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Title: Assessing impacts of solar power facilities on pronghorn in the Carrizo Plain

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INTRODUCTION

Pronghorn (*Antilocapra americana*) inhabiting the Carrizo Plain in California are a species of management and conservation concern. Historically, pronghorn were abundant within this region of the San Joaquin Valley grassland ecosystem, but were extirpated in the late 1940's due to over-hunting and conversion of native perennial grasslands to agriculture (Koch and Yoakum 2002). During a series of reintroductions from 1987 to 1990, pronghorn were released onto the Carrizo Plain (Clausen 1999). The translocated population initially increased; however, numbers began to decline following a period of prolonged drought and currently remain critically low (Koch and Yoakum 2002; California Department of Fish and Game (CDFG) unpubl. data). Population size is of particular concern to resource managers because small populations can suffer from weak or even negative growth rates, referred to as an Allee effect (Allee 1931; Stephens et al. 1999; Courchamp et al. 2008). Populations exhibiting an Allee effect are highly vulnerable to extinction from stochastic events (ie., drought) or rapid environmental change (ie., anthropogenic effects) (Courchamp et al. 2008). Recently, large-scale construction of two solar photovoltaic (PV) plants in California Valley, on the northern Carrizo Plain, has raised concern for local pronghorn. One of these facilities, the Topaz Solar Farm, is located in an area containing known fawning and foraging habitat for this population. Elimination of, or reduced access to these habitats has the potential to decrease offspring recruitment (survival to breeding age) and limit population recovery. Although mitigation lands have been set aside, it is largely unknown how pronghorn will utilize those lands. Here, we provide specific information on the significance of the northern Carrizo Plain as habitat for a small, highly reduced pronghorn population and propose a study to evaluate fawn production, survival and habitat use on mitigation lands and in areas surrounding the Topaz Solar Farm.

Previous information collected for pronghorn on the Carrizo Plain, suggest that the northern portion of the plain, in areas within, and directly adjacent to, recent solar power development, may provide important habitat for a source pronghorn population. Although the southern end of the Carrizo Plain is composed of expansive federally protected lands within the Carrizo Plain National Monument (CPNM), pronghorn abundance and fawn:doe ratios are consistently higher in the privately owned agricultural areas of the northern plain (unpubl. data. CDFG). Agricultural practices, including crop harvest and soil tilling, likely promote growth of nutritious forbs, which are preferred by pronghorn and are important for healthy fawn production and survival (Koch and Yoakum 2002). In contrast, the CPNM provides marginal nutritional quality for pronghorn, particularly during summer and fall when foraging opportunities are limited in exotic annual grasslands (Longshore and Lowrey 2008). Marginal ranges produce unstable population fluctuations (Vriend and Barrett 1978) and can serve as population sinks (Buechner 1950, Ellis 1970, Pryah 1987).

Analysis of population size data (2001-2012 unpubl. data CDFG) indicates evidence of an Allee effect within the CPNM, but not in the northern plain (Johnson et al. 2012, in review). While density-dependent factors appear to reduce per capita growth rates at small population sizes on the CPNM, growth rates are not limited by small population size in the north. This discrepancy suggests that better habitat conditions in the northern plain could prevent an Allee effect. Mechanisms for the Allee effect in pronghorn are understudied (but see Hoffman et al. 2010). However, recent evidence collected by Longshore et al. 2012 suggests that growth of small populations may be limited by a collapse of birth synchrony (high offspring production during a short interval of time). Pronghorn exhibit birth synchrony to reduce overall predation rates of neonatal fawns (Gregg et al. 2001). The benefits of synchronous birth distributions, however, are density dependent and small populations may not produce sufficient numbers of offspring to reduce predation, and ultimately increase population size. Offspring survival on the CPNM is significantly increased for individuals that are born during periods of high fawn production compared to those born during periods of low fawn production (Johnson et al. 2012, in review). This suggests that reduced birth frequency in small populations, may produce an Allee effect. Although fawn recruitment on the CPNM (27%, n=45) from 2009-2011 was similar to survival for larger populations in other states (29%, n=995), survival may need to be higher than average in small populations to overcome stochastic events and prevent Allee effects. Offspring recruitment in the northern plain has not yet been investigated. Increased fawn survival in the north, due to higher quality habitat and larger population size, may be preventing an Allee effect. If the north is producing a source population, then alterations to existing habitat present significant risk for pronghorn across the Carrizo Plain.

In this study, we examine pronghorn offspring recruitment and fawn habitat selection on the northern Carrizo Plain in areas adjacent to the Topaz Solar Farm and within mitigation lands. Results from this study will provide agencies with an important resource for making management decisions to improve habitat on mitigation lands and to reduce potential negative impacts of future solar development. Additionally, this study will be a valuable extension of previous research on the CPNM, where results may be compared, or combined, to contribute to long-term regional management goals for pronghorn.

OBJECTIVES

1. Measure fawn survival and determine causes of mortality in areas surrounding solar power development and within mitigation lands.

2. Examine the relationship between fawn habitat selection and survival in areas surrounding solar power development and within mitigation lands.

Methods

1. *Measure fawn survival and determine causes of mortality in areas surrounding solar power development and within mitigation lands.*

To collect baseline information on survival and causes of mortality, we equipped fawns (< 5 days of age) with lightweight GPS/VHF collars (weight = 80 grams; Telonics, Inc.) during spring 2013 using capture methods described in O’Gara et al. (2004) and Gregg et al. (2001). A large net (approx. 3 ft dia.) was placed gently over bedded fawns to assure capture and prevent bolting. Surgical gloves, previously stored in bags with local vegetation, were used to minimize human scent while handling fawns. Fawns were not captured at less than 4-6 hours to allow doe-fawn imprinting. We recorded age, sex, weight, and body measurements. For fawns whose birth was not observed, birth dates were estimated by behavioral criteria, condition of pelage, umbilical cord desiccation, and hoof development (O'Gara and Shaw 2004). Collars collected and stored locations every 2 hours and were specifically designed to accommodate for the developmental growth of fawns by gently expanding and detaching (approx. 2 months). A mortality sensor on each collar alerted researchers of fatalities and necropsies were conducted in the field or, when possible, in a laboratory (San Bernardino Wildlife Investigations Laboratory, California Department of Fish and Game). Identification of uncollared fawns was possible through the collaring of a sibling, the general daily location of an individual or identifiable pelage of the mother (Byers 1997). Fawns which lived > 60 days were considered to have been recruited based on abundant evidence from similar studies which have documented that 95% of fawn mortality takes place ≤ 18 days of age (Gregg et al. 2001) and that predation on fawns > 20 days of age is atypical (Byers 1997, Von Gunten 1978, Barrett 1978, Byers 1997). Results for survival and causes of mortality were compared to previous local research within the CPNM (Johnson et al. 2012, in review) and to eighteen other similar studies conducted within 10 different states as reported by O'Gara and Shaw (2004).

