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Renewable Energy Development on Department of Defense Installations in the Desert Southwest: Identifying Impacts to Species at Risk – Final Report

RENEWABLE ENERGY DEVELOPMENT ON DEPARTMENT OF DEFENSE INSTALLATIONS IN THE DESERT SOUTHWEST: IDENIFYING IMPACTS TO SPECIES AT RISK

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Edwards Air Force Base
Davis-Monthan Air Force Base
U.S. Army Yuma Proving Ground

Final Report

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EXECUTIVE SUMMARY

Sustaining and conserving suitable habitats and resources for sensitive species allow military installations to manage potential risk and maintain compliance with Federal regulations such as the Endangered Species Act (ESA). Each military installation has an Integrated Natural Resource Management Plan (INRMP) identifying potentially sensitive taxa existing on those lands administered by the installation. However, with new mandates and missions to achieve the status of a net zero status, it is imperative to understand the potential impacts of meeting both the net zero standards while adhering to their INRMP guidance. The presence and distribution of small mammal and reptile communities in relation to solar development can provide direction for future solar development. Therefore, we designed a study to assess the presence and distribution of two taxa across three military installations in the southwestern U.S. through four primary objectives: 1) Quantify differences in reptile and small mammal diversity and abundance between solar development sites and un-impacted sites on DoD installations; 2) Identify the spatial extent of solar development impacts on wildlife communities with application to Species at Risk; 3) Evaluate the mitigation value of "soft-footprint" solar development when compared to standard "hard-footprint" development; and 4) Provide management recommendations to mitigate and monitor impacts of current and future solar development projects on DoD installations in the desert southwest. Through these four objectives we developed data-driven management recommendations that can be applied across military installations.

Our trapping efforts occurred from 7 November 2014 – 2 April 2015 for small mammals and 21 April 2015 – 17 July 2015 for reptiles. We caught 10 species of small mammals and 15 species of reptiles for all installations combined. Results from these effort indicated that species richness, species diversity, and abundance estimates are all highest at distance between 20 m and 400 m form the solar facility. Furthermore, trapping results within the solar facility boundary were so low that it precluded quantitative analyses. This suggests that small mammal and reptile communities are utilizing our sample solar arrays in very low densities. The likely mechanism of this response is displacement into the surrounding habitat. We speculate that the construction and maintenance of these solar arrays creates unsuitable or low quality habitat for these small mammal and reptile communities. Comparison of different footprint designs do not suggest that these communities are responding to the maintenance as expected. This is likely due to the fossorial nature of these communities in the Desert Southwest and their dependence on suitable low compaction soils for burrows.

From these results we identified five potential management recommendations. These are as follows: prioritization of proposed solar development towards existing or previously disturbed areas; an initial survey be conducted at all proposed solar development sites; monitoring the immediate and adjacent landscapes (up to 400 m from proposed facility) if at risk species are identified; trap and relocate individuals within the physical footprint of the facility to beyond 400 m; and installing openings for fossorial species at the base of fenced enclosures around the constructed facility.

INTRODUCTION

The high biodiversity of the Sonoran and Mohave deserts present an increased probability of conflict between at risk species management and renewable energy development (Lovich and Bainbridge 1999; Mittermeier et al. 2002; Randall et al. 2010; Lovich and Ennen 2011). Specifically, there is limited empirical information on the impact of renewable energy development on wildlife or at risk species. The limited work that has been conducted on the impact of renewable energy development has focused on wind facilities (Kuvlesky et al. 2007; Gill 2005). Thus, there is an absence of data on the impact of solar development on at risk species (Lovich and Ennen 2011; Turney and Fthenakis 2011; Northrup and Wittemyer 2013). While, one model has been proposed to develop a wildlife centered suitability index for solar development (Stoms et al. 2013) it is based on broad scale habitat patterns rather than site specific data collection. Therefore, the site specific impacts of solar development exist only in compliance documents and other sources of "gray" literature (Lovich and Ennen 2011), and focus on hydrologic impacts and not at risk species (Duane and McIntyre 2011). The majority of diversity in the Mohave and Sonoran deserts is made up of birds, mammals, and reptiles with many of the terrestrial at risk wildlife composed of small mammals and reptiles (Randall et al. 2010). Since many of the at risk species in the Sonoran and Mohave deserts are small mammals and reptiles (Randall et al. 2010) any evaluation of the impact of solar development should be focused on these taxa. Small mammals are often used as indicators of ecosystem health across a variety of habitats (Chase et al. 2000; Pearce and Venier 2005). Thompson and Thompson (2005) suggest that reptiles are also indicators of ecosystem health. Thus, by monitoring these two taxa together we can better assess the impact of solar development on the landscape.

The term "Soft Footprint" has been used to suggest a low impact physical disturbance (Gatlin 2012). This is usually expressed as a surface maintenance similar to the surrounding landscape. This term suggests that if there is a "soft footprint" there are also "hard" and potential "intermediate" footprints. Although these terms are not specifically defined and prone to subjectivity, we define these terms as follows: soft footprint – surface maintenance similar to the surrounding landscape; intermediate footprint – surface maintenance is modified from surrounding landscape but is highly limited in vegetation composition and structure; and hard footprint – highly modified surface maintenance to eliminate vegetation growth and ground permeability often resulting from gravel or stone deposition. The types of footprints as defined above may have varying levels of effect on the surrounding landscape.

Mitigating the potential impacts that utility-scale solar energy developments may have on at risk species and communities requires that we identify the spatial extent at which the impacts occur. Only when the extent of the impacts is known can appropriate mitigation strategies be developed. The overall goal of this project was to answer the critical questions: 1) What impacts do solar developments have on wildlife communities and Species at Risk in the Desert Southwest; and 2) At what spatial-scale should mitigation occur? An opportunity to evaluate these questions arose with the installation of utility-scale solar developments on Department of Defense (DoD) managed lands in the Sonoran and Mohave deserts. The Sonoran Desert Military Ranges Conservation Partnership Team and collaborators at the Yuma Proving Ground (YPG), Davis-Monthan Air Force Base (DMAFB), and Edwards Air Force Base (EAFB) identified the evaluation of solar development impacts as a priority project to help implement their Net Zero Energy concept (Booth et al. 2010). Our specific objectives were:

OBJECTIVES

1) Quantify differences in reptile and small mammal diversity and abundance between solar development sites and un-impacted sites on DoD installations;

2) Identify the spatial extent of solar development impacts on wildlife communities with application to Species at Risk;

3) Evaluate the mitigation value of "soft-footprint" solar development when compared to standard "hard-footprint" development; and

4) Provide management recommendation to mitigate and monitor impacts of current and future solar development projects on DoD installations in the desert southwest.

