Ecology

Authors: Kowalski B, Watson F, Garza C, Delgado B

Abstract

Mammalian carnivores are affected by various anthropogenic disturbances near urban environments. Urban expansion and increased anthropogenic activity near and in preserved habitats may cause shifts in current spatial distribution of those species. To predict the effects of future land use changes on mammalian carnivores, we modeled their current occurrence across former Fort Ord Army base as a function of urban proximity and road/trail density. We collected detection/nondetection data for domestic dogs, coyotes, gray foxes, raccoons, striped skunks, and bobcats using scent stations. We analyzed our data with likelihood-based occupancy modeling, and used evidence ratios based on AIC weights to infer the effect of each variable on occurrence and detection probabilities for each species. We used the estimated weighted model coefficients of the predictive variables to create current and future species distribution maps given proposed landscape changes in the study area. Occurrence varied across the species. Domestic dogs were more likely to use areas closer to the urban edge, while gray foxes showed a preference toward inland areas. Detection probability was highest in areas closer to the urban edge for striped skunks, and in areas with high road/trail densities for raccoons. Our results suggest that the distribution of domestic dogs will most likely expand with future development, while those of gray foxes will contract. We predict that future land use changes outside of the preserved habitat will have an adverse effect on gray fox population within the protected areas.

Keywords; Mammalian Carnivores, Occupancy modeling, Scent stations, Road density, Urban wildlife, Recreation, Landscape ecology, California

Introduction

Urbanization is a major reason behind species endangerment in the continental United States, but its effects are also associated with other human activities such as outdoor recreation (Czech et al. 2000). While urbanization causes species' displacement due to direct habitat loss, human recreational activities within protected habitat may also be a cause of endangerment; in California alone 32 species are endangered by recreation (Czech et al. 2000). Mammalian carnivores may be especially susceptible to the effects of anthropogenic disturbances because they occur at low population densities and require large areas (Woodroffe and Ginsberg 1998; Woodroffe 2000; Crooks 2002).

Mammalian carnivores play important roles in ecological communities, and may serve as indicators of overall ecosystem health and robustness (Noss et al. 1996; Weaver et al. 1996; Lambeck 1997; Prugh 2009). Carnivores contribute to regulation of prey populations and energy transfer within the ecosystem, act as seed dispersers and scavengers, and have a selective effect on the evolution of prey (Buskirk 1999; Minta et al. 1999; Terborgh et al. 2001). Mammalian carnivores can also have a strong influence on the structure of vertebrate communities (Crooks and Soulé 1999; Crooks 2002; Prugh 2009), and the absence of predators can cause trophic cascades throughout the ecosystems (Terborgh et al. 2001; Ritchie and Johnson 2009). A recent National Fish, Wildlife, and Plants Climate Adaptation Strategy (NFWPCAP 2012) identified a goal to "manage species and habitats to protect ecosystem functions and provide sustainable cultural, subsistence, recreational, and commercial use in a changing climate", and advised natural resources managers to "slow, mitigate, and reverse where feasible ecosystem degradation from anthropogenic sources". Since mammalian carnivores play such an important role in their ecosystems and are particularly vulnerable to anthropogenic activities, knowledge of their distribution is an important metric for land managers to assess and protect the health of the ecosystem on the local scale.

Sensitivity of mammalian carnivores to urbanization varies by species; while some seem to have disappeared from fragmented landscapes, others seem tolerant of this anthropogenic disturbance (Crooks 2002). Similarly, mammalian carnivores' response to recreation may vary by species as well (George and Crooks 2006). Human recreation may affect wildlife activity, reproduction, and survival (Knight and Gutzwiller 1995; Whittaker and Knight 1998), it can cause higher energetic costs due to alarmed responses (Papouchis et al. 2001; Miller et al. 2001; Taylor and Knight 2003), and it can alter carnivore behavior and distribution (Olson et al. 1997; White et al. 1999; Nevin and Gilbert 2005; George and Crooks 2006). Reed and Merenlender (2008, 2011) found significant differences in carnivore composition and relative abundance between protected areas with and without quiet non-consumptive recreation. Thus, recreational activities as well as land use changes may have cumulative but varied effects on activity and the distribution of mammalian carnivores.

Protected areas often serve many uses, including conservation of natural resources and human recreation, and land managers are faced with a difficult task of balancing adequate protection to sensitive species and providing ample recreational opportunities for the public. Knowledge of the spatial distribution of sensitive species allows land managers to accommodate recreational uses with minimal impact to such species. Openings and closures of roads and trails are common and cost effective management practices that are used to steer recreationists from sensitive areas such as newly restored sites, locations of listed species, or areas prone to erosion. Such decisions are rarely made based on the knowledge of the distribution of mammalian carnivores, which is often lacking, yet road/trail density may be a limiting factor for mammalian carnivore distribution (Whittington et al 2005; Hilty and Merenlender 2011).

We studied the distribution of domestic dogs (*Canis lupus familiaris*), coyotes (*Canis latrans*), gray foxes (*Urocyon cinereoargenteus*), raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), and bobcats (*Lynx rufus*) as a function of distance to urban edge, and road/trail density on former Fort Ord Army base located in central coastal California. We analyzed our data with likelihood-based occupancy modeling (MacKenzie et al. 2002; MacKenzie et al. 2006) which incorporate probability of detection to account for imperfect detectability (false negatives), and allows for analysis of habitat suitability without the need for estimating actual population parameters (Long et al. 2011). We postulated that, for at least some species, occupancy would be related to both proximity to urban edge and road/trail density. We also modeled probability of detection as a function of those covariates, because to the best of our knowledge no studies considered whether distance to urban edge or road/trail density affect detection probabilities of mammalian carnivores. Our overall goal was to help enhance management approaches currently being used by wildlife managers, and to provide useful information to predict mammalian carnivores' distribution on former Fort Ord under different land use and management scenarios. Specifically, we aimed to (1) develop reproducible, efficient, sound and non-invasive monitoring protocol that would yield sufficient data for future studies of effects of land use change on mammalian carnivores, (2) create distribution maps for mammalian carnivores on the former Fort Ord army base, and (3) create a predicted future distribution map for the studied species. Based on projected land use changes on former Fort Ord, we aimed to gain an understanding of how the studied landscape variables will influence carnivore distribution. This is the first study on the distribution of mammalian carnivores on former Fort Ord (but see Quinn 2008). To the best of our knowledge this is also the first or one of the first attempts in using occupancy modeling to address the effect of human recreation on mammalian carnivores.

Methods

Study Area

Our study area comprised the former Fort Ord Army base (113 km^2), located in the north-western part of Monterey County, California, bordering Monterey Bay (Figure 1). The area's maritime climate is characterized by cool, overcast, foggy summers, and cool rainy winters, with the warmest days generally occurring in late summer and early fall (Quinn 2008). There are 17 distinct habitat types found on former Fort Ord, however a vast majority of total natural habitat area consists of maritime chaparral (52%), coastal oak woodland (12%), inland oak woodland (6%), and annual grasslands (18%) (USACE 1992). The NE side of the study area is bordered by extensive agriculture adjacent to the Salinas River, the SE side is bordered by low density residential, commercial, and recreational areas, and the NW side is adjecent to high density residential areas. The study area is under management of several public agencies, with varied protection and public access status. Over 59 km^2 have been recently designated as a Fort Ord National Monument, with 33 km^2 open to the public, and other 26 km^2 inaccessible due to ongoing environmental cleanup operations (Figure 1).