2. Examine the relationship between fawn habitat selection and survival in areas surrounding solar power development and within mitigation lands.

To collect baseline information about the quality of available fawning habitat, and to understand which environmental features were selected for by fawns and their does, we compared micro- and macro-habitat variables between collared fawn locations and random locations (generated using ArcMap 10.1). Micro-habitat variables, including vegetation height, visibility at adult height (1 m), visibility at fawn height (0.5 m), and percent composition of forbs (forbaceous plants), grasses, shrubs and bare ground, were measured along four one-hundred meter transects, placed in equal-distant compass directions, at distances of 0, 5, 10, 20, 30, 40, 50 and 100 meters (modified from Canon and Bryant 1997 and Bonham 1989). Principle Component Analysis (PCA) was used to reduce the dimensionality of the data set and derive independent PCs for mathematical modeling. We then generated macro-habitat information (i.e., distances to ephemeral drainages, major roads, minor roads, water sources, and solar development as of June 2013) using a GIS (ArcMap 10.1; ESRI 2012). Macro-habitat variables and significant micro-habitat variables (from PCA results) were then used to generate candidate binary logistic regression models. Akaike's information criteria adjusted for small sample size (AIC_c) was used for model selection (Burnham and Anderson 2002). The log-likelihood estimates from each of the alternative logistic regression models were used to determine AIC_c and ΔAIC_c values. We used the AIC_c differences to rank the set of candidate models. We considered approximating models with ΔAIC_c of ≤ 2 as possible competing models. We used Akaike weights (w_i) and evidence ratios to assess the relative strength of evidence for each competing model. To assess model fit, we calculated the area under a Receiver Operating Curve (ROC) using SAS (SAS Institute, Inc., Cary, NC; version 9.3). With information from additional years, these results can be used to construct a pronghorn fawn survival model for this site.

Results

1. *Measure fawn survival and determine causes of mortality in areas surrounding solar power development and within mitigation lands.*

A total of 25 pronghorn births took place on the northern Carrizo Plain during a 21 day period from May 3 to May 23 (Fig. 1). Of these individuals, 14 were equipped with GPS/VHF collars (8 females and 6 males). Fawns were captured between 8 hours and 4 days of age (mean = 1.5 days, SE = 0.3). Mean weight was 3.7 kg (range = 3.3 – 4.5 kg, SE = 0.11). Body measurements and processing information can be found in Appendix A. The remaining 11 uncollared fawns were monitored through field observation. Birth sites of both collared fawns (Fig. 2) and uncollared fawns were primarily concentrated between 1 – 2 km south of current Topaz solar development (as of June 2013), within zones designated for future solar construction and within mitigation lands. Additional fawns were born on mitigation lands approximately 2 km north of the Topaz Solar Farm along Bitterwater Road, as well as on private lands immediately southwest of the junction of California State Route 58 (SR 58) and Soda Lake Road. Information from nearly 1,000 GPS locations collected from collared individuals indicated that fawns made use of habitat within relatively close proximity to their respective birth sites, with the exception of some individuals moving short distances (< 2.5 km) as they developed (Fig 3.).

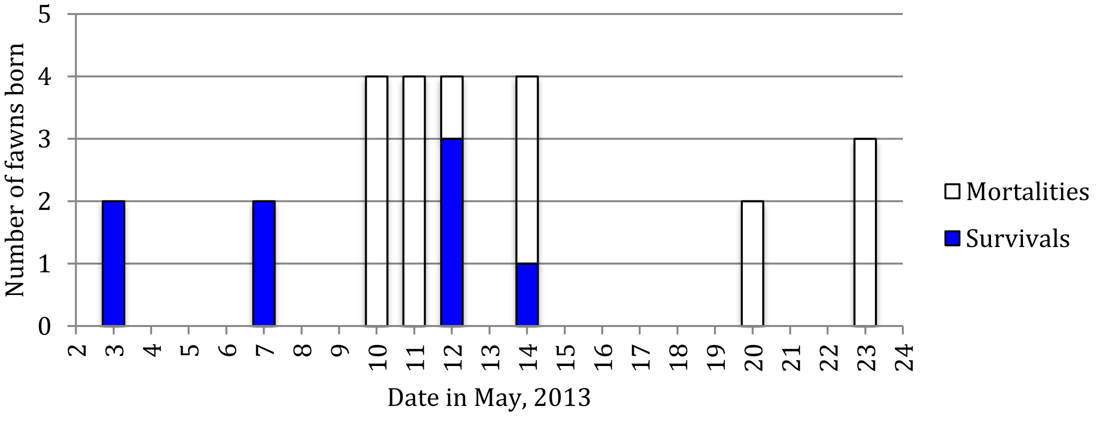

Figure 1. Birth distribution and survival outcomes for 25 pronghorn fawns observed on the northern Carrizo Plain during 2013.