METHODS

Study Area

Our study areas consisted of three DoD installations within the Mohave and Sonoran deserts (Figure 1A). Each installation had an existing photo-voltaic solar array. (Figure 1B, 1C, and 1D).

Davis-Monthan Air Force Base, Arizona – Davis-Monthan Air Force Base (DMAFB; Figure 1C) is located in Pima County within the city limits of Tucson, Arizona totaling approximately 43 km^2 (10,681 ac). DMAFB lie in an ecotone zone where the Arizona Upland subdivision of the Sonoran Desert intersects with Chihuahuan Desert grassland (Brown, 1994). Plant species that occur in this area include prickly pear (*Opuntia spp.*), cholla (*Cylindropuntia spp.*), and saguaro (Carnegiea gigantea) cacti, mesquite (*Prosopis spp.*), palo verde (*Parkinsonia spp.*), creosote bush (*Larrea tridentata*), acacia (*Acacia spp.*), yucca (*Yucca spp.*), as well as numerous species of native and exotic grasses. The Tucson basin is characterized by broad alluvial fans, dissected upland bajadas, and four major mountain ranges: the Santa Catalina, Tucson, Santa Rita, and Rincon mountains. DMAFB lies between 773 m and 891 m (2,536 ft and 2,923 ft) in elevation with average precipitation between 27.9 and 33.0 cm/year (11 and 15 in/year). Average temperatures range from 4^0C (39^0F) for lows during the winter to 38^0C (101^0F) for highs during the summer.

Yuma Proving Ground, Arizona – Yuma Proving Ground (YPG; Figure 1B) lies within La Paz and Yuma counties near Yuma, Arizona and totals approximately 3,450 km^2 (852,514 ac). The Lower Colorado River Subdivision of the Sonoran Desert is the predominate vegetative community. This vegetative community is the largest and most arid component within the Sonoran Desert and characterized by extremely drought-tolerant plant species such as creosote bush (*Larrea tridentata*), bursage (Ambrosia spp.), palo verde (*Parkinsonia spp.)* and cacti (*e.g.*, prickly pear cacti [*Opuntia spp.*] and saguaro [Carnegiea gigantea]) (Olson and Dinerstein 2002, Brown 1994). The broad, flat, and sparsely vegetated desert plains of YPG are dissected by numerous incised washes that support ironwood (Olneya tesota), smoketree (*Psorothamnus spinosus*), acacia (*Acacia spp*.), mesquite (*Prosopis spp*.) and numerous shrub species. Elevated hills and mountain slopes within the Arizona Upland Subdivision of the Sonoran Desert are vegetated with, cacti and agave (*Agave spp.*). Elevation on YPG ranges from sea level to 878 m (2,881 ft) with average precipitation is approximately 7.6 in/year (3 cm/year). Average temperatures range from 8ºC (46ºF) for lows during the winter to 42ºC (107ºF) for highs during the summer.

Edwards Air Force Base, California – Edwards Air Force Base (EAFB; Figure 1D) lies within Kern, Los Angeles, and San Bernardino counties near Lancaster, California and totals approximately 1,262 km² (311,943 ac). EAFB lies completely in the Mojave Desert. Dominant vegetation on our EAFB sites included creosote bush (*Larrea tridentata*), white bursage (*Ambrosia dumosa*), saltbush (*Atriplex confertifolia*), blackbrush (*Coleogyne ramosissima*), as well as numerous annual forbs and grasses (Brown, 1994). Elevation on EAFB ranges from 690 m to 1,039 m (2,264 ft to 3,409 ft) with average precipitation is between 6 and 7 in/year (15.2 and 17.8 cm/year). Average temperatures range from 1ºC (33ºF) for lows during the winter to 36ºC (97ºF) for highs during the summer months.

