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Authors: Germano, David J., Salaw, Lawrence R., and Tennant, Erin N.

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Effects of Oil Fields on Home Range, Movements, and Rates of Predation of Blunt-nosed Leopard Lizards (*Gambelia Sila*)

David J. Germano[1A], Lawrence R. Salaw[2], Erin N. Tennant[3]

[1] Department of Biology, California State University, Bakersfield,
[2] Endangered Species Recovery Program, California State University, Stanislaus,
[3] California Department of Fish and Wildlife, Central Region - Lands Unit, Fresno, California

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Abstract

Extraction of oil and gas occurs around the world and associated worksite activity can affect native species, even when some good habitat remains. Understanding the possible negative effects is important for management of protected species. Blunt-nosed Leopard Lizards (*Gambelia sila*) are a state- and federally listed endangered species in the San Joaquin Desert of California, and part of their remaining range coincides with oil field operations. In 2015 and 2016, we used radiotelemetry to study home ranges and movements of *G. sila* living in an oil field with limited infrastructure and roads (a light-density oil field constructed from 2011 to 2014) and at a control site of native habitat about 3 km away. We did not find significant differences between the oil field and control site in either home-range size or daily distances moved. We did, however, find that the number of predation events was significantly greater at the oil field site, assuming that known predation occurrences represented all predation. Predation by birds was greater at the oil field site and likely was facilitated by predator perching locations provided by power poles, transmission lines, and other tall vertical structures associated with the oil field. No similar structures or other perching locations for large predatory birds existed at the control site. Only a twin-pole, three-wire transmission line existed adjacent to the oil field prior to its development. Given that *G. sila* are endangered largely because of habitat loss, their recovery may benefit from minimizing these hazards in oil fields that currently support the species.

Loss and degradation of habitats are two main causes of species endangerment worldwide (Fischer & Lindenmayer, 2007; Pekin & Pijanowski, 2012; Wilcove et al., 1998). Fragmentation of habitats can also be a problem as development extends into species ranges (Mullu, 2016; Munguia-Vega et al., 2013; Walker et al., 2017). Even linear development such as roads, railroads, and pipeline right-of-ways can fragment habitats and introduce additional predator pressure for small terrestrial animals, especially amphibians, reptiles, and mammals (Forman & Alexander, 1998). Oil and gas production is widespread throughout the world, and oil production on land can be so intensive that no habitat remains for vertebrate animals; however, some production is less intense, and the remaining habitat may still support native wildlife (Chalfoun, 2021; Jones et al., 2015; Northrup & Wittemyer, 2013).

Even in areas of moderate to low-density oil development (i.e., few roads, low vehicle traffic, limited infrastructure) that maintain some habitat, activity in oil fields might jeopardize small species, such as lizards (Smolensky & Fitzgerald, 2011). The bare ground of pads, road activity, power poles, and noise and disturbance from drilling operations have potential negative impacts on the resident species in the remaining habitat. If a lizard uses the bare ground of an oil pad, it could be more susceptible to predators than in vegetated areas. Roads increase the chance of a lizard being killed by vehicle strikes (Andrews et al., 2006; Rytwinski & Fahrig, 2015; Tanner & Perry, 2007) and cause crossing avoidance (Andrews et al., 2006; Hibbitts et al., 2017), and power poles that supply energy to oil pumps increase perches for predatory birds, especially in desert areas that typically do not have perches over wide areas of habitat (Dwyer & Doloughan, 2014; Slater & Smith, 2010). Noise associated with industrial operations can impact various animals (Rosa & Koper, 2021; Rutherford & Maxwell, 2023), including lizards (Mancera et al., 2017), and activity of moving oil pumps along with occasional attendance by humans may also negatively affect lizards. Furthermore, surface oil spills at wells and from pipelines could be harmful to lizards, although toxic gasses from oil have not been found to be lethal although arthropod prey abundances have been diminished by oil extraction activity (Weir et al., 2016).

Blunt-nosed Leopard Lizards (*Gambelia sila*) are an endemic species of the San Joaquin Desert of California (Germano, 2009; Germano et al., 2011; Montanucci, 1965). Largely due to land conversion to agricultural, urban, and industrial activities covering about 59% of the area (Germano et al., 2011), suitable habitat for *G. sila* has become smaller and fragmented, and the species is currently federally and state-listed as endangered (California Dept of Fish and Wildlife, 2015; US Fish and Wildlife Service, 1967). Part of the range of *G. sila* occurs in areas with oil development, and Kern County, at the southern end of the range, has the largest producing oil fields in California (California Geologic Energy Management Div., 2020). Although *G. sila* can be found in areas with low to moderate density oil operations (Chesemore, 1980; EG&G Energy Measure-

A Corresponding author. E-mail: dgermano@csub.edu

ments Group, 1980, 1986; Germano et al., 1993), population characteristics of *G. sila* such as home range, movements, and predation rates have not been studied. Noise associated with oil production could cause lizards to avoid parts of habitats with higher resources, such as food and nesting areas, thus causing them to expand home ranges to acquire these resources. Also, roads and oil pads could remove better habitat areas for the species and tall vertical structures, such as power transmission lines and oil-production structures, may provide perching sites for large predatory birds, increasing the likelihood of predation on *G. sila* (Germano, 2018; Germano & Brown, 2003). Together, these impacts have the potential to compromise long-term persistence of the species in these areas even when habitat is available.

