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Research Article

Mammalian carnivore use of a high-severity burn in conifer forests in the San Bernardino mountains of Southern California, USA

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Abstract

Using camera trapping, I investigated carnivore occurrence in a high severity burn for four years in mixed conifer forests in the San Bernardino Mountains of southern California, USA. The objectives of this study were to catalog carnivores present in burned and unburned forests and, employing negative binomial regression analysis, to compare visitation of the burned and unburned forests by three carnivores: *Lynx rufus*, *Canis latrans* and *Urocyon cinereoargenteus*. In the summer of 2008, I placed 12 cameras along roads in a 9 km^2 area that burned in a stand-replacing wildfire and another 12 cameras in an adjacent unburned area of similar size. Ten mammalian carnivores were photo-captured in 2976 camera days; all the species were captured in the burn area and seven in unburned area. *Lynx rufus* was equally frequent in the burned and unburned forests. *Canis latrans* was more prevalent in unburned than burned forests and *Urocyon cinereoargenteus* preferred the burn area and was highly nocturnal in burned and unburned forests.

Introduction

Fire is a major force shaping the Mediterranean-climate vegetation of southern California. For decades fire suppression has been highly effective in preventing wildfires in montane conifer forests in this region but beginning in 2003, wildfires, especially high-severity fires, have become more prevalent in these forests (Franklin et al., 2005; Keeley et al., 2007). In the Peninsular Ranges, for example, stand-replacing fires burned thousands of hectares severely impacting mixed conifer forests in the Laguna Mountains (Franklin et al., 2006; Goforth and Minnich, 2008). Similar large, and equally destructive fires also burned in the San Bernardino Mountains (Keeley et al., 2007) and San Gabriel Mountains of the Transverse Ranges.

Recognition that stand-replacing fires have increased both in size and frequency in forests of the western United States (Littell et al., 2009) has stimulated research on the response of terrestrial vertebrates to these events. Birds have been the most popular topic of post-fire studies although some research has been devoted to amphibians, reptiles and small mammals (reviewed in Kennedy and Fontaine 2009). There is, however, a conspicuous lack of research on the response of carnivores to stand-replacing fire in forested ecosystems (Fisher and Wilkinson, 2005; Nelson et al., 2008). Few studies provide a comprehensive list of carnivores occupying burned and unburned habitats over an extended period of time (Soyumert et al., 2010). Instead, post-fire carnivore studies have focused on the responses of individual species (e.g. Cunningham and Ballard 2004; Duncan and King 2009; Thompson et al. 2008). Therefore, the object-

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ives of this study were (1) to list carnivore species occurring in burned and unburned conifer forests after a high-severity wildfire in the San Bernardino Mountains and (2) to compare the frequency of occurrence of three carnivores in burned and unburned forests.

Study Area and Methods

Study Area

I conducted camera trapping in an 18 km^2 area approximately 2 km northwest of Fawnskin, California (34° 16.51' N, 116° 58.18' W) in the San Bernardino Mountains. The study area ranges in elevation from 2166 m to 2490 m. The wildfire began on 14 September 2007 and burned a 5670 ha area, most of which ($\sim$80%) burned at high severity. The topography of the eastern portion (4.7 km^2) of the burned areas is flat to gently undulating (slopes $<5°$) while the western burned portion (4.3 km^2) is mountainous with steep, dissected slopes and numerous large rock outcrops. The eastern unburned area (9.0 km^2) is mountainous but slopes are more linear and less rugged than the burned area. The dominant forest type is *Pinus jeffreyi*/*Quercus kelloggii* which changes to mixed conifer forests on more mesic north-facing aspects. In addition to *Pinus jeffreyi* and *Q. kelloggii*, mixed conifer forests contain *Abies concolor* and *P. lambertiana*.

Climate of the study area is Mediterranean, which is characterized by cold, wet winters and warm, dry summers. Average annual precipitation recorded at the nearest weather station (Big Bear Lake, California) is 558 mm, most of which falls as snow from November to April. Average annual precipitation for 2008–2011 was 598 mm. Average temperature for August for the four years was 18.2°C and for September 15.7°C.