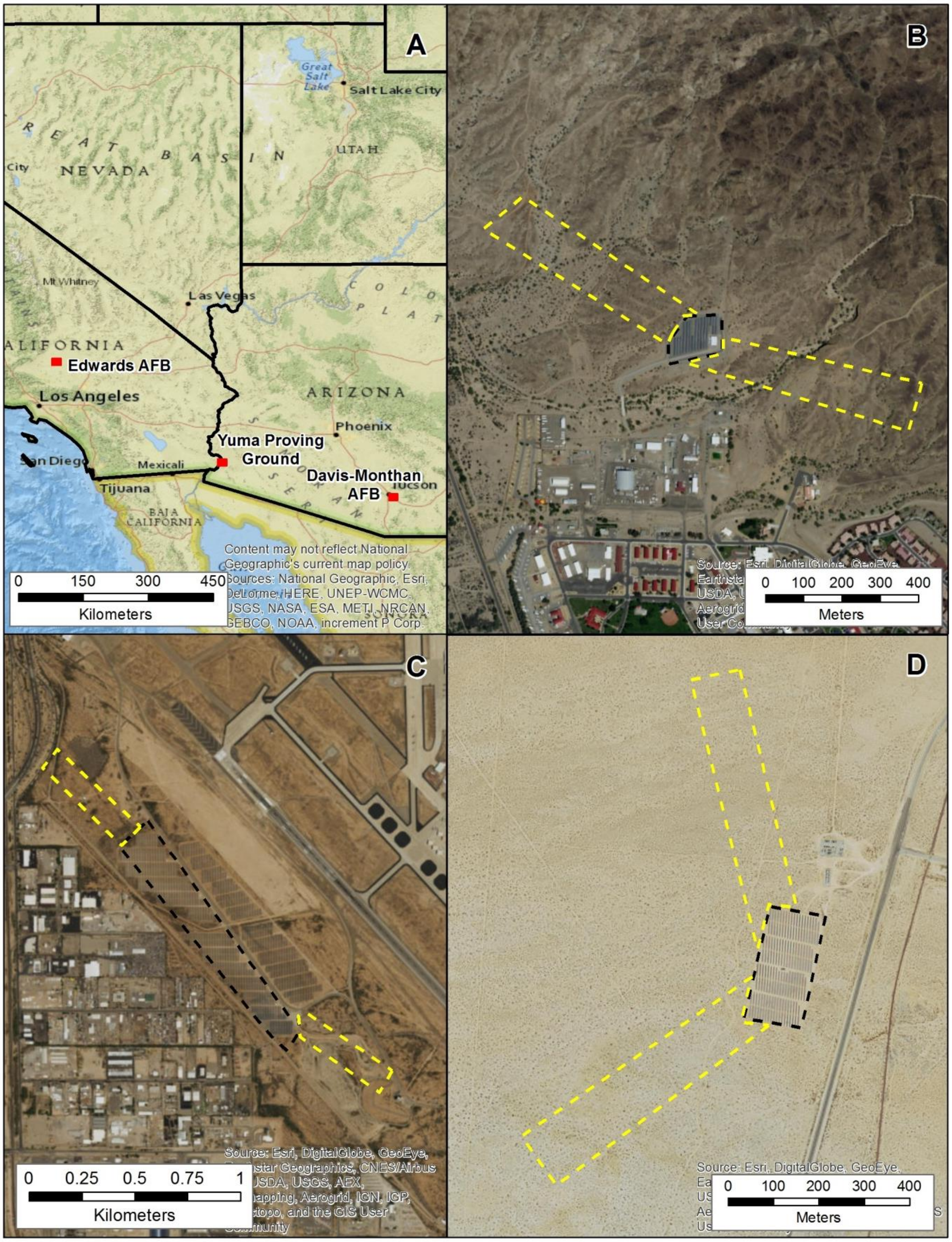


Figure 1. Overview of each military installation within our study area of the Desert Southwest (A). Solar arrays are depicted in black hash line for Yuma Proving Ground (B), Davis-Monthan Air Force Base (C) and Edwards Air Force Base (D). Trapping occurred within the general areas depicted by the yellow hash line in 2014-2015.

Study Design

We developed an effective trap design to measure the ecological gradient of a small mammal community from an anthropogenic disturbance by reviewing different trap designs, arrangements, and appropriate analyses to measure community effects. We reviewed literature on three different trapping designs: grid (Dice 1938; Pelikan et al. 1964; Southern 1973), web (Anderson et al. 1983), and transect (Read et al. 1988; Pearson and Ruggiero 2003). Each had advantages and disadvantages, but the assessment for this project related to understanding the dynamics of the small mammal community in relation to the disturbance and not population estimation.

After reviewing the strengths and weakness of each sampling scheme (grid, web, and transect), we determined that in order to measure the effect of a solar facility on the surrounding landscape's small mammal community, we needed the strengths of both a grid and transect design (Figure 2). Our design included 2 super-transects on opposite sides of the solar facility and directed away from the source of disturbance within homogeneous habitat. Each super-transect originated at the fence line surrounding the solar facility (this appeared to be the most obvious and consistent barrier) and extended away from the facility. A super-transect consisted of up to 5 grids spaced with 100 m intervals. A grid consisted of 50 traps set in a 40 m by 100 m rectangle with traps spaced 10 m apart. By combining both methods, we had the 1st grid(s) located within the fence boundary and extending along the super-transect line for 40 m at which a 100 m interval was measured before the placement of the next grid. This continued until 5 trap grids were placed along both super-transect lines. The grids within the solar facility represented the "Treatment" (Figure 2) with grids 2 and 3 representing the "edge" and grids 4 and 5 representing the "control" or un-impacted site. The 100m interval between most grids was based on a literature review of the primary taxonomic families home range sizes (Cricetidae, Heteromyidae, Sciuridae and Soricidae) of small mammals found within our study area (Table 1). With the exception of a few sciurid species, most small mammals have home ranges smaller than the 100 m interval distance. We assumed for comparison purposes that at least the furthest grids away from the solar facility on each of the super-transects were un-impacted by the disturbance associated with the facility. These "controls" were set as our baseline comparison for "treatment" effect.

Modification for reptile grids included 3 transects per grid while maintaining the super-transect design. Each grid was composed of 3 transects with 3 paired box traps (total of 6 traps) placed along each transect (identified by a drift fence with substrate along the bottom instead of a trench; Figure 3). No trenches were dug for the drift fence due to inconsistent digging requirement and potentially significant cultural areas at each of the installations. Complete independence between the two grids within the solar facility and the first grid along the super-transect was not be possible in all cases; however, for data analysis we will assume independence.

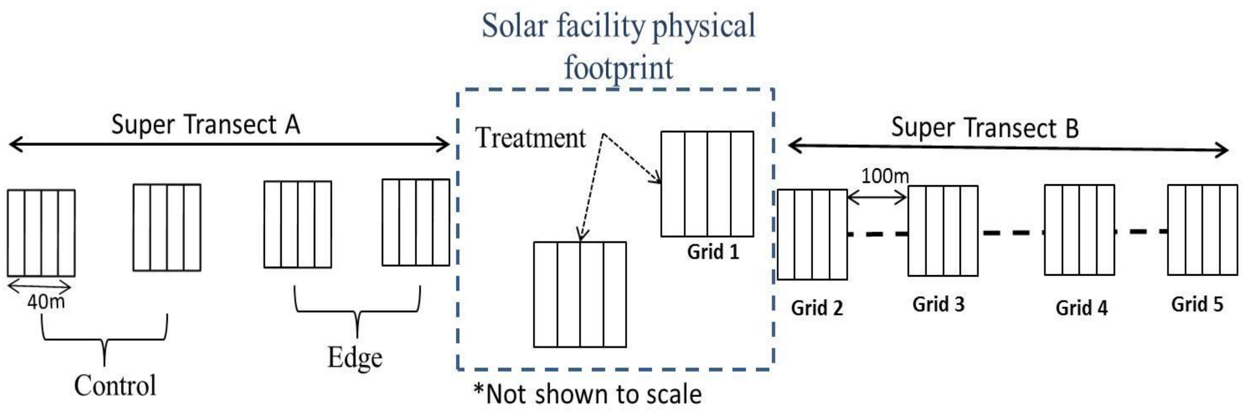


Figure 2. Schematic of sampling design for small mammals in proximity to solar development. Blue hashed line (encompassing "treatment") represents the solar facility as outlined by a physical fence barrier, black hashed line represents super-transects and boxes represents grids.

Table 1. Literature review of maximum home range size by small mammal Family.