Over 2 years, we determined home ranges, movements, and rates of predation of *G. sila* in a lightly developed oil field and a nearby control site on the Lokern, western Kern County, California. We hypothesized that home-range size and distances moved per day of *G. sila* would be affected by oil field development. We predicted that home-range size would be smaller in a natural area than in an oil field and that lizards would move greater distances in an oil field than in natural habitat because of degradation caused by oil operations. We also predicted that predation rates would be higher in an oil field site than a control site because of increased perch and nest structures for predatory birds.

Materials and Methods

Study Area.—We studied *G. sila* at the Lokern Natural Area, in the southwestern portion of the San Joaquin Desert, about 50 km northwest of Bakersfield in Kern County, California. The oil field site (35°19’50" N, 119°34’58" W, 230 m elevation; datum WGS84) was located in the Railroad Gap Oil Field on a broad alluvial fan at the base of the Elk Hills, southeast of Highway 58. All the existing well pads, associated pipelines, and upgraded roads were constructed between 2011 and 2014. Two additional well pads and access roads were excluded by using aluminum flashing prior to and during the study. The site had power lines to supply electricity to oil pumps and the habitat was crossed by several dirt roads that carried work trucks daily. Besides dirt roads within the oil field, we tracked lizard movement through five unfenced well pads. There were also two proposed, unconstructed well pads that were fenced with 1 m tall aluminum flashing; we tracked several *G. sila* that used the habitat directly adjacent to these fenced areas. In a study of impacts of oil fields on vertebrates in Kern County, Fiehler et al. (2017) surveyed low-density plots (1–9 oil well pads/36 ha), medium-density plots (11–15 pads/36 ha), and high-density plots (102–393 pads/36 ha). Based on our calculations of the amount of habitat disturbance due to oil pads and dirt roads in the area with *G. sila* (11.2%), we considered the oil field site to be a light-density field. By using a perimeter that contained all the lizards we tracked, our oil field site had five oil pads in 127 ha. The perimeter that contained lizards we tracked had an area of 76 ha at the control site.

The undisturbed control site was located on the California Resources Corporation (Elk Hills) Conservation parcel (35°21’03" N, 119°33’00" W, 155 m elevation; datum WGS84), approximately 3.2 km northeast of the oil field site. One lightly traveled dirt road bordered the north edge of the conservation parcel and one unmaintained, rarely used road crossed a portion of the study area. There were no tall vertical structures (e.g., power poles) in or near the control plot, although the site was a conservation area with a three-strand barbed wire fence around its perimeter. Much of the Lokern area burned in 1993 (Germano et al., 2023) and again in 1997 (Germano et al., 2012) up to the Elk Hills. Because of this, both sites only had some scattered Allscale (*Atriplex polycarpa*) with non-native annual grasses and native annual forbs dominating sites. At the control site, there also were scattered Cheesebush (*Ambrosia salsola*) and California Matchweed (*Gutierrezia californica*). At the oil field site, shrubs were generally 1–2 m tall, but were 1 m tall or less at the control site.

Data Gathering.—We intensively walked both sites during optimal daytime temperatures (23–38 °C; Germano, 2019) and used a pole and noose to catch lizards. Once captured, we determined sex of lizards (Germano, 2009) and measured their snout-vent length (SVL; to 1 mm), total length (to 1 mm), and mass (to 0.1 g). We attached radio transmitters (Holohil Systems, Carp, Ontario, Canada; model BD-2, frequency 164–166 MHz, battery life 16–18 weeks, weight 2.0 g) to *G. sila* with aluminum beaded chain collars (Harker et al., 1999). We attached transmitters to the chain by winding several loops of thin brass wire around transmitters and chains before covering wires with epoxy glue. We attached collars only to adult *G. sila* and we did not radio-tag lizards < 96 mm SVL. Transmitters with collars weighed 2.2 g, which, except for one lizard, was < 7.9% of the weight of the smallest lizards we collared. We collared one lizard that was 96 mm SVL and weighed 22 g (collar weight was 10.0% of its weight).

We released lizards at their capture site within 24 h. We radio-tracked *G. sila* from 27 April 2015 through 22 July 2015 and 13 May 2016 through 15 July 2016. We used H-Adcock two-element or Yagi three-element receiving antennae with Communications Specialists receivers (Model R-1000) to radio-locate collared lizards by the homing method (T. R. Kenward, 2001). We recorded GPS locations with a Motorola Moto G smart phone with differential and real-time correction (± 5 m resolution) using Locus Pro, GPS Averaging, and ASTRO File Manager applications. We located lizards every 1–5 d with the aim to gather 40–50 locations for each individual lizard (Stone & Baird, 2002). We were not able to collect the intended number of locations for all lizards because some lizards were preyed upon or their signal was lost. We did not use data from individuals with fewer than 18 locations, and most had > 24 locations.

