Monitoring Bobcat (*Lynx rufus*) Activity at Watering Sites via Camera Traps

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ABSTRACT

To more rigorously examine the impact of drought and climate change on terrestrial mammals in Mediterranean ecosystems, in-depth ecological studies of particular species are required. As a top predator, bobcats are key indicators of ecosystem health. This research aimed to quantify bobcat activity at watering sites on a privately owned, 2,500-acre ranch consisting of predominantly blue-oak woodland and annual grassland habitat in San Benito County, CA. We looked for patterns of visitation related to vegetation, temperature, availability of bait and water, age class, time of day, season, and annual variation in relation to climate change and the ongoing drought. To examine bobcat activity on Ventana Ranch, 13 camera traps were installed throughout the study area at or near water sources, and have continuously recorded data from 2006-2015. Data were entered into MAPVIEW and analyzed in Excel and SYSTAT 13. We recorded 3,110 total bobcat visits over 34,525 trap-nights. Our results suggest that bobcat detections are quite variable, but some patterns of activity do occur, such as preference for habitats with increased vegetative cover, crepuscular behavior, an increase in drinking frequency at manmade watering sites during higher temperatures, and an increase in detections at watering sites during the dry spring and summer months.

KEYWORDS

Bobcat ecology, *Lynx rufus*, activity patterns, camera trap, blue-oak woodland

INTRODUCTION

Climate change and ongoing drought in California have inflicted substantial stress in terrestrial Mediterranean ecosystems (Lavorel et al. 1998). As a result of record-low precipitation since 2012, California is in the midst of one its most severe droughts in the past several hundred years (Dettinger and Cayan 2014). Extreme weather events, such as heat waves and drought, are expected to increase in California (Hayhoe et al. 2004). With mild climates consisting of wet, cool winters and dry, hot summers, Mediterranean ecosystems such as California are one of the most rich and complex regions on Earth in terms of biological and geological diversity (Maiorano et al. 2011). Mediterranean regions are also thought to experience the most severe changes in climate worldwide as a result of a climate change. In California, it is expected that there will be reduced forest productivity, increased fire hazard, reduced water levels, and damage to wildlife (Wilhite et al. 2007). Thus, the alteration of environmental conditions may have drastic effects on the structure and dynamics of animal communities.

Population dynamics of terrestrial mammals can be greatly affected by environmental fluctuations resulting from regional climate change (Bellard et al. 2012). Climate change impact manifests itself on individuals and populations either directly through physiological processes or indirectly through the ecosystem, including prey, predators, and competitors (Stenseth et al. 2002). Responses by individual species to climate change may disrupt their interactions with other species at the same or different trophic levels. Resource availability is a key variable in all terrestrial mammal communities, and can act as indicators of climate change. For example, availability and distribution of water sources in Mediterranean ecosystems can greatly influence ecosystem structure and function on many scales due to its influence on various feedbacks and processes affecting both animals and plants (Gaylard et al. 2003). Recent empirical studies have shown that wildlife species are already responding to global warming trends and consequent stresses on essential resources such as water with significant shifts in range distribution (Burns et al. 2003). Currently, only limited attention has been given to the effects of future climate changes on mammalian ecology, especially in Mediterranean climates (Maiorano et al. 2011).

To investigate the impact of drought and climate change on terrestrial mammals in Mediterranean ecosystems, in-depth studies of key species are required. As an apex predator, the bobcat (*Lynx rufus*) can strongly influence species in lower trophic levels through direct predation or by modifying the behavior of prey species (Anderson and Lovallo 2003), which allows them to serve as indicators of ecosystem health. This makes the bobcat an important species to study to better understand changes in behavioral patterns and population ecology in relation to climate change. Due to their wide habitat range and diverse prey selection, bobcats are the most widely distributed native felid in North America, ranging from southern Canada to southern Mexico. It is estimated that bobcat density ranges between 0.25-0.40 bobcats per km^2 in California wild lands (Larrucea et al. 2007). Interest in bobcats has increased in recent years due to their high value in the fur market after restrictions in the trade of other spotted felines by the Convention on International Trade in Endangered Species Act of 1973 (Dyer 1979). Between 1970-1976, the annual harvest of bobcats in the U.S. rose by over 25,000, and the average price per pelt rose from $10 to $125 (Anderson and Lovallo 2003), making them prime targets for commercial trapping. While much interest has been placed on obtaining estimates of bobcat abundance and activity, their secretive nature and ability to roam large home ranges make it difficult to obtain accurate information (Larrucea et al. 2007). Predicting behavioral changes in bobcats within Mediterranean ecosystems can provide key information on mammalian wildlife ecology in relation to climate change and drought, which has important management and conservation implications (Knick 1990).