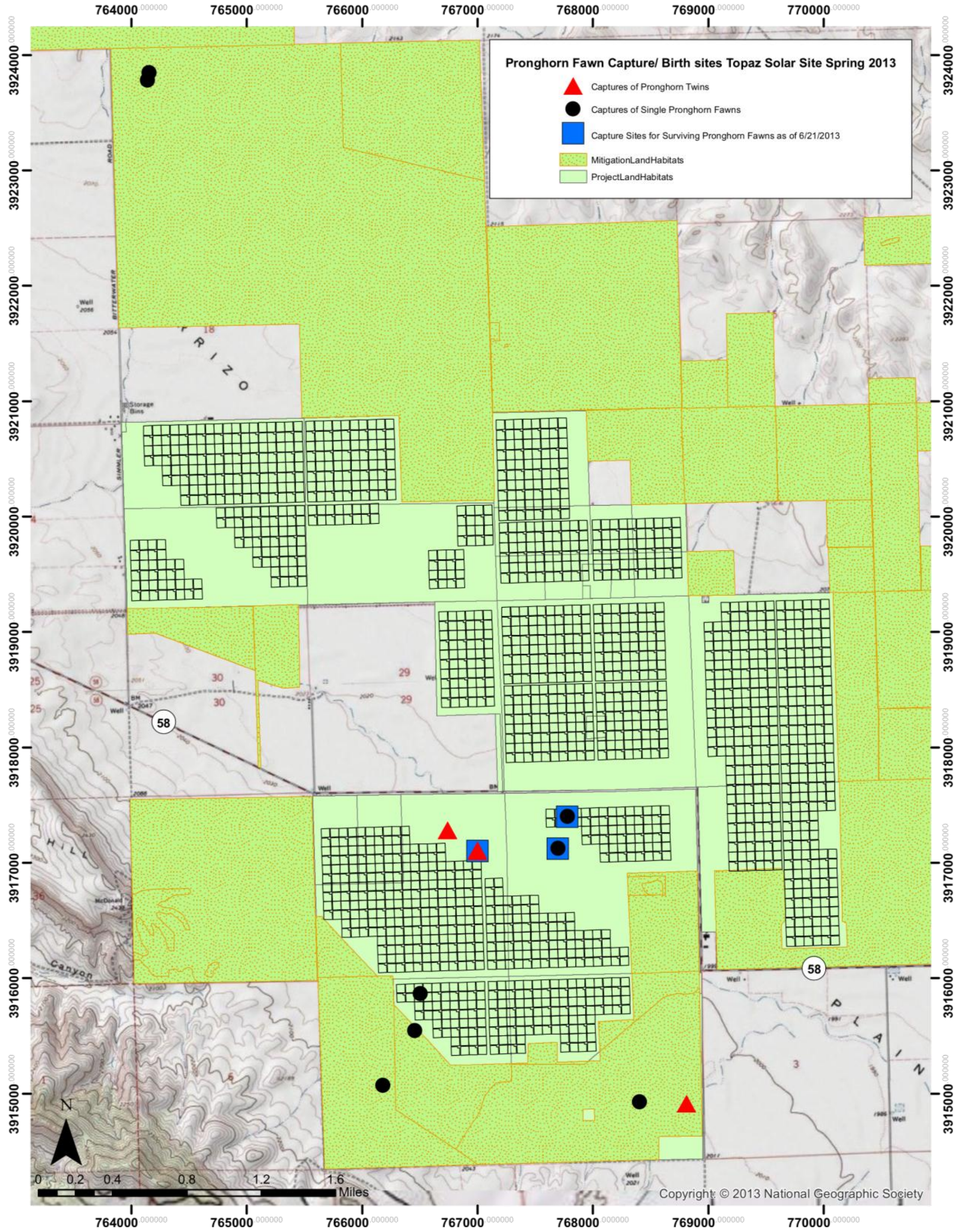

Figure 2. Locations of fourteen GPS-collared pronghorn fawn birth sites on the northern Carrizo Plain in areas surrounding solar power development and within mitigation lands during May-June 2013.

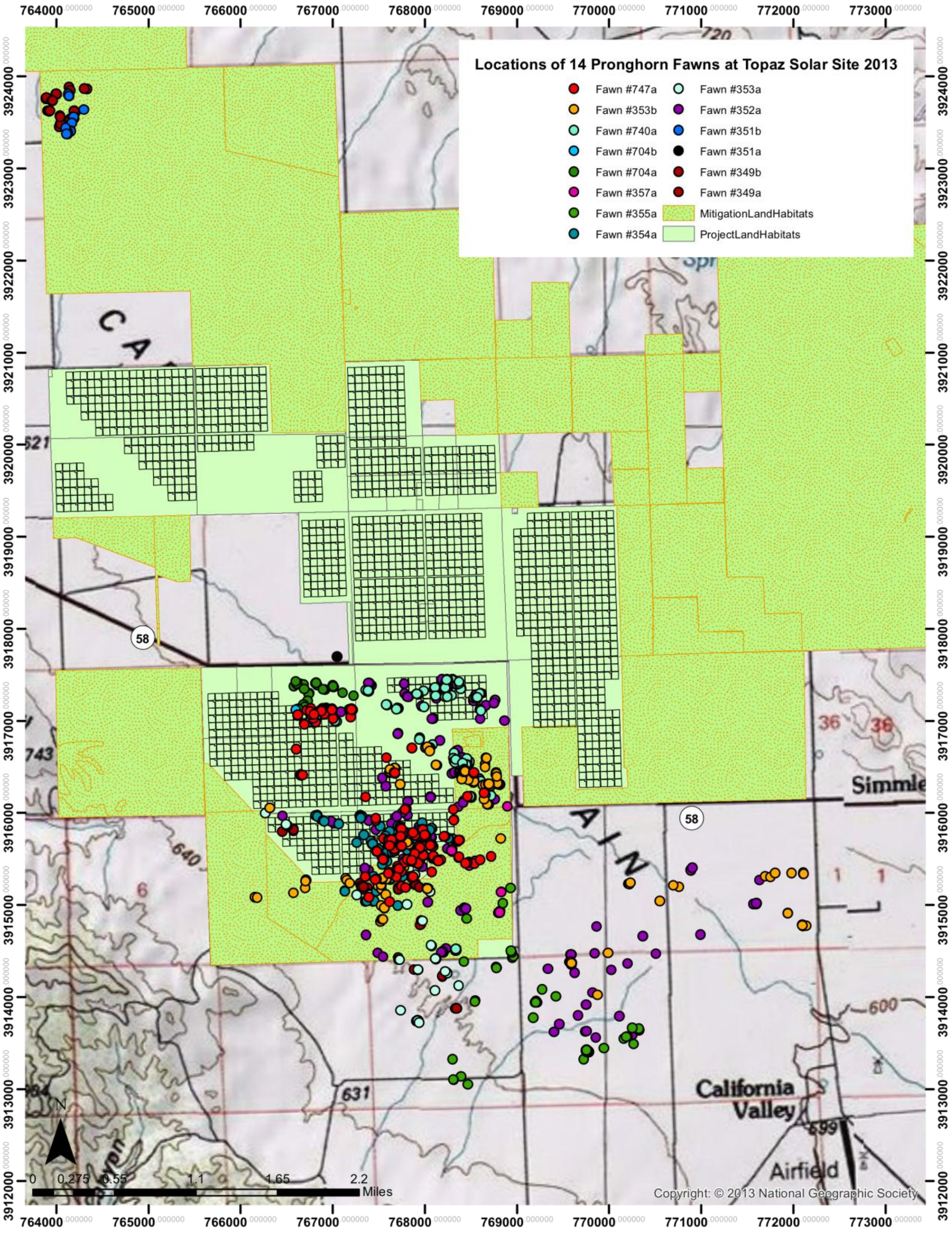

Figure 3. Locations of fourteen GPS-collared pronghorn fawns on the northern Carrizo Plain in areas surrounding solar power development and within mitigation lands during May-June 2013.

