KANGAROO RAT POPULATION RESPONSE TO SEISMIC SURVEYS FOR HYDROCARBON RESERVES

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EXECUTIVE SUMMARY

"Seismic surveys" are a method used to locate commercially producible deposits of crude oil and natural gas. These surveys entail generating energy waves that reflect off of subterranean strata and return to the surface where they are recorded and interpreted. In the southern San Joaquin Valley of California, a region rich in hydrocarbon deposits, the 2 common methods of creating these energy waves include detonating buried explosive charges ("shot-hole" method) and generating strong ground-penetrating vibrations ("vibroseis" method). However, this region also supports a number of rare and endangered species including several endemic species of kangaroo rats (*Dipodomys spp.*). We investigated the effects of a seismic survey on kangaroo rats, including 2 rare species, the giant kangaroo rat (*D. ingens*) and the short-nosed kangaroo rat (*D. nitratoides brevinasus*), to determine whether seismic survey activities reduced kangaroo rat abundance, survival, or condition. In 2011, 18 study plots were established: 8 subjected to shot-holes, 6 subjected to vibroseis, and 8 controls with no energy source activities. A live-trap grid consisting of 30 traps was established on each plot, and kangaroo rats were captured and marked for 4 consecutive nights during trapping sessions 1-2 weeks prior to the seismic survey (pre-survey), 1-2 weeks after the survey (post-survey), and 5 months after the survey (long-term). Based on capture rates of unique individuals, abundance was similar among shot-hole, vibroseis, and control plots in each of the trapping sessions. Based on recaptures of marked individuals from previous sessions, survival was similar among treatments. Based on mass measurements, condition was similar among treatments. We did not detect adverse impacts to kangaroo rats from a seismic survey. At least in part, the lack of impacts detected may have been attributable to mitigation measures implemented to avoid or reduce adverse effects. These measures included restricting vibroseis trucks to existing roads, limiting off-road vehicle activity to small tractor-mounted drilling rigs with balloon tires, and attempting to avoid all kangaroo rat burrows by at least 10 m. Similar measures are recommended for any future seismic surveys in this region and elsewhere when sensitive burrowing species may be present.

INTRODUCTION

Exploration for new oil and gas deposits commonly is conducted using geophysical, or seismic, surveys. In areas with potential hydrocarbon resources, these surveys are conducted by generating energy waves that reflect off of subterranean strata and return to the surface where they are recorded using geophones. The resulting data then are interpreted to identify oil and gas deposits (Milligan 2004). Two common methods of creating these energy waves include detonating buried explosive charges ("shot-hole" method) and generating strong ground-penetrating vibrations ("vibroseis" method) (Milligan 2004).

The effects of the drilling and hydrocarbon extraction activities on wildlife have been well documented (Flickinger 1981, Kaplan et al. 1996, Lyon and Anderson 2003, Ingelfinger and Anderson 2004, Trail 2006, Ramirez 2010). Also, the effects of seismic exploration activities on large mammals have received some attention (Hook 1986, Joslin 1986, Reynolds et al. 1987, McClellan and Shackleton 1989, Blix and Lentfer 1992, Bradshaw et al. 1997). However, the effects of seismic surveys on smaller wildlife, particularly on semi-fossorial species, are virtually unstudied. The southern San Joaquin Valley in central California is a major hydrocarbon production region. This region also supports a number of rare and endangered species (U.S. Fish and Wildlife Service 1998, Germano et al. 2011), including several endemic species of kangaroo rats (*Dipodomys spp.*). These species include the giant kangaroo rat (*D. ingens*; Federal Endangered, California Endangered), Tipton kangaroo rat (*D. nitratoides nitratoides*; Federal Endangered, California Endangered), and short-nosed kangaroo rat (*D. n. brevinasus*; Federal Species of Concern, California Species of Special Concern). Another species, the Heermann's kangaroo rat (*D. heemanni*), is widespread and abundant, and is an important prey item for endangered San Joaquin kit foxes (*Vulpes macrotis mutica*; Federal Endangered, California Threatened) (Nelson et al. 2007). Kangaroo rat burrows also provide important refugia for blunt-nosed leopard lizards (*Gambelia sila*; Federal Endangered, California Endangered) (U.S. Fish and Wildlife Service 1998, Davidson et al. 2008). The Lokern Natural Area is considered critical for the conservation and recovery of these listed species (U.S. Fish and Wildlife Service 1998).