We radio-collared 21 *G. sila* (13 males, 8 females) in the 127-ha oil field in 2015 (0.165 lizards/ha) and 17 (11 males, 6 females) in 2016 (0.134 lizards/ha). At the 76-ha control site, we radio-collared 22 *G. sila* (12 male, 10 female) in 2015 (0.289 lizards/ha), and 14 (10 males, 4 females) in 2016 (0.184 lizards/ha). We obtained 18 or more locations for 70% of lizards we collared to calculate home ranges at both sites (Table 1). In total, we determined home ranges for six lizards with 18–22 locations, and 45 HRs based on 24 or more locations (mean number of locations = 32.3; range = 18–47; n = 51).

TABLE 1. Sample size (*n*), mean, standard error (SE), and range of the number of radio locations of collared male and female Blunt-nosed Leopard Lizards (*Gambelia sila*) in 2015 and 2016 from the oil field and control areas at the Lokern study site in the southern San Joaquin Desert of California, USA. Numbers are only for lizards for which we gathered 18 or more locations.

	Oil field				Control			
Year/Sex	*n*	Mean	SE	Range	*n*	Mean	SE	Range
2015								
Male	9	34.0	0.324	22–47	9	31.2	0.337	18–44
Female	5	31.8	0.398	27–37	9	30.1	0.289	20–42
2016								
Male	9	35.2	0.263	25–42	7	31.7	0.304	25–39
Female	3	34.3	1.095	22–42	2	32.0	1.189	28–36

Data Analysis.—We calculated home-range sizes of *G. sila* using two methods: the Minimum Convex Polygon (MCP) technique and the Fixed Kernal Local Convex Hull (LoCoH), or Kernel Nearest Neighbor Convex Hull method (Getz et al., 2007; Getz & Wilmers, 2004). We used the package adehabitatHR (Calenge, 2006) in R (version 3.6.2; R Core Team, 2019) for both analyses of home ranges. The MCP allowed us to compare home ranges with published data and this may be the best estimate of home-range size in areas that lack obstacles to movement (Germano & Rathbun, 2016). We used the LoCoH method because it more accurately reflects where lizards spend time in their habitat if obstacles are part of their home range (see R. E. Kenward et al., 2014). In particular, LoCoH home range allowed us to determine if oil pads were avoided by lizards.

Because of small sample sizes, especially for females at both sites in 2016, we compared home-range sizes using the non-parametric Kruskal-Wallis test by sex, site (oil field, control), and year. We used R to determine distances that *G. sila* moved between consecutive daily locations (ignoring distances from locations taken > 1 d apart). We also compared average distance moved and greatest distance moved by sex, site (oil field, control), and year using the Kruskal-Wallis test.

We compared the number of *G. sila* known or suspected to have been killed between sites using a contingency table test (see below for explanation of how we quantified predation). We also quantitatively assessed *G. sila* survival using the program Micromort (Heisey & Fuller, 1985), which produces a maximum likelihood estimate of probability of surviving ($\hat{S}_i$) for a specified interval of time based on the number of days collared *G. sila* survived. Use of number of days as the metric for survival allows staggered entry of individuals (Pollock et al., 1989), accommodating data from individuals collared on different dates. The interval of time we used was 60 d, and we calculated survival for *G. sila* by sex, year, study area, and various permutations thereof. We compared survival probabilities using a two-tailed *z* test (Heisey & Fuller, 1985):

$$z = \frac{\hat{s}_1 - \hat{s}_2}{\sqrt{var\hat{s}_1 + var\hat{s}_2}}$$

where $var\ \hat{S}_i$ is the variance for survival probability *i* as calculated by Micromort. For all tests, $\alpha = 0.05$.

RESULTS

In the oil field in 2015, mean MCP home-range size of males was similar to females, but in 2016 male mean home range was almost 8.4 times larger than for females (Table 2). Similarly, at the control site in 2015, male and female mean home-range size were about the same, but in 2016, male mean home-range size was about 3.2 times that of females (Table 2). There was a significant difference in mean MCP home-range size across sex, year, and site ($H = 26.36$, df = 7, $P < 0.001$). Mean MCP home-range sizes of females on the control site in 2015 (1.44 ha) and the oil field site in 2016 (0.74 ha) were significantly smaller than that of males on the control (6.28 ha) and oil field sites (6.19 ha) in 2016 (adjusted *P*s < 0.05; Table 2). No other comparisons differed significantly. There was a significant difference in mean LoCoH home-range size across sex, year, and site ($H = 28.57$, df = 7, $P < 0.001$) and intergroup-significant differences were the same as for MCP home range (Table 2). LoCoH home ranges showed that *G. sila* at the oil field site avoided the five unfenced well pads in their area (Fig. 1).

