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STATEMENT OF JOURNAL INTENT

Western Wildlife is the revised journal of the *Transactions of the Western Section of The Wildlife Society*. It was formed to provide a more immediate outlet for wildlife studies than was possible by publishing the traditional paper Transactions. *Western Wildlife* is an open-access, peer-reviewed journal that publishes original research, reviews, perspectives, and correspondence on the ecology, natural history, management, and conservation biology of animals. All taxa will be considered, although species or groups other than vertebrates must be of interest to a wildlife audience. The editor will decide which topics will be considered. Geographic coverage is western North America (to Hawaii). Studies outside this general area will be considered on a case by case basis. The journal will continue to cover traditional wildlife species and management topics related to these species, but the coverage is broadened to reflect the need for information on species and topics that are affected by human growth and development. The journal also will

publish basic biology of species if the data are robust and soundly collected. Papers on new techniques and methods are welcome. Surveys and population monitoring data are within the scope of the journal, especially if the groups studied are of conservation concern.

Papers accepted for publication will be converted to Portable Document Format (PDF) files and uploaded to the web site of the journal within days of acceptance. At the end of each year, we will produce a PDF that includes all papers published in a calendar year, as well as news of the Society. *Western Wildlife* is the official journal of the Western Section of The Wildlife Society, and we hope this re-imagined journal fulfills the needs and desires of wildlife biologists in western North American.

David J. Germano, Editor
Brian L. Cypher, Associate Editor
Howard O. Clark, Jr., Production Manager

SEASONAL SPATIAL PATTERNS OF TWO SYMPATRIC FROGS: CALIFORNIA RED-LEGGED FROG AND AMERICAN BULLFROG

DAVID G. COOK¹ AND ANDREA F. CURRYLOW²

¹Environmental Resources, Sonoma County Water Agency, 404 Aviation Boulevard, Santa Rosa, California 95403, USA,
e-mail: dcook@scwa.ca.gov

²Purdue University, Department of Forestry and Natural Resources, 715 W. State Street,
West Lafayette, Indiana 47907, USA

Abstract.—The introduced American Bullfrog (*Lithobates catesbeianus*) has been implicated in the decline of native amphibians. Bullfrogs have become widespread in California and are a threat to the native California Red-legged Frog (*Rana draytonii*). The two species are ecologically similar, and the bullfrog is a predator to the red-legged frog that may influence its habitat use patterns. We analyzed the spatial and temporal locations and body sizes of both frog species within a large, fishless seasonal marsh during 1996. Overall, California Red-legged frogs and American Bullfrogs showed similar spatial distributions; however, seasonal changes were observed. California Red-legged Frogs increased their mean distances between conspecifics in the marsh seasonally from winter through summer while frog numbers decreased. In contrast, bullfrogs showed the opposite pattern where mean distances between conspecifics decreased over time, but the abundance of bullfrogs increased from winter through summer. During each season the mean distances between red-legged frogs and bullfrogs was greater compared to distances to their respective conspecifics, except for spring when bullfrog conspecifics were slightly more distant than red-legged to bullfrog distances. American Bullfrogs were significantly larger than California Red-legged Frogs at our site. Our findings suggest that frog abundance, which is strongly influenced by breeding behavior, changing habitats, and possibly predation risk of red-legged frogs by bullfrogs are the dominant factors driving the spatial patterns observation at Ledson Marsh. Also, once winter breeding was completed, California Red-legged Frogs seemed to avoid predation by American Bullfrogs by spatial separation within the marsh or by leaving the marsh altogether.

Key Words.—amphibians; distribution; *Lithobates catesbeianus*; predator avoidance; *Rana draytonii*; size

INTRODUCTION

Unlike most birds and reptiles, ecologically similar species of amphibians have been found to overlap spatially more often than expected at random (Hofer et al. 2004). This spatial overlap is likely due to limited resources such as breeding ponds (following the resource tracking hypothesis), suggesting that resource effects override direct interspecific competition or predation (Hofer et al. 2004). However, ecologically similar species should spatially partition the use of these resources at a microhabitat scale if predation, in fact, influences amphibian assemblages (Sredl and Collins 1992).

The American Bullfrog (*Lithobates catesbeianus* [= *Rana catesbeiana*]) is native to eastern North America and are among the largest amphibians on the continent (Bury and Whelan 1984). Adult bullfrogs are a gape-limited, sit-and-wait predator that can take relatively large prey (Bury and Whelan 1984). Within their native range, bullfrogs play an important role in structuring amphibian assemblages through intraspecific predation and competition (Werner 1994; Hecnar and M'Closkey 1997).

In its introduced range, the American Bullfrog has been implicated in the decline and extirpation of many native ranid frogs (Licht 1974; Nussbaum et al. 1983; Hayes and Jennings 1986; Kiesecker and Blaustein 1997; Kupferberg 1997; Rosen and Schwalbe 2002) and is an invasive species in the western United States (Meshaka 2005). In California, American Bullfrogs were first in-

troduced in 1896 (Jennings and Hayes 1985) and now occur throughout the state except in desert and alpine areas. American Bullfrogs are known to prey on a variety of native aquatic and terrestrial vertebrate species in their introduced range (Bury and Whelan 1984; Wu et al. 2005; Govindarajulu et al. 2006), including the California Red-legged Frog (*Rana draytonii*) federally listed as threatened (Moyle 1973; Cook and Jennings 2001; Cook 2002). The California Red-legged Frog and American Bullfrog are ecologically similar. Both frog species are highly aquatic and mainly nocturnal (Lannoo 2005; Stebbins 2003; Storer 1925; pers. obs.). Maintaining endangered species populations where the invasive bullfrog is established is challenging, but is imperative for conservation efforts.

Seasonality of available habitat and animal activity play important roles in spatio-temporal frog assemblages (Kopp and Eterovick 2006) and may contribute to the persistence of red-legged frogs despite the predatory effects of the larger bullfrogs (Adams et al. 2011). Nonetheless, seasonal variation in activity of the California Red-legged Frog (e.g. breeding phenology) along with spatial distributions has not been assessed in the presence of American Bullfrogs. Complex interactions between pond breeding species are often difficult to discern, but microcosm experiments have elucidated some of these interactions (Luckinbill 1973; Morin 1986; Wilbur 1987; Kiesecker et al. 1998; Hero et al. 2001). However, few studies have examined this in a natural field setting. The

study of American Bullfrogs and prey interactions has been confounded by the presence of predatory fish and habitat alteration (Adams 1999; Kiesecker et al. 2001).

Our study was undertaken at a large, fishless marsh with stable wetland habitats. We analyzed body size and the spatial and temporal patterns of American Bullfrogs and California Red-legged Frogs to determine spatial partitioning and how it may be attributable to physical and biological factors, such as predation risk. Based on the size and immobile feeding behavior of American Bullfrogs, we predict that predation risk is related to relative abundances of both frog species and the proximity of individual frogs.