We established 66 sites located 1 km apart along roads and trails. Site selection was random, with a constraint that sites in areas undergoing munitions remediation had to be along existing roads. Using Geographic Information Software (ArcGIS; Environmental Systems Research Institute, Redlands, CA), and Spatial Ecology Tools (SpatialEcology.com) we created a 1 km grid with a random orientation, and snapped the grid vertices to the closest road or trail. In instances where adjacent stations were too close to each other (< 1 km) we manually adjusted the site location. The resulting site locations represented a wide range of possible values of distance to urban edge, and road/ trail density.

Carnivore Surveys

We created a 1 m diameter scent station (Ray and Zielinski 2008) at each pre-selected site location with fine sifted sand, and baited it with a liquid carnivore scent lure (Caven's Gusto, Murray's Lures & Trapping Supplies, Walker, WV). We conducted the surveys during three weeks of October 2011. We visited each site between 3 and 14 times, identified all clear tracks to species level, and cleared and re-baited them for the next survey. Unclear tracks were not used in the analysis to limit the chances of incorrect detections.

Overall modeling framework

We drew statistical inference about the existence of specific influences on carnivore occurrence and detection through a formal comparison of multiple models of occurrence and detection; and we predicted future occurrence patterns based on formal model averaging (eg. Joern et al. 2012; Becker et al. 2013; Balkenholt et al. 2013). Drawing on the statistical methods of MacKenzie et al. (2006), we developed a function for the likelihood of a model of occupancy and detection probabilities given data on detection at repeated visits to a number of sites. The function incorporated probability of detection in order to address the issue of false absences (species occurred at a site but was not detected). We could not assume the number of visits to each site and the number of days between visits would be constant, so we incorporated those variables into our likelihood function as follows:

$$L(\Psi, p|Y) = \prod_{i \in V}\left[\Psi_i \prod_{t=1}^{T}\left(Y_{i,t}(1-(1-p_i)^{D_{i,t}}) + \left(1-Y_{i,t}\right)(1-p_i)^{D_{i,t}}\right)\right] \times \quad (Eq.1)$$

$$\prod_{i \notin V}[(1-\Psi_i) + \Psi_i((1-p_i)^{D_{i,t}})^T]$$

where Ψ is the probability of occupancy and p is the probability of detection; Y is field observed detection (Y=1) versus non-detection (Y=0); V is the set of all sites where at least one detection occurred; T is the number of distinct sampling occasions; and $D_{i,t}$ is the number of days corresponding to each observation at each site.

We developed a number of hypotheses about the dependence of occupancy and detection probabilities on environmental covariates. Each hypothesis was expressed as a logistic function:

$$\Psi_i = \text{logit}^{-1}(\boldsymbol{\beta}^T \boldsymbol{X}_i) \qquad (Eq.2)$$

$$p_i = \text{logit}^{-1}(\boldsymbol{\gamma}^T \boldsymbol{X}_i) \qquad (Eq.3)$$

$$\textit{where}\ \text{logit}^{-1}(x) = \frac{1}{(1+e^{-x})} \qquad (Eq.4)$$

$\boldsymbol{\beta}^T$ and $\boldsymbol{\gamma}^T$ are transposed vectors of coefficients for the covariates, and $\boldsymbol{X}_i$ is a vector of covariates of interest measured at ith sampling unit.

We allowed both Ψ_i and p_i to vary spatially but not temporally (since we controlled our data collection to occur within a relatively short time-frame).

Model development and variable selection

Our goal was to develop a resource management tool that could be utilized by land managers to help guide their decisions regarding land use on former Fort Ord. Hence we chose variables that were likely to be directly affected by management of the protected areas and land use planning of the surrounding landscape. Specifically, we were interested in seeing whether road/trail density (*R*; calculated as sum of all road/trail lengths divided by the area within 500 m radius), and distance to urban edge (*U*; urban being defined as all residential and industrial areas, as well as the Laguna Seca Raceway), were good predictors of carnivores' occurrence, and we used those variables as our landscape covariates.

We determined the values of landscape covariates using GIS. We used Association of Monterey Bay Area Governments (AMBAG 2007) and National Agriculture Imagery Program (NAIP 2010) orthoimagery to digitize urban areas, United States Army Corps of Engineers GIS data to calculate road/trail density, and orthoimagery and LiDAR data (2010) to visually inspect if all trails were included. Where possible, we conducted field visits to check the accuracy of the data. We used ArcInfo 10 (ESRI 2011) to calculate distances to urban edge and road/trail densities within 500 m radius of each site. While such an area is smaller than home ranges of coyotes and bobcats (Crooks 2002), even if detections at adjacent sites were of the same individual, we assumed that at this scale they could be viewed as independent events of habitat use. Therefore Ψ can be interpreted as occurrence probability (e.g.Walpole et al. 2012).

A priori, we considered a candidate set of eight models including all possible combinations of *U* and *R* as influences on Ψ, and *R* as an influence on *p* (Table 1). We computed a full AIC table for these, summed the AIC weights (AIC_w) to yield relative importance values (RI) for each influence (Burnham and Anderson 2002; Arnold 2010), and divided these by their complement to yield evidence ratios (ER) for each covariate influence that were used as the basis for all formal inference. This overall strategy mirrors that of Joern et al. (2012), Becker et al. (2013), and Balkenholt et al. (2013). To achieve a priori consistency in language used to interpret ERs, we followed the thresholds suggested by Kass and Raftery (1995) and Becker et al. (2013); $1 < \text{ER} \leq \sqrt{10}$ was 'equivocal', $\text{ER} > \sqrt{10}$ was 'substantial', $\text{ER} \geq 10$ was 'strong', $\text{ER} \geq 10\sqrt{10}$ was 'very strong', and $\text{ER} \geq 100$ was 'decisive' evidence for an effect. Post hoc, we considered four additional models with *U* as an influence on *p* for all species but domestic dogs, and eight models for dogs that incorporated a covariate for fencing (*F*). The lack of inclusion of this variable might have obscured evidence for the effect of other covariates on detection rates of domestic dogs, so we explored the potential importance of *F* by adding its effect to the eight a priori models (Table 1). As with the a priori steps, we computed RI and ER values for *U* and *F* as influences on *p*. Finally, we conducted a model comparison of all a priori and post hoc models together to determine weighted covariate coefficients for each species. We computed the AIC weighted mean of each coefficient, assuming 0 as the value of any coefficients that were absent from specific models (Burnham and Anderson 2002; Arnold 2010).

Power analysis

Prior to conducting field work, we performed a power analysis to determine if we would be able to detect the postulated effects with the limited time and resources available. Based on literature review we assumed plausible values of Ψ and *p* for each species, expressed as functions of road/trail density and distance to urban edge. We simulated stochastic data sets (following Bolker 2008) using Equations 2 and 3 under a range of different values for sampling occasions

(T) and number of sites (S). We fit models to the simulated data using Equation 1 in the *optim* function in R (R Development Core Team 2010), computed corresponding AIC weights, and based on those, we compared models in terms of ERs. We determined the optimal values of T and S by checking which data sets produced a substantial evidence ratio of the best model to the second best. We examined the fitted model coefficients and visually inspected whether they were close to the known values used to derive the simulated data. Our simulation showed we could obtain good results with 60 sites sampled over a three-week period, with the exception of cases where p was low ($p < 0.2$).

Predictive mapping

We mapped estimated occurrence probability under present (2011) and future scenarios using the weighted covariate coefficients. We created a GIS layer of future urban areas based on proposed development areas in the habitat management plan (USACE 1997), and used ArcGIS to create a distance raster representing the distance to the nearest urban edge. We assumed all areas proposed for development to be urban. Specific plans for future road and trail networks were not yet finalized, so we used road/trail density raster layer that reflected 2011 conditions.