Potential adverse impacts to kangaroo rats from seismic surveys could include direct mortality or impaired fitness resulting in reduced survival or reproduction, any or all of which could reduce population sizes. Kangaroo rats use relatively shallow burrows (Culbertson 1946, Germano and Rhodehamel 1995) that are vulnerable to collapse from seismic survey activities. Kangaroo rats also have extremely large auditory bullae (Lay 1993) that might be sensitive to intense energy waves (e.g., subterranean explosions, ground-penetrating vibrations) produced during seismic surveys. Hearing impairment potentially could reduce predator detection capacity or intraspecific communication, thereby reducing survival or reproductive success.

The goal of this study was to assess the effects of a seismic survey on kangaroo rats, including 2 rare species. Specific objectives were to determine whether seismic survey activities reduced kangaroo rat abundance, survival, or condition.

STUDY AREA

This study was conducted in the Lokern Natural Area (LNA) in western Kern County, California (Fig. 1). The LNA encompasses about 17,800 ha (44,000 ac) at an elevation of 122 -200 m (400-660 ft), and lies within the boundaries of the San Joaquin Desert (Germano et al. 2011). The region has an arid Mediterranean climate with hot, dry summers and cool, wet winters (Dallman 1998). At Buttonwillow 13.5 km east of the study area, average high temperatures in August are 35.8 C and lows are 17.4 C, and average highs in January are 13.0 C and lows were 1.1 C (World Climate 2010). Average yearly rainfall at Buttonwillow is 169 mm (6.7 in; 20-yr average; Buttonwillow Water Storage District, unpublished data), with virtually no rain falling from early April through October.