Family	Length (m)*	Area (ha)	Source
Heteromyidae			
kangaroo rat	21.6	0.05	Schroder 1979
kangaroo rat	37.5	0.14	Maza et al. 1973
kangaroo rat	18.7	0.03	Braun 1985
pocket mouse	31.0	0.10	Maza et al. 1973
Cricetidae			
woodrat	47.8	0.23	Cranford 1977
woodrat	66.8	0.45	Lynch et al. 1994
woodrat	23.1	0.05	Thompson 1982
mouse	60.1	0.36	Shurtliff et al. 2005
mouse	80.0	0.64	Ribble et al. 2002
Sciuridae			
squirrel	245.6	6.03	Bradley 1967
squirrel	54.7	0.30	Drabek 1973
squirrel	30.0	0.09	Boellstorff and Owings 1995
squirrel	281.1	7.90	Ortega 1990
Family	**Length (m)***	**Area (ha)**	**Source**
Soricidae			
shrew	133.9	1.79	Blair 1940
shrew	46.3	0.21	Kollars 1995
shrew	72.5	0.53	Hawes 1977

* Length assumes length on a side of a square home range area.

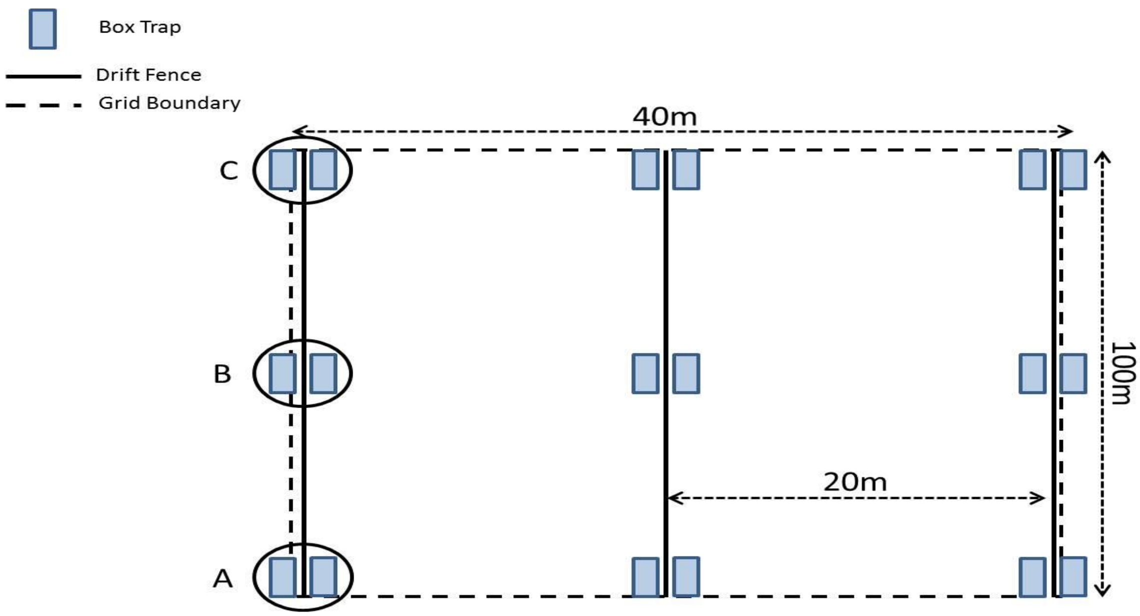


Figure 3. Example of reptile grid design to follow the sampling design depicted in Figure 2. The drift fence was staked for support with the bottom piled with dirt to prevent movement under the fence line. Box traps were paired into trap stations A, B, and C. (Figure not to scale)

Small mammal trapping protocol

Three trapping sessions for small mammals began in mid-November 2014 and ran through April 2015 and consisted of a single 8-day trapping session with one session each month. All traps were individually marked.

For small mammals, we used 600 folding Sherman Model LFATDG live traps (3 X 3.5 X 9 in). Traps were baited with sweet feed as traps were opened. A handful of cotton batting or poly-fill was placed inside each trap to provide insulation. Traps were opened one hour prior to sunset and left open during the night. We began checking traps one hour prior to sunrise. Trap stations were marked with a pinflag, and traps were no more than 1 m from each flag.

Trapped animals were identified to species, weighed, sexed, and had the following metrics taken: tail length, body length, length of the hind foot and pinnae (ear) length. Animals were placed in 1 gallon zip-lock bags to be weighed. Bags were discarded as they become soiled or developed holes. Each animal was marked using standard techniques (Silvy 2012) with a numeric ear tag and colored washer so we could identify individuals during subsequent trapping efforts. Application of ear tags included iodine to prevent possible infection (Silvy 2012). Animals were handled for no more than 5 minutes, using standard methods described in Wilson et al. (1996), so as to reduce stress and released promptly at the point of capture after all metrics were taken. All traps were sanitized between each trapping session with QUAT 128 disinfectant.

Herp trapping protocol
Three trapping sessions for reptiles began in mid-April and consisted of a single 8-day trapping session with approximately one session each month during April, May, June and July 2015.

For reptiles (lizards and snakes) we utilized box traps with funnel entrances. These traps were built specifically for this project to maximize the breadth of species that may be captured. Box traps were constructed with a wood frame and 3.18 mm aluminum mesh and a funnel opening (~3.81 – 4.45 cm) on both ends of the box. Traps had a removable insulated lid (to reduce heat exposure) which could be opened to remove specimens caught in the trap (Figure 4). Captured individuals were marked with either a toe-clip for small and potential juveniles to recognize subsequent captures (McDiarmid et al. 2012) while we will use permanent marker for adults. Animals were released promptly at the point of capture after being measured and marked. Traps were checked daily between 0600 hrs and 1100 hrs. We did not employ pit-fall traps as these were prohibited in California. To maintain consistency, we used these box traps throughout on each installation.

Figure 4. Example of a reptile funnel box trap placed against drift fencing. A dirt ramp was scrapped up next to both trap entrances. The lid was insulated to reduce heat exposure.

Objective 1. Quantify differences in reptile and small mammal diversity and abundance between solar development sites and un-impacted sites on DoD installations.

Mammals - Spellerberg and Fedor (2003) suggest more rigorous use of the definitions between species richness and species diversity. For this reason we provided information for both the Shannon-Wiener index for diversity and providing species richness measurements as described in Kessler et al. (2001). For each installation, we pooled data between the two super-transects for each unique grid number to generate species diversity indices (Shannon–Weiner Index; Shannon and Weaver 1949; Magurran, 2004), species richness (Kessler et al. 2001) and relative abundance estimates using mark-recapture methods. These unique grid numbers represented generally similar distances from the solar facility. In this way, we increased our species representation and inferences by sampling more area along a similar distance from the facility.