Results

Carnivore surveys

We made a total of 504 observations, with a mean of 7.64 observations per station for all detected carnivores. Detection rates were 36% for domestic dogs, 70% for coyotes, 20% for gray foxes, 52% for striped skunks, 21% for raccoons, 11% for bobcats, and only 1.5% for badgers which precluded occurrence probability calculations for this species. These are naïve estimates of occupancy because they do not take into account detection probability.

Variable selection

For domestic dogs there was very strong evidence that occurrence was greater near the urban edge, decisive evidence that detection was dependent on presence of fencing, but only equivocal evidence that it was dependent on road/trail density (Table 2). There was no evidence that coyotes favored any particular areas, but there was substantial evidence they were more likely to be detected near the urban edge (Table 3). In the a priori analysis there was strong evidence that gray fox occurrence was lower near the urban edge, and that evidence was very strong in post hoc analysis. There was also substantial evidence that probability of detection was lower at high road/trail densities for gray foxes. Raccoon models demonstrated substantial evidence that occurrence was greater at low road/trail densities, and strong evidence that probability of detection was greater at high road/trail densities. For striped skunks, there was decisive evidence that probability of detection was higher near the urban edge, although neither variable stood out as a good predictor of their occurrence. There was no support for any spatial pattern in bobcat occurrence and detection probabilities, possibly because of overall low detection rates.

Predictive mapping

We mapped current occurrence probabilities for domestic dogs, gray foxes, and raccoons using weighted coefficients for those species. We did not map coyote, striped skunk or bobcat distribution, because distance to urban edge did not have a substantial or greater evidence it was a good predictor of those species' occurrence, and we assumed constant road/trail density (Table 2).

Domestic dog had a high occurrence ($\Psi > 0.5$) in areas near urban edge ($R < 1$ km), and a very low occurrence in the center of former Fort Ord ($\Psi < 0.25$) (Figure 2). Based on the projected land use changes, the area of very low domestic dog occurrence will shrink from 15 km^2 to 3.7 km^2 in the future.

The largest area with very high gray fox occurrence ($\Psi > 0.75$) was within the center of former Fort Ord (Figure 3). For most of the areas near urban edge the occurrence was low ($\Psi < 0.25$). Based on the projected land use changes, high gray fox occurrence areas decreased from 9.4 km^2 to 0.58 km^2, and were fragmented down to two small pockets within the newly declared Fort Ord National Monument, while areas with very high occurrence were nonexistent.

Raccoon occurrence probability was negatively correlated with road/trail density. Raccoons were widely distributed in protected areas, as well as urban areas where road/trail density was low, but had very low occurrence in and near the urban areas with high road/trail densities (Figure 4). Their future distribution will not change substantially assuming road/trail density will stay the same.

Discussion

Our results provided evidence that mammalian carnivores occurred in different habitats with different probabilities within our study area, and that our (occurrence-conditioned) ability to detect them also varied between habitats. We were able to collect sufficient detection/non-detection data with noninvasive and short duration surveys to develop distribution maps for domestic dogs, gray foxes, and raccoons.

Domestic dog

As expected, distance to urban edge was an important predictor of the distribution of domestic dogs, with over 50% occurrence within 1 km of urban areas (Figure 3A), but dropping below

20% in areas 2.5 km out. This result was similar to the findings of Reed and Merenlender (2008) who found that domestic dog densities were about four times higher at the edges of natural protected areas than in their interiors. Ordeñana et al. (2010) however, found no significant correlation between domestic dog occurrence and distance to urban edge, but they did find significant correlation between the percentage of urban areas and domestic dog occurrence, suggesting human visitation rates are higher in densely urban areas. Not surprisingly, detection probability of dogs was decisively and negatively dependent on presence of fencing.

The estimated future domestic dog distribution (Figure 2B) shows a significant increase in the occurrence across former Fort Ord. The effect of domestic dogs on wild carnivores is still not well understood. Presence or absence of domestic dogs does not seem to affect carnivore abundance and species richness (Reed and Merenlender 2011), but it does negatively affect bobcat daytime activity (George and Crooks 2006). Dogs may disrupt native carnivore behavior by chasing, barking, or scent marking on their territories, and dog activity is associated with human use (George and Crooks 2006). Hence, future expansion of dog occurrence across the National Monument could cause a shift in temporal activity of bobcats and perhaps other carnivores as well. We observed an instance of a coyote running away from a domestic dog, but it is also known from opportunistic interviews coyotes will prey on domestic dogs in the study area.

Coyote

Our results did not determine if either variable we considered was a good predictor of coyote occurrence, but the fact they were detected at 70% of our sites suggests they were quite ubiquitous across our study area. Previous studies showed that coyotes can be found close to the urban edge as well as in the interior of habitat patches (Crooks 2002), they often use dirt roads in suburban environments (Way et al 2004), and are generally tolerant of human development and activity (Grinder and Krausman 2001; Crooks 2002; Gehring and Swihart 2002). Ordeñana et al. (2010) showed coyotes had a positive response to urban intensity and were more likely to occur near the urban edge, but Reed (2011) found coyote habitat use in a non-urban environment was positively related to distance to park boundary. Our results suggest that more data are needed to understand the effects of urban edge and road/trail density on coyote distribution in this region.

We found substantial evidence coyotes might be less likely detected further away from the urban edge, which could positively bias occurrence estimates toward urban areas if detection probability was not considered. This could occur if coyotes had smaller home range sizes near urban areas, as was the case in Indiana (Atwood et al. 2004). In metropolitan areas of southern California and Illinois however, the opposite was true (Riley 2003; Gehrt et al. 2009), while another southern California study found no significant difference in coyote home range size between fragmented and non-fragmented habitats (Tigas et al. 2002). Given coyotes' adaptability to human disturbance, future expansion of urban areas on former Fort Ord will not likely affect their spatial distribution, but it may result in a smaller functional area for resting and rearing young, it could increase competition among individual coyotes, between coyotes and other species, and could alter their temporal activity patterns.

Gray fox

Gray foxes strongly preferred inland areas away from the urban edge, which contrasted with the findings by Crooks (2002), Riley (2006), and Temple et al. (2010), but agreed with Ordeñana et al. (2010). In other studies gray foxes selected areas with higher abundance of small mammal prey (Chamberlain and Leopold 2000; Gehring and Swihart 2002), but fell prey to coyotes (Fedriani et al. 2000; Farias et al. 2005). Gray foxes also chose areas that were less likely to be occupied by their feline competitors (Chamberlain and Leopold 2005; Riley 2006; Temple et al. 2010). Hence gray foxes might be forced into habitats in which they can easily avoid larger predators, but that still provide sufficient opportunities for hunting and foraging, such as thick chaparral areas. During the study we observed gray fox scat with large quantities of Manzanita berries, suggesting chaparral areas may serve double function of providing cover and food source for gray foxes.

Road/trail density did not seem to be a strong predictor of gray fox occurrence, but there was substantial evidence it had a negative effect on their detection probability. In southern California Markovchik-Nicols et al. (2008) found gray fox presence to be significantly and negatively correlated with road intensity, but they did not incorporate detection probability into their study. Our results suggest not taking detection probability into gray fox distribution models may bias them against high road/trail density areas.