Three collared fawns survived (lived > 60 days) and 11 suffered mortalities (Fig. 4). Of the uncollared fawns, we estimate that 5 individuals survived and 6 suffered mortalities based on observational surveys. We were able to conduct 9 field necropsies (8 collared fawns and one uncollared fawn) and one laboratory necropsy (uncollared fawn). Evidence of predation by coyote was detected for 7 of the mortalities. Predation by other species (e.g., golden eagle or bobcat) was not detected during the study although both golden eagles and coyotes were regularly observed and documented (Fig. 5). Predation was not involved for 3 deceased fawns and cause of mortality for these individuals remains unknown. Conducting necropsies for the remaining deceased fawns was not possible due to either a lack of conclusive evidence (collared fawns) or because carcasses were not recovered (uncollared fawns).

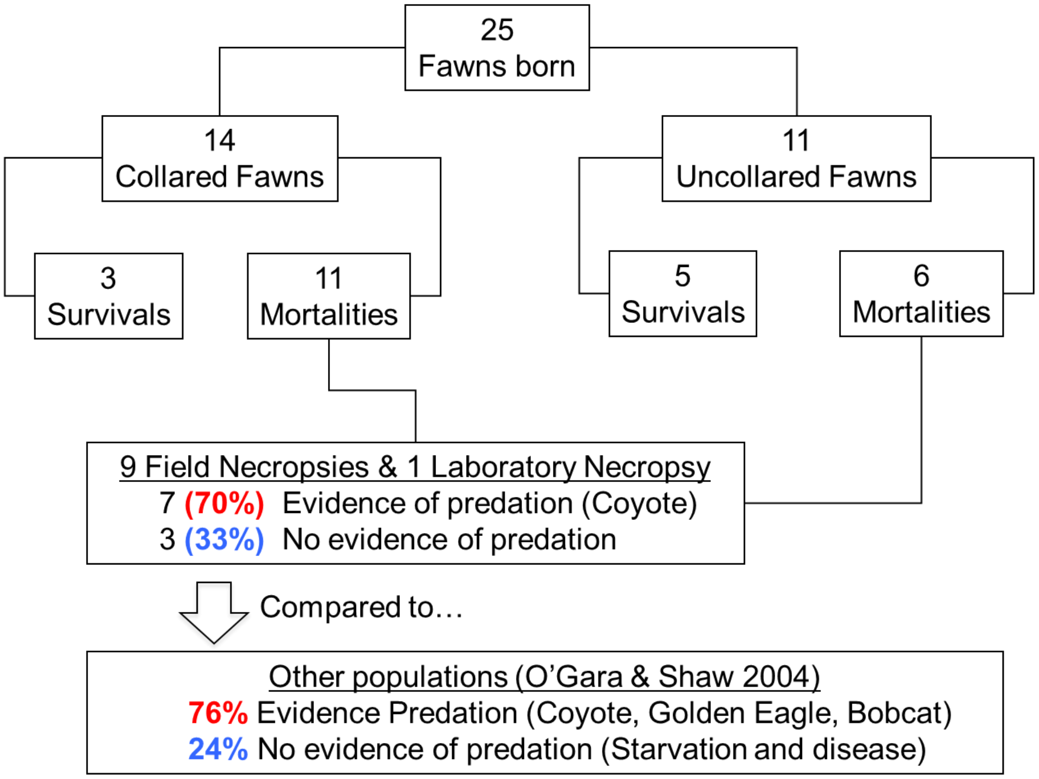

Figure 4. Flowchart indicating the survival outcomes for 25 pronghorn fawns observed on the northern Carrizo Plain, California during 2013. Results are compared to information from similar studies across the species' range (O'Gara and Shaw 2004).