On average, across years and sites, male *G. sila* moved about 86–121 m from one day to the next, whereas females moved about 48–62 m (Table 3). There was a significant difference in mean average daily movement across sex, year, and site ($H = 36.55$, df = 7, $P < 0.001$; Table 3). Average distance moved in a day for females at the control site in 2015 (47.6 m) was significantly less than that of males in both the control (86.4 m) and oil field (92.6 m) sites in 2015 and 2016 (control: 121.3 m; oil field: 109.0 m; adjusted *P*s < 0.05; Table 3). Average distances moved in a day for females on the oil field site in both 2015 (56.8 m) and 2016 (56.3 m) were significantly less than that of males in the control site (121.3 m) in 2016 (adjusted *P*s < 0.05; Table 3). Mean greatest daily movement across sex, year, and site differed significantly ($H = 36.55$, df = 7, $P < 0.001$), but only for females on the control plot in 2015 (139.6 m), which was lower than for males on the control plot (357.3 m) in 2016 (adjusted *P* < 0.05; Table 3). The longest one-day move (irrespective of site) for a male was 673.8 m and for a female was 356.6 m (Table 3).

Of the 21 *G. sila* we radio-collared at the oil field in 2015, only 7 lizards (33.3%) retained their collars long enough for us to remove them. Based on remains of lizards found

TABLE 2. Sample size (n), mean, standard error (SE), and range of 95% Minimum Convex Polygon (MCP) and Local Convex Hull (LoCoH) home-range sizes (ha) of male and female Blunt-nosed Leopard Lizards (*Gambelia sila*) in 2015 and 2016 from the oil field and control areas at the Lokern study site in the southern San Joaquin Desert of California, USA. Significant differences within MCP and LoCoH are means that do not share common letters.

	MCP				LoCoH			
Site/Sex	n	Mean (ha)	SE	Range	n	Mean (ha)	SE	Range
Oil field								
2015								
Male	9	3.34a,b	0.65	1.39–6.62	9	3.12a,b	0.62	1.32–7.33
Female	5	2.53a,b	0.83	0.15–5.04	5	1.91a,b	0.57	0.13–3.46
2016								
Male	9	6.19a	1.42	1.36–12.6	9	4.33a	0.96	0.67–8.42
Female	3	0.74b	0.19	0.50–1.11	3	0.88b	0.45	0.33–1.78
Control								
2015								
Male	9	2.19a,b	0.20	1.44–3.23	9	1.82a,b	0.20	1.01–2.97
Female	9	1.44b	0.30	0.69–3.13	9	1.12b	0.17	0.72–2.25
2016								
Male	7	6.28a	1.02	3.57–10.8	7	5.05a	0.68	3.31–7.37
Female	2	1.92a,b	1.00	0.92–2.91	2	1.63a,b	0.52	1.11–2.15

in bird nests on poles, at the base of power poles, or on a shrub, we suspect that five lizards were killed by birds, two of which we are confident were eaten by Red-tailed Hawks (*Buteo jamaicensis*; Appendix Table 1). Because snakes eat *G. sila* and the radio and collar defecated by snakes show signs of passing through a digestive system (Germano et al., 2015; Germano & Saslaw, 2015), we also suspect that one *G. sila* was killed by a snake. We found one lizard dead on the ground, although we could not determine what caused its death (Appendix Table 1). On the oil field site in 2016, 10 of the 17 (58.8%) *G. sila* we radio-collared retained their collars to the end of radio tracking. Of the seven lizards that did not last to the end of radio tracking, we think one lizard was killed by a bird, one was found dead on the ground, and one we know was eaten by a Northern Pacific Rattlesnake (*Crotalus oreganus*) because its radio signal came from inside the snake (Appendix Table 1).

On the control site in 2015, 12 of 22 (54.5%) *G. sila* lasted until the end of radio tracking and in 2016, nine of 14 (64.3%) lasted until the end of radio tracking. Of the 10 lizards for which we did not remove their collar in 2015, we know that one lizard was eaten by a Long-nosed Snake (*Rhinocheilus lecontei*), and we suspect snake predation in another case (Appendix Table 2). In 2016, we suspect one lizard was also eaten by a snake (Appendix Table 2).

Assuming all lizards for which we did not remove collars at the end of tracking (i.e., were not known to be alive) died, 17 lizards on the oil field site were alive (years combined) and 21 died. On the control site, 21 lizards were alive at the end of tracking in 2015 and 2016 and 15 died. Proportions of dead to alive lizards did not differ significantly between oil field (1.23) and control (0.71) sites ($X^2 = 1.35$, df = 1, $P > 0.5$). If we assume that only those lizards known to be predated were dead at the end of tracking, 28 *G. sila* were alive on the oil field site (years combined) and 10 were known to have died. On the control site, 33 lizards were alive and only 3 were known to have been killed. Proportions of dead to alive lizards were significantly different between oil field (0.36) and control (0.09) sites when we used only known deaths ($X^2 = 4.11$, df = 1, $P < 0.05$).