METHODS

Study area.—Ledson Marsh is a seasonal wetland encompassing approximately 11 ha when fully hydrated, located in Annadel State Park, Sonoma County, California. It lies at an elevation of 476 m on a hilly plateau surrounded by native grassland, oak woodland (*Quercus* spp.), and Douglas-fir (*Pseudotsuga menziesii*) forest. Ledson Marsh was created in 1930 by the construction of a small earthen dam and has had established marsh vegetation for over half a century. Dominant plants include California Bulrush (*Scirpus californicus*), Broad-leaved Cattail (*Typha latifolia*), Spikerush (*Eleocharis macrostachya*), and Smartweed (*Polygonum hydropiperoides*). During winter the marsh fills to a maximum depth of approximately 1.5 m. Water levels slowly recede during spring and summer and the marsh is typically completely dry in early fall, a pattern likely prevalent under natural conditions prior to widespread manipulation of California's hydrology during the past century. Red-legged frog breeding occurs during winter whereas the bullfrog breeding period is longer, occurring in spring and summer.

Data collection.—We collected field data in 1996 from winter until the marsh dried in the fall (17 January to 23 September). Surveys were performed at one to four week intervals depending on frog activity. We conducted nocturnal frog surveys with headlamps by walking through the marsh or by poling an inflatable boat. We identified frogs to species in the water and we estimated their sizes. When possible, we hand-captured frogs and we recorded snout-vent length (SVL). We grouped all frogs either observed in situ or captured into three size categories based on SVL: small (50–100 mm), medium (101–150 mm), and large (> 150 mm [American Bullfrog only]). We classified season based on observed frog activity patterns: winter (17 January to 10 March), spring (11 March to 9 June), summer (10 June to 14 August), and fall (15 August to 23 September). We recorded frog and egg mass locations with a Trimble Navigation Explorer GPS. We rectified coordinates using a base station resulting in GPS accuracy ≤ 2 m.

Data analysis.—To compare frog size data, we used a Pearson's chi-square test using the aforementioned size categories for both species. We used the frog location data to create point layers in ArcGIS Desktop 9 (version 9.3.1; ESRI 2009) then used Hawth's Analysis Tools (Beyer 2004) to calculate distance metrics from those point layers. We measured Euclidian distances between each individual frog and the nearest red-legged frog and bullfrog for each survey visit. To detect differences in Euclidian distances within groups by season and in inter- and intra-specific mean distances over all seasons combined, we used full factorial generalized linear mixed models with unbounded variance components in JMP (SAS 2008). We used survey visit, season, species pair, and their interactions as fixed effects and randomized individuals nested in survey visit. Hence, we treated each survey visit as an independent survey and we accounted for repeated measures of any individual in the model. We chose the more conservative method of a repeated-measures technique here because we could not rule out the possibility of re-recording the same individuals each survey visit. To detect significant differences across effect levels, we used post-hoc Tukey-Kramer pairwise comparisons or Student's *t*-tests (for single comparisons) where appropriate. For all tests, $\alpha = 0.05$.

RESULTS

Frog sizes.—During 22 sampling nights at Ledson Marsh, we estimated the sizes of 202 California Red-legged Frogs and 113 American Bullfrogs (Table 1). American Bullfrogs were significantly larger than California Red-legged Frogs across all study seasons ($\chi^2 = 136.05$, $df = 131$, $P < 0.001$). American Bullfrogs were predominantly of adult size, with 54% > 150 mm SVL. In comparison, California Red-legged Frogs were composed entirely of small and medium-sized frogs. The largest frog we recorded at Ledson Marsh was an American Bullfrog at 210 mm SVL, whereas the largest California Red-legged Frog we found was little more than half this size at 135 mm SVL. In comparison, the maximum reported size of an American Bullfrog size is about 200 mm SVL (Bury and Whelan 1984) and 138 mm SVL for the California Red-legged Frog (Hayes and Miyamoto 1984).

Seasonal frog patterns and habitat.—Overall, both California Red-legged Frogs and American Bullfrogs showed similar spatial distributions under changing seasonal habitats at Ledson Marsh (Fig. 1). The exception was during winter when the marsh was inundated and California Red-legged Frogs were aggregated mainly in two breeding areas along the southern edge of the marsh where most eggs were deposited (Fig. 1-A). Although fewer in number, American Bullfrogs were located peripherally around the marsh. Very few frogs of either species were in the deep, open water at the interior of the

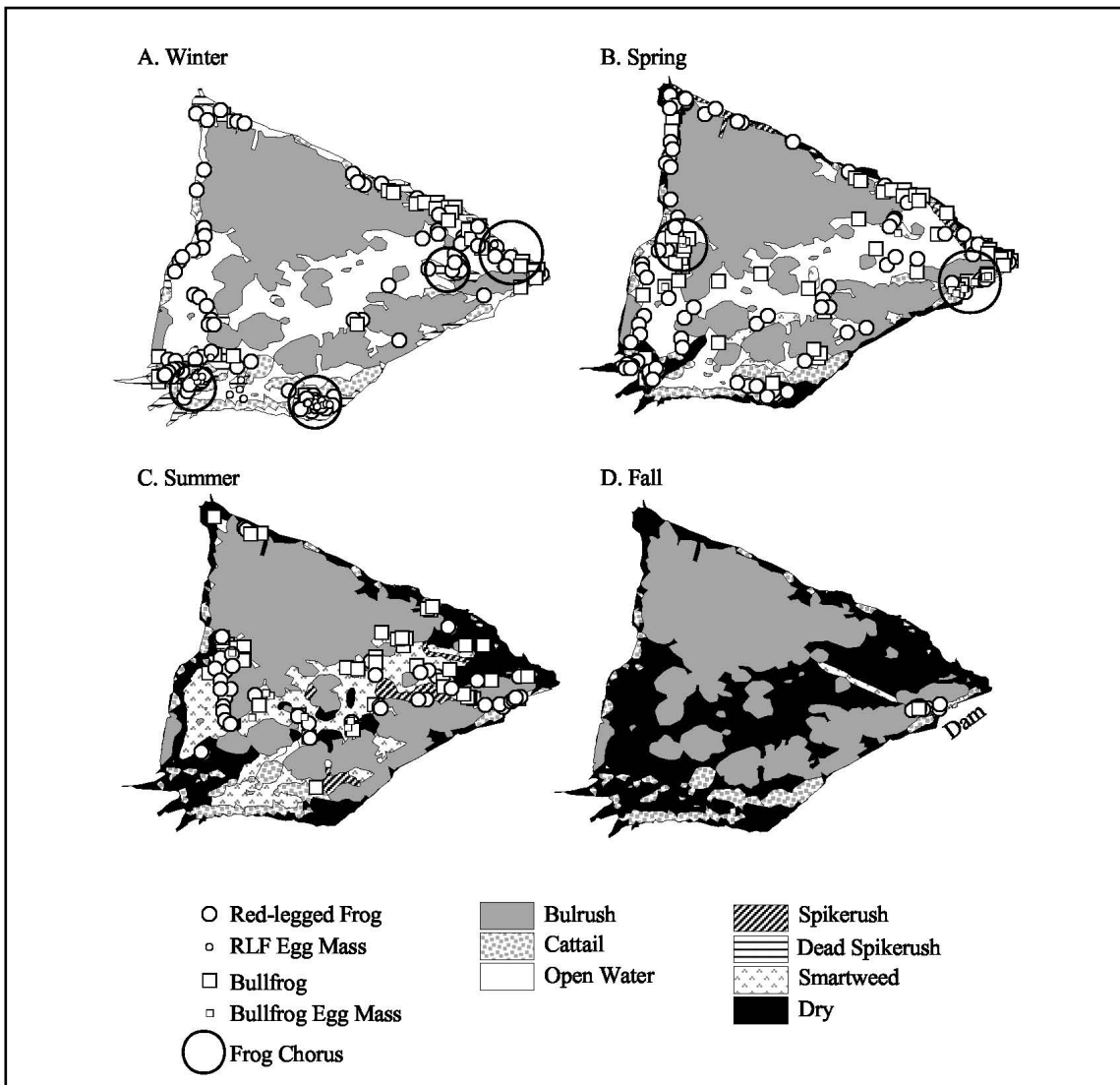


Figure 1. Seasonal distribution of California Red-legged Frogs (*Rana draytonii*) and American Bullfrogs (*Lithobates catesbeianus*), egg masses, breeding chorus', and habitats at Ledson Marsh in Sonoma County, California, in 1996. During fall season most cattail and bulrush contained wet soils and limited standing water. North is up and the maximum width of the marsh is 515 m.