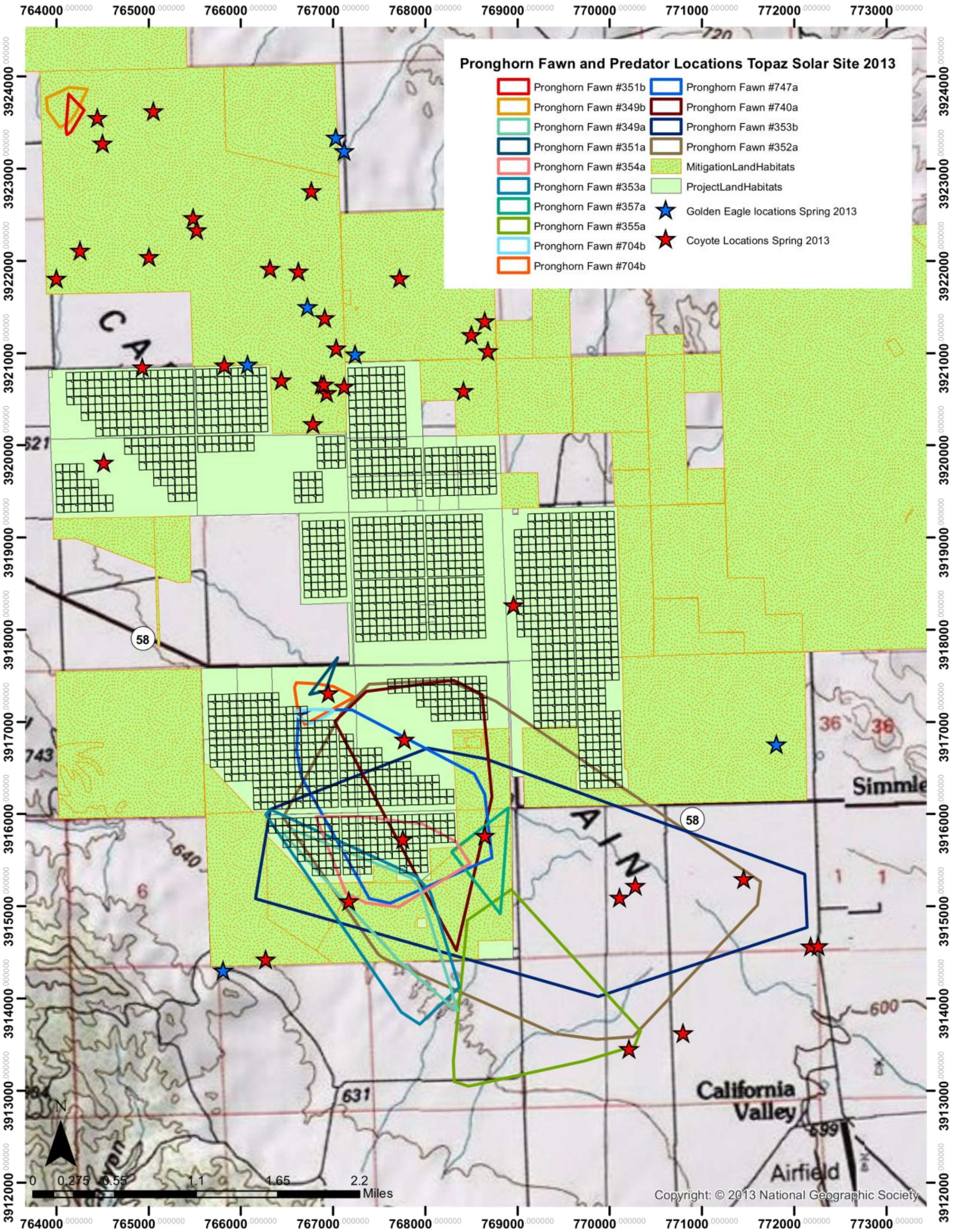

Figure 5. Areas used by fourteen GPS collared pronghorn fawns (minimum convex polygons), as well as incidental predator sightings (coyote and golden eagle), in areas surrounding Topaz solar power development on the northern Carrizo Plain, April 15 - June 21 2013.

We compared our results for fawn survival and cause of mortality during this first year study with that reported for the CPNM from 2009-2011 (Johnson et al. 2012, in review) and across the species' range from 1976-1999 (O'Gara and Shaw 2004). Percent survival (32%) did not differ from mean percent survival on the CPNM (31%, SE = 8.5%, n = 45; z = -0.18, p = 0.86) or across the species' range (29%, SE = 3.5%, n = 995; z = 0.10, p = 0.92). Predation accounted for 70% (n = 10) of fawn mortalities and did not differ from mean percent predation reported for the CPNM (58%; n = 12, z= 0.-1.30, P = 0.20) or across the species' range (75%; n = 702, z = -1.07, p = 0.29). A comparison of survival curves among collared fawns born during this study and those born within the CPNM indicated differences in age specific mortality (Fig. 6). Mean survival time was less (6.75 days, SE = 1.35) than for the CPNM (14.4 days, SE = 2.9) (t = 2.013, df = 21, p = 0.04). Additionally, the mortality rate (% deceased/number of days) between 0 – 10 days of age was 5.8 %/day compared to 2.1 %/day for the CPNM; and between 11 – 20 days of age was 1.4 %/day compared to 3.8 %/day for the CPNM.

Table 1. A comparison of pronghorn fawn productivity and survival in the northern Carrizo Plain during 2013, within the Carrizo Plain National Monument during 2009-2011, and across the species' range according to information from eighteen similar studies from 1976-1999 (O'Gara and Shaw 2004).

Location	**Year**	**Number of fawns born**	**Number of fawns survived**
Northern Carrizo Plain	2013	25	8 (32%)
Carrizo Plain National Monument	2011	11	4 (36%)
Carrizo Plain National Monument	2010	12	5 (42%)
Carrizo Plain National Monument	2009	22	3 (14%)
Other (O'Gara and Shaw, 2004)	1976 - 1999	995	293 (29%)

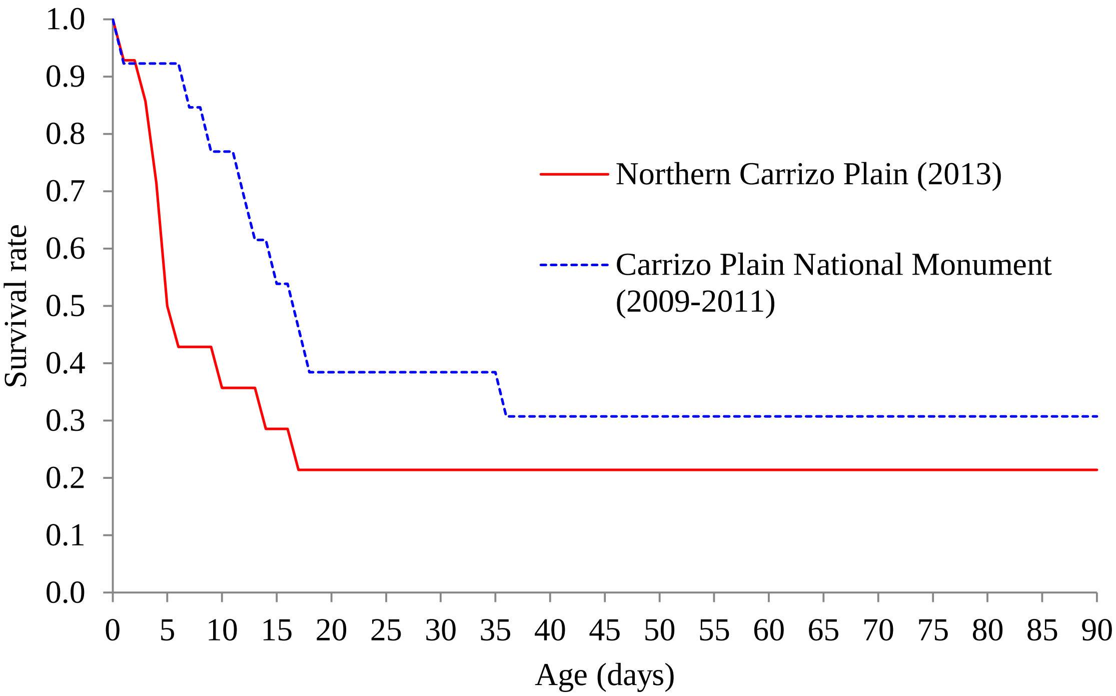

Figure 6. A comparison of age specific mortality, represented by survival curves, for pronghorn fawns on the northern Carrizo Plain in 2013 (solid line) and the Carrizo Plain National Monument from 2009-2011 (dotted line). Survival rate was calculated as the number of fawns alive out of the number of fawns born for each respective age category.