This research aimed to quantify bobcat activity at watering sites on a privately owned ranch consisting of predominantly blue-oak woodland and annual grassland habitat in San Benito County, CA. We looked for patterns of visitation related to vegetation, temperature, availability of bait and water, age class, time of day, season, and annual variation in relation to climate change and the ongoing drought. This study specifically sought to:

A.) Evaluate spatial covariates of habitat use by bobcats

B.) Evaluate drivers of intraannual (within year) variability of bobcat occurrence, focusing on temperature, bait, age class, season, and diel patterns

C.) Evaluate drivers of interannual (across year) variability of bobcat occurrence, focusing on drought and temperature patterns

To address these objectives, we analyzed Ventana Ranch camera trap data from 2006-2015, and compared frequency of bobcat visits to watering site locations with available weather data.

METHODS

Study site

This study took place on a privately owned, 2,500-acre rangeland in southern San Benito County, CA (36° 22'N, 120° 55 'W) (Figure 1). It is characterized by a Mediterranean climate with hot, dry summers and cool, moist winters, and consists of grassland, chaparral, and oak woodland vegetation. Elevation ranges from 1,700 feet to 3,600 feet. Eighty-eight wildlife species have been documented on the ranch, including wild pigs (*Sus scrofa*), mule deer (*Odocoileous hemionus*), wild turkeys (*Meleagris gallopavo*), coyotes (*Canis latrans*), and mountain lions (*Puma concolor*) (Voelker 2010). While this paper focuses on the bobcat (*Lynx rufus*), the property is also the site of a larger study documenting the status of terrestrial vertebrates for habitat conservation and restoration purposes (Voelker 2010).

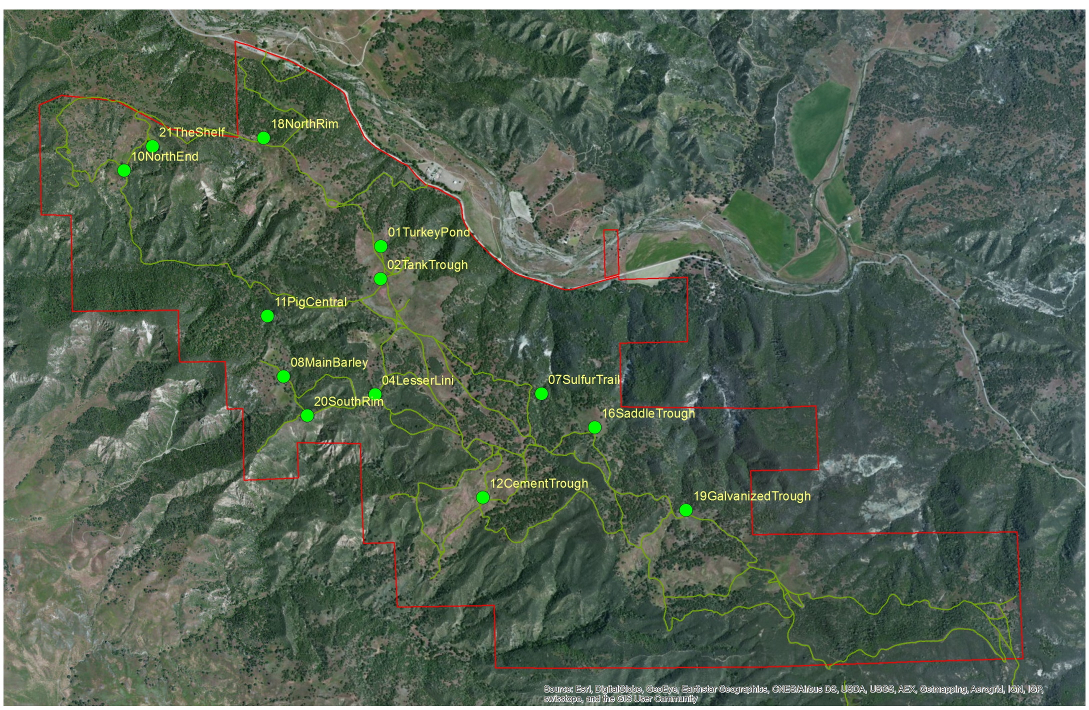

Figure 1.---An aerial view of Ventana Ranch, with the 13 camera trap sites shown in green.

Study Population

Our population of interest is bobcats, which can be distinguished by their short tails and defined spots. They are solitary, crepuscular creatures that favor rocky terrain with heavy vegetative cover (Litvaitis et al. 1986), but can be found in many habitat types. While lagomorphs (rabbits and hares) are the most common prey species, bobcats are opportunistic feeders that eat whatever prey is most abundant and readily available (Anderson and Lovallo 2003). The majority of bobcat breeding occurs in February and March, and gestation averages 63 days (Hemmer 1976). Bobcats can live up to 15 years in the wild (Knick et al. 1985).