marsh. American Bullfrogs began to breed in the spring when the water level began to decrease. At this time both frog species were distributed along the perimeter of the marsh and some occupied the interior (Fig. 1-B). During summer, the shoreline had substantially receded and both frog species used the marsh interior (Fig. 1-C). During fall most of the marsh was dry and the few active frogs of either species were clustered in a small wetted area near the dam (Fig. 1-D).

Spatial distribution and distances between individual frogs.—Overall, the distances between frog conspecifics were similar to the abundance of frogs observed at the marsh, except during fall (Tables 2 and 3). California Red-legged Frogs increased their mean distances between conspecifics in the marsh seasonally from winter through summer while frog numbers decreased. Also, the

wetted surface area of the marsh decreased during this period. Only during fall, when the marsh was nearly dry and red-legged frog abundance was low, did distances between California Red-legged Frogs decrease from the previous season. In contrast, American Bullfrogs showed the opposite pattern where mean distances between conspecifics decreased from winter through fall; however, the abundance of bullfrogs increased from winter through summer.

The annual mean distances of American Bullfrogs to conspecifics ($\bar{X}_{B:B} = 59.8$ m) was significantly less compared to red-legged frog to bullfrog distances ($\bar{X}_{R:B} = 86.8$ m; $F_{1,90} = 4.16, P = 0.044$). Also, the California Red-legged Frog to conspecific distances ($\bar{X}_{R:R} = 26.9$ m) compared to red-legged frog to bullfrog distances ($\bar{X}_{R:B} = 86.8$ m) for all seasons was significantly different ($F_{1,168} = 46.23, P < 0.001$). This indicates that overall there was

Table 1. Sample size (n) and sizes of California Red-legged Frogs (*Rana draytonii*) and American Bullfrogs (*Lithobates catesbeianus*) at Ledson Marsh in Sonoma County, California, in 1996. Size categories are from captured and observed frogs recorded during evening surveys from all seasons. The sizes of 22 California Red-legged Frogs and six American Bullfrogs were not recorded during field surveys.

Species	n	Size Category (SVL)		
		Small (50–100 mm)	Medium (101–150 mm)	Large (>150 mm)
California Red-legged Frog	202	36.1%	63.9%	0%
American Bullfrog	113	20.3%	25.7%	54.0%

Table 2. Season and number of surveys, number found, and abundances (frogs per survey) of California Red-legged Frogs (RLF; *Rana draytonii*) and American Bullfrogs (BF; *Lithobates catesbeianus*) at Ledson Marsh in Sonoma County, California, in 1996. Frogs were observed during evening spotlight surveys.

Season	Surveys	Number Found		Abundance	
		RLF	BF	RLF	BF
Winter	5	78	13	15.6	2.6
Spring	9	91	60	10.1	6.7
Summer	5	38	41	7.6	8.2
Fall	3	17	5	5.7	1.7
All	22	224	119	10.2	5.4

Table 3. Mean, standard deviation (s), minimum (Min), and maximum (Max) of relative distances between California Red-legged Frogs (*Rana draytonii*) and American Bullfrogs (*Lithobates catesbeianus*) at Ledson Marsh in Sonoma County, California, in 1996. Frog groupings for red-legged frog (R) and bullfrog (B) are listed by season. Frog groups within a season that share the same letter are not significantly different ($P > 0.05$).

	Mean (m)	s	Min	Max
Winter				
R:R	16.3a	25.5	2.47	155.0
R:B	176.9b	162.4	3.77	441.0
B:B	93.8b	138.4	6.67	329.0
Spring				
R:R	33.9a	41.7	1.6	258.0
R:B	58.3b	56.0	2.0	258.0
B:B	61.9b	111.0	5.6	453.0
Summer				
R:R	35.6a	31.2	2.2	110.0
R:B	57.9a	60.2	1.9	283.0
B:B	51.8a	57.0	2.9	248.0
Fall				
R:R	18.2a	39.5	2.4	170.0
R:B	30.1ab	44.1	2.9	208.0
B:B	8.4b	6.5	2.7	14.0

more spatial separation between California Red-legged Frogs and American Bullfrogs than to conspecifics of either species at the marsh.

The distance patterns between California Red-legged Frogs and American Bullfrogs differed during the four seasons studied (Table 3). During each season the mean distances between red-legged frogs and bullfrogs was greater compared to distances to their respective conspecifics, except for spring when American Bullfrog conspecifics were slightly more distant than red-legged to bullfrog distances. When comparing distances between frog groups (R:R, R:B, and B:B) within each season, significant differences were found between American Bullfrog conspecifics (B:B) and red-legged frogs conspecifics (R:R) during the winter, spring, and fall. Additionally, the distances between red-legged frogs and bullfrogs (R:B) were more distant than between red-legged frog conspecifics (R:R) during all seasons, but was significant only in winter and spring (Table 3).

DISCUSSION

There are several physical and biological factors that could be influencing spatial patterns of California Red-legged Frogs and American Bullfrogs at Ledson Marsh. Possible factors include competition, habitat and resource use, breeding and foraging behavior, and predation. Ecologically similar species, such as the California Red-legged Frog and American Bullfrog, should show spatial separation if one or more of these factors are present (Toft 1985; Cook and Jennings 2007). Also, the confounding indirect effects from predatory fish introductions or habitat alterations (Kiesecker and Blaustein 1997) are absent from Ledson Marsh, and therefore can be eliminated from further consideration.

Although competition for food resources may influence the distribution of California Red-legged Frogs and American Bullfrogs, it is unlikely that the high frog densities and resource limits necessary for competition to occur (Hayes and Jennings 1986) would be present at Ledson Marsh because of the productive, eutrophic marsh with an abundance of aquatic and semi-aquatic prey (pers. obs.; also see Cook and Jennings 2007).

Cook and Jennings (2007) compared habitat uses of California Red-legged Frogs and American Bullfrogs at Ledson Marsh during 1996. Their study emphasized the similarities of habitat use between frog species, but there was more separation in habitat use during winter than other seasons. We found a congruent spatial pattern where both frog species were most spatially separated during winter. However, this spatial separation between frog species continued into spring and fall even though their use of habitat overlapped (Cook and Jennings 2007). This suggests that habitat use cannot explain the spatial patterns between frog species at Ledson Marsh.