Probability of survival ($\hat{S}$) of *G. sila* for all comparisons of sex, site, and year varied from 0.613–1.00 (Table 4). Survival of lizards on the control site compared to the oil field site, irrespective of sex, did not differ significantly in 2015 (control: 0.876, oil field: 0.643; $z = 1.536$, $P > 0.05$), in 2016 (control: 0.894, oil field: 0.767; $z = 0.820$, $P > 0.05$), or for years combined (control: 0.883, oil field: 0.696; $z = 1.758$, $P > 0.05$). The only significant difference in survival was for females on the control site ($\hat{S} = 1.00$) compared to females on the oil field ($\hat{S} = 0.714$) when years were combined ($z = 2.058$, $P > 0.05$).

DISCUSSION

We predicted that home-range size estimates and daily movement distances for *G. sila* living in a light-density oil field would be larger than at our control site a few kilometers away, but this prediction was not met. Using only confirmed predation events, our prediction of higher predation rates at the oil field site than at the control site was substantiated. Lizard home ranges encompassed areas with trafficked roads in the oil field, but we did not find any dead *G. sila* on roads, suggesting they generally avoid death by vehicle strikes. Leopard Lizards avoided using unfenced oil well pads, although we found occasions when

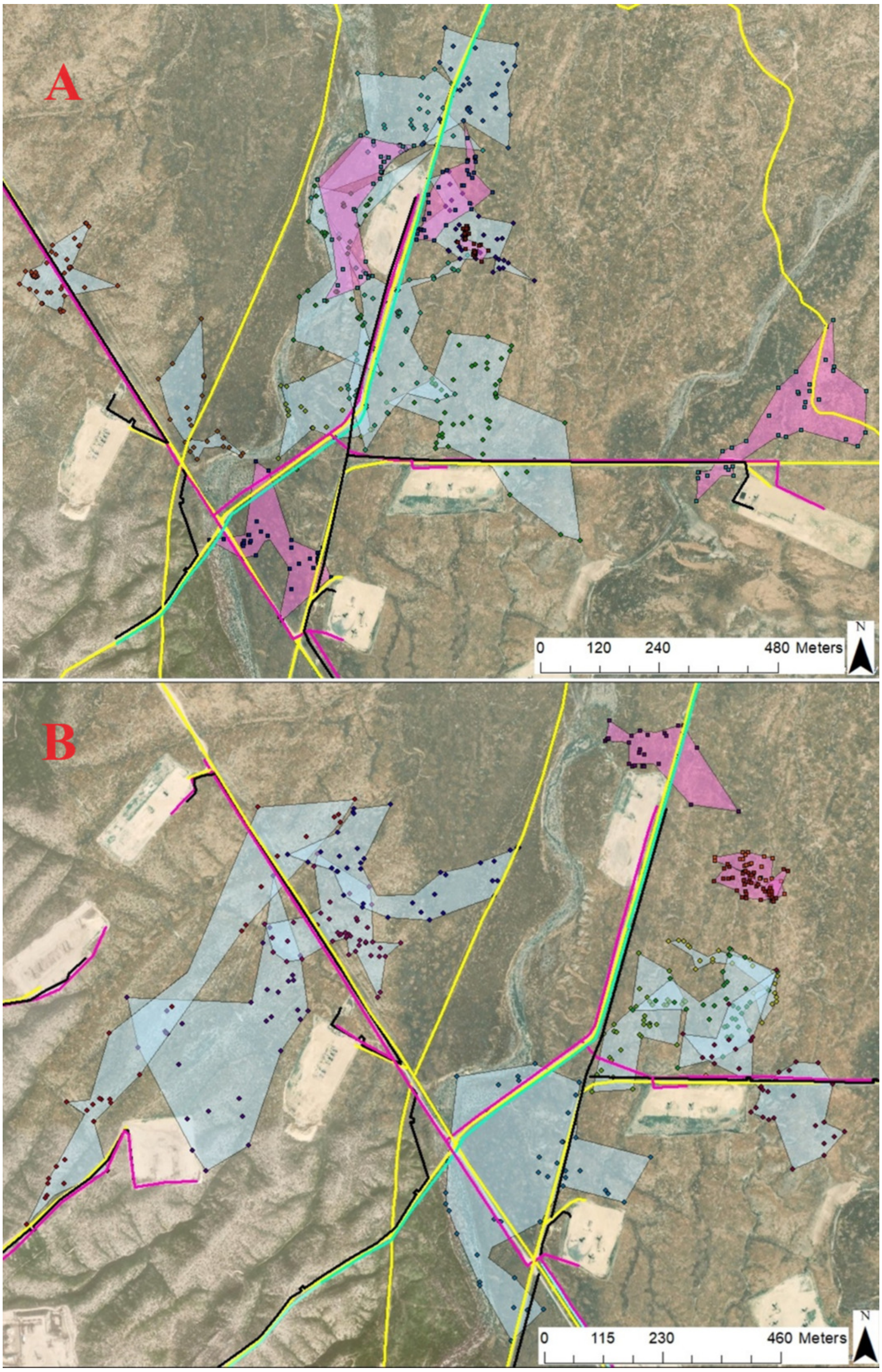

FIG. 1. Local Convex Hull (LoCoH) home ranges of Blunt-nosed Leopard Lizards (*Gambelia sila*) on the oil field site in (A) 2015 and (B) 2016. Male home ranges are blue, and females are pink. Note that in 2015, one female home range was within a male home range, and in 2016, two female home ranges extensively overlapped each other. Dirt roads (yellow), power lines (pink), abandoned water line (green), and oil-production lines (black) are highlighted and oil well pads are the large open areas (light brown).