2. Examine the relationship between fawn habitat selection and survival in areas surrounding solar power development and within mitigation lands.

We measured and compared micro-habitat characteristics (i.e., vegetation height, vegetation composition, and visibility) in areas surrounding 136 collared fawn locations and 132 random locations (Table 2). Mean vegetation height within 100 m radius was lower at fawn locations (3.63 cm, SE = 0.24 cm) than at random locations (5.9 cm, SE = 0.3 cm) (T = 36, p = <0.001). No other differences were detected.

Table 2. A comparison of mean vegetation height, percent adult visibility (1 m height) and fawn visibility (0.5 m height), and percent composition of forbs, grasses, shrubs and bare ground within 100 meters surrounding collared fawn locations and random locations on the northern Carrizo Plain, 2013. Standard error is shown in parentheses.

	Mean vegetation height	Mean adult visibility	Mean fawn visibility	Mean vegetation composition			
				Forb	Grass	Shrub	Bare ground
Fawn locations	3.6 cm (0.2 cm)	97.8 % (0.8 %)	97.7 % (0.9 %)	17.7 % (0.3 %)	32.1 % (0.7 %)	0.0 % (0.0 %)	50.1 % (0.9 %)
Random locations	5.9 cm (0.3 cm)	94.2 % (2.2 %)	92.0% (2.7 %)	18.7 % (0.7 %)	34.7 % (1.0 %)	0.3 % (0.1 %)	46.3 % (1.3 %)

Principle Component Analysis (PCA) of micro-habitat variables indicated significance for PC 4 and PC 7 ($p < 0.001$ and $p = 0.03$, respectively) and marginal significance for PC 6 ($p = 0.60$). Together, these three PCs accounted for 13.06% of the total variance in the original data set. Variables with the highest loading (> 0.60) included adult and fawn visibility at distances of 50 meters (0.74 and 0.76, respectively) and 100 meters (0.82 and 0.88, respectively) from fawn locations (PC 4), adult and fawn visibility at fawn locations (0.98 and 0.98, respectively) (PC 7), and vegetation height at fawn locations (0.79) and at distances of 5 meters (0.76) and 10 meters (0.63) from fawn locations (PC 6).

We developed 11 candidate binary logistic regression models using biologically relevant combinations of significant micro-habitat (from PCA results) and macro-habitat parameters (Table 3). The habitat parameters used in the global model are indicated at the bottom of Table 3. Two candidate models, Model 1 ($w_i = 0.62$) and Model 2 ($w_i = 0.34$), showed substantial support as the best approximating models ($\Delta AIC_c < 2$). The area under the ROC was 0.82 for both model 1 and model 2. Parameter estimates (β), standard errors (SE) of the estimates, odds ratios, and 95% confidence intervals (CI) for the odds ratios of the variables in the two models are shown in Table 4. Model 1 showed that fawn locations were positively associated with distance to water sources, solar development and minor roads; and negatively associated with distance to major roads and ephemeral drainages. Model 2 showed that fawn locations were positively associated with adult visibility at 100 m from fawn locations and distance to water sources and solar development; and negatively associated with adult visibility at fawn locations and at distances of 50 m from fawn locations, and distance to major roads and ephemeral drainages.

The two best approximating models for fawn habitat selection were:

Model 1: Fawn habitat = -1.229 + (0.000636) Distance to water sources - (0.000990) Distance to major roads - (0.00127) Distance to ephemeral drainages + (0.00107) Distance to solar development + (0.000155) Distance to minor roads.

Model 2: Fawn habitat = 63.519 - (0.657) Adult visibility at fawn locations - (0.0110) Adult visibility at 50 m distance + (0.0240) Adult visibility at 100 m distance + (0.000595) Distance to water sources - (0.000965) Distance to major roads - (0.00118) Distance to ephemeral drainages + (0.00101) Distance to solar development.

Table 3. Comparison and relative ranking of candidate models for pronghorn fawn habitat selection on the northern Carrizo Plain in 2013. Akaike's Information Criteria (AIC) corrected for small sample sizes (AIC_c) was used for model selection. Included for each candidate model are values for log-likelihood, number of parameters (*k*), AIC_c values, Δ AIC_c values, and Akaike weights (w_i). Relative ranking of models was determined using Δ AIC_c.

	Model	-2LogL	*k*	AIC_c	ΔAIC_c	w_i
1	dws+dmajr+ded+dsd+dminr	251.06	4	259.22	0.00	0.62
2	av0+av50+av100+dws+dmajr+ded+dsd	245.99	7	260.43	1.21	0.34
3	Global model[a]	237.67	13	265.15	5.93	0.03
4	ht0+fv0+ht5+ht10+dws+dmajr+ded+dsd	249.99	8	266.57	7.35	0.02
5	av50+fv50+av100+fvis100+dws+ded	279.94	6	292.27	33.05	<0.01
6	ht0+ht5+ded	297.27	3	303.37	44.15	<0.01
7	av0+fv0+av100+fv100+ht0+ht5+ht10	326.02	7	340.46	81.25	<0.01
8	fv0+fv50+fv100+ht0+ht5+ht10	328.22	6	340.55	81.33	<0.01
9	av0+fv0+av50+fv50+av100+fv100+ht0+ht5+ht10	325.86	9	344.58	85.36	<0.01
10	av50+av100+dws	342.42	3	348.51	89.29	<0.01
11	dsd+ht0+ht5	353.54	3	359.64	100.42	<0.01

[a] Global model includes distance to water sources (dws), major roads (dmajr), minor roads (dminr), ephemeral drainages (ded), and solar development (dsd); adult visibility at fawn locations (av0) and at distances of 50 m (av50) and 100 m (av100); fawn visibility at fawn locations (fv0) and at distances of 50 m (fv50) and 100 m (fv100); and vegetation height at fawn locations (ht0) and at distances of 5 m (ht5) and 10 m (ht10).