A possible explanation for the observed spatial patterns could be breeding behavior of frogs that affects their abundance and, in turn, the distances between frogs. Both California Red-legged Frogs and American Bullfrogs had their highest abundance and shortest conspecific distances during their respective breeding periods. The exception was during fall when the marsh was nearly dry and neither frog was breeding. Frogs clustered seasonally at breeding sites and formed a ring of frogs around the margins of the marsh that shrank with the receding shoreline. This suggests that frogs were not randomly distributed and frog abundances alone cannot entirely explain spatial patterns at Ledson Marsh.

Both American Bullfrogs and California Red-legged Frogs are opportunistic, gape-limited predators with similar diets (Lannoo 2005). Although breeding aggregates of California Red-legged Frogs can explain winter spatial patterns, the similar foraging behavior and habitat overlap of both frog species coupled with the contrasting spatial separation during spring and fall cannot entirely explain the observed spatial pattern of these frogs at Ledson Marsh during all seasons. Kiesecker et al. (2001) showed that native frogs have the ability to chemically detect American Bullfrogs and alter their habitat use and foraging behavior to avoid predators. Our spatial analysis suggests that California Red-legged Frogs may possess such ability and respond similarly. We found potential predation is lowest during the winter season when American Bullfrogs have the broadest spatial distribution and low abundances. However, when American Bullfrogs increased in numbers during the spring season, California Red-legged Frogs appeared to avoid American Bullfrogs by congregating with conspecifics, even though both frog species used similar microhabitats (Cook and Jennings 2007) and California Red-legged Frog breeding aggregations had dispersed.

Although predation may be reciprocal between frog species through ontogeny, size disparity suggests higher predation on California Red-legged Frogs by American Bullfrogs. Due to the seasonally fluctuating water levels at Ledson Marsh, American Bullfrog reproduction is minimal and most individuals apparently are adult immigrants (Cook and Jennings 2007; pers. obs.). Based on the size structure of frogs at Ledson Marsh, it is reasonable to conclude that California Red-legged Frogs of all sizes are vulnerable to predation by the predominantly large-sized American Bullfrog.

We conclude that frog abundance, which is strongly influenced by breeding behavior, changing habitats, and possibly predation risk of California Red-legged Frogs by American Bullfrogs are the dominant factors driving the spatial patterns observation at Ledson Marsh. Despite the lack of replication that would be seen in a long-term study over many years, the decrease we found in inter-specific distances and corresponding decrease in California Red-legged Frogs abundances at the marsh suggests

that once winter breeding is completed, red-legged frogs avoid predation from American Bullfrogs by distancing themselves spatially or by leaving the marsh altogether. Also, post-breeding California Red-legged Frogs that remain at the marsh have a relatively high exposure to American Bullfrog predation.

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DAVID G. COOK is a Wildlife Biologist interested in natural history, population ecology, and conservation of endangered species. David received a B.S. from California Polytechnic at San Luis Obispo in 1991 and an M.A. from Sonoma State University in 1997. His recent studies include biotic and abiotic factors affecting the long-term coexistence of the threatened California Red-legged Frog and introduced American Bullfrog, metapopulation dynamics and preserve viability of the endangered California Tiger Salamander (*Ambystoma californiense*), road mortality effects on California Tiger Salamander populations, Chinook Salmon (*Oncorhynchus tshawytscha*) spawning distribution in the Russian River basin, and Western Pond Turtle (*Actinemys marmorata*) demography. (Photographed by Rich Stabler).



ANDREA F. CURRYLOW received her B.S. from the University of California at Davis in 2003. She worked as an Environmental Consultant, focusing on Mojave Desert Tortoises (*Gopherus agassizii*) before earning her M.S. from Purdue University in 2011 studying the effects of timber harvests on the ecology and behavior of Eastern Box Turtles (*Terrapene carolina*). Andrea is currently a Ph.D. student at the University of Southern California studying comparative ecophysiology of the Critically Endangered Ploughshare Tortoise (*Astrochelys yniphora*), Radiated Tortoise (*Astrochelys radiata*), and Spider Tortoise (*Pyxis arachnoides*) in Madagascar. (Photographed by Angelo Mandimbihasana).

NOTES

**ECTOPARASITES ON THE GIANT KANGAROO RAT, CARRIZO PLAIN
NATIONAL MONUMENT, SAN LUIS OBISPO COUNTY, CALIFORNIA**

**HOWARD O. CLARK, JR.^{1,3,4}, HELEN K. PIGAGE², COLIN A. WILKINSON¹, AND
ROBERT K. BURTON¹**

¹H.T. Harvey & Associates, 7815 N Palm Avenue, Suite 310, Fresno, California 93711-5511, USA

²University of Colorado, Colorado Springs, 1420 Austin Bluffs Parkway, Colorado Springs, Colorado 80918-3733, USA

³Current address: Garcia and Associates, 993 Ezie Avenue, Clovis, California 93611-2019, USA

⁴Corresponding author; e-mail: hclark@garciaandassociates.com

Abstract.—The Giant Kangaroo Rat (*Dipodomys ingens*) is a keystone species endemic to the San Joaquin Valley of California and adjacent valleys, and is listed by both California and the federal government as Endangered. Little is known regarding the occurrence of ectoparasites on Giant Kangaroo Rats. Previous work resulted in the identification of two flea species (*Hoplopyllus anomalus* and *Meringis californicus*) and ticks (*Ixodes* sp.) on Giant Kangaroo Rats on the Carrizo Plain in San Luis Obispo County, California (Tabor et al. 1993). One additional flea species, *Echidnophaga gallinacea*, was identified on Giant Kangaroo Rats during trapping efforts within the same geographical location.

Key Words.—California; *Dipodomys ingens*; endangered species; fleas; kangaroo rat; parasites

The Giant Kangaroo Rat (*Dipodomys ingens*) is a keystone species endemic to the San Joaquin Valley of California and adjacent valleys (Goldingay et al. 1997; Schiffman 1997), and is listed by both California and the federal government as Endangered (U.S. Fish and Wildlife Service 1998). The primary causes of endangerment are loss of habitat due to land conversion (urban development and agriculture) and fragmentation by the development of highway and water delivery infrastructures (U.S. Fish and Wildlife Service 1998). Little is known regarding the occurrence of ectoparasites on the Giant Kangaroo Rat. Previous work resulted in the identification of two flea species (*Hoplopyllus anomalus* and *Meringis californicus*) and ticks (*Ixodes* spp.) on Giant Kangaroo Rats on the Carrizo Plain, San Luis Obispo County, California (Williams and Kilburn 1991; Williams 1992; Tabor et al. 1993). Here we identify one additional flea species occurring on the Giant Kangaroo Rat not previously reported.

From 27–28 October 2011, we established one trapping grid on a private inholding within the Carrizo Plain National Monument (T11N, R26W, Sec 1; elevation 670 m). We used Sherman live traps (7.5 × 9.5 × 30.5 cm; H.B. Sherman Traps, Tallahassee, Florida) in a 10 × 10 grid with 10-m centers (100 total traps). We baited traps with white proso millet and placed an unbleached paper towel inside. We set traps shortly before sunset and closed them 3–4 h later. All captured rodents were identified to species and we recorded mass, hind foot length, sex, general health, age, and reproductive condition. To permanently mark animals, we injected a passive integrated transponder (PIT) tag under the dorsal surface between the shoulder blades. We collected fleas from Giant

Kangaroo Rats and placed them in a glass vial (6 × 60 mm) filled with 70% isopropyl alcohol. Following data and flea collection, we released captured rodents at the trap site. We identified fleas to species using field keys (Hubbard 1947; Holland 1949; Campos 1971; Lewis et al. 1988), mounted fleas on glass slides, and deposited them at the Denver Museum of Nature & Science (DMNS; 2001 Colorado Boulevard, Denver, Colorado 80205).