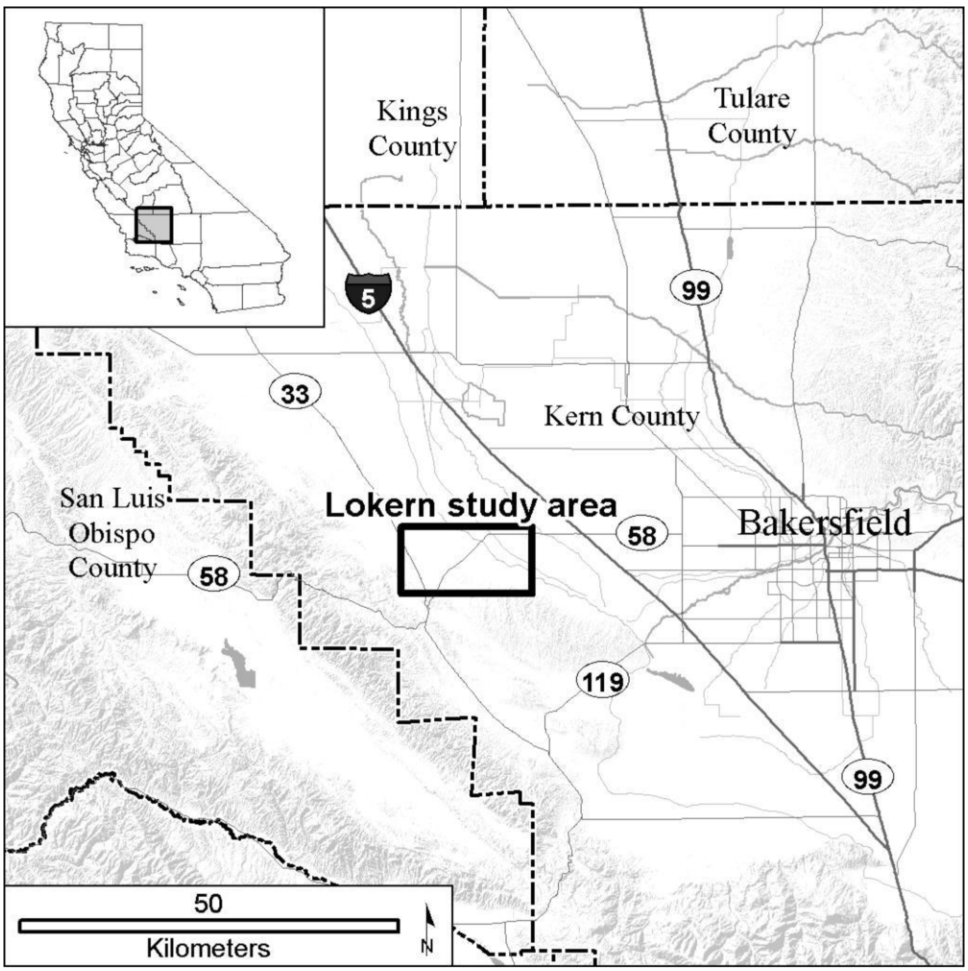

Figure 1. Study site location in the Lokern Natural Area, Kern County, California.

Our study area encompassed ca. 1,000 ha (2,500 ac) in the central portion of the LNA. The area was a gently sloping (2–5%) alluvial plain with soils classified as Kimberlina sandy loam and Kimberlina gravelly sandy loams, which are derived mostly from granitic and sedimentary rock (Soil Conservation Service 1988). The vegetation was a mosaic of arid shrubland and annual grassland. The predominant natural community was Valley Saltbush Scrub, as defined by Holland (1986). This community is characterized by open shrublands with a forb understory comprised of annual plants representative of Nonnative

Grassland (Holland 1986). Common shrubs on the plots included desert saltbush (*Atriplex polycarpa*), spiny saltbush (*A.spinifera*), and common herbaceous plants included red-stemmed filaree (*Erodium cicutarium*), red brome (*Bromus madritensis* ssp. *rubens*), Arabian grass (*Schismus arabicus*), layia (*Layia pentachaeta*), and tansy-leaved phacelia (*Phacelia tenacetifolia*).

METHODS

This seismic survey, referred to as the Cymric survey, covered ca. 11,750 ha (ca. 29,000 ac). Two energy sources were used to generate seismic waves: explosive charges placed down in "shot-holes" and vibrations produced by vibroseis vehicles. Shot-holes were created with small drill rigs mounted on small tractors with balloon tires. Shot-holes were spaced at 33-m (110-ft) intervals along lines spaced 200 m (660 ft) apart, and were 15 m (50 ft) deep. A 5-kg charge of pentolite was placed down in each shot-hole. Lines of shot-holes were detonated in a sequential manner across the survey area. Vibroseis was conducted along selected dirt roads in the survey area. At 33-m intervals, 4 vibroseis trucks traveling in tandem simultaneously produced high-intensity ground-penetrating vibrations for ca. 16 sec. To record seismic energy returning to the surface from the detonations and vibrations, geophones were placed on the ground in 33-m intervals along lines spaced 200 m apart. Geophones were deployed on foot.

Numerous mitigation measures were implemented during the seismic survey to reduce environmental impacts. Biologists conducted surveys throughout the project site to locate sensitive resources (e.g., kit fox dens, giant kangaroo rat colonies). All workers received environmental training prior to conducting field work. Except for the small drilling rigs, all vehicles were restricted to roads. A small portable drilling rig was transported by helicopter to more remote locations. Equipment also was delivered to field sites by helicopter to reduce vehicle traffic. To the extent practicable, shot-holes and geophones were placed ≥ 10 m from burrows and dens, and damage to shrubs was avoided. Biologists accompanied all seismic survey teams in the field to assist in avoiding impacts to sensitive biological resources (e.g., burrows, shrubs).

To assess kangaroo rat abundance, survival, and relative condition, 18 monitoring plots were established. Eight plots were located in areas with shot-holes, 6 plots were located along roads were vibroseis was conducted, and 4 control plots were located in areas ca. 0.3-0.5 km from the nearest shot-hole or vibroseis point. At each plot, a trapping grid was established consisting of 3 parallel lines of 10 traps. The lines were spaced 20 m apart and traps were spaced at 15-m intervals along each line. On the shot-hole and vibroseis plots, the center line of traps was located directly along a shot-hole line or 1 m adjacent to a road where vibroseis was conducted.