Camera trapping

I conducted surveys for 31 consecutive days in August and September from 2008 to 2011. Twelve cameras were deployed along three unpaved Forest Service roads that traversed 9 km^2 of the burned area. In the juxtaposed eastern unburned area of similar size, I placed another 12 cameras along two Forest Service roads. Ten cameras were placed in the middle of the burned area with two cameras $\sim$1 km from the burn edge. I placed cameras at random locations $\sim$1 km apart and located at least 15 m from roads. The closest burned and unburned cameras were 1.24 km apart. Roads in the burned area were closed to vehicular traffic while those in the unburned area were open. Traffic volume on open roads was extremely light on week days and low on the weekends.

At each station a passive infrared-triggered Cuddeback Excite™ camera (Non typical, Park Falls, WI 54552) was mounted on a tree bole 30-50 cm above the ground and set for 24-hour operation with a delay of 5 minutes between consecutive photographs. Time and date were imprinted on each photograph. Camera stations were scented by dipping the cotton bud on one end of an 8-cm stick into Canine Call™ and the bud on the other end into Russ Carman's Pro-Choice™ carnivore lures (Minnesota Trapline Products, Pennock, MN 56279). Scent sticks were stapled to a piece of wood and placed 2.0-3.5 m from the camera. Every 6-7 days I collected photographs and replaced scent sticks with freshly treated ones. Cameras sometimes malfunctioned so I increased the number of days the camera was in the field to compensate for lost days. Because the number of cameras was small, trapping sessions were 31 days to increase the number of photo-captures (Larrucea et al., 2007; Tobler et al., 2008).

Statistical analysis

Each day was considered an independent sample in the analysis and multiple photographs of a species taken the same day were analysed as a single sample. Initially, I attempted to use occupancy analysis to relate species captures to covariates. However, multi-season models using the Program PRESENCE (v. 4.4, U.S. Geological Survey, Patuxent Research Center) indicated that detection probabilities for the three carnivore species were low, ranging from 0.001 to 0.049. MacKenzie et al. (2006) recommend occupancy modeling when detection probabilities are >0.20 and O'Connell et al. (2006) question the use of occupancy modeling for detection probabilities between 0.05 and 0.15. Thus, in lieu of occupancy modeling, I used negative binomial regression (NBR) to relate the number of photo-captures to covariates. Negative binomial regression is appropriate when a high proportion of zero captures results in a variance that exceeds the mean (Lindén and Mäntyniemi, 2011). I analyzed the data using the function "`glm.nb`" in the MASS package of R as outlined in Zuur et al. (2009).

Separate NBRs were carried out for three carnivore species with a sufficient number of captures: *Lynx rufus* (bobcat), *Canis latrans* (coyote), and *Urocyon cinereoargenteus* (gray fox). I related captures of each species to six covariates: post-fire percent tree cover of a 0.03 ha plot (radius 100 m) around the camera station, years after the 2007 fire, camera distance to the burn perimeter (km), station elevation (m), average slope (in degrees) within a 100 m radius of the camera tree and station distance to the road (m). Percent tree cover was estimated to the nearest 5% for each station pre- and post-fire using color photography at a scale of 1:10000. Finally, because *C. latrans* may kill *U. cinereoargenteus* in interspecific encounters (Farias et al., 2005), I added *C. latrans* captures as a variable in the regression analysis of *U. cinereoargenteus*.

I first carried out univariate analysis of each covariate for each species and then combined variables into a regression that included only the significant covariates. In addition, I tested for differences in diel activity between burned and unburned forests for individual species using chi-square analyses (Yates correction factor).

Table 1 – Mammalian carnivores photo-captured in the high-severity burn and unburned area after 2976 camera days. Values are the total number of captures in four years.