We captured 16 Giant Kangaroo Rats (three males; 13 females) and collected six fleas that we identified to three species, one of which has not been previously reported as occurring on Giant Kangaroo Rats: *Echidnophaga gallinacea*. *Meringis californicus* ($n = 1$; DMNS accession number ZE.45276; Fig. 1) are commonly associated with *Dipodomys* species (Ewing and Fox 1943) and *Echidnophaga gallinacea* ($n = 2$; accession numbers ZE.45280 and ZE.45281; Fig. 2) are typically found on domestic poultry and rodents (Koehler et al. 2009). *Hoplopyllus anomalus* ($n = 3$; accession numbers ZE.45277, ZE.44278, and ZE.45279; Fig. 3) are commonly associated with sciurids, but on the Carrizo Plain, Giant Kangaroo Rats have largely filled the sciurid niche (Tabor et al. 1993).

Tabor et al. (1993) collected 283 fleas from 67 Giant Kangaroo Rats, with an average of 4.34 fleas per kangaroo rat. Of these 283 fleas, all were *Hoplopyllus anomalus* (92 males, 189 females, one unknown) except for one male *Meringis californicus*. All fleas collected in our study were female. Tabor et al. (1993) also had a female-biased sampling, with two females collected for every male. Females are larger than males and are typically able to survive longer than males (Krasnov 2008).

Fleas and other parasites can potentially adversely affect their host species (Clark et al. 2006). However, from examining the Giant Kangaroo Rats with fleas during our study, we did not observe unhealthy or weakened kangaroo rats due to infestations. Fleas rarely numbered more than two or three on any individual, with many kangaroo rats not harboring fleas. Precinct excavation work occurring on a nearby study site did not show any noticeable infestations of the burrow systems (Howard Clark, unpubl. data). Low numbers of fleas may be a function of the time of the year fleas were collected. For example, *E. gallinacea* were primarily collected during the spring in one study (Metzger 2000) where soil moisture is relatively higher than in the fall when our study occurred. Both *E. gallinacea* and *H. anomalus* are commonly associated with California ground squirrels (*Otospermophilus beecheyi*) and although no ground squirrels were within the immediate vicinity of our study grids, the species occurs regionally and may facilitate parasite exchange.

Occasionally, when a burrow or den system of a mammal becomes infested, the host will abandon the burrow or den (Kilgore 1969). Abandonment of precincts by Giant Kangaroo Rats due to parasite infestations has not been documented and it appears that flea loads on Giant Kangaroo Rats is low to moderate at most. Our finding of multiple species of fleas on Giant Kangaroo Rats at one locality show that parasitic biodiversity can be high and further research is needed to determine how Giant Kangaroo Rats manage flea loads and what effects fleas have on kangaroo rat populations, if any.

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Figure 1. Female *Meringis californicus* collected from a Giant Kangaroo Rat (*Dipodomys ingens*) on the Carrizo Plain National Monument, San Luis Obispo County, California. (Photographed by Helen Pigage).



Figure 2. Female *Echidnophaga gallinacea* collected from a Giant Kangaroo Rat (*Dipodomys ingens*) on the Carrizo Plain National Monument, San Luis Obispo County, California. (Photographed by Helen Pigage).



Figure 3. Female *Hoplopyllus anomalus* collected from a Giant Kangaroo Rat (*Dipodomys ingens*) on the Carrizo Plain National Monument, San Luis Obispo County, California. (Photographed by Helen Pigage).

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HOWARD O. CLARK, JR., is a Certified Wildlife Biologist® with nearly 20 years of professional wildlife and research experience. He earned his Master's degree in Biology from California State University, Fresno in 2001. His work as a researcher focused on the fauna and ecosystems of Northern, Central, and Southern California, and the Mojave Desert provinces and included extensive baseline mammalian inventories, surveys focused on rare animals, habitat assessment, radio telemetry, and long-term ecological studies on several endangered species. He regularly works with the Western Burrowing Owl (*Athene cunicularia*), San Joaquin Kit Fox (*Vulpes macrotis mutica*), Giant Kangaroo Rat (*Dipodomys ingens*), Salt Marsh Harvest Mouse (*Reithrodontomys raviventris*), and the Mohave Ground Squirrel (*Xerospermophilus mohavensis*). He is currently a senior wildlife ecologist with Garcia and Associates, Fresno, California. (Photographed by Graham Biddy).



HELEN K. PIGAGE earned her D.A. from the University of North Dakota in 1979. She taught biology courses (Anatomy and Physiology, Microbiology, Parasitology, and General Biology) for 43 years before retiring in July 2012. Her college teaching experience included work at West Liberty State College (West Virginia), Elmhurst College (Illinois), and the United States Air Force Academy (Colorado Springs, Colorado). She has conducted research on pocket gophers (*Thomomys bottae*), Eastern Woodrats (*Neotoma floridana*), and Mule Deer (*Odocoileus hemionus*). She is currently investigating molecular genetics of Abert's Squirrels (*Sciurus aberti*) with several colleagues. In addition, she is a Research Associate in the Zoology Department of the Denver Museum of Nature & Science working on the Department's flea collection. (Photographed by Rick Clawges).



COLIN A. WILKINSON earned his Bachelor's degree from the University of California, Santa Cruz in 2006. He worked for the California State University, Endangered Species Recovery Program from 2007 to 2010. He has conducted research on Giant Kangaroo Rats (*Dipodomys ingens*), Fresno Kangaroo Rats (*D. nitratoides exilis*), Tipton Kangaroo Rats (*D. n. nitratoides*), Spotted Owls (*Strix occidentalis*), California Tiger Salamanders (*Ambystoma californiense*), California Red-legged Frogs (*Rana draytonii*), and San Joaquin Kit Foxes (*Vulpes macrotis mutica*). He is currently working as a Plant and Wildlife Ecologist for H. T. Harvey & Associates in Fresno, California. (Photographed by Howard Clark).



ROBERT K. BURTON earned his Ph.D. from the University of California, Santa Cruz in 2000. He has worked with a wide variety of species including the Western Snowy Plover (*Charadrius nivosus nivosus*), California Least Tern (*Sternula antillarum browni*), Southern Sea Otter (*Enhydra lutris nereis*), Giant Kangaroo Rat (*Dipodomys ingens*), San Joaquin Kit Fox (*Vulpes macrotis mutica*) as well as riparian restoration in California and Arizona. He is currently an Associate Wildlife Ecologist with H. T. Harvey & Associates, an ecological consulting group in California. (Photographed by Kristy Uschyk).

PEER EDITED

COMPILATION OF KIT FOX AND SWIFT FOX LITERATURE

HOWARD O. CLARK, JR.