Our model forecasted a greatly reduced future gray fox occurrence compared to the current estimates. Very high probability of occurrence areas ($\Psi > 0.75$) will disappear completely, and total area where occurrence is greater than 0.50 will decrease from 12 km^2 to just over 0.5 km^2.

Raccoon

The raccoon distribution map showed they were very likely to be found across the entire former Fort Ord except urban areas with high road/trail densities (Figure 5). Raccoon positive association with urban areas is well documented (Crooks and Soulé 1999; Crooks 2002; Prenge and Gehrt 2004; Randa and Younger 2006; Ordeñana 2010). Randa and Younger (2006) also showed a positive correlation of raccoon distribution to weighted road density.

In our study there was strong evidence raccoon detection probability was positively dependent on road/trail density. Cove et al. (2012) however, showed that the cumulative length of roads did not affect raccoon detection probability at a 2 km scale, and instead was negatively dependent on patch size. The relatively large area of our study, different scale, as well as the fact we incorporated trails into our analysis make it hard to compare our results with those of Cove et al. (2012). Our raccoon results may have been affected by model selection uncertainty due to overall low detection probability.

Striped skunk

Striped skunk occurrence did not depend on either urban or road/trail effects, but detection probability was decisively and negatively correlated with distance to urban edge (Tables 2 and 3). Striped skunks did not show a preference to any particular land use type in Texas (Neiswenter and Dowler 2007), but noninvasive studies from southern California showed striped skunk abundance to be highest near urban edges (Crooks 2002; Ordeñana et al. 2010). Striped skunks' higher probability of detection near urban edge might be due to different activity patterns in those areas. They might take advantage of the available food sources there, but perhaps prefer more natural areas with ample cover and den sites for resting (Ordeñana et al. 2010).

Bobcat

Our results for bobcats were inconclusive because they were detected only at 11% of the sites in our study. Although detection probability might depend on the type of method utilized (Reed

2011), low bobcat detection rates were also reported by Long et al. (2011) and Hilty and Merenlender (2004) who used different methodologies. Hence our low detection rates suggest that more than three weeks of sampling effort is needed to gather sufficient data for bobcat analysis.

Other Species

We detected a badger only at one station in the grassland area of former Fort Ord, where they predominantly occur (Quinn 2008). Quinn (2008) compared several methods for detection of badgers, and found scent stations had very low detection rates. Lay (2008) used transect surveys for badger burrows, which are easily distinguishable and long-lasting (Messick and Hornocker 1981). We were unable to use this methodology due to the access restrictions to parts of former Fort Ord during the study period, but future studies should consider them.

We did not detect any mountain lions, opossums, red foxes, or long tailed weasels, all of which were known to occur on former Fort Ord.

We found that scent stations were a viable and simple method for studying mammalian carnivore distribution. The overall costs of setting up, maintaining, and surveying the sites for tracks is comparatively lower than other methods (Ray and Zielinski 2008). The absence of expensive equipment, such as remote cameras, prevents the possibility of vandalism or robbery; both of which are issues of concern near densely populated areas. Combining several different methods would most likely result in an increase of detection probabilities for several species of carnivores (Gompper et al. 2006). Reed (2011) demonstrated detection probability varied for gray foxes, coyotes, and possibly bobcats between several noninvasive methods. Occurrence modeling allows for an easy comparison of different method effects on detection probability, as well as for integrating several methods into one study. However, employing too many methods, besides being financially costly, would also result in lower power of predictive models due to the cost of estimating extra variables. A careful consideration should be given to the potential gain in detectability of several surveying methods vs. the loss of models' predictive power. We were able to collect sufficient data on domestic dogs and gray foxes. Analysis of coyotes, striped skunks, raccoons, and bobcats would benefit from more data. Longer sampling period and possible alteration to the type of lure used might help increase detection probabilities. The observed detection rates in our study can and should be incorporated in designing optimal future studies of carnivores on the California central coast.

While setting aside protected areas for the sole use of conservation might be the most effective policy (Reed and Merenlender 2011), it is unlikely that it would be a common practice in areas bordering large urban development with high demand for recreational opportunities. Instead, land managers might continue to use road/trail openings and closures as their strategy for mitigating impact due to recreation. Our results show such actions would potentially benefit raccoons, but would not affect the distribution of domestic dogs and gray foxes.

The available evidence suggests that future urban expansion inward toward the center of former Fort Ord would increase the distribution of domestic dogs, and decrease the distribution of gray foxes. In terms of the predicted area of suitable gray fox habitat, the protected lands would not offer enough buffer to mitigate the effects of urban expansion. Under the scenario where all development areas are converted to urban use, we project gray fox occurrence will decrease sharply across the entire study area, and their distribution will be limited to areas well within the boundary of the national monument. This might have an adverse effect on connectivity between the monument and other open spaces, and result in decreased genetic diversity among gray foxes in the region.

The area surrounding Fort Ord National Monument is projected to undergo land use changes and the expansion of urban development, and it is a unique opportunity to study the effects of such changes before they take effect. Our study established the baseline for future work, and we hope it will help guide land use planning and management of former Fort Ord and other areas with similar challenges. Our study provides useful information for land managers who want to be successful at maintaining healthy, viable populations of native mammalian carnivores and their ecosystems' robustness.

Acknowledgements

James Rote Research Grant, Undergraduate Research Opportunity Center (UROC), Bureau of Land Management, US Army, UC Natural Reserve, The Watershed Institute

Christina Salomone, Ryan Basset, Erin Stanfield, Patty Cubanski, Steve Quan, Polly Perkins, Roger Arenas, David Styer, Rose Ashbach

The study protocol was approved by CSUMB's Institutional Animal Care and Use Committee (Protocol A11-011).

References

Arnold TW. 2010. Uninformative Parameters and Model Selection Using Akaike's Information Criterion. Journal of Wildlife Management 74(6):1175- 1178

Atwood TC, Weeks HP, Gehring TM. 2004. Spatial ecology of coyotes along a suburban-to-rural gradient. Journal of Wildlife Management 68(4): 1000-1009

[AMBAG] Association of Monterey Bay Area Governments. 2007. Central Coast Orthoimagery

Balkenhol N, Pardini R, Cornelius C, Fernandes F, Sommer S. 2013. Landscape-level comparison of genetic diversity and differentiation in a small mammal inhabiting different fragmented landscapes of the Brazilian Atlantic Forest. Conservation Genetics 14:355-367

Becker M, McRobb R, Watson F, Droge E, Kanyembo B, Murdoch J, Kakumbi C. 2013. Evaluating wire-snare trends and the impacts of by-catch on elephants and large carnivores. Biological Conservation 158:26-36

Bolker BM. 2008. Ecological models and data in R. Princeton University Press, Princeton

Bradley LC, Fagre DB. 1988. Coyote and bobcat responses to integrated ranch management practices in south Texas. Journal of Range Management 41:322-327

Burnham KP, Anderson DR. 2002. Model selection and multimodel inference. Springer, New York

Buskirk SW. 1999. Mesocarnivores of Yellowstone. In: Clark TW, Minta SC, Karieva PK, Curlee AP (eds) Carnivores in ecosystems: the Yellowstone experience. Yale University Press, New Haven 165-187

Chamberlain M J, Leopold BD. 2005. Overlap in space use among bobcats (Lynx rufus), coyotes (Canis latrans) and gray foxes (Urocyon cinereoargenteus). American Midland Naturalist 153(1):171-179

Chamberlain MJ, Lovell CD, Leopold BD. 2000. Spatial-use patterns, movements, and interactions among adult coyotes in central Mississippi. Canadian Journal of Zoology-Revue Canadienne De Zoologie 78(12):2087-2095