Family and scientific name	High-severity burn area	Unburned area
Canidae		
Canis domesticus	1	1
Canis latrans	16	58
Urocyon cinereoargenteus	39	11
Felidae		
Lynx rufus	8	10
Puma concolor	4	1
Mephitidae		
Mephitis mephitis	1	0
Spilogale gracilis	2	3
Procyonidae		
Bassariscus astutus	1	0
Procyon lotor	1	0
Ursidae		
Ursus americanus	4	3

Results

In 2976 camera trap days ten mammalian carnivores were photo-captured in 164 useable photographs (Tab. 1). All species were captured at least once in the burn area while seven were captured in the unburned area. In the four years, *C. latrans* were photographed most often (45%), followed by *U. cinereoargenteus* (30%) and *L. rufus* (11%).

Pre-fire tree cover of the 24 stations was 60.6% (SD $\pm$16.0) while post-fire tree cover of the burned stations was 4.6% (SD $\pm$6.2), an average cover loss of 51.7%.

Lynx rufus

Lynx rufus captures were significantly related to years post-fire (Tab. 2) and decreased in the burned area over the four years (Fig. 1a) but the mean number of captures did not differ between burned and unburned areas (Fig. 1a). Although sample sizes were small, there was no significant difference in captures between burned and unburned areas related to the time of day this species was active (χ^2 = 1.9, df = 3, $p < 0.58$) (Fig. 2a).

Canis latrans

Canis latrans captures were significantly related to tree cover (Tab. 2). Mean capture numbers were significantly higher in the unburned vs. the burned area in 2008 and 2011 (Fig. 1b). Captures were negatively related to years after fire as shown by the decrease in captures in the unburned area (Fig. 1b; Tab 2). Diel capture distributions did not differ significantly between the burned and unburned areas (χ^2 = 3.62, df = 3, p = 0.31) (Fig. 2b).

Urocyon cinereoargenteus

Urocyon cinereoargenteus captures were significantly related to both tree cover and slope (Tab. 2). In 2008 and 2011 mean captures were significantly higher in the burned vs. the unburned area (Fig. 1c), especially on the steeper slopes below Butler Peak. *Urocyon cinereoargenteus* was not captured in the unburned area in 2008 or 2011 (Fig. 1c). For this species diel capture distributions differed significantly between the burned and unburned areas (χ^2 = 23.49, df = 3, $p < 0.001$) (Fig. 2c). In the burned area *U. cinereoargenteus* was more active at night and somewhat more active at sunrise in the unburned area (Fig. 2c).

Table 2 – Significant covariates in negative binomial regressions for photo-captures of *Lynx rufus, Canis latrans* and *Urocyon cinereoargenteus.* Significant p-values are highlighted in bold. SE is one standard error of the regression coefficient.

	Regression coefficient	SE	z-statistic	*p*-value
Lynx rufus				
Intercept	-0.681	0.525	-1.298	0.194
Years post-fire	-0.475	0.239	-1.989	**0.047**
Canis latrans				
Intercept	0.581	0.338	1.713	0.087
Tree cover	-0.726	0.174	-4.168	**≤0.001**
Years post-fire	-0.476	0.141	-3.384	**≤0.001**
Urocyon cinereoargenteus				
Intercept	-1.341	0.289	-4.652	**≤0.001**
Tree cover	-1.248	0.295	-4.227	**≤0.001**
Slope	0.503	0.234	2.149	**0.032**

Discussion

More mammalian carnivore species were photo-captured in the burned than the unburned area although the three species found exclusively in the burned area were captured only once (Tab. 1). Of particular interest is *Spilogale gracilis* (western spotted skunk) because it has not been previously recorded in burn areas. In fact, in the earliest survey of the San Bernardino Mountains, Grinnell (1908) failed to capture this species although he did trap *Mephitis mephitis* (striped skunk), which I captured once (Tab. 1). *Spilogale gracilis* was present in both forest types at elevations of 2293 m – 2352 m, considerably higher than elevations reported for the Pacific Northwest (Carey and Kershner, 1996) but similar to elevations of conifer forests bordering the Grand Canyon in Arizona (Reed and Leslie, 2005).