Garcia and Associates, 993 Ezie Avenue, Clovis, California 93611-2019, USA
e-mail: hclark@garciaandassociates.com

Key Words.—desert; Kit Fox; Swift Fox; North America; *Vulpes macrotis*; *Vulpes velox*

When a large body of knowledge has been produced on a group of closely related species, especially when they are becoming comparatively rare on the landscape, it is paramount that these works be easily accessible to researchers, students, and the general public. With the advent of the World Wide Web, it may seem that bibliographies are becoming obsolete, but after a brief search, an interested party will soon discover that there is no logical order behind the results they obtain. Further confusion results from searches that yield articles that are mainly opinion or conjecture rather than peer-reviewed material. In addition, it is becoming increasingly difficult to keep abreast on the emerging new literature, even when using internet search engines, because of the continual increase of potential article outlets. A concise catalog of available peer-reviewed material is necessary for any researcher wishing to extract the available information on a given species. Herein is a compilation of the large body of peer-reviewed information on two species of fox: the Kit Fox, *Vulpes macrotis*, and the Swift Fox, *V. velox*. These two foxes are closely related and are often used as umbrella species in conservation efforts of their ecosystems, which include grassland prairie and arid deserts. The conservation of these two fox species will in turn provide protection for a suite of other plant and wildlife species in dire need of preservation. For every peer-reviewed article included in this compilation, there are likely three or four “gray literature” reports, theses, dissertations, and inter-agency articles; these are not included because, ideally, anything noteworthy in these publications has also been published in scientific journals. On the other hand, as unorthodox as it may seem, popular magazine articles about these foxes have also been included in the compilation. Typically, such material is not included in a scientific venue such as this, but it is important that the public finds this compilation useful as well. Articles in magazines such as *Smithsonian* and *National Wildlife* are crucial in educating the public about endangered species. Such references are included here, in a separate section, because they typically have a much larger readership and distribution than other forms of gray literature and, as a result, make a larger impact on wildlife conservation awareness. Also included in this collection are significant conference proceedings, book chapters, and books written on these foxes. Caution should be exercised

when reading older works. Recent works either confirm or invalidate older hypotheses, and cross-referencing by the reader is recommended.

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Clark • Kit Fox and Swift Fox Literature

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HOWARD O. CLARK, JR., is a Certified Wildlife Biologist® with nearly 20 years of professional wildlife and research experience. He earned his Master's degree in Biology from California State University, Fresno in 2001. His work as a researcher focused on the fauna and ecosystems of Northern, Central, and Southern California, and the Mojave Desert provinces and included extensive baseline mammalian inventories, surveys focused on rare animals, habitat assessment, radio telemetry, and long-term ecological studies on several endangered species. He regularly works with the Western Burrowing Owl (*Athene cunicularia*), San Joaquin Kit Fox (*Vulpes macrotis mutica*), Giant Kangaroo Rat (*Dipodomys ingens*), Salt Marsh Harvest Mouse (*Reithrodontomys raviventris*), and the Mohave Ground Squirrel (*Xerospermophilus mohavensis*). He is currently a senior wildlife ecologist with Garcia and Associates, Fresno, California. (Photographed by Graham Bidy).

EFFECTS OF GEOPHYSICAL SURVEY ENERGY SOURCES ON KANGAROO RAT ABUNDANCE

CRAIG M. FIEHLER¹, BRIAN L. CYPHER¹, AND LARRY R. SASLAW²

¹*Endangered Species Recovery Program, California State University, Stanislaus, P.O. Box 9622, Bakersfield, California 93389, USA, e-mail: craig.fiehler@wildlife.ca.gov*

²*United State Bureau of Land Management, 3801 Pegasus Drive, Bakersfield, California 93308, USA*

Abstract.—We assessed the effects of geophysical (i.e., seismic) survey energy sources on local kangaroo rat abundance on study sites in the Lokern area of California. Seismic surveys are routinely conducted in this region where several rare kangaroo rat species occur. We monitored kangaroo rat abundance by live-trapping on three study plots: one subjected to a “vibroseis” energy source, one subjected to a “shot-hole” energy source, and one control. Compared to capture rates prior to the simulated seismic surveys, rates were higher immediately after and one month later on all plots. Trends in rates were nearly identical on all three plots indicating that the seismic energy sources had no detectable effects on abundance. Although we did not detect adverse effects during this simulated survey, potential impacts also should be assessed during an actual full-scale seismic survey.

Key Words.—capture rate; *Dipodomys*; gas; oil; seismic survey; shot-hole; vibroseis

INTRODUCTION

Over 95% of the San Joaquin Valley floor in California has been converted from native habitat to urban sprawl or agricultural land (USFWS 1998). A large portion of the remaining area has been developed by the petroleum industry for oil and gas production (US Fish and Wildlife Service [USFWS] 1998). Since the early 1900s, the San Joaquin Valley has experienced substantial physical alteration of its natural environment from oil and gas exploration, drilling, and extraction.

Oil and gas exploration often occurs in the form of geophysical, or seismic, surveys. Geophysical surveys are routinely conducted in areas with potential hydrocarbon resources in an effort to locate crude oil and natural gas reserves. These surveys are conducted by generating energy waves that reflect off of subterranean strata (Milligan 2004). Two common methods of creating these energy waves include generating strong vibrations (“vibroseis”) and detonating a buried explosive charge (“shot-hole;” Milligan 2004). The seismic images produced by the resulting energy waves are recorded by geophones to produce an underground map of oil and gas deposits. Some of these deposits are chosen for drilling and extraction.

The effects of drilling and resource extraction processes on wildlife have been well documented. Such effects can include habitat loss, disturbances associated with noise and activity from production operations, exposure to toxins, and entrapment and drowning in spilled oil or waste water from wells (Flickinger 1981; Kaplan et al. 1996; Cypher et al. 2000, Lyon and Anderson 2003; Ingelfinger and Anderson 2004; Trail 2006; Ramirez 2010). However, the effects of geophysical surveys have not been well studied. Because these surveys involve the generation of subterranean energy waves, fossorial animals may be particularly vulnerable to effects. The ob-

jective of this project was to determine the effects of two common forms of exploratory seismic surveys on semi-fossorial mammals, particularly kangaroo rats (*Dipodomys* spp.). In the San Joaquin Valley, seismic surveys are routinely conducted in habitats occupied by kangaroo rats, including several rare species.

METHODS

Study area.— We studied the effects of exploratory seismic surveys in the Lokern Natural Area in western Kern County, California (35.43N, 119.62W; Fig. 1). The study area encompassed approximately 47 ha consisting entirely of the U.S. Bureau of Land Management land. The Lokern Natural Area is within a region considered to be important habitat for federally listed species such as San Joaquin Kit Fox (*Vulpes macrotis mutica*), Blunt-nosed Leopard Lizard (*Gambelia sila*), and Giant Kangaroo Rat (*D. ingens*; USFWS 1998).

Vegetation on the three plots was a mosaic of arid shrubland and annual grassland. The predominant natural community in the study area was Valley Saltbush Scrub (Holland 1986). This community is characterized by open shrublands with a forb understory comprised of annual plants representative of Non-native Grassland (Holland 1986). Common shrubs on the plots included Desert Saltbush (*Atriplex polycarpa*) and Russian Thistle (*Salsola tragus*). Other plant species included Red-stemmed Filaree (*Erodium cicutarium*), Red Brome (*Bromus madritensis* ssp. *rubens*), and Arabian Grass (*Schismus arabicus*).