Data collection

Equipment

To examine bobcat activity on Ventana Ranch, 13 camera traps were installed throughout the study area at or near water sources, and have been continuously recording data since 2006. RECONYX camera models used were RM30, PM35T, and PC 900 (RECONYX, Inc. Holmen, Wisconsin 54636). Camera traps were placed at a height of about two meters, and were about four meters away from bait and water. The cameras were set to high sensitivity, no delay, continuous operation, and one photo per trigger, which capture one photo every other second if an animal was in sight and moving. There was a natural or man-made water source provided at or near each site. Bait ("HogGrower 16% protein" pellets; Masterfeeds, London, Ontario, Canada) was often present at sites, and was added approximately monthly. Camera traps recorded time, date, location, temperature, and moon phase for each photo.

Data examination

We uploaded the camera data to Excel via MAPVIEW (RECONYX, Inc.) and used Macintosh Preview to examine photos individually. We noted if bait was present and if the bobcats fed, if water was available and if bobcats drank, total number of bobcats present, and if any juveniles were present. We rounded the duration of each visit to the nearest minute. A gap of at least six minutes between photos was used as the threshold to define a new visit.

Statistical analysis

We imported the Excel data into SYSTAT 13 (Systat Inc. 2009), a comprehensive statistical software package. Bobcat activity was expressed as the proportion of total visits detected, and visits detected per 100 trap-days (Marsh and Barrett 2015). Because there was little difference between sites in terms of temperature, data was pooled from across sites to assess significance of most of the variables. However, for frequency patterns pertaining to vegetative cover we compared different sites. The proportion of grassland, shrubland, and woodland in a 100-meter radius circle around each trap site was determined via a GIS of the ranch (Voelker 2010). We calculated mean (±95% CI) visitation rates across the 13 trap locations, and used two-way comparisons and chi-squared tests to look for statistical significance within the variables of temperature, vegetation, presence of bait, time of day, date within the year, and between years. Assumptions were that our sample size is large enough (3,110 total visits) to assume normal distribution, and that each observation is independent of the others, which we controlled for by calling any bobcat detection longer than 6 minutes apart a separate visit. Graphs were created using Excel.

RESULTS

To determine general activity patterns of bobcats in San Benito County, California, the 13 camera traps recorded a total of 3,110 visits by bobcats in 34,525 trap-nights (2006-2015). The mean annual temperature recorded among all visits was 15.5 °C.

Habitat Preferences

When comparing vegetation indices (proportion of grassland, shrubland, and woodland) for the 13 camera trap sites, we found a negative correlation between bobcat visits and the proportion of grassland around the site (Figure 2).

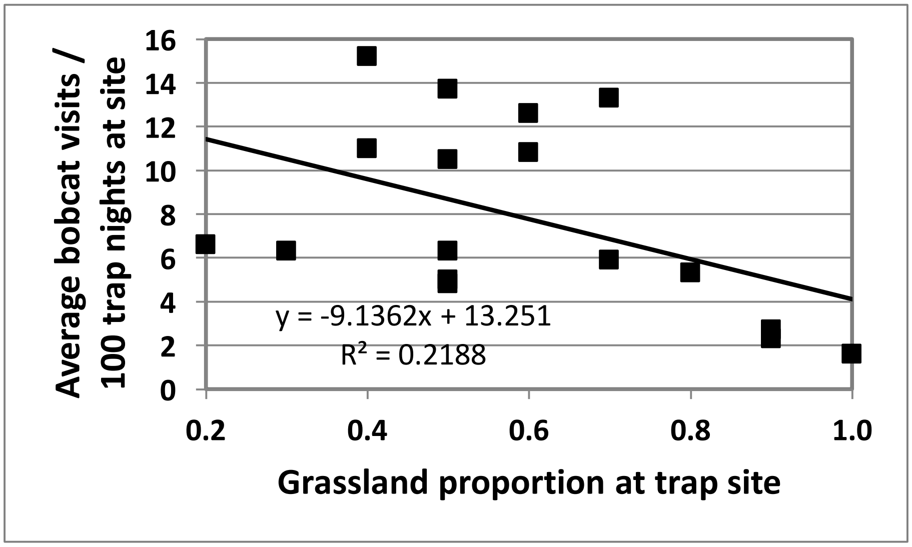

Figure 2.---Bobcats at the Ventana Ranch, San Benito County, California, 2006-2015, tended to visit sites with more shrubs and trees than open grassland. Thirteen camera trap sites detected 3,110 bobcat visits over nine years of continuous monitoring.

Effect of Temperature on Bobcat Visitation

Of the 2,694 visits when water was in the field of view, bobcats drank 685 times (25.4% of visits). Bobcats visited cameras 416 times when water was not available, mainly at two sites where water was not in the field of view, but were set on trails leading to water. We recorded bobcats drinking available water primarily in the summer months of the year. Bobcat drinking rate increased as mean monthly temperature increased (Figure 3).