Lynx rufus, a solitary, nocturnal and strictly carnivorous species, was equally frequent in the burned and unburned areas (Fig. 1a). Captures of this felid were much lower than either *C. latrans* or *U. cinereoargenteus* (Tab. 1). Although scent station visitation rates are positively correlated with the actual abundance of this carnivore (Dieffenbach et al., 1994), camera trapping still may have underestimated its true abundance (Harrison, 2006). In a study comparing carnivore abundance in burned and unburned Californian chaparral, Schuette (2007) reported a higher incidence of *L. rufus* in unburned vs. burned chaparral. In Arizona, *L. rufus* moved out of burned chaparral after three weeks (Cunningham et al., 2006).

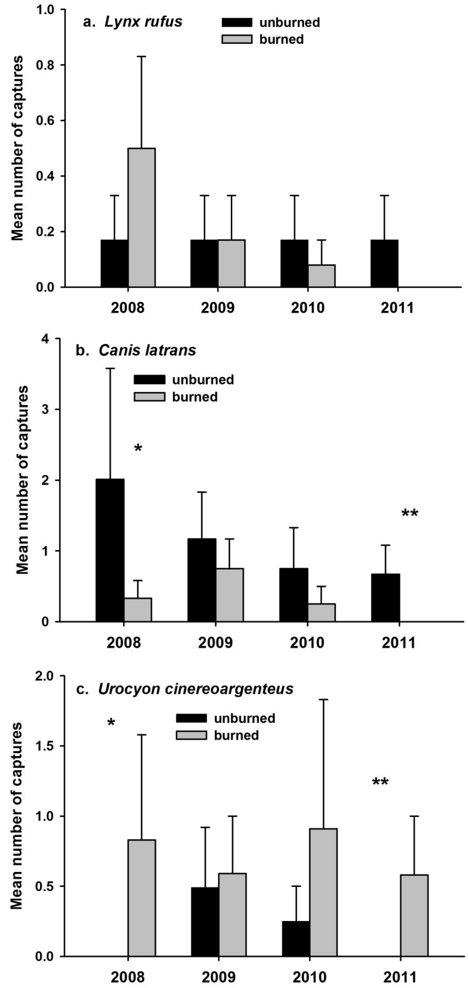

Figure 1 – Mean number of photographic captures of a) *Lynx rufus,* b) *Canis latrans* and c) *Urocyon cinereoargenteus* in the unburned and burned areas. Significant differences in means were calculated using the Mann-Whitney U test. Error bars are 2 SE. Significant differences in means are indicated by * for $p < 0.05$ and ** for $p < 0.01$.

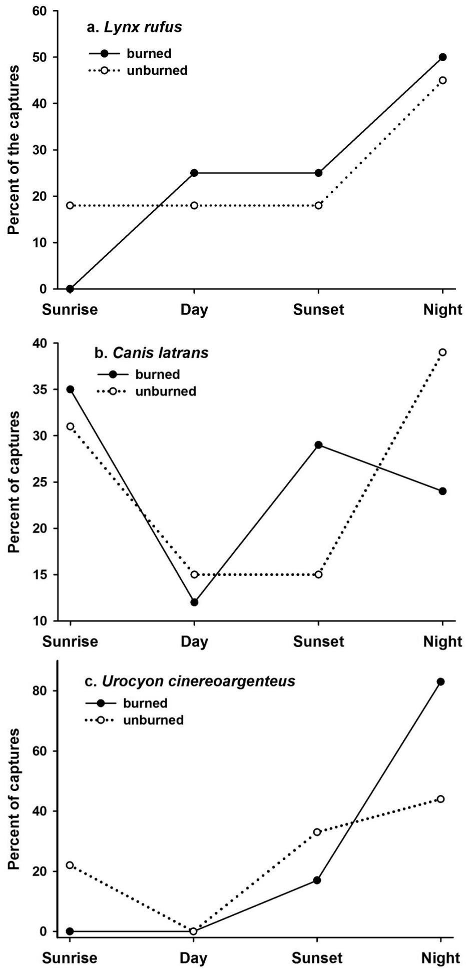

Figure 2 – Percent of the total photographic captures by time of day for a) *Lynx rufus*, b) *Canis latrans* and c) *Urocyon cinereoargenteus*. Sunrise is from 0500-0659, day is 0700-1859, sunset is 1900-2159 and night is 2100-0459.