Field methods.—From 15 October 2008 to 21 November 2008, we conducted small mammal surveys to census and mark small mammals on the study plots. On each plot we established a grid of 60 trap stations (5 × 12 pattern) with 10-m spacing, and placed a 7.6 × 8.9

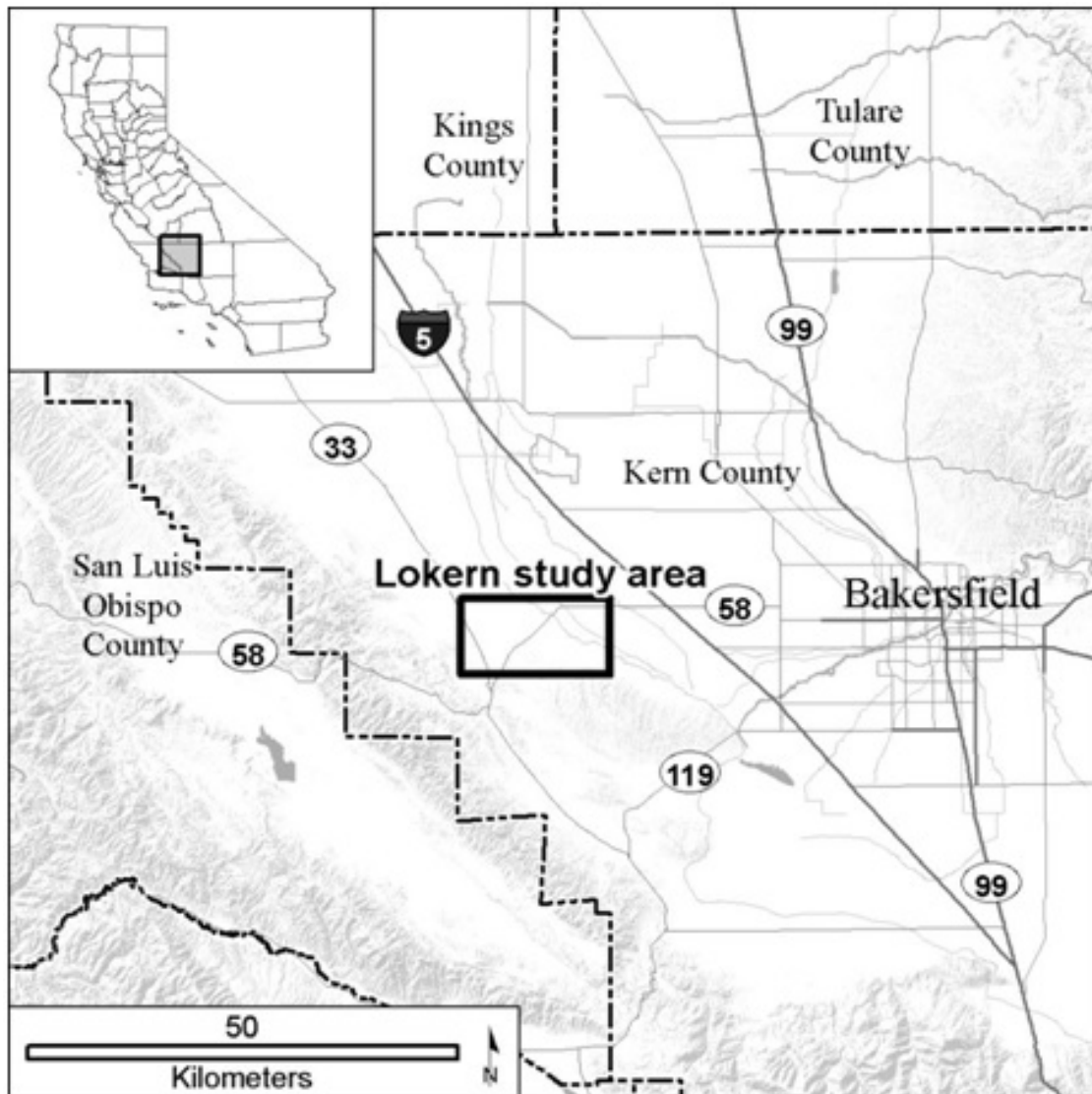


Figure 1. Location of the Lokern study site in the San Joaquin Valley, California used to study the effect of seismic activity on abundances of kangaroo rats (*Dipodomys* spp.).

× 33.3-cm Sherman live trap (model XLKR; H.B. Sherman Traps, Tallahassee, Florida) at each station. The grids were approximately 100 m apart to reduce the potential for treatments to affect other plots and for individual rodents to use more than one plot. We trapped small mammals on each plot for four nights just prior to vibroseis and shot-hole activities (beginning 14 October 2008), two nights immediately after (beginning 22 October 2008), and four nights four weeks after (beginning 18 November 2008) seismic activities. We marked all individuals captured for the first time with a numbered eartag (1005 size 1 monel; National Band and Tag Co., Newport, Kentucky).

Seismic exploration events (shot-hole and vibroseis) were simulated by personnel of Occidental Petroleum on two of the study plots with the third site serving as a control where no activity occurred. Shot-holes were drilled to a depth of 6.1 m and a 1-kg charge of Geoprime dBX pentolite (Dyno Nobel Inc., Salt Lake City, Utah) was

placed down hole to be detonated. A total of 10 shot-holes were drilled at 34-m spacing along the edge of one study plot. Charges were detonated sequentially at ca. 5-min intervals. We established 10 vibroseis points at 34-m spacing along the edge of a second plot. One 22,246-kg vibroseis truck was used operating at an 80% drive level for 10 s at each point. Each linear sweep was 10 s in duration and ranged from 8-100 Hz. We located the lines of shot-holes and vibroseis points ca. 10 m from the edge of their respective trapping plots. Shot-hole detonations and vibroseis were conducted between late-morning and mid-afternoon when small mammals were down in burrows. We watched for any animals appearing above-ground during the activities. After the conclusion of the simulated seismic surveys, we immediately inspected nearby small mammal burrows for collapse or damage.

Statistical analysis.—We compared the abundance of kangaroo rats between trapping before seismic activity

and one month later and among vibroseis, shot-hole, and control plots using contingency table analysis ($\alpha = 0.05$).

RESULTS

We restricted our analyses to kangaroo rat species because we did not capture the other small mammal species in sufficient numbers to include them. Kangaroo rat species we captured included Giant Kangaroo Rats (federally and state-listed as endangered), Heermann's Kangaroo Rats (*D. heermanni*), and Short-nosed Kangaroo Rats (*D. nitratoides brevinasus*; federal species of concern, state Species of Special Concern). Other species we captured were North American Deermice (*Peromyscus maniculatus*) and Tulare Grasshopper Mice (*Onychomys torridus*).

Across all trapping sessions, we caught 39, 63, and 105 individual kangaroo rats on the vibroseis, shot-hole, and control plots, respectively (Table 1). Capture rate trends for the three sessions were virtually identical on all three plots (Fig. 2). Capture rates increased markedly during the "after" trapping session. The capture rates for the "one month" session were slightly higher than the "before" session rates on all three plots. Changes in the number of individuals captured between the initial session and one month later did not differ among plots ($\chi^2 = 0.02$, 2 df, $p = 0.99$). The proportion of recaptured individuals after one month on the vibroseis, shot-hole, and control plots was 60%, 85%, and 79%, respectively, and did not differ among plots ($\chi^2 = 3.22$, 2 df, $p = 0.20$). We did not observe small mammals exiting burrows after shot-hole detonation or during the vibroseis survey, and we did not detect any physical damage to small mammal burrows near the seismic survey sample points, including several burrows that were within 1 m of shot-holes.