At each military installation we were able to sample areas at least three home ranges away from the solar facility as summarized in Table 1 using the basic configuration of Figure 2. For EAFB reptile trapping, we were not able to set complete grids for Super Transect B due to cultural sensitivity concerns. An archeologist was able to position at least a single transect of traps for grids 4 and 5.

Objective 2. Identify the spatial extent of solar development impacts on wildlife communities with application to Species at Risk.

By using the furthest grids as controls and comparison of each grid closer to the solar facility, we calculated changes across each of the super-transects to the treatment estimates. We compared the rate of change across this gradient and identified the extent of impact as defined by the "edge."

Objective 3. Evaluate the mitigation value of "soft-footprint" solar development when compared to standard "hard-footprint" development.

We evaluated species diversity and abundance based on the physical construction of each solar facility. Prior to this project we identified three military installations with different types of solar installation ranging from "hard" to "soft" footprint design. DMAFB included 18.8 ha (46.4 ac) of solar development in our focus area and included both a "hard" footprint which included a graded surface compacted and leveled with coarse stone below the solar panels. The "soft" footprint design included a graded surface but revegetated with grasses to help control erosion. YPG is characterized by a 1.4 ha (3.4 ac) "hard" footprint design as it was graded and terraced with coarse stone. EAFB was compacted, but native soil was left in place and was likely more of a "soft" footprint design consisting of 3.2 ha (7.9 ac).

Objective 4. Provide management recommendation to mitigate and monitor impacts of current and future solar development projects on DoD installations in the desert southwest.

By interpreting the results of this project, we developed a set of data-driven management recommendations that can provide useful guidance on both existing and future solar developments. As of this report, there have been no established management recommendations beyond minimal disturbance to a site.

RESULTS

Our trapping efforts (Table 2) occurred from 7 November 2014 – 2 April 2015 for small mammals and 21 April 2015 – 17 July 2015 for reptiles. All of our results are represented from these efforts. We caught 10 species of small mammals and 15 species of reptiles for all installations combined (Table 2). Table 3 displays each of the acronyms with the associated scientific name and common name used in subsequent tables and figures.

Table 2. Trapping efforts across three military installations from 7 Nov. 2014 to 17 Jul. 2015. Military installations include: Davis-Monthan Air Force Base (DMAFB), Yuma Proving Ground (YPG), and Edwards Air Force Base (EAFB).

Cumulative Trapping Efforts

	Small Mammals				
	# Traps	# Trap-nights	# Captures	# Recaptures	# Species*
DMAFB	440	21,569	177	211	7
YPG	450	22,051	54	12	7
EAFB	500	24,500	33	12	2
Totals	1,390	68,120	264	235	10

	Reptiles				
	# Traps	# Trap-nights	# Captures	# Recaptures	# Species*
DMAFB	90	540	175	17	10
YPG	81	486	71	1	5
EAFB	69	414	21	1	6
Totals	240	1,440	267	19	15

* Cumulative number of species at each installation and overall.

Table 3. Acronym key for all species caught during all trapping sessions at three military installations.

Small Mammals

Acronym	Scientific Name	Common Name
AMHA	*Ammospermophilus harrisii*	Harris' antelope squirrel
AMLE	*Ammospermophilus leucurus*	White-tailed antelope squirrel
CHBA	*Chaetodipus baileyi*	Bailey's pocket mouse
CHIN	*Chaetodipus intermedius*	Rock pocket mouse
CHPE	*Chaetodipus penicillatus*	Desert pocket mouse
DIME	*Dipodomys merrriami*	Merriam's kangaroo rat
NEAL	*Neotoma albigula*	White-throated woodrat
PEER	*Peromyscus eremicus*	Cactus mouse
SIAR	*Sigmodon arizonae*	Arizona cotton rat
XETE	*Xerospermophilus tereticaudus*	Round-tailed ground squirrel

Reptiles

Acronym	Scientific Name	Common Name
ASTI	*Aspidoscelis tigris*	Tiger whiptail
CADR	*Callisaurus draconoides*	Zebra-tailed lizard
COVA	*Coleonyx variegatus*	Western banded gecko
COFL	*Coluber flagellum*	Coachwhip
CRAT	*Crotalus atrox*	Western Diamond-backed rattlesnake
CRSC	*Crotalus scutulatus*	Mojave rattlesnake
DIDO	*Dipsosaurus dorsali*	Desert iguana
HYCH	*Hypsiglena chlorophaea*	Desert nightsnake
PHSO	*Phrynosoma solare*	Regal horned lizard
PICA	*Pituophis catenifer*	Gophersnake
SAHE	*Salvadora hexalepis*	Western patch-nosed snake
SCMA	*Sceloporus magister*	Desert spiny lizard
UROR	*Urosaurus ornatus*	Ornate tree lizard
UTST	*Uta stansburiana*	Common side-blotched lizard
XAVI	*Xantusia vigilis*	Desert night lizard

Objective 1. Quantify differences in reptile and small mammal diversity and abundance between solar development sites and un-impacted sites on DoD installations.

We captured a total of 16 reptiles within the solar arrays at all installations combined (DMAFB = 6, YPG = 8, EAFB = 2). DMAFB had the highest diversity while YPG had the highest abundance (Figure 5A). YPG abundance consisted of a single species, common side-blotched lizard (Table 3). Our control sites indicated the inverse with YPG having the greatest diversity and DMAFB having the highest abundance of reptiles (Figure 5B). In all cases treatment sites resulted in lower metrics than controls.