One Sherman aluminum box trap (7.6 cm x 9.5 cm x 30.5 cm; H. B. Sherman Traps Inc., Tallahassee, FL) modified to prevent injury to kangaroo rat tails was placed at each trap station. Each trap was provisioned with a handful (ca. 20 ml) of millet seed for bait and an unbleached paper towel or wad of cotton batting for bedding and thermal insulation. Traps were opened near dusk and checked beginning just before sunrise the next morning. All rodents captured were identified to species and marked ventrally with a non-toxic felt-tipped marker to identify recaptured animals within a trapping session. For kangaroo rats, we determined sex, estimated age (adult or juvenile based on size and pelage), measured mass at first capture each session, and applied a uniquely numbered tag (Model 1005 size 1 monel; National Band and Tag Co., Newport, KY) in one ear.

On each plot, traps were operated for 4 consecutive nights during each of 3 trapping sessions. The “pre-survey” session was conducted in April 2011ca. 1-2 weeks prior to the seismic survey. The “post-survey” session was conducted in May 2011 ca. 1-2 weeks after the seismic survey. The “long-term” session was conducted in October 2011ca. 5 months after the seismic survey.

For each plot within each trapping session, kangaroo rat abundance was estimated by calculating the number of unique individuals captured per 100 trap-nights. Survival rates between trapping sessions were estimated by calculating the proportion of ear-tagged animals that were recaptured. Survival rates were calculated for the pre-survey/post-survey, pre-survey/long-term, and post-survey/long-term inter-sessions. Relative condition, based on mass measurements of adult kangaroo rats, was assessed by species and sex (kangaroo rats are sexually dimorphic with males being larger). For each trapping session, mean kangaroo rat abundance was compared among treatments (shot-hole, vibroseis, and control) using a one-way analysis of variance. Mean inter-session survival rates were compared between treatments using a one-way analysis of variance. Because the rates were expressed as proportions, an arcsin transformation was applied to the rates prior to analysis (Zar 1984). For each trapping session, mean mass for each species-sex cohort was compared among treatments using a one-way analysis of variance. P-values < 0.05 were considered significant. Abundance and mass were not compared between trapping sessions to control for natural seasonal variations in these life-history parameters.

RESULTS

Rodent species captured during live-trapping included giant kangaroo rats, short-nosed kangaroo rats, Heermann’s kangaroo rats, deer mice (*Peromyscus maniculatus*), San Joaquin antelope squirrels (*Ammospermophilus nelsoni*), and San Joaquin pocket mice (*Perognathus inornatus*). Deer mice, antelope squirrels, and pocket mice were infrequently captured, and these low capture rates precluded any quantitative analysis. Heermann’s kangaroo rats also were only infrequently captured. Data for this species were included in kangaroo rat abundance and survival estimates, but were insufficient to conduct mass comparisons.

Mean kangaroo rat capture rates did not differ significantly among shot-hole, vibroseis, and control plots during pre-survey ($F_{2,15} = 0.34$, $p = 0.72$), post-survey ($F_{2,15} = 1.22$, $p = 0.32$), and long-term ($F_{2,15} = 2.10$, $p = 0.16$) trapping sessions (Fig. 2). Mean proportions of recaptured kangaroo rats also did not differ significantly among shot-hole, vibroseis, and control plots for the pre-survey/post-survey ($F_{2,15} = 2.62$, $p = 0.11$), post-survey/long-term ($F_{2,15} = 1.89$, $p = 0.19$), and pre-survey/long-term ($F_{2,15} = 2.36$, $p = 0.13$) inter-sessions (Fig. 3). Mean mass of adult kangaroo rats did not differ significantly among shot-hole, vibroseis, and control plots during any of the trapping sessions for any of the species-sex cohorts (Table 1).