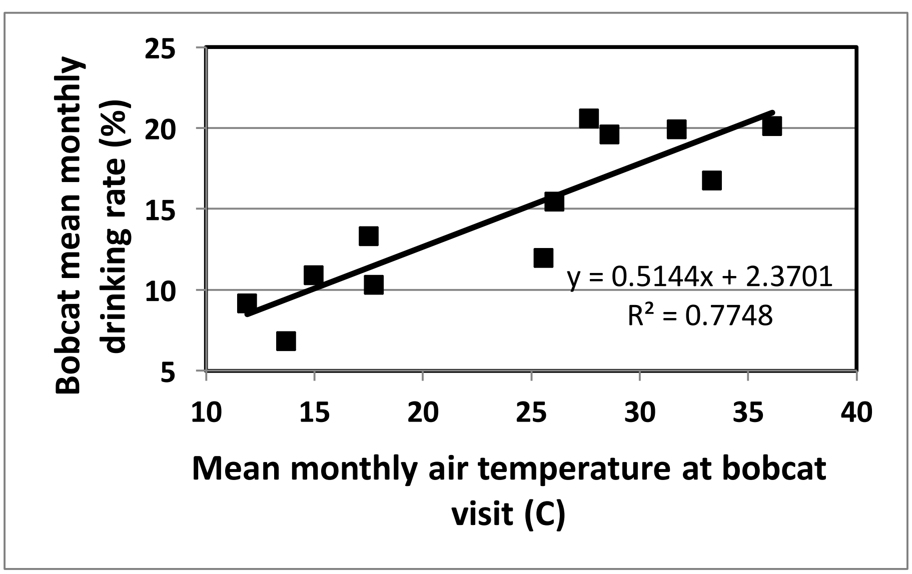

Figure 3.---Bobcats at the Ventana Ranch, San Benito County, California, 2006-2015 tended to drink more often as temperatures increased. N = 3110 bobcat visits over nine years of continuous monitoring.

Duration of Visits

Cameras recorded 2,750 visits of 1 minute or less, which was the most frequent duration of visit (88.4 % of visits). The longest visit by an individual was 15 minutes. Duration of visit was highest in summer months and lowest in winter months (Figure 4). Presence of bait was not correlated with visit duration, and we noted no response by bobcats to the presence of bait.

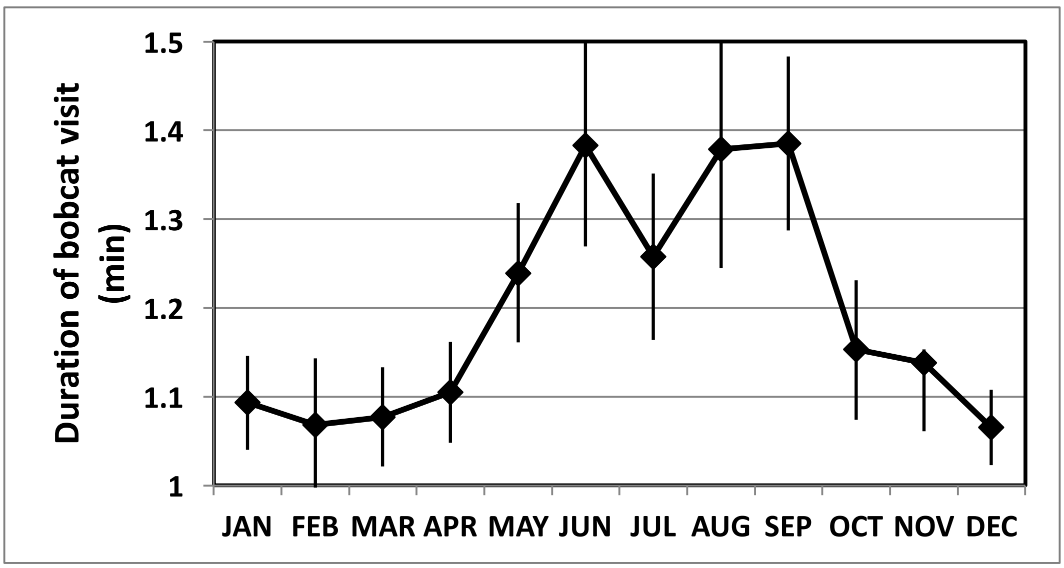

Figure 4.---Bobcats at the Ventana Ranch, San Benito County, California, 2006-2015, tended to spend more time at camera trap sites during the hot summer months. N = 3,110 bobcat visits over nine years of continuous monitoring. Vertical bars are 95% confidence limits.

Bobcat Visitation Frequency in Relation to Age Class

We recorded bobcats as adults or juveniles. Of the 3,110 total bobcat visits, 3,107 (99.9%) were adults and 3 (0.1%) were juveniles. Juvenile frequency was so low that no temporal or environmental patterns could be determined in relation to age class.

Diel Activity

Bobcat detections at watering sites were most frequent during night, with 4AM being the most frequent hour of bobcat visit. Visits were lowest in the middle of the day, with 1PM being the least frequent hour of bobcat visit (Figure 5). Bobcat activity showed a much stronger nocturnal pattern during summer months than winter months (Figure 6).