Canis latrans was more frequent in unburned than burned forests in the study area (Tab. 1; Fig. 1b). This canid is omnivorous and consumes more lagomorphs, ungulates, fruits and seeds than *L. rufus* (McKinney and Smith, 2007; Neale and Sacks, 2001; Thornton et al., 2004). In fact, it may prey on *L. rufus* (Gipson and Kamler, 2002). In southern Californian chaparral, *C. latrans* was more abundant in unburned vs. burned chaparral (Schuette, 2007) but in a 3-year study of carnivore abundance after a wildfire in Arizona chaparral, *C. latrans* showed no clear preference for burned over unburned areas (Cunningham et al., 2006). Instead, it was highly opportunistic in response to food availability and readily shifted from one area to the other. They found that in the unburned chaparral *C. latrans* consumed soft mast for several years but changed to small mammals in the burned area in other years. In this study, high-severity fire killed nearly all of the soft-mast producing shrub *Arctostaphylos patula* and hard-mast of the oak *Quercus kelloggii*. Because of the paucity of soft and hard mast, *C. latrans* probably depended on small mammals when visiting the burned area.

In this study *U. cinereoargenteus* had a high frequency of occurrence in the burn area (Fig. 2c). Although *U. cinereoargenteus* is considerably smaller than *C. latrans* (3-5 kg vs. 8-20 kg), they share a diet that consists primarily of small mammals and fruit (Cunningham et al., 2006; Fedriani et al., 2000; Neale and Sacks, 2001). However, *C. latrans* appears to consume more lagomorphs and ungulates than *U. cinereoargenteus* (Neale and Sacks, 2001). Since fruit was not readily available in the burned area, it possibly was responding to the changes in the abundance of small mammals (Cunningham et al., 2006), or perhaps avoiding interspecific interactions with the dominant *C. latrans* (Atwood et al., 2011; Farias et al., 2005; Fedriani et al., 2000). Both Schuette (2007) and Cunningham et al. (2006) found that *U. cinereoargenteus* preferred burned over unburned chaparral.

For three of the four years *U. cinereoargenteus* and *C. latrans* did not overlap spatially in the study area (Fig. 1b and 1c). *Urocyon cinereoargenteus* occupied the burned area while *Canis latrans* was more prevalent in the unburned area. In southern California, *C. latrans* is a primary source of *U. cinereoargenteus* mortality (Farias et al., 2005) and *L. rufus* predates them as well (Fedriani et al., 2000). *Urocyon cinereoargenteus* avoids these two predators spatially and temporally by choosing habitats where the numbers of both species, especially *C. latrans* are low (Fedriani et al., 2000). Moreover, it is active during times of the day when it is less likely to encounter the two predators (Farias et al., 2012). In the regression analysis, captures of *C. latrans* did not have a significant negative effect on *U. cinereoargenteus* (p = 0.12). Nevertheless, the lack of spatial overlap during most of the study suggests *U. cinereoar-*

genteus may have been avoiding encounters with *C. latrans* in unburned forests. Alternatively, *U. cinereoargenteus* may have been attracted to a more abundant supply of small mammals in the burned area (Chamberlain and Leopold, 2005). Telemetry studies would elucidate the interaction of these two species in burned and unburned habitats.

Home ranges of the three species are large relative to the 1-km distance between camera stations. Because it was not possible to identify individuals in the photographs, the number of animals sampled in the study area is unknown, and may be small. In other words, captures cannot be assumed to be independent events since a single individual may have visited multiple camera stations in its home range, thus making captures spatially auto-correlated. Greater distances between cameras would have reduced the likelihood of spatial auto-correlation but the size of the study area did not permit greater camera spacing.

In conclusion, as the climate in southern California becomes drier, fire risk in the coming decades is expected to increase in the San Bernardino Mountains (Westerling and Bryant, 2008) and the incidence of high-severity fire is likely to increase. Results of this study show that carnivores are not negatively affected by high severity fire but studies in other fires are needed to confirm these findings. A more complete understanding of the response of carnivores to fires of all types is vital to their conservation and management as fire regimes are altered by climate change.

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