DISCUSSION

We did not detect any immediate or long-term impact to kangaroo rat abundance from the simulated seismic surveys. Population reductions could have resulted from direct mortality due to energy sources or burrow collapse, or from indirect mortality due to physical impairment (e.g., inability to forage, increased predation) or emigration. However, capture rates on all three study plots were higher both immediately after the simulated seismic surveys and one month later. We suspect that the marked increase in rates immediately after the surveys may have been an artifact, as capture rates for kangaroo rats commonly increase during a trapping session as additional animals discover, habituate to, and enter traps. We observed this same trend within sessions. The "after" trapping session commenced just five days following the conclusion of the "before" session, and so animals were probably still habituated to the traps, resulting in the high capture rates. The decrease in rates by the "one month" session likely reflects a decline in habituation and not a decline in abundance because the rates were still higher

Table 1. Total number of individual kangaroo rats captured on each study plot during each trapping session during simulated seismic survey activity in the San Joaquin Valley, California, in 2008. The number of recaptured marked individuals is given in parentheses.

Plot	Trapping session		
	Before	After	1 month
Vibroseis	12	12 (9)	15 (9)
Shot-hole	16	25 (13)	20 (17)
Control	29	37 (34)	38 (30)
Trap nights/plot	240	120	240

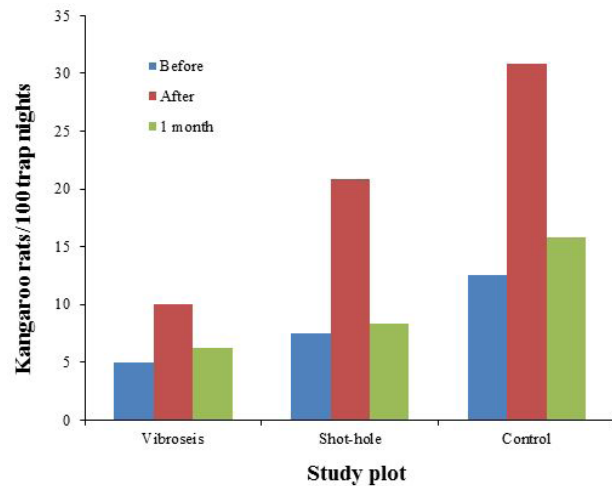


Figure 2. Number of kangaroo rats trapped per 100 trap nights during three trapping sessions on three seismic survey study plots in the Lokern area of Kern County, California, in 2008.

compared to the "before" session. Regardless of the reasons for the variation in capture rates, the trends were nearly identical on all three plots, indicating that the differences were attributable to factors other than the simulated seismic surveys.

Environmental monitoring studies following geophysical exploration projects that employed vibroseis and shot-hole source methods in the southern San Joaquin Valley reported a decline in the number of small mammal burrows within vibroseis corridors 90 days and one year following surveys compared to control areas, but a substantial increase in burrows two years following the surveys (Steve Tabor and Rex Thomas, unpubl. report). The results of these monitoring studies indicated no long-term impact to the habitat or to the small mammal species following vibroseis activities (Steve Tabor and Rex Thomas, unpubl. report). Similarly, in another unpublished report (George Menkens and Stanley Anderson), vibroseis activity did not impact the physical living space, vegetation structure, or population dynamics of White-tailed Prairie Dogs (*Cynomys leucurus*) in Wyoming.

Other research has suggested that loud noises, such as those from off-road vehicles, can lead to temporary hearing impairment in kangaroo rats and may lead to higher levels of depredation (Brattstrom and Bondello

1983). Several kangaroo rat species use foot-drumming to communicate identity and to advertise territory (Randall 1984; 1989; 1997; Shier et al. 2012). It has been suggested that kangaroo rats, including *D. ingens*, 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). Shier et al. (2012) found that Stephen's kangaroo rats (*D. stephensi*) foot-drummed in response to low frequency vehicle traffic noise and concluded that such noise potentially disrupted intraspecific communication. We did not attempt to assess physiological impacts from seismic energy sources to kangaroo rat individuals. More research investigating the effects of the seismic energy sources on kangaroo rats at an individual level would be necessary to evaluate potential physiological impacts to these species. If such impacts did occur on our study site, they did not affect kangaroo rat abundance during the monitoring period.

This study was designed to investigate population level effects of the energy sources used in seismic exploration on resident small mammals and not the physical impacts to the habitat. Although we did not detect any adverse effects to kangaroo rat abundance in our study area from simulated vibroseis and shot-hole surveys, actual surveys are more extensive and have the potential to impact small mammal populations both directly and indirectly. To detect petroleum resources further beneath the surface, two to four vibroseis trucks typically are needed, along with support vehicles (Milligan 2004). Shot-hole surveys may produce less environmental impact as fewer and smaller vehicles are required. Anytime vehicles are operated off-road, the tracks created can persist for months or years, particularly in arid areas like the San Joaquin Valley, and there is always a danger of others following these tracks and effectively converting them into roads. Such conversion could further fragment and degrade these already dwindling habitats.

Management implications.—We did not detect any adverse impacts to kangaroo rat abundance from underground vibrations and noise associated with vibroseis and shot-hole survey methods. However, in an actual seismic survey, impacts could result from associated activities, such as extensive off-road vehicle use. In current seismic surveys conducted in the southern San Joaquin Valley, various mitigation measures are required in an effort to reduce or avoid impacts to kangaroo rats and other small mammals. These measures include balloon tires to reduce burrow collapse, avoiding sensitive resources including rodent burrows, and restricting activities to daylight hours when most animals in this region are inactive (William Dixon, pers. comm.). It is important to maintain these mitigation measures to avoid impacts to small mammals as well as other burrow-dependent species such as endangered Blunt-nosed Leopard Lizards and San Joaquin Kit Foxes.

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CRAIG FIEHLER (left) received his Bachelor's degree in Ecology, Behavior, and Evolution from UCLA and his Master's degree in Wildlife Biology from Humboldt State University. He has worked for the California Department of Fish and Wildlife since 2009. His professional interests remain focused on wildlife ecology and management.

BRIAN CYPHER (center) is the Associate Director and a Research Ecologist with the Endangered Species Recovery Program of California State University, Stanislaus. Since 1990 he has been involved in research and conservation efforts for endangered and other sensitive species in the San Joaquin Valley of California. Although his primary research interest is the ecology and conservation of wild canids, he works with a variety of animal and plant species.

LARRY SASLAW (right) worked as a Wildlife Biologist in the Bakersfield office of the Bureau of Land Management between 1985 and 2011 where he collaborated on studies that investigated the effects of livestock grazing, fire, and oil and gas activities on several San Joaquin Valley listed species. Other work has included monitoring kangaroo rat species distributions and abundance, evaluation kangaroo rat translocations, developing habitat management prescriptions, and restoring previously disturbed habitats in the San Joaquin Desert region. (Photographed by Christine Van Horn Job).