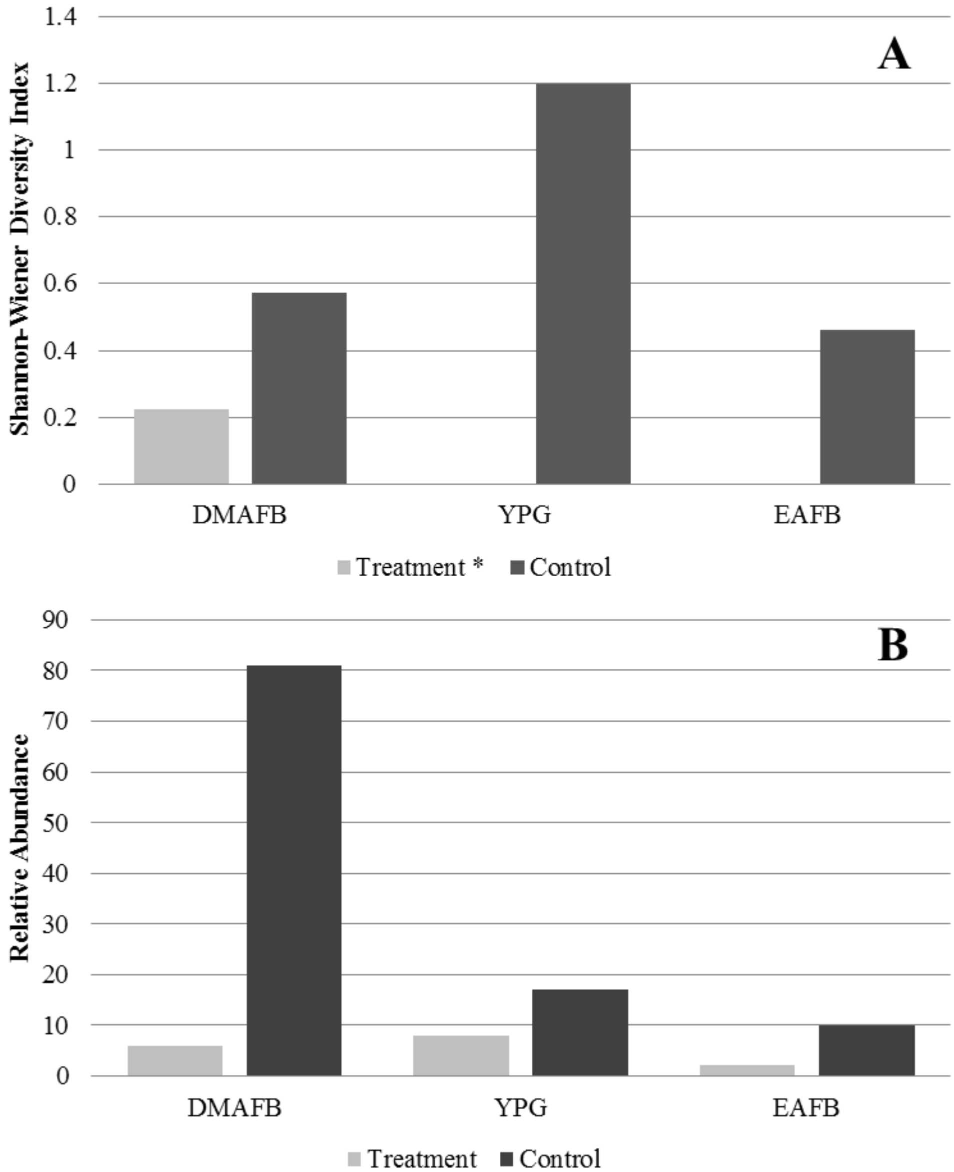
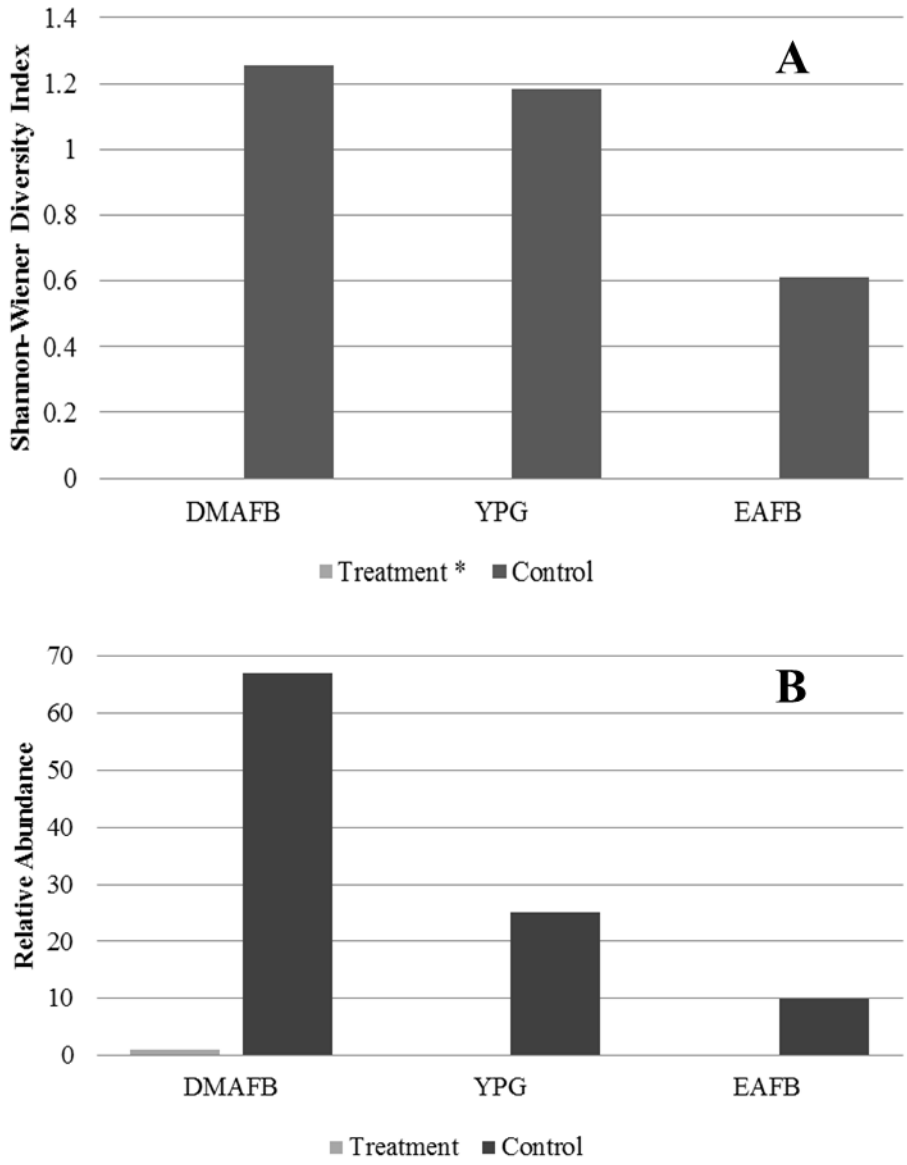


Figure 5. Comparison of reptile diversity (A; Shannon-Wiener Index) and relative abundance (B) between treatment (solar field) and control (un-impacted) sites at three military installations across the Desert Southwest: Davis-Monthan Air Force Base (DMAFB), Yuma Proving Ground (YPG), and Edwards Air Force Base (EAFB) in 2015.