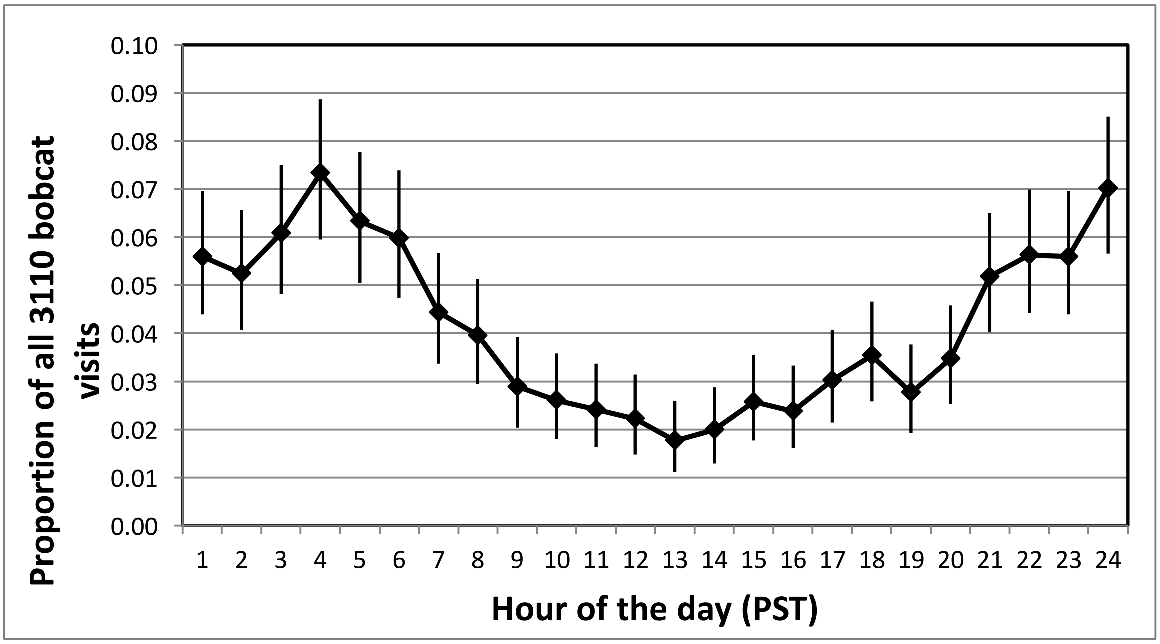

Figure 5. --- Diel Pattern for Bobcat Visits to Water Sources at the Ventana Ranch, San Benito County, California, 2006-2015. Camera traps detected 3,110 bobcat visits over nine years of continuous monitoring. Vertical bars are 95% confidence limits.

a.) b.)

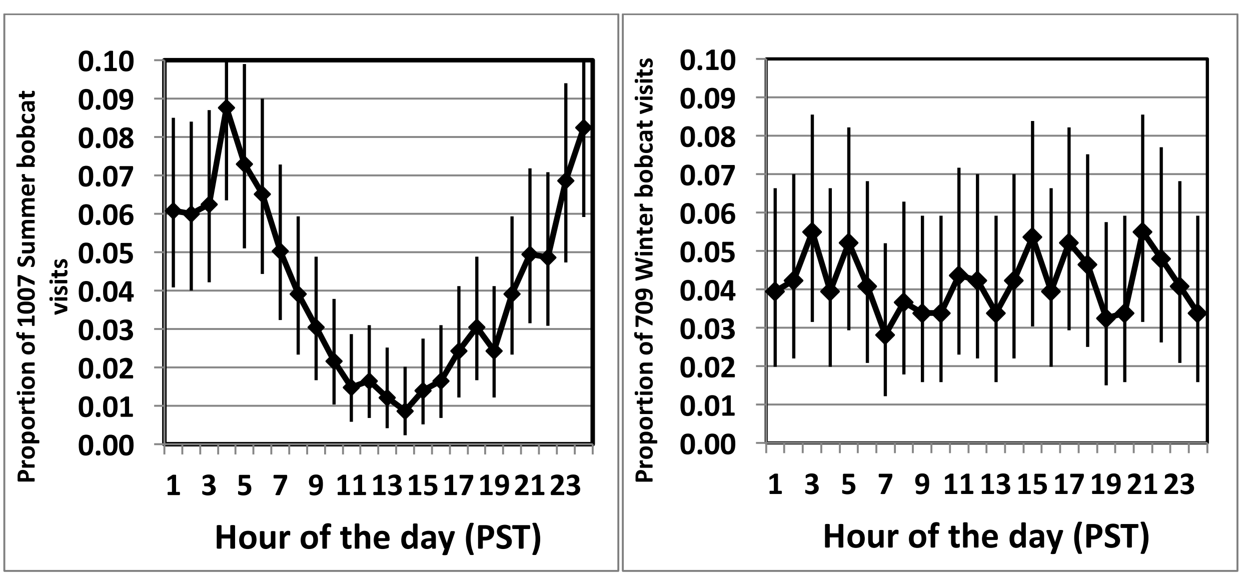

Figure 6. ---(a.) Summer (Jul-Sep) diel pattern for bobcat visits to water sources at the Ventana Ranch, San Benito County, California, 2006-2015. Camera traps detected 1007 bobcat visits during summer over nine years of continuous monitoring. Vertical bars are 95% confidence limits. **(b.)** Winter (Jan-Mar) diel pattern for bobcat visits to water sources at the Ventana Ranch, San Benito County, California, 2006-2015. Camera traps detected 709 bobcat visits during winter over 9 years of continuous monitoring. Vertical bars are 95% confidence limits.