Table 4. Parameter estimates (β), standard errors (SE) of the estimates, odds ratios, and 95% confidence intervals (CI) for the odds ratios of the variables in the two best approximating models for the occurrence of pronghorn fawns on the northern Carrizo plain.

Effect	β	SE	Odds ratio	95% CI
Model 1:				
dws	0.000636	0.000223	1.001	1.000 - 1.001
dmajr	0.000990	0.000248	0.999	0.999 - 0.999
ded	0.00127	0.000256	0.999	0.998 - 0.999
dsd	0.00107	0.000271	1.001	1.001 - 1.002
dminr	0.000155	0.000372	1.000	0.999 - 1.001
Model 2:				
av0	0.657	74.279	0.518	3.078^{-064} - $>1^{40}$
av50	0.0110	0.0223	0.989	0.947 - 1.033
av100	0.0240	0.0168	1.024	0.991 - 1.058
dws	0.000595	0.000225	1.001	1.000 - 1.001
dmajr	0.000965	0.000240	0.999	0.999 - 1.000
ded	0.00118	0.000261	0.999	0.998 - 0.999
dsd	0.00101	0.000267	1.001	1.000 - 1.002

Variables include distance to water sources (dws), major roads (dmajr), minor roads (dminr), ephemeral drainages (ded), and solar development (dsd); adult visibility at fawn locations (av0) and at distances of 50 m (av50) and 100 m (av100).

Discussion

1. *Measure fawn survival and determine causes of mortality in areas surrounding solar power development and within mitigation lands.*

Percent survival of pronghorn fawns did not differ from mean percent survival reported for the Carrizo Plain National Monument (CPNM; Johnson et al. 2012, in review) or for other populations across the species' range (O'Gara and Shaw 2004). It is important to consider, however, that for small populations, seemingly adequate percent survival can only produce limited raw numbers of recruited individuals. During this study, a relatively small number of individuals survived (n = 8; lived >60 days). Additionally, high variability in annual recruitment is known to occur among pronghorn (Vriend and Barrett 1978, Kohlmann 2004), as observed during three years on the CPNM. Small or sparse populations which exhibit high variability in recruitment are vulnerable to environmental and demographic stochasticity (e.g., drought and chance variation of births/deaths, respectively) (Courchamp et al. 2008).

The causes of mortality typically attributed to deceased pronghorn fawns include predation, starvation, exposure and disease (O'Gara and Shaw 2004). Of these mortality factors, we found evidence for predation only. For one-third of deceased fawns, predation was not involved and the cause of mortality for these individuals remains unknown. The percentage of predator related deaths did not differ from that found within the CPNM or across the species' range. Although predation is not generally considered to drive pronghorn population dynamics, the importance of predation increases for static or declining populations (O'Gara and Shaw 2004), such as the one inhabiting the Carrizo Plain. Additionally, the impact of predation increases for populations occupying marginal habitats or areas where the number of predators is high in relation to the number of pronghorn (Lee et al. 1998). Habitat quality immediately south, within the CPNM, has been ranked as moderate to poor for pronghorn (Longshore and Lowrey 2008), where limited shrub cover likely restricts adequate concealment from predators (Johnson et al. 2012, in review). These findings are supported by similar results for habitat availability found during this study (see discussion on habitat below). Regional information on the abundance and dispersal of fawn predators is limited, however, incidental sightings of both coyotes and golden eagles were common and well dispersed throughout the study site. Scavenging by golden eagle was observed for one pronghorn fawn and predation by golden eagle was observed for two elk calves. During four independent occasions, coyotes were observed chasing pronghorn fawns, as well as adults, along fence lines boarding solar development and mitigation lands. Artificial barriers can influence habitat quality, as fences and roads are well known to impede pronghorn movements and likely limit escape opportunities from pursuing predators (Spillet et al. 1967, Howard et al. 1990).

We used survival curves to explore and compare patterns in age-specific mortality between fawns at this site and fawns within the CPNM. The number of days lived for deceased fawns in this study was less than half that found for the CPNM. Byers 1997 reported that mortality is highest for pronghorn fawns between 11 and 20 days of age, suggesting that, as fawns develop, the slow transition from hiding to cursorial behavior (i.e., running) causes them to become increasingly visible to predators while still vulnerable to attack. Supporting evidence for this was found on the CPNM, where predation increased as fawns moved greater distances per day (Johnson et al. 2012, in review). However, during this study, we observed that predation primarily took place at an age when fawns typically remain hidden. These results may imply that other factors, such as insufficient cover for hiding or high predator density, are influencing the age at which fawns succumb to predation. Fawn running ability increases with age and sufficiently developed individuals are able to successfully escape from pursuing predators (O'Gara 2004); therefore, increased survival times are likely important for reducing predation risk.

2. Examine the relationship between fawn habitat selection and survival in areas surrounding solar power development and within mitigation lands.

Model results indicated that both pronghorn does and their fawns selected for a combination of environmental conditions at both micro- and macro-habitat scales. At the micro-habitat scale (< 100 m) fawn locations were associated with decreased visibility at close distances (0 m and 50 m) and increased visibility at far distances (100 m). Pronghorn fawns typically select bed sites which provide adequate vegetative concealment from predators while still providing long-range visibility of the surrounding area (Bodie 1979, Autenrieth 1982, Canon and Bryant, 1997). However, vegetation height was not a significant micro-habitat feature and did not appear to be an important source of cover in our study. While concealment is often available as vegetative cover, hiding fawns can also benefit from physiographic features found within the surrounding landscape (e.g. rolling terrain or ridgelines) (Einarsen 1948, Yoakum 2004). Model results for macro-habitat features supported this, where fawn locations were in closer proximity to ephemeral drainages. The advantages of selecting sites near drainages may be two-fold: 1) The complex and variable physiography created by drainages at this site offer abundant topographic concealment opportunities for hiding fawns; and 2) ephemeral drainages contain higher soil moisture content and therefore provide important late-season forage opportunities for adult does and developing fawns.