For small mammals, we captured a single individual (Merriam's kangaroo rat) on the DMAFB solar array. This produced no measurable results on the treatment areas for either YPG or EAFB. In addition a single individual or species is represented as zero in the Shannon-Wiener index (Figure 6A). For relative abundance (Figure 6B), metrics were negligible for all sites.



* No diversity was recorded at any of the military installations.

Figure 6. Comparison of small mammal diversity (A; Shannon-Wiener Index) and relative abundance (B) between treatment (solar field) and control (un-impacted) sites at three military installations across the Desert Southwest: Davis-Monthan Air Force Base (DMAFB), Yuma Proving Ground (YPG), and Edwards Air Force Base (EAFB) in 2014-2015.

Objective 2. Identify the spatial extent of solar development impacts on wildlife communities with application to Species at Risk.

Trap grids resulted in sample coverage within the solar arrays to a maximum centroid distance of 496 m from a solar facility (Table 4). Table 4 displays the centroids of each trapping grid for both small mammals and reptiles. Differences in centroid distances are due to the configuration of the different trapping designs (Figures 2 and 3).

Table 4. Average distance of trapping grids from the solar array (m) at each of three military installations.

	Small Mammal Traps				Reptile Traps				
	DMAFB	YPG	EAFB	Average Distance		DMAFB	YPG	EAFB	Average Distance
Grid 1	0	0	0	0	Grid 1	0	0	0	0
Grid 2	20	30	20	23	Grid 2	22	30	11	21
Grid 3	168	196	189	184	Grid 3	167	249	180	199
Grid 4	336	351	340	342	Grid 4	331	328	340	333
Grid 5	480	476	500	485	Grid 5	320	486	496	434

All small mammal trapping efforts resulted in seven species recorded at DMAFB and YPG, and two species at EAFB (Tables 2 and 5). The greatest number of species for both DMAFB and YPG occurred at middle distances represented between grids 2 and 4, while the same 2 species were recorded at each grid at EAFB.

Table 5. Small mammal species richness at each grid for three military installations in the Desert Southwest, 2014-2015. See Table 3 for average distance of each grid. Parentheses indicate the type of foot-print for each installation.

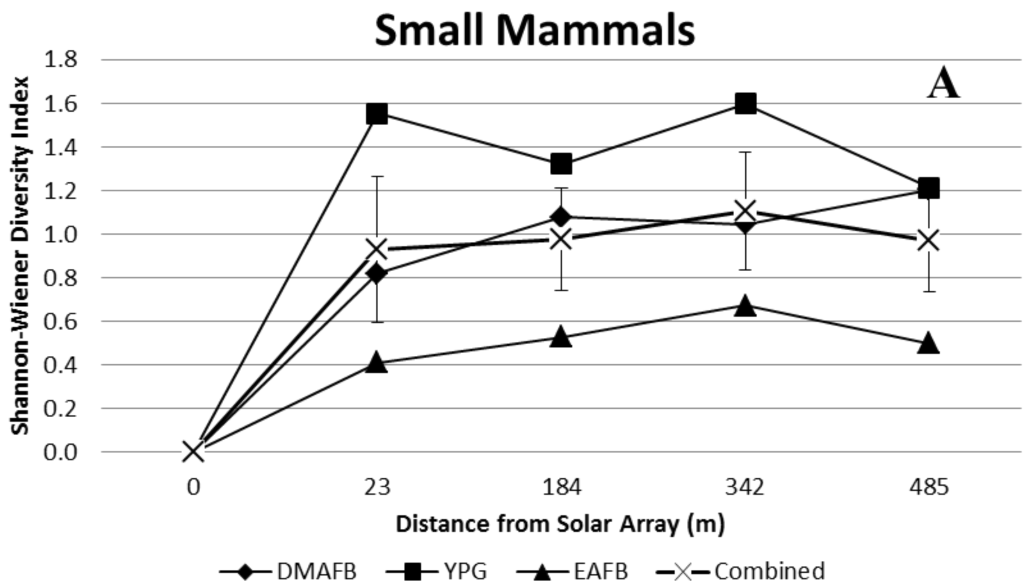
	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5
DMAFB (Intermediate)	DIME	CHIN DIME SIAR	AMHA CHIN DIME NEAL XETE	AMHA CHIN CHPE DIME SIAR XETE	CHIN DIME NEAL SIAR
YPG (Hard)	N/A	AMHA CHBA CHIN CHPE DIME PEER	AMHA CHBA CHIN CHPE DIME	AMHA CHBA CHIN CHPE DIME XETE	AMHA CHBA CHIN CHPE
EAFB (Soft)	AMLE DIME	AMLE DIME	AMLE DIME	AMLE DIME	AMLE DIME

All reptile trapping efforts resulted in ten species recorded at DMAFB five at YPG and 6 at EAFB (Tables 2 and 6). For all installations species richness was greatest at intermediate distances represented by Grids 2 – 4.

Table 6. Reptile species richness at each grid for three military installations in the Desert Southwest, 2014-2015. See Table 3 for average distance of each grid. Parentheses indicate the type of foot-print for each installation.

	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5
DMAFB (Intermediate)	ASTI	ASTI	ASTI	ASTI	ASTI
	PICA	CRAT	CADR	CADR	CADR
	UROR	PHSO	COVA	COVA	UROR
		UTST	UTST	HYCH	
				SCMA	
				UROR	
YPG (Hard)	UTST	ASTI	ASTI	ASTI	ASTI
		CADR	DIDO	CADR	UTST
		COVA	UTST	COVA	
		UTST		DIDO	
				UTST	
	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5
EAFB (Soft)	ASTI	ASTI	ASTI	ASTI	ASTI
		COFL	SAHE	COFL	
		UTST	UTST	CRSC	
		XAVI	XAVI		

Diversity of small mammals species using the Shannon-Wiener Diversity Index resulted in indices of H = 1.21, 1.77, and 0.52 for DMAFB, YPG, and EAFB respectively. Figure 7 displays the relationship between diversity and average distance from the solar array. In both cases, diversity is highest in the middle distances and lowest within the solar array.