Seasonal Activity

Bobcat detections were most frequent in September and least frequent in November (Figure 7). As a general trend, bobcat visits were more frequent during the warm, dry spring and summer months and less frequent during the cool, wet fall and winter months.

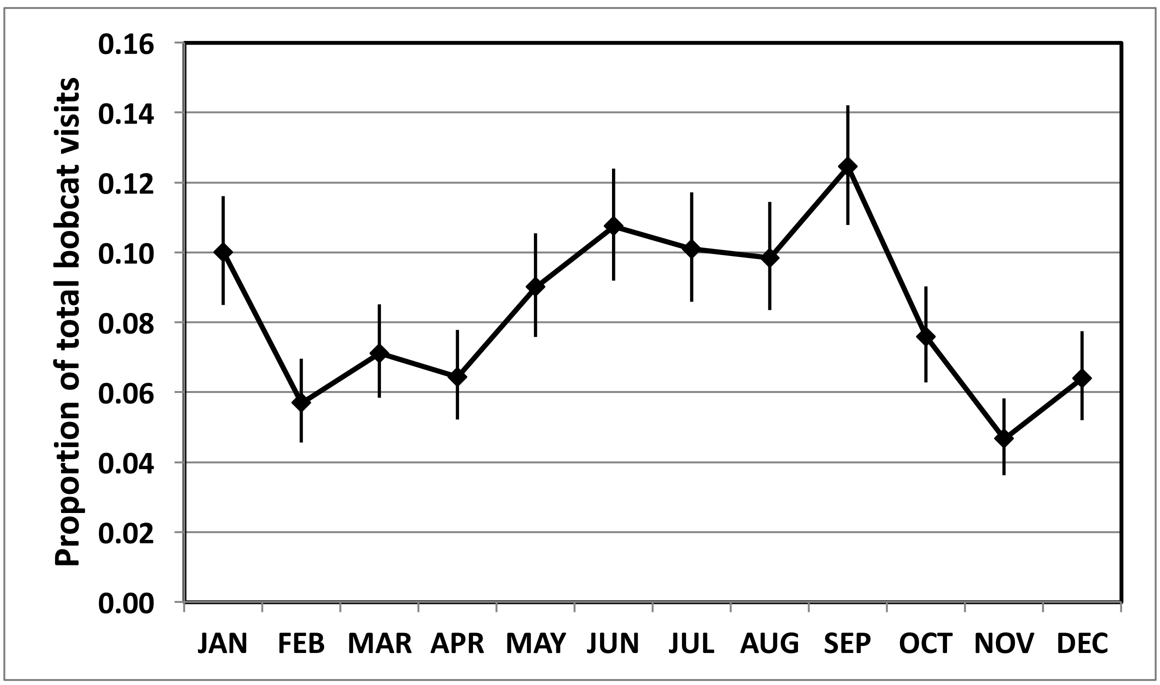

Figure 7.---Seasonal activity pattern for bobcats at the Ventana Ranch, San Benito County, California, 2006-2015. Camera traps detected 3,110 bobcat visits to water sources over nine years of continuous monitoring. Vertical bars are 95% confidence limits.

Yearly Activity

Bobcat detection peaked in 2012, and was lowest in 2008 (Figure 8). There was a general trend of increasing bobcat detections from 2006-2012, and then decreasing detections from 2012-2015.