Cove MV, Niva LM, Jackson VL. 2012. Use of probability of detection when conducting analyses of surveys of mesopredators: a case study from the Ozark highlands of Missouri. Southwestern Naturalist 57(3):257-261

Crooks KR, Soulé ME. 1999. Mammalian carnivore release and avifaunal extinctions in a fragmented system. Nature 400(6744):563-566

Crooks KR. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. Conservation Biology 16(2):488-502

Czech B, Krausman PR, Devers PK. 2000. Economic Associations among Causes of Species Endangerment in the United States. BioScience 50(7):593-601

Farias V, Fuller TK, Wayne RK, Sauvajot RM. 2005.Survival and cause-specific mortality of gray foxes in southern California. Journal of Zoology 266:249-254

Fedriani JM, Fuller TK, Sauvajot RM, York EC. 2000. Competition and intra guild predation among three sympatric carnivores. Oecologia 125:258-270

Gehring TM, Swihart RK. 2003. Body size, niche breadth, and ecologically scaled responses to habitat fragmentation: mammalian predators in an agricultural landscape. Biological Conservation 109(2):283-295

Gehrt S D, Anchor C, White LA. 2009. Home range and landscape use of coyotes in a metropolitan landscape: conflict or coexistence? Journal of Mammalogy 90(5): 1045-1057

George SL, Crooks KR. 2006. Recreation and large mammal activity in an urban nature reserve. Biological Conservation 133(1):107-117

Gompper ME, Kays RW, Ray JC, Lapoint SD, Bogan DA, Cryan JR. 2006. A comparison of noninvasive techniques to survey carnivore communities in northeastern North America. Wildlife Society Bulletin 34(4):1142-1151

Grinder MI, Krausman PR. 2001. Home range, habitat use, and nocturnal activity of coyotes in an urban environment. Journal of Wildlife Management 65:887–898

Hilty JA, Merenlender AM. 2004. Use of riparian corridors and vineyards by mammalian predators in northern California. Conservation Biology 18(1): 126-135

Joern A, Provin T, Behmer SY. 2012. Not just the usual suspects: Insect herbivore populations and communities are associated with multiple plant nutrients. Ecology 93(5):1002-1015

Knight RL, Gutzwiller KJ. 1995. Wildlife and recreationists: coexistence through research and management. Island Press, Washington

Lambeck RJ. 1997. Focal species: a multi-species umbrella for nature conservation. Conservation Biology 11: 849–856

Lay C. 2008. The status of the American badger in the San Francisco Bay Area. Master’s thesis, San Jose State University

Long RA, Donovan TM, MacKay P, Zielinski WJ, Buzas JS. 2011. Predicting carnivore occurrence with noninvasive surveys and occupancy modeling. Landscape Ecology 26(3): 327-340

MacKenzie DI, Nichols JD, Royle JA, Pollock KH, Bailey LL, Hines JE. 2006. Occupancy estimation and modeling. Academic Press, Burlington, San Diego, London

MacKenzie DI, Nichols JD, Lachman GB, Droege S, Royle JA, Langtimm CA. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83(8):2248-2255

Markovchik-Nicholls L, Regan HM, Deutschman DH, Widyanata A, Martin B, Noreke L, Hunt TA. 2008. Relationships between human disturbance and wildlife land use in urban habitat fragments. Conservation Biology 22(1):99-109

Messick JP, Hornocker MG. 1981. Ecology of the badger in southwestern Idaho. Wildlife Monographs (76): 1-53

Miller SG, Knight RL, Miller CK. 2001. Wildlife responses to pedestrians and dogs. Wildlife Society Bulletin 29(1):124-132

Minta SC, Kareiva PM, Peyton AC. 1999. Carnivore research and conservation: learning from history and theory. In: Clark TW, Minta SC, Karieva PK, CurleeAP (eds). Carnivores in ecosystems: the Yellowstone experience. Yale University Press, Yale, p165-187

[NFWPCAP] National Fish, Wildlife and Plants Climate Adaptation Partnership. 2012. National Fish, Wildlife and Plants Climate Adaptation Strategy. Available from: http://www.wildlifeadaptationstrategy.gov/pdf/NFWPCAS-Final.pdf

Nevin OT, GilbertBK. 2005. Perceived risk, displacement and refuging in brown bears: positive impacts of ecotourism? Biological Conservation 121: 611-622

Newmark WD. 1995. Extinction of mammal populations in western North American national parks. Conservation Biology 9(3):512-526

Noss RF.,Quigley HB, Hornocker MG, Merrill T, Paquet PC. 1996. Conservation biology and carnivore conservation in the Rocky Mountains. Conservation Biology 10(4): 949-963

Olson TL, Gilbert BK, Squibb RC. 1997. The effects of increasing human activity on brown bear use of an Alaskan river. Biological Conservation 82(1):95-99

Ordeñana MA, Crooks KR, Boydston EE, Fisher RN, Lyren LM, Siudyla S, Haas CD, Harris S, Hathaway SA, Turschak GM, A. K. Miles AK, Van Vuren DH. 2010. Effects of urbanization on carnivore species distribution and richness. Journal of Mammalogy 91(6):1322-1331

Papouchis CM, Singer FJ, Sloan WB. 2001. Responses of desert bighorn sheep to increased human recreation. Journal of Wildlife Management 65(3):573-582

Prugh LR, Stoner CJ, Epps CW, Bean WT, Ripple WJ, Laliberte AS, Brashares JS. 2009. The rise of the mesopredator. Bioscience 59(9):779-791

Quinn JH. 2008. The ecology of the American badger (*Taxidea taxus*) in California: assessing conservation status on multiple scales. Dissertation, University of California, Davis

Randa LA, Yunger JA. 2006. Carnivore occurrence along an urban-rural gradient: a landscape-level analysis. Journal of Mammalogy 87:1154-1164

Ray JC, Zielinski WJ. 2008. Track Stations. In: Long RA, MacKay P, Zielinski WJ, Ray JC (eds) Noninvasive Survey Methods for Carnivores. Island Press, Washington DC p 75-109

Reed SE. 2011. Non-invasive methods to assess co-occurrence of mammalian carnivores. Southwestern Naturalist 56(2): 231-240

Reed SE, Merenlender AM. 2008. Quiet, nonconsumptive recreation reduces protected area effectiveness. Conservation Letters 1(3): 146-154

Reed SE, Merenlender AM. 2011. Effects of management of domestic dogs and recreation on carnivores in protected areas in Northern California. Conservation Biology 25(3): 504-513

Riley SP, Sauvajot DRM, Fuller TK, York EC, Kamradt DA, Bromley C, Wayne RK. 2003. Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California. Conservation Biology 17(2): 566-576

Riley SPD. 2006. Spatial ecology of bobcats and gray foxes in urban and rural zones of a national park. The Journal of Wildlife Management 70(5):1425-1435

Ritchie EG, Johnson CN. 2009. Predator interactions, mammalian carnivore release and biodiversity conservation. Ecology Letters 12(9):982-998

Taylor AR, Knight RL. 2003. Wildlife responses to recreation and associated visitor perceptions. Ecological Applications 13(4):951-963

Temple DL, Chamberlain MJ, Conner LM. 2010. Spatial ecology, survival and cause-specific mortality of gray foxes (Urocyon cinereoargenteus) in a longleaf pine ecosystem. American Midland Naturalist 1(632): 413-422

Terborgh J, Lopez L, Nunez PV, Rao M, Shahabuddin G, Orihuela G, Riveros M, Ascanio R, Adler GH, Lambert, TD, Balbas L. 2001. Ecological meltdown in predator-free forest fragments. Science 294:1923–1925