Fawn locations were also farther from solar development and minor roads, but closer to major roads. Anthropogenic disturbances (e.g., traffic or large-scale construction) have been shown to reduce foraging efficiency, reproductive rates and population density in pronghorn (Berger et al. 1983, Easterly and Guenzel 1992). However, pronghorn can, and regularly do, adapt to high levels of disturbance if given reasonable consideration (U.S. Fish and Wildlife Service 1998, Yoakum 2004). Although we considered anthropogenic disturbance along minor roads to be relatively insignificant at this site, extensive dirt roads may: 1) increase predation risk by providing movement corridors for coyotes (Larrucea et al. 2007); and 2) reduce foraging and concealment opportunities by limiting vegetative growth (personal observ., 2013).

Lastly, fawn locations were associated with increased distance from water sources. For pronghorn occupying arid rangelands, the availability and dispersal of open drinking water directly affects adult health and reproduction, as well as fawn productivity and survival (McKee and Wolf 1963, Beale and Smith 1970, Ockenfels et al. 1992). Although neonatal fawns acquire water through nursing, sources of open drinking water can influence the location of fawn bed sites (Ockenfels et al. 1992). A fawn survival model for the CPNM showed that proximity to water sources increased fawn survival times (Johnson et al. 2012, in review). The fact that fawns were located closer to major roads and farther from water sources may indicate that environmental conditions within the primary fawning area (e.g., higher quality forage, increased topographic cover, or lower predator density) outweighed the costs normally associated with increased distance to water (e.g., energy expense of travel to water sources). It should be noted that additional water sources were installed during the end of the fawning season (June 2013).

The availability and composition of forbs, grasses, shrubs, and bare ground are important in determining the quality of fawn habitat (O'Gara and Yoakum 2004). In comparison to measurements generally reported for grassland habitats (modified from Allen et al. 1984, O'Gara and Yoakum 1992, Ockenfels et al. 1996, and Yoakum 2004c), percent cover of forbs was within the expected range (10-20%). However, percent cover of shrubs and grasses was lower (< 5% and 50-80%, respectively) and percent bare ground was higher than typically reported (20-30%), indicating low overall forage availability and vegetative cover for concealment.

Discussion summary: Our results provide important baseline data for pronghorn occupying the northern Carrizo Plain. Additional data on: 1) recruitment rates, 2) mortality factors, 3) habitat selection, and 4) effects of anthropogenic development and environmental conditions (i.e., weather, water availability, and forage availability) will be required to create a suitable model for assessing the potential impacts of continued solar development and to inform management practices at this site. Information on population density and birth synchrony is also needed to assess the potential for Allee effects and their impact on population growth.

Appendix A. Information for fourteen pronghorn fawns collared on the northern Carrizo Plain, California in 2013.

Fawn ID	VHF frequency	Ear tag (number-color-side)	Sex	Date of birth (mm/dd/yyyy)	Survival or Mortality	Date of death (mm/dd/yyyy)	Age at death (days)	Evidence of predation?	Date of capture	Age at capture (days)
670352a	165.5812	11-blue-right	Female	05/06/2013	Survival	n/a	n/a	n/a	05/07/2013	1
657740a	165.5187	86-red-right	Female	05/06/2013	Survival	n/a	n/a	n/a	05/07/2013	1
657704a	165.5062	34-yellow-right	Female	05/09/2013	Mortality	05/14/2013	5	no	05/09/2013	0.3
670351a	165.56875	49-white-right	Male	05/09/2013	Mortality	05/10/2013	1	yes	05/09/2013	0.3
670349a	165.5562	75-green-right	Male	05/09/2013	Mortality	05/14/2013	5	no	05/09/2013	0.4
670353a	165.59375	20-blue-left	Female	05/09/2013	Mortality	05/13/2013	4	unknown	05/10/2013	1
670355a	165.6187	32-yellow-left	Male	05/10/2013	Mortality	05/20/2013	10	unknown	05/12/2013	2
670357a	165.54375	47-white-left	Male	05/10/2013	Mortality	05/13/2013	3	yes	05/12/2013	2
670354a	165.6062	100-red-left	Female	05/10/2013	Mortality	05/24/2013	14	yes	05/14/2013	4
657704b	165.50625	76-green-left	Male	05/11/2013	Mortality	05/17/2013	6	no	05/14/2013	3
657747a	165.5312	117-black-right	Male	05/11/2013	Survival	n/a	n/a	n/a	05/14/2013	3
670349b	165.5562	39-yellow-left	Female	05/22/2013	Mortality	05/27/2013	5	yes	05/23/2013	1
670351b	165.5687	4-blue-left	Female	05/22/2013	Mortality	05/26/2013	4	yes	05/23/2013	1
670353b	165.5937	52-white-left	Female	05/22/2013	Mortality	06/08/2013	17	yes	05/23/2013	1

UTM location (easting)	UTM location (northing)	Start time	End time	processing time (minutes)	Weight (kg)	Body length (cm)	Tarsus length (cm)	Neck girth (cm)	Body girth (cm)	Body temperature (fahrenheit)	Number of incisors
0767778	3917403	0811	0829	18	-	64.50	16.00	17.50	-	-	2
0767697	3917129	1748	1804	16	3.7	58.00	19.00	19.00	26.00	-	2
0766740	3917287	1645	1706	21	3.5	60.9	20.3	17.5	40.5	102.5	4
0766740	3917286	1645	1706	21	3.4	57.5	21	21.4	38.6	104.4	2
0766455	3915550	1849	1906	17	3.5	64.5	18.5	17.5	39.5	101.5	2
0766503	3915869	1025	1042	17	3.7	63.5	17.5	16.5	36.8	103.8	2
0768811	3914918	1352	1415	23	3.9	60.1	20.5	18.4	37.9	-	2
0768811	3914918	1352	1415	23	-	62.5	19.5	19.2	35.5	106.5	2
0769404	3914931	1423	1437	14	4.5	67.2	22.7	18.8	40.7	105.4	2
0766999	3917116	1718	1738	20	-	62.3	21.2	18	-	-	2
0766998	3917104	1718	1738	20	4.3	-	21	17.5	-	-	4
0764153	3923847	1107	1117	10	3.8	64.2	17.4	18.6	38.2	103.1	2
0764141	3923781	1046	1104	18	3.5	62.7	18	17.8	37.7	102.7	2
0766182	3915075	1517	1528	11	3.3	59.3	16.5	16.9	-	102.7	2

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