TABLE 3. Sample size (n), mean, standard error (SE), and range of the average and greatest distance moved (m) between consecutive days by Blunt-nosed Leopard Lizards (*Gambelia sila*) in 2015 and 2016 on the oil field and control areas at the Lokern study site in the southern San Joaquin Desert of California. Significant differences within average and greatest distances are means that do not share common letters.

	Average Distance Moved				Greatest Distance Moved			
Site/Sex	*n*	Mean (m)	SE	Range	*n*	Mean (m)	SE	Range
				Oil field				
2015								
Male	9	92.6b,c	5.69	75.0–123.0	9	244.7a,b	27.0	146.4–381.2
Female	7	56.8a,b	8.11	18.2–82.0	7	178.1a,b	36.9	56.7–356.6
2016								
Male	9	109.0b,c	13.3	63.2–163.6	9	294.1a,b	41.6	153.2–507.8
Female	5	56.3a,b	10.4	30.2–80.1	5	175.5a,b	40.1	75.2–250.8
				Control				
2015								
Male	11	86.4b,c	5.10	50.7–110.9	11	193.1a,b	11.8	137.3–282.5
Female	9	47.6a	4.69	29.4–78.2	9	139.6a	19.7	70.1–241.6
2016								
Male	7	121.3c	9.91	89.3–155.0	7	357.3b	61.7	201.3–673.8
Female	2	61.7a,b,c	8.88	52.8–70.6	2	259.8a,b	49.6	210.2–309.4

TABLE 4. Probability of survival ($\hat{S}$) of radio-collared male and female Blunt-nosed Leopard Lizards (*Gambelia sila*) in 2015 and 2016 from the oil field and control sites at the Lokern study site in the southern San Joaquin Desert of California, USA. Abbreviations: s^2 = variance, CI = confidence interval.

	Oil field			Control		
Year/Sex	$\hat{S}$	s^2	95% CI	$\hat{S}$	s^2	95% CI
2015						
Male	0.613	0.0225	0.379–0.983	0.782	0.0184	0.556–1.0
Female	0.690	0.0328	0.411–1.0	1.00	0	1.0–1.0
Combined	0.643	0.0135	0.451–0.915	0.876	0.0067	0.729–1.0
2016						
Male	0.773	0.0197	0.541–1.0	0.876	0.0173	0.635–1.0
Female	0.753	0.0456	0.431–1.0	1.00	0	1.0–1.0
Combined	0.767	0.0138	0.568–1.0	0.894	0.0101	0.717–1.0

males perched on top of berms on the edge of pads. Male *G. sila* are territorial and often use mounds or berms to scan surrounding habitat (Germano & Carter, 1995; Montanucci, 1965; Tollestrup, 1983) and will even climb into shrubs (Germano & Williams, 2005; Montanucci, 1965).

Although not significantly different, our estimates of home-range sizes for males were almost twice as large in 2016 than in 2015 on the oil field site and were almost three times larger in the control site. We do not have an explanation for this large difference. If larger home-range size was due to reduced food supply (mostly Coleopterans and Orthopterans; Germano et al., 2007; Montanucci, 1965) in 2016, we would expect that females also would have much larger home ranges between years, but they did not. Furthermore, although drier conditions in deserts can affect abundances (Flesch et al., 2017; Germano et al., 1994) and home-range sizes (Ariano-Sánchez et al., 2020) of lizards, there was no significant difference in the amount of rain that fell in the 2015 rain year (Lokern Triangle rain gauge; 102.0 mm) and 2016 (106.7 mm). In addition, sample sizes were equal or about equal between years and the number of times we located a lizard was similar (Oil 2015: mean = 32.9 ± 2.92 SE; Oil 2016: mean = 31.7 ± 1.71; Control 2015: mean = 34.0 ± 2.84; Control 2016: mean = 35.2 ± 1.87). For whatever reason, although again not significantly different, males moved on average a greater distance each day in 2016 than in 2015, which likely accounts for larger home-range sizes because, in most situations, home-range size and movement distances are probably not independent measures.