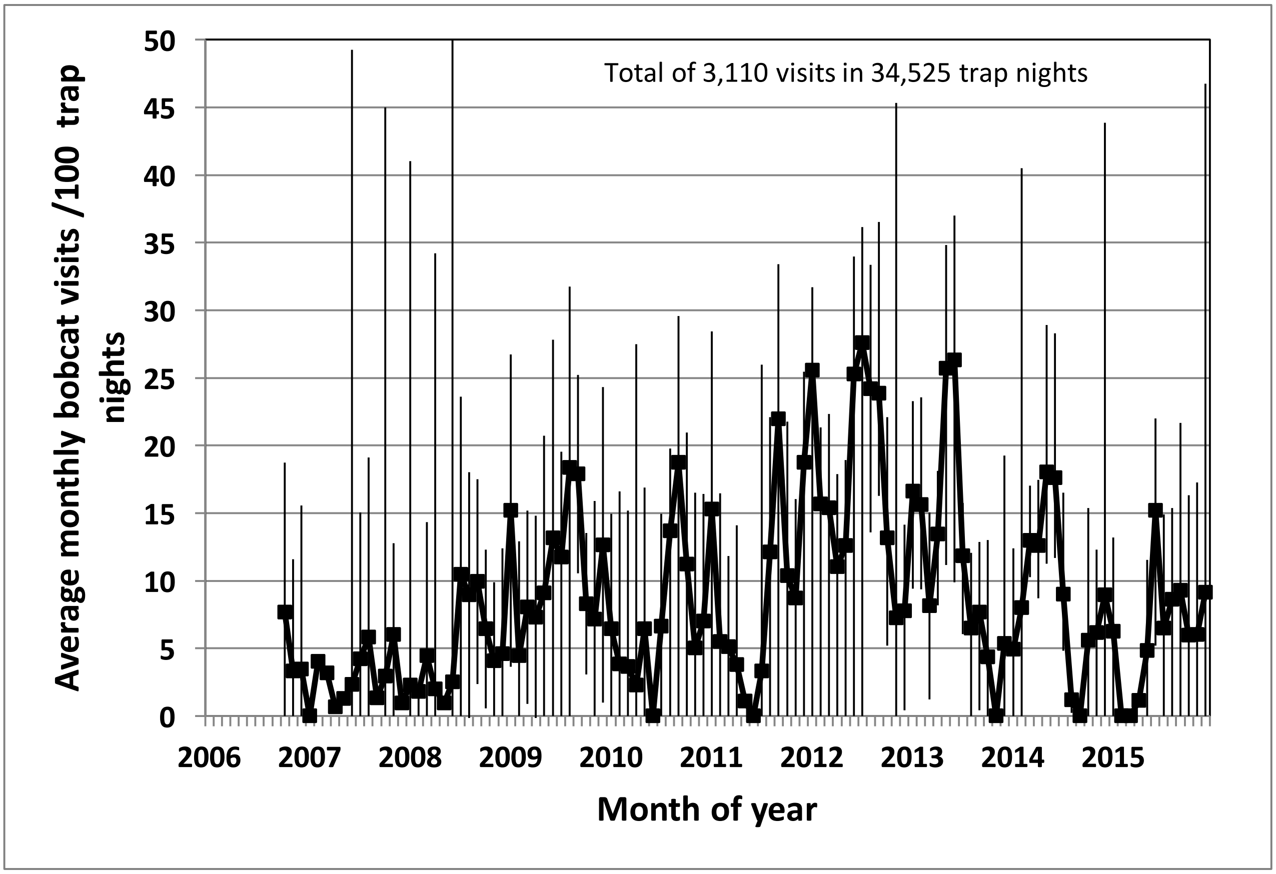

Figure 8. ---Monthly Frequency Patterns for Bobcat Visits to Water Sources at the Ventana Ranch, San Benito County, California, 2006-2015. Camera traps detected 3,110 bobcat visits over nine years of continuous monitoring. Vertical bars are 95% confidence limits.

DISCUSSION

Our goal was to document bobcat activity at watering sites via camera trapping in blue oak woodland habitat, specifically looking at vegetative preferences, intraannual patterns of frequency (temperature, duration, water and bait presence, age class, time of day, season), and interannual patterns of frequency. We aimed to provide insight on bobcat behavioral ecology, particularly in response to drought and periods of increased temperature, to aid in management and conservation efforts. Our findings suggest that bobcat behavior is relatively variable, but some general patterns of activity do occur, such as preference for habitats with increased vegetative cover, crepuscular behavior, an increase in drinking frequency at manmade watering sites during higher temperatures, and an increase in frequency at watering sites during the warm, dry spring and summer months.

Habitat selection

We found that bobcats were more frequently captured by camera traps surrounded by heavier vegetation cover and less grassland, which suggests that bobcats are elusive creatures that like to stay out of sight and have ample cover in order to stalk and hunt prey. These findings are consistent with many other studies performed on bobcat habitat preference (Litvaitis et al. 1986; Lovallo and Anderson 1996; Kelly and Holub 2008).

Intraannual patterns

We found a positive correlation between bobcat visits to watering sites and mean monthly temperature, which suggests that physiological need for water drives bobcats to visit these manmade water sources. Similar studies found that an increase in days since rainfall led to an increase in bobcat occurrences at manmade watering sites (Atwood et al. 2011; Calvert 2015). This study also suggests that physiological need, whether it stems from an increase in temperature or from a prolonged period without rainfall, seems to be a driving factor in bobcat detections at manmade watering sites.