Tigas, LA, Van Vuren DH, Sauvajot RM. 2002. Behavioral responses of bobcats and coyotes to habitat fragmentation and corridors in an urban environment. Biological Conservation 108:299–306

[USACE] United States Corps of Engineers.1992. Flora and fauna baseline study of Fort Ord, California. Available from: http://www.fortordcleanup.com/adminrec/ar_pdfs/ar-bw-1938/bw-1938.pdf

[USACE] United States Corps of Engineers.1997. Installation-wide multispecies habitat management plan for former Fort Ord, California. Available from: http://www.fortordcleanup.com/adminrec/ar_pdfs/ar-bw-1787/bw-1787.pdf

Way JG, Ortega IM, Strauss EG.2004. Movement and activity patterns of eastern coyotes in a coastal suburban environment. Northeastern Naturalist 11(3):237-254

Walpole AA, Bowman J, Murray DL, Wilson PJ. 2012. Functional connectivity of lynx at their southern range periphery in Ontario, Canada. Landscape Ecology 27:761-773

Weaver JL, Paquet PC, Ruggiero LF. 1996. Resilience and conservation of large carnivores in the Rocky Mountains. Conservation Biology 10:964–976

White D, Kendall KC, Picton HD. 1999. Potential energetic effects of mountain climbers on foraging grizzly bears. Wildlife Society Bulletin 27(1):146-151

Whittaker D, Knight EL. 1998. Understanding wildlife responses to humans. Wildlife Society Bulletin 26(2):312-317

Whittington J, St Clair CC, Mercer G. 2005. Spatial responses of wolves to roads and trails in mountain valleys. Ecological Applications 15(2): 543-553

Woodroffe R. 2000. Predators and people: using human densities to interpret declines of large carnivores. Animal Conservation 3:165-173

Woodroffe R, Ginsberg JR. 1998. Edge effects and the extinction of populations inside protected areas. Science 280(5372):2126-2128

Table 1. List of a priori and post hoc logistic models for each mammalian carnivore species tested to predict the occurrence on former Fort Ord. Each model denotes a logistic regression model with the listed covariates. The symbols β_o and γ_o indicate a constant null model for Ψ and *p* respectively. *R*, *U*, and *F* stand for road/trail density, distance to urban edge, and fencing, respectively. All species include domestic dogs, coyotes, gray foxes, raccoons, striped skunks, and bobcats.

Name	K	Ψ model	*p* model	Type	Species
m0.0	2	β_0	γ_0	*a priori*	all
m*U*.0	3	*U*	γ_0	*a priori*	all
m*R*.0	3	*R*	γ_0	*a priori*	all
m*UR*.0	4	*U*+*R*	γ_0	*a priori*	all
m0.*R*	3	β_0	*R*	*a priori*	all
m*U*.*R*	4	*U*	*R*	*a priori*	all
m*R*.*R*	4	*R*	*R*	*a priori*	all
m*UR*.*R*	5	*U*+*R*	*R*	*a priori*	all
m0.*U*	3	β_0	*U*	*post hoc*	all but dog
m*U*.*U*	4	*U*	*U*	*post hoc*	all but dog
m*R*.*U*	4	*R*	*U*	*post hoc*	all but dog
m*UR*.*U*	5	*U*+*R*	*U*	*post hoc*	all but dog
m0.*F*	3	β_0	*F*	*post hoc*	dog
m*U*.*F*	4	*U*	*F*	*post hoc*	dog
m*R*.*F*	4	*R*	*F*	*post hoc*	dog
m*UR*.*F*	5	*U*+*R*	*F*	*post hoc*	dog
m0.*RF*	4	β_0	*R*+*F*	*post hoc*	dog
m*U*.*RF*	5	*U*	*R*+*F*	*post hoc*	dog
m*R*.*RF*	5	*R*	*R*+*F*	*post hoc*	dog
m*UR*.*RF*	6	*U*+*R*	*R*+*F*	*post hoc*	dog

Table 2. Results of model comparison for six species as determined by ER values. Models with decisive support are marked in bold and a box, those with very strong support are marked in bold, and those with strong support are underlined. *U* stands for distance to urban edge, *R* stands for road/trail density, and *F* stands for presence of fencing. Letters before the dot stand for Ψ variables, while letters after the dot represent *p* variables.

ER	Domestic Dog		Coyote		Gray Fox		Raccoon		Striped Skunk		Bobcat	
	a priori	post hoc	a priori	post hoc	a priori	post hoc	a priori	post hoc	a priori	post hoc	a priori	post hoc
U.	**66.32**	**36.12**	0.33	0.39	28.66	**59.50**	0.66	0.40	0.33	1.01	0.94	0.91
R.	0.40	1.73	0.48	0.47	0.86	0.33	2.68	3.85	0.84	0.79	1.41	0.97
.R	0.40	0.31	1.82		5.80		18.61		1.14		0.62	
.U				4.77		0.45		0.40		**2621.43**		0.46
.F		**726.30**										

Table 3. Model weighted coefficient values for intercept, distance to urban edge, road/trail density and fencing estimates for the studied species.

Model	Occupancy Probability			Detection Probability			
	β_0	β_U	β_R	γ_0	γ_U	γ_R	γ_F
Domestic Dog	1.300	-1.030	-0.006	-1.933		0.001	-1.957
Coyote	1.270	0.051	-0.026	-1.891	-0.131	0.013	
Gray Fox	-4.320	1.255	0.147	0.605	-0.019	-0.303	
Striped Skunk	0.601	0.361	-0.054	-1.715	-0.516	0.000	
Raccoon	17.504	0.583	-1.285	-7.307	0.000	0.315	
Bobcat	0.863	10.763	4.136	-4.425	0.037	-0.062	