Our mean home-range sizes, which did not differ significantly between sites, were similar to those reported for *G. sila* in other areas nearby. In the Buena Vista Valley, about 10 km south of our sites on the other side of the Elk Hills, Warrick et al. (1998) estimated the average MCP home-range size of 11 males as 4.24 ha and 5 females as 2.02 ha. On the Elkhorn Plain, west of Lokern and over the Temblor Mountains, home-range sizes were estimated to be 5.14 ha for males and 1.87 ha for females (Westphal et al., 2018). Our MCP estimate of the average size of a home range at the oil field site (years combined) was 4.74 ha for males and 1.86 ha for females. On the control site (years combined) average home-range size was 4.09 ha for males and 1.53 ha for females. In contrast, average MCP home-range size in the Lokern Natural Area, just to the northwest of our sites, was 8.61 ha for males (average of 2003 and 2004) and 5.18 ha for females(Germano & Rathbun, 2016). The Lokern Natural Area is like our study site, with saltbush present at similar levels as on the oil field site, although the control site was virtually devoid of saltbush but did have smaller shrubs over part of the area where we tracked lizards. Also, although precipitation amounts can affect food supply, abundances of lizards, and home-range sizes, precipitation during the study on the Lokern Natural Area was nearly identical (Lokern Triangle rain gauge: 113.5 mm in 2002–2003 and 94.2 mm in 2003–2004) to that in 2015 and 2016 of our current study.

We found that there was more confirmed predation, especially by birds, at the oil field site than at the control site, and this difference was significant if we assume that only confirmed deaths of *G. sila* were predation events. Power poles, transmission lines, and vertical oil-production structures that are part of the oil field operation provided predatory birds dozens of tall perch sites compared to the relatively open desert habitat of the control site. Bird predation on *G. sila* has been found at several sites (Germano, 2018; Germano et al., 2015; Germano & Carter, 1995; Montanucci, 1965), and in most cases either tall trees or power pole lines were nearby. There are exceptions, though; a male *G. sila* was taken by a Prairie Falcon (*Falco mexicanus*) on the Elkhorn Plain (Germano & Carter, 1995). No perch sites were near, but these birds often strike from the air. In another instance, we found a *G. sila* torn apart by what we suspected was a bird in a relatively open desert site (Semitropic Natural Area, Germano et al., 2015). Within about 50 m from where we found the remains of this lizard was a gas pipeline structure that was about 4 m tall with the nest of a pair of Common Ravens (*Corvus corax*; personal observation). In open desert habitats typical of *G. sila*, few perches exist for predatory birds large enough to kill adults, although Loggerhead Shrikes (*Lanius ludovicianus*) use shrubs in New Mexico to kill lizards (Hathcock & Hill, 2019). In the San Joaquin Desert, *L. ludovicianus* perch on saltbush shrubs and fence posts and kill juvenile *G. sila* by impaling them on sharp objects (Montanucci, 1965; pers. obs.). Snakes, which are known predators of *G. sila* (Germano & Brown, 2003; Germano & Saslaw, 2015; Montanucci, 1965; Tollestrup, 1979), also killed lizards at the oil field site, but this occurred at about the same frequency at the control site.

Despite being federally listed as an endangered species since 1967 (U.S. Fish and Wildlife Service, 1967), effects of oil fields on *G. sila* have been mostly neglected, which is surprising because oil production has occurred in the range of this species for over a century. Although there have been several unpublished reports produced since the 1980s with titles that suggest data have been collected determining impacts of oil operations on *G. sila* (Chesemore, 1980; EG&G Energy Measurements Group, 1980, 1986), these reports have found only a few lizards, even in control sites, and no conclusions could be made from the scarce data sets. Only one published study compared abundances of species and groups of species among levels of oil development and control sites in the range of *G. sila* (Fiehler et al., 2017), but the general surveying methods were not specific to *G. sila*, and none were found in oil fields or control sites. They did find, however, that as oil field development and associated habitat disturbance increased, generalist lizard, bird, and mammal species increased, although most species/groups declined in number at the highest level of oil development. Interestingly, both Side-blotched Lizard (*Uta stansburiana*) and Western Whiptail (*Aspidoscelis tigris*) numbers did not decrease in high-density oil development. In New Mexico, Smolensky and Fitzgerald (2011) studied the effects of oil and gas development on Dunes Sagebrush Lizards (*Sceloporus arenicolus*), but the complexity of habitats across study sites prevented them from determining the effect that oil and gas development had on lizard abundance. To our knowledge, the only other studies on effects of oil operations on lizards focused on the toxic effects of oil pollution (Al-Hashem, 2009a, 2009b; Al-Hashem et al., 2008; Al-Hashem & Brain, 2009; Weir et al., 2016).

We did not have the resources to replicate our sites, therefore we lack the ability to make broad general statements about the effects of oil fields on *G. sila*, but this is the first controlled study that gathered specific data on the possible effects of oil production on this federally and state-listed endangered species. More studies need to be conducted on the potential impact of oil and gas operations on *G. sila* because we still do not understand if infrastructure and road systems of oil fields cause harm to populations of this species when habitat is available. It is possible that light to moderate density oil fields do not reduce populations of these lizards because sufficient habitat remains, although we did find a possible higher rate of predation on *G. sila* at our light-density oil field site. We suspect, however, that high-density oil fields likely have a profound negative impact on *G. sila* because of the great distances moved by individuals that causes them to cross many highly trafficked roads contained in high-density operations. Also, habitat needed for foraging, escaping predators, and reproducing is scarce in high-density oil fields. It would be important to understand whether reproductive output differs among high-density oil field sites and natural sites. It is relatively easy to palpate females for the number of eggs they contain (Germano & Williams, 1992, 2005).