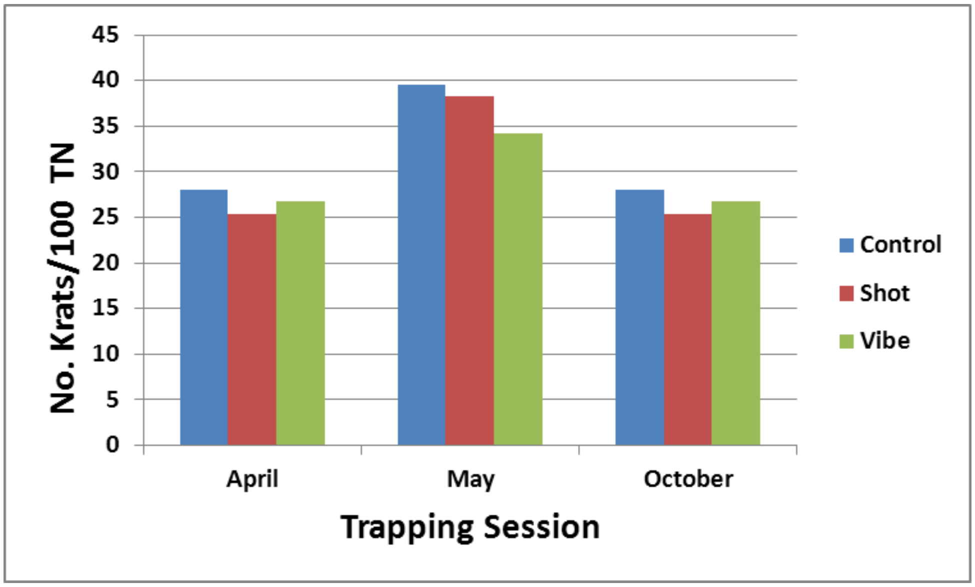

Figure 2. Mean numbers of unique kangaroo rats captured per 100 trap-nights on shot-hole ("Shot"), vibroseis ("Vibe"), and control plots 2 weeks before (April), 2 weeks after (May), and 5 months after (October) a seismic survey conducted in the Lokern Natural Area, Kern County, California in 2011.

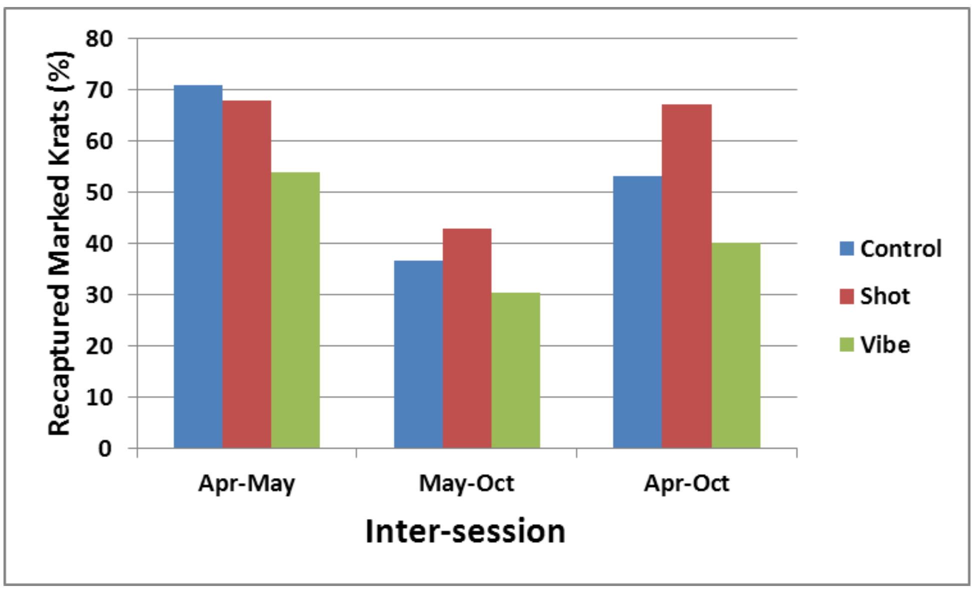

Figure 3. Mean proportions of marked kangaroo rats recaptured on shot-hole ("Shot"), vibroseis ("Vibe"), and control plots in the Lokern Natural Area, Kern County, California in 2011. Apr = 2 weeks pre-seismic survey; May = 2 weeks post-seismic survey; Oct = 5 months post-seismic survey.