Figures

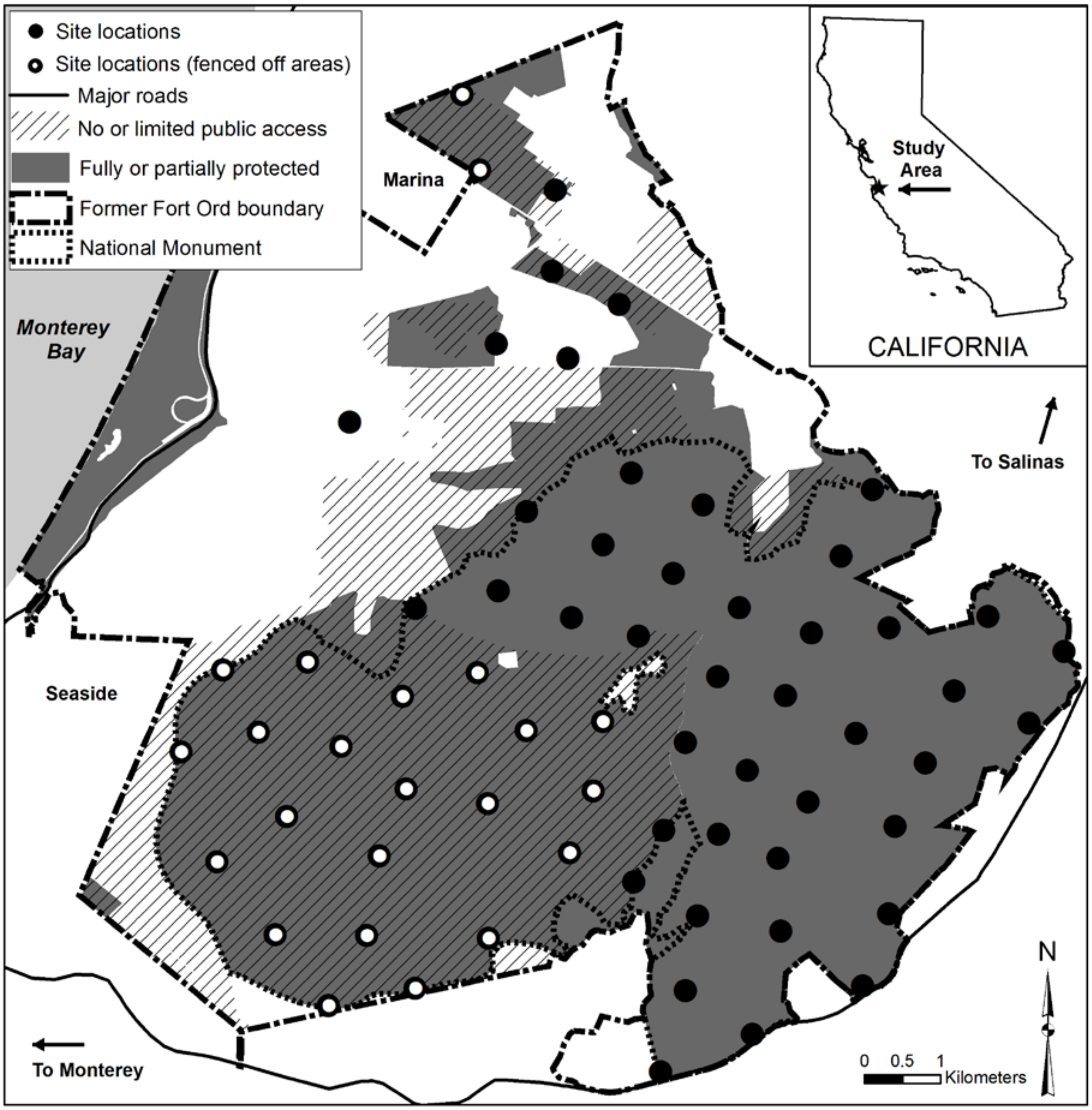

Figure 1. Map of 66 scent station sites surveyed for mammalian carnivores on former Fort Ord during October 2011, depicting fully or partially protected areas, and the status of public access.

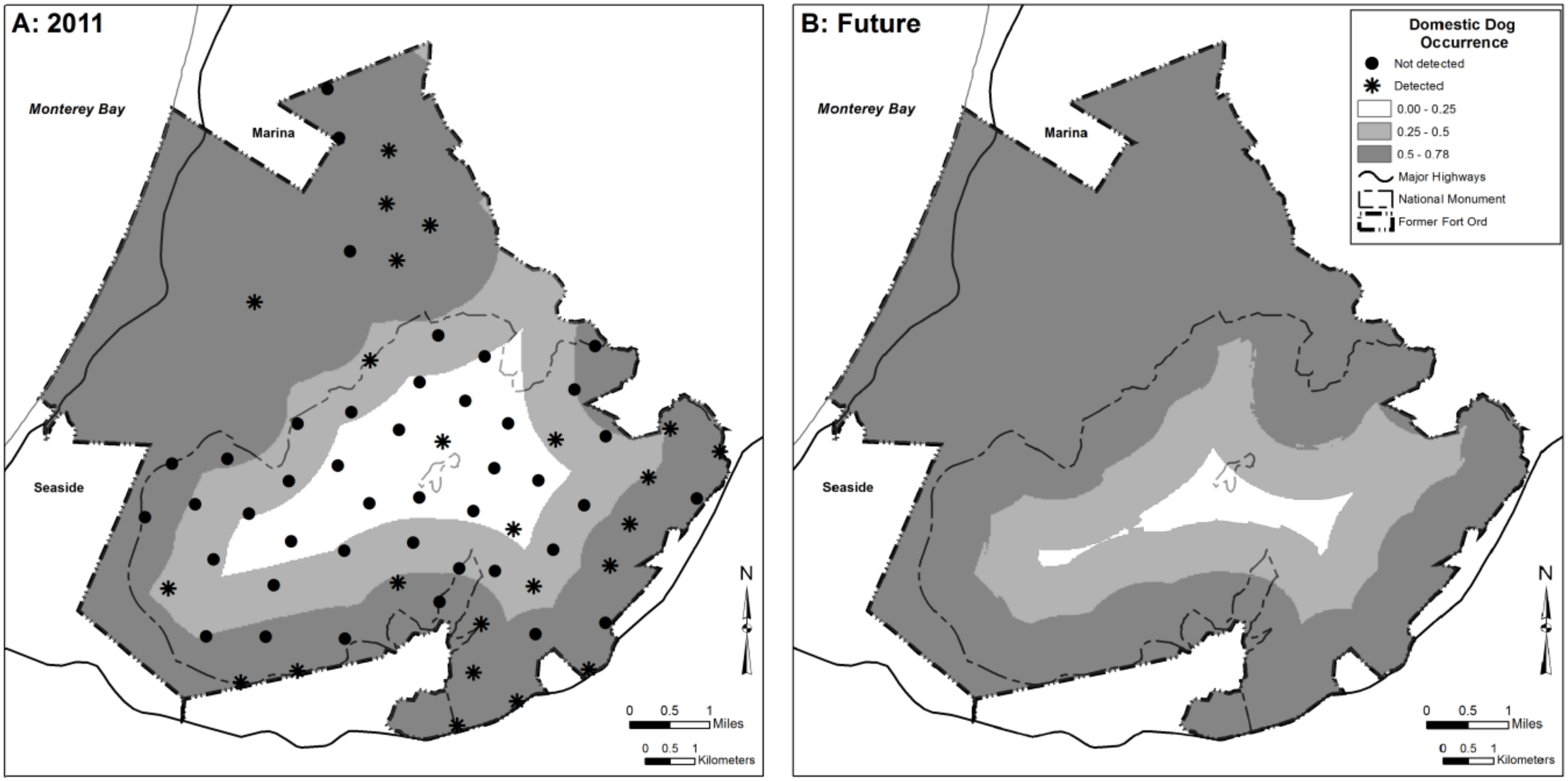

Figure 2. Comparison of the domestic dog occurrence in 2011 (A) and in the future (B) based on projected land use changes. High probability of detection ($\Psi > 0.50$) is shown in dark gray, while lighter shades depict lower probabilities. Expansion of urban edge is predicted to increase domestic dog's occurrence on former Fort Ord.