Having detailed information about the population biology of *G. sila* will help identify which operational oil fields still provide viable habitat, and/or whether modifications to infrastructure can improve habitat to the point of being meaningful for the recovery of this species. Areas with light to medium levels of oil and gas development may serve to contribute to the conservation and recovery of *G. sila* with implementation of surveys, minimization of habitat disturbance, and take-avoidance measures required for California and Federally authorized oil and gas operations. Such an effect is consistent with the objective of the U.S. Bureau of Land Management of limiting habitat disturbance to 10% in critical reserve lands for Lokern-listed species (US Bureau of Land Management, 2014).

At our oil field site, the only potential impact to the population of *G. sila* seems to have been related to aerial electrical transmission systems and possibly other tall structures in the oil field. If it is possible to modify electrical power systems to eliminate raptor nesting and perching structures (high poles), the increased number of bird kills we found might be reduced. Although not always effective, structures have been modified to deter large bird use by placing spikes and caps on tops of poles and cross arms, adding deterrents to insulators, using angled cross arms (Dwyer & Doloughan, 2014; Slater & Smith, 2010), using non-lethal electrical shocks (Schwartz & Kays, 2001), and affixing brightly colored spinning disks on electrical lines near poles (McIvor et al., 2012) among other methods. Overall, other than possible bird predation differences between sites, we did not find significant effects of oil operations on *G. sila* populations relative to home ranges or movements.

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APPENDIX

APPENDIX TABLE 1. Fates of Blunt-nosed Leopard Lizards (*Gambelia sila*) that were predated or otherwise died or their collars were found on the ground or in a burrow at the oil field site on the Lokern Natural Area, Kern County, California, 2015–2016.

Year	Sex	ID	Date	Fate	Notes
2015	M	4.169	30 April	Unknown	Radio not recovered; in burrow
2015	F	4.095	1 May	Bird predation?	Radio under power pole
2015	F	4.283	4 May	Unknown	Radio not recovered; in burrow
2015	F	4.198	18 May	Bird predation?	Radio in shrub
2015	F	4.021	18 May	Unknown	Lost radio signal
2015	M	4.498	24 May	Dead on ground	Inside exclusion fence
2015	M	4.146	25 May	Bird predation?	Radio on wooden post
2015	M	4.206	4 June	Red-tailed Hawk predation	Radio recovered from nest on power pole
2015	M	4.344	4 June	Red-tailed Hawk predation	Radio recovered from nest on power pole
2015	M	4.832	8 June	Unknown	Lost radio signal
2015	F	3.067	10 June	Unknown	Radio not recovered; in burrow
2015	M	4.408	15 July	Unknown	Collar intact on ground
2015	M	4.531	15 July	Snake predation?	Radio in burrow; digested
2015	F	4.746	15 July	Unknown	Collar intact on ground
2016	M	4.109	23 May	Unknown	Collar intact on ground
2016	F	6.167	25 May	Bird predation?	Radio under power pole
2016	M	4.647	30 May	Dead on ground	
2016	F	4.205	1 June	Unknown	Lost radio signal
2016	F	4.282	13 June	Unknown	Radio not recovered; in burrow
2016	F	3.616	16 June	Unknown	Radio recovered from ant nest
2016	M	4.005	17 June	Eaten by rattlesnake	Signal from inside rattlesnake

Abbreviation: ID = indentification number (from radio frequency).

Appendix Table 2. Fates of Blunt-nosed Leopard Lizards (*Gambelia sila*) that were predated or otherwise died or their collars were found on the ground or in a burrow at the control site at the Lokern Natural Area, Kern County, California, 2015–2016. In notes, Radio in burrow; digested means that the radio transmitter and collar had passed through the digestive system of an animal (see Germano et al., 2015).

Year	Sex	ID	Date	Fate	Notes
2015	M	4.021	5 May	Long-nosed Snake predation	See Germano & Saslaw, 2015
2015	F	4.296	18 June	Unknown	Collar intact on ground
2015	M	4.683	19 June	Unknown	Collar intact on ground
2015	M	4.980	2 July	Unknown	Radio not recovered; in burrow
2015	F	4.198	2 July	Unknown	Radio not recovered; in burrow
2015	F	4.233	2 July	Unknown	Radio not recovered; in burrow
2015	F	4.783	9 July	Unknown	Collar intact on ground
2015	M	4.095	13 July	Snake predation?	Radio in burrow; digested
2015	F	4.558	13 July	Unknown	Collar intact on ground
2015	M	4.498	13 July	Unknown	Collar apart 150 cm inside burrow
2016	M	5.401	20 May	Unknown	Lost radio signal
2016	F	4.508	27 May	Unknown	Collar apart on ground
2016	M	4.260	7 June	Snake predation?	Radio in burrow; digested
2016	F	4.531	5 July	Unknown	Collar clean and intact inside burrow
2016	M	4.109	8 July	Unknown	Collar intact on ground

Abbreviation: ID = indentification number (from radio frequency).