Table 1. Mean mass for adult kangaroo rats by species and sex for 3 trapping sessions on seismic survey study plots in the Lokern Natural Area, Kern County, California in 2011.

Kangaroo rat species	Sex	Trapping session[a]	Mean (± SE) mass: Control plots	Shot-hole plots	Vibroseis plots	$F_{(df)}$	p
Giant	M	Apr	117.5 ± 3.3	124.9 ± 2.1	120.8 ± 2.5	$2.00_{(2,112)}$	0.14
	M	May	123.3 ± 2.8	127.1 ± 1.8	126.5 ± 2.3	$0.65_{(2,104)}$	0.53
	M	Oct	134.9 ± 2.4	132.4 ± 1.4	129.2 ± 2.2	$1.59_{(2,130)}$	0.21
	F	Apr	120.6 ± 3.6	116.7 ± 1.9	111.3 ± 2.4	$2.78_{(2,110)}$	0.07
	F	May	119.3 ± 3.4	119.5 ± 2.1	120.6 ± 2.6	$0.06_{(2,123)}$	0.94
	F	Oct	123.9 ± 3.4	124.1 ± 2.0	119.2 ± 2.8	$1.10_{(2,113)}$	0.34
Short-nosed	M	Apr	41.1± 1.5	42.3 ± 1.5	44.9 ± 1.6	$1.51_{(2,99)}$	0.23
	M	May	36.4 ± 3.4	41.6 ± 3.1	44.9 ± 3.6	$1.52_{(2,65)}$	0.23
	M	Oct	38.2 ± 2.5	42.9 ± 2.4	36.0 ± 2.7	$1.92_{(2,115)}$	0.15
	F	Apr	37.2 ± 2.1	39.6 ± 1.6	41.9 ± 1.7	$1.64_{(2,105)}$	0.20
	F	May	37.7 ± 3.0	41.5 ± 2.2	43.4 ± 2.8	$0.97_{(2,80)}$	0.38
	F	Oct	35.4 ± 1.8	37.8 ± 1.5	34.5 ± 1.6	$1.17_{(2,81)}$	0.32

[a] Apr = 2 weeks pre-seismic survey; May = 2 weeks post-seismic survey; Oct = 5 months post-seismic survey.

DISCUSSION

The methodologies used in the Cymric seismic survey were typical of those commonly employed in seismic surveys conducted in the oil and gas production areas in the San Joaquin Valley of California. Thus, the environmental impacts associated with this survey were considered to be representative of contemporary regional surveys.

We did not detect any short-term or long-term adverse impacts to kangaroo rat abundance, survival, or condition. Kangaroo rat abundance was similar among shot-hole, vibroseis, and control plots prior to the survey, and also was similar among plots 2 weeks and 5 months after the survey. Furthermore, to confirm that kangaroo rat numbers were adequate to assess effects, preliminary trapping was conducted in November 2010 when the shot-hole and control plots were established. Kangaroo rat abundance was not different between shot-hole and control plots (L. Saslaw, U.S. Bureau of Land Management, unpublished data), and the similar findings during the April 2011 trapping session suggest that preparations for the survey (e.g., shot-hole drilling, geophone deployment) also had no detectable impacts.

Likewise, kangaroo rat survival, as measured by recaptures of marked individuals, did not appear to be adversely impacted by the seismic survey. Although there were no statistical differences among treatments, mean recapture rates were noticeably lower for the vibroseis plots. One of the roads used by the vibroseis trucks ran under a high-tension powerline, and 2 of the vibroseis plots were located along this road. During the study, we noticed high use of the powerline towers by raptors, particularly red-tailed hawks (*Buteo jamaicensis*), and ravens (*Corvus corax*). We also occasionally found fresh kangaroo rat remains along the road, possibly resulting from avian predation. Although kangaroo rat abundance did not appear to be affected, predation by avian predators may have resulted in higher population turnover rates on these 2 plots. Indeed, when we removed these 2 plots from our analysis, the mean recapture rates for vibroseis plots for all sampling periods were even more similar to rates for the shot-hole and control plots.