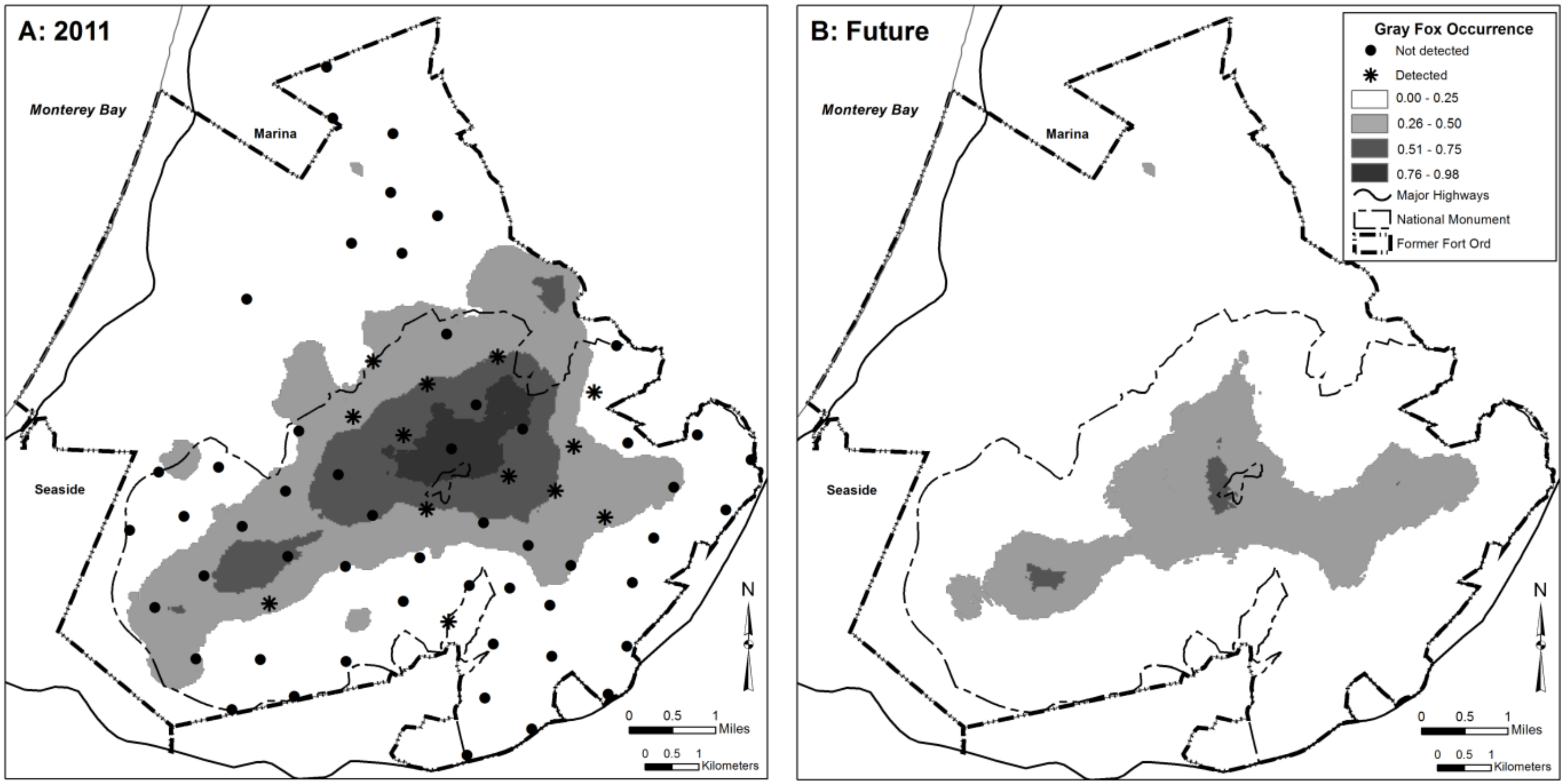

Figure 3. Comparison of the gray fox occurrence in 2011(A) and in the future (B) based on projected land use changes. Very high probability of detection (Ψ > 0.75) is shown in dark gray, while lighter shades depict lower probabilities. Expansion of urban edge is predicted to substantially decrease gray fox occurrence on former Fort Ord.

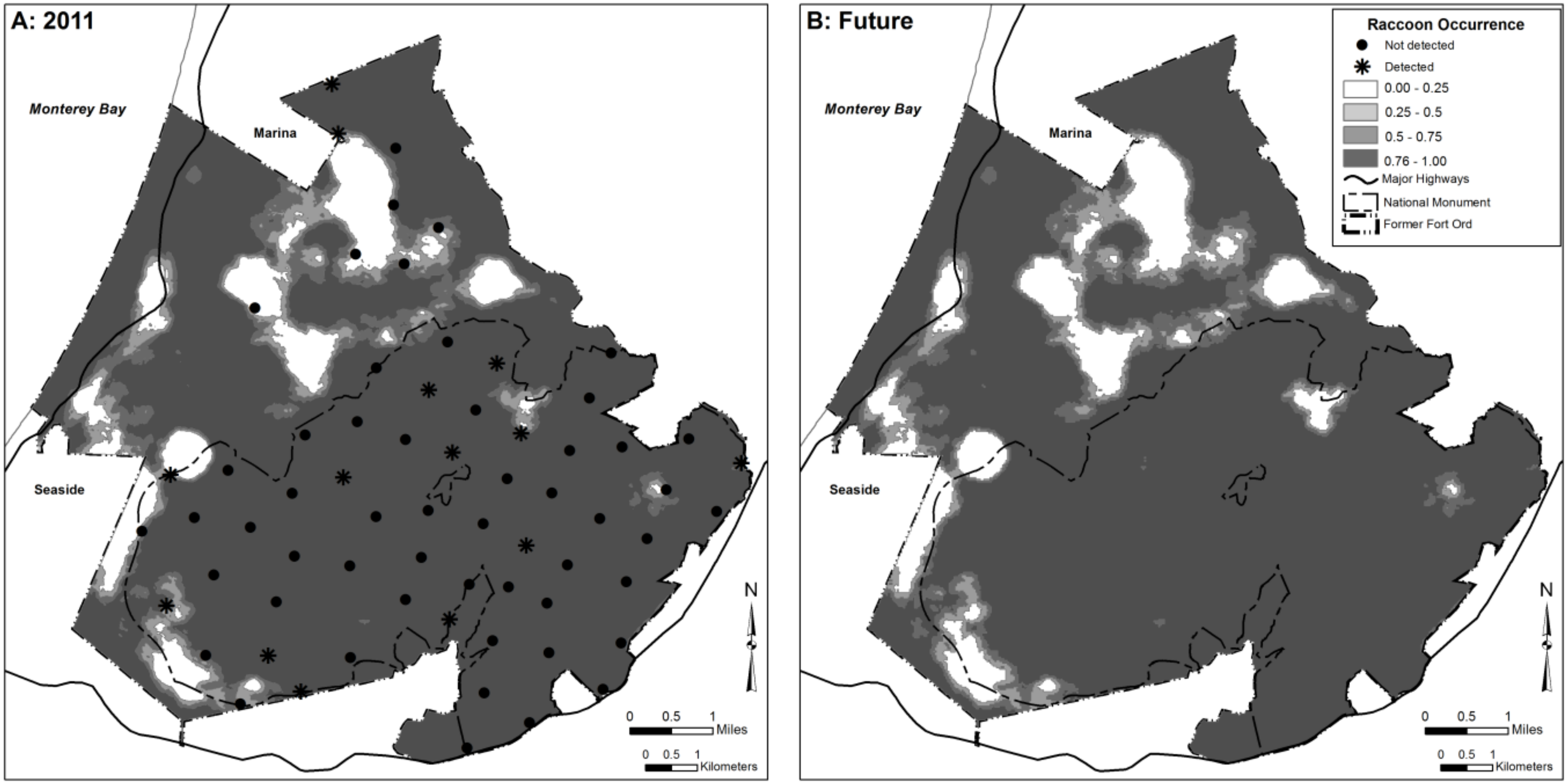

Figure 4. Comparison of raccoon occurrence in 2011(A) and in the future (B) based on projected land use changes. Very high probability of detection (Ψ > 0.75) is shown in dark gray, while lighter shades depict lower probabilities. Raccoons showed a very high probability of detection all across the former Fort Ord, except in areas with high road/trail density. Future distribution will not change much unless there are major changes to road/trail density.