We found the vast majority of bobcat visits to be one minute or less in duration, which suggests that bobcats are mobile and alert species that don't like to be as exposed as they are at a watering source for longer than necessary. The increase in duration during summer months were likely due to an increased drinking rate as the temperatures increased. We also found no correlation between bait and duration. This was likely due to the bobcat's indifference to the hog bait. There were no instances where bobcats ate or even paid attention to the bait, except for one circumstance where the bobcat rolled in the bait for several minutes. This behavior was particular, but perhaps the bait provides a cover scent for hunting and stalking.

Only three visits out of 3,110 total visits showed juveniles present. Of those three visits, two of them showed juveniles alone, and the other showed a mother with her cub. There were more instances where two adult bobcats were seen together (seven occasions) than there were mothers with her juveniles (one occasion), which is surprising because bobcats are usually solitary creatures with the exception of a mother and her cubs (Bailey 1974). The two visits of juvenile bobcats by themselves were in the fall, which makes sense considering juveniles usually start to mature enough to disperse from their mothers by the end of their first year (Anderson and Lovallo 2003). The overall lack of juveniles detected strongly suggests that mothers avoided taking their cubs to watering sites, perhaps for protection purposes. The watering sites are all, to an extent, in open areas, which bobcats tend to avoid. Underestimation could also be a reason why so few juveniles were recorded; larger juveniles could have been mistaken as adults.

We found that bobcat activity at watering sites peaked during the night hours, showing crepuscular and nocturnal behavior. This is consistent with literature across many feline species (Anderson and Lovallo 2003). Prey is the main driver of bobcat diel activity, and since lagomorphs are thought to exhibit nocturnal behavior, bobcat activity would most likely follow that of their main prey source (Rolley 1985; Harris et al. 2015). Also, diurnal activity leads to increased susceptibility of predation, so avoidance of people or mountain lions might be a driver of crepuscular patterns.

We found a slight overall increase in bobcat activity at watering sites during spring and summer months, which is likely due to higher temperatures, thus higher need for water, during those months. This pattern could also be due to the fact that suitable resting places were more limited during fall and winter months (Bailey 1974), so bobcats may have decreased their range size and movements during fall and winter months. Bobcat detections peaked in January, however, which could be due to an increase in bobcat mobility during breeding season, which begins in January (Anderson and Lovallo 2003). Another notable seasonal pattern was diel activity. Bobcats shifted to more diurnal behavior in the winter months, most likely because prey is not as abundant in winter months so they spend more time hunting during the day. Increased crepuscular patterns during the summer months and increased diurnal patterns in winter months have been observed in numerous studies (Marshall and Jenkins 1966; Shiflet 1984; Chamberlain et al. 1998).

Interannual patterns

When comparing average monthly bobcat visits across the years of study (2006-2015), we found a steadily increasing trend until it peaked in 2012 and started to decrease. However, there was much variation in monthly detection rates, or "noise", within the years. I believe this noise is largely due to the general unpredictability of bobcat behavior, and not necessarily due to specific environmental factors. The trend of low detection rates prior to the drought was an unanticipated result, as those years had good acorn crops, leading to a probable increased prey base due to abundant forage opportunities. The decline in bobcat detections at watering sites after 2012 could be attributed to the drought in California, which began roughly around the time of bobcat visitation drop-offs. However, the decreasing trend is the opposite of what we expected, as we thought a decrease in natural water sources during drought years would lead to an increase in bobcat detections at manmade water sources. The drought could have lead to an increase in bobcat mortality, thus leading to a decrease in detections during drought years. However, due to possible confounding factors and unreliable precipitation data, no conclusions can be made as to why the observed interannual trends occurred.

Limitations and future directions

Because the study area was relatively small, it is likely few bobcat territories were sampled. Therefore, our results may not be representative of bobcats occupying blue oak woodlands. Also, because the total number of bobcats recorded was relatively unknown (we could distinguish at least 5 individuals over the years), the experimental results were likely based on pseudo-replication, defined by Hurlbert (1984) as the use of inferential statistics to test for treatment effects with data from experiments where either treatments are not replicated or replicates are not statistically independent. If this is the case, the observed trends might be biased by small number of individuals. Therefore, we recommend the conduction of similar experiments on different bobcat populations to test the reliability of the findings generated by this study.

For future projects within this data set, one could use photo-identification to get an estimate of the abundance of bobcats on the ranch, and to examine range shifts and sex differences in response to environmental variables. Another direction is to look at prey abundance, such as rabbits and deer, in greater depth. Examining trends in prey species could better help us explain trends in bobcats, since bobcat behavior is strongly regulated by food availability (Anderson and Lovallo 2003).

Broader implications

Understanding the impact of drought and other environmental variables on mammalian ecology is a necessary objective when considering impending global warming. The intensity and occurrence of drought and temperature shifts will increase in Mediterranean climates, and understanding how key species like bobcats respond to environmental pressures will aid in their management and conservation, as well as provide broad understandings of terrestrial communities as a whole. Our research served as a prolonged case study of bobcats in Mediterranean ecosystems, which can help further understand the factors as to why bobcats visit watering sources and the role that managed water sources play in bobcat ecology.

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