Kangaroo rat condition, as measured by mass, also did not appear to be adversely affected by the seismic survey. This was true for both giant and short-nosed kangaroo rats, and for both males and females of each species. Reduced condition (i.e., lower mass) might have been observed on shot-hole or vibroseis plots if seismic activities had disrupted physiological processes or caused physical impairments. If such effects had occurred, reduced mass would most likely have been noticeable in the post-survey trapping session (May 2011), but no differences in mass were detected during this or any other trapping session.

Reductions in abundance, survival, or condition associated with the seismic survey potentially could have resulted from direct mortality due to energy sources (e.g., shot-hole explosive detonations, intense vibroseis vibrations) or burrow collapse, or from physiological or physical impairment that interfered with foraging or predator avoidance. If such impacts occurred, they were not of a sufficient magnitude to produce detectable impacts to the population attributes we monitored. Instances of accidental burrow collapse were recorded by biological monitors during the survey, but these occurrences were very infrequent.

Noise during seismic surveys is a concern. Several kangaroo rat species use foot-drumming to communicate identity and to advertise territory (Randall 1984; 1989; 1997). Giant kangaroo rats may use their acute low frequency hearing to detect and interpret foot-drumming signals from conspecifics and to avoid predation (Webster and Webster 1980; Randall 1984). Brattstrom and Bondello (1983) reported temporary hearing impairment in kangaroo rats that were subjected to simulated off-road vehicle noise for 500 sec. In the Cymric seismic survey, the longest a kangaroo rat conceivably would have been exposed to nearby loud noise would have been ca. 16 sec during vibroseis operations.

In a previous pilot project in the Lokern Natural Area, a seismic survey was simulated to assess the effects of shot-hole detonations and vibroseis vibrations on kangaroo rats (Fiehler et al. submitted). Only 10 shot-holes and 10 vibroseis source points were used and all were located along the edges of existing dirt roads. Also, only 1 vibroseis truck was used instead of 4. An avoidance buffer was not employed around burrows and some shot-holes and vibroseis points were within 1 or 2 m of kangaroo rat burrows. Kangaroo rat abundance was monitored by live-trapping < 1 week before the simulated survey, < 1 week after the survey, and again 4 weeks after the survey. No effect on kangaroo rat abundance was detected (Fiehler et al. submitted). Furthermore, 10 active kangaroo burrows located 2-250 m from shot-holes or vibroseis points were monitored during the simulated survey and none collapsed or exhibited any sign of damage (Burgus 2008).

Environmental monitoring following previous seismic surveys that employed vibroseis methods in the southern San Joaquin Valley revealed a decline in the number of small mammal burrows within vibroseis corridors immediately following a survey, but no long-term effects on the number of active burrows (Tabor et al. 1995). However, vibroseis vehicles were operating off-road during these seismic surveys, unlike in the current survey. In northern Utah, Wilson (2011) reported that some entrances of pygmy rabbit (*Brachylagus idahoensis*) burrows were collapsed when directly contacted by vibroseis pads or truck tires and that some minor damage occurred to burrows within 25 m of vibroseis lines. However, burrows >25 m from vibroseis lines exhibited no damage, and no radio-collared rabbits were displaced from home ranges by seismic survey activities. Menkens and Anderson (1985) reported that vibroseis activity did not impact the physical living space, vegetation structure, or population dynamics of white-tailed prairie dogs (*Cynomys leucurus*) in Wyoming.

The lack of detectable adverse effects in this study likely was at least partly attributable to the impact avoidance measures implemented during the seismic survey. In particular, the restriction of off-road vehicular traffic to relatively small, light-weight tractor-mounted drilling rigs with balloon tires and the requirement to avoid burrows by 10 m probably were the measures that most limited impacts to kangaroo rat populations. Similarly, Wilson (2011) concluded that 15-m (50-ft) buffers around pygmy rabbit burrows were adequate to avoid impacts. Whether adverse effects would have been detected in the current study in the absence of mitigation measures is unknown. However, a conservative approach was adopted and the such measures were implemented because of the presence of sensitive species, the lack of information on impacts from previous seismic surveys, and the potential for such impacts to occur. This approach appears to have been successful, and the implementation of similar mitigation measures is recommended for any future seismic surveys in this region and elsewhere when sensitive burrowing species may be present.

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