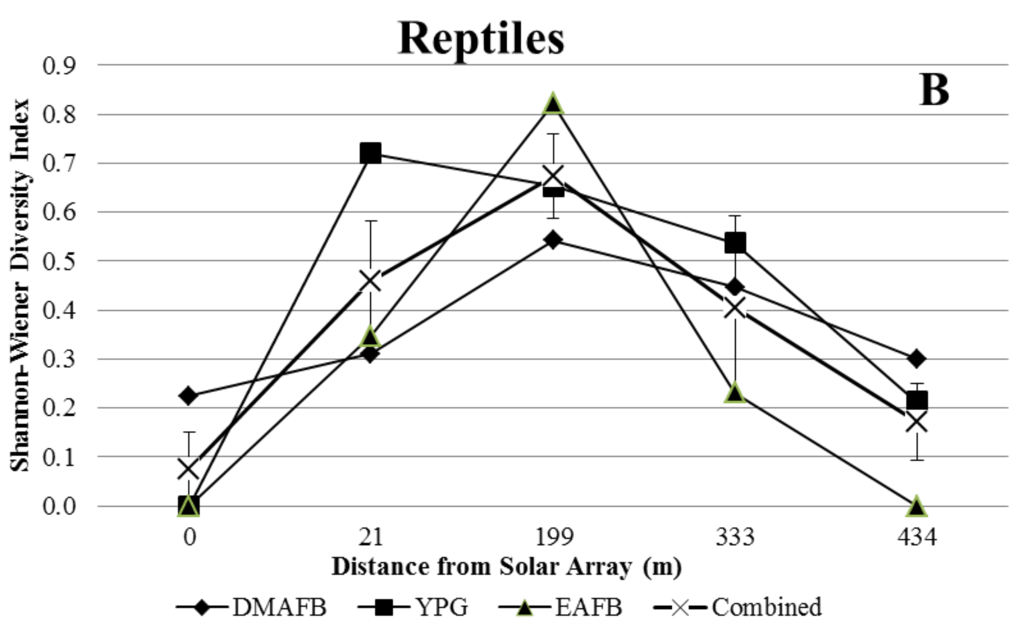
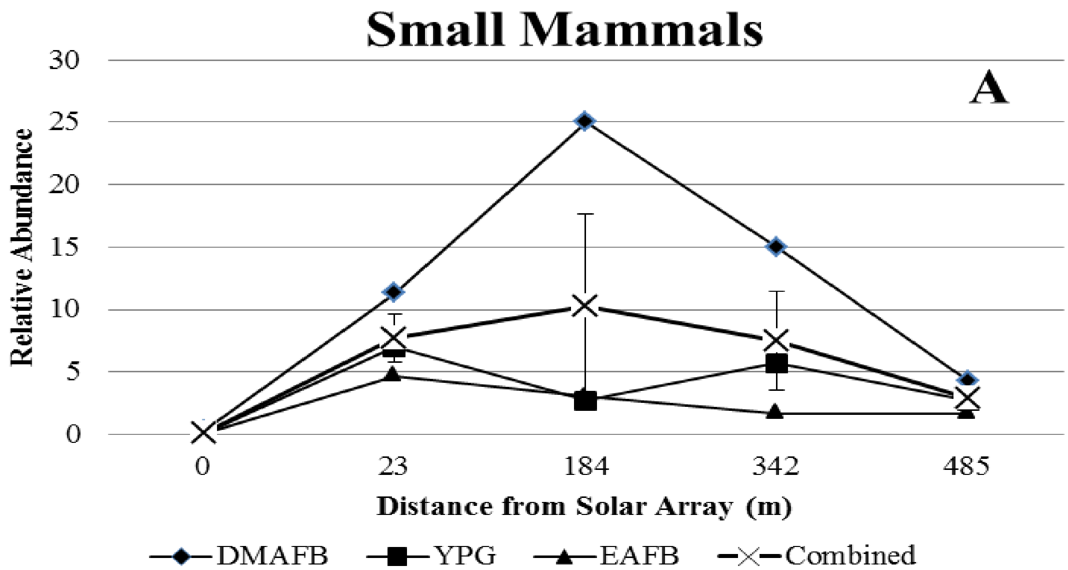


Figure 7. Diversity index of small mammals (A) and reptiles (B) at each of three military installations in the Desert Southwest during trapping efforts between November 2014 and July 2015.

Relative abundance for each installation was highest at DMAFB and lowest at EAFB (Figure 8). In general, peak abundance numbers were observed at middle distance with few individuals caught within the solar array.



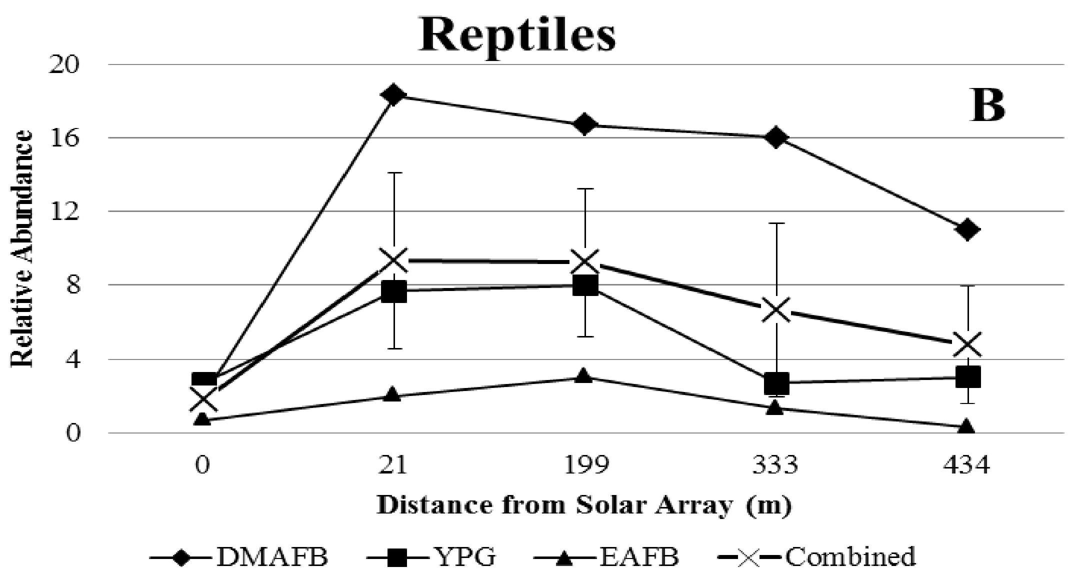


Figure 8. Relative abundance of small mammals (A) and reptiles (B) at each of three military installations in the Desert Southwest during trapping efforts between November 2014 and July 2015.

Objective 3. Evaluate the mitigation value of "soft-footprint" solar development when compared to standard "hard-footprint" development.

Our trapping efforts within the solar arrays resulted in a combined 17 captured individuals including both small mammals and reptiles. Only the intermediate type of footprint (DMAFB) captured any individuals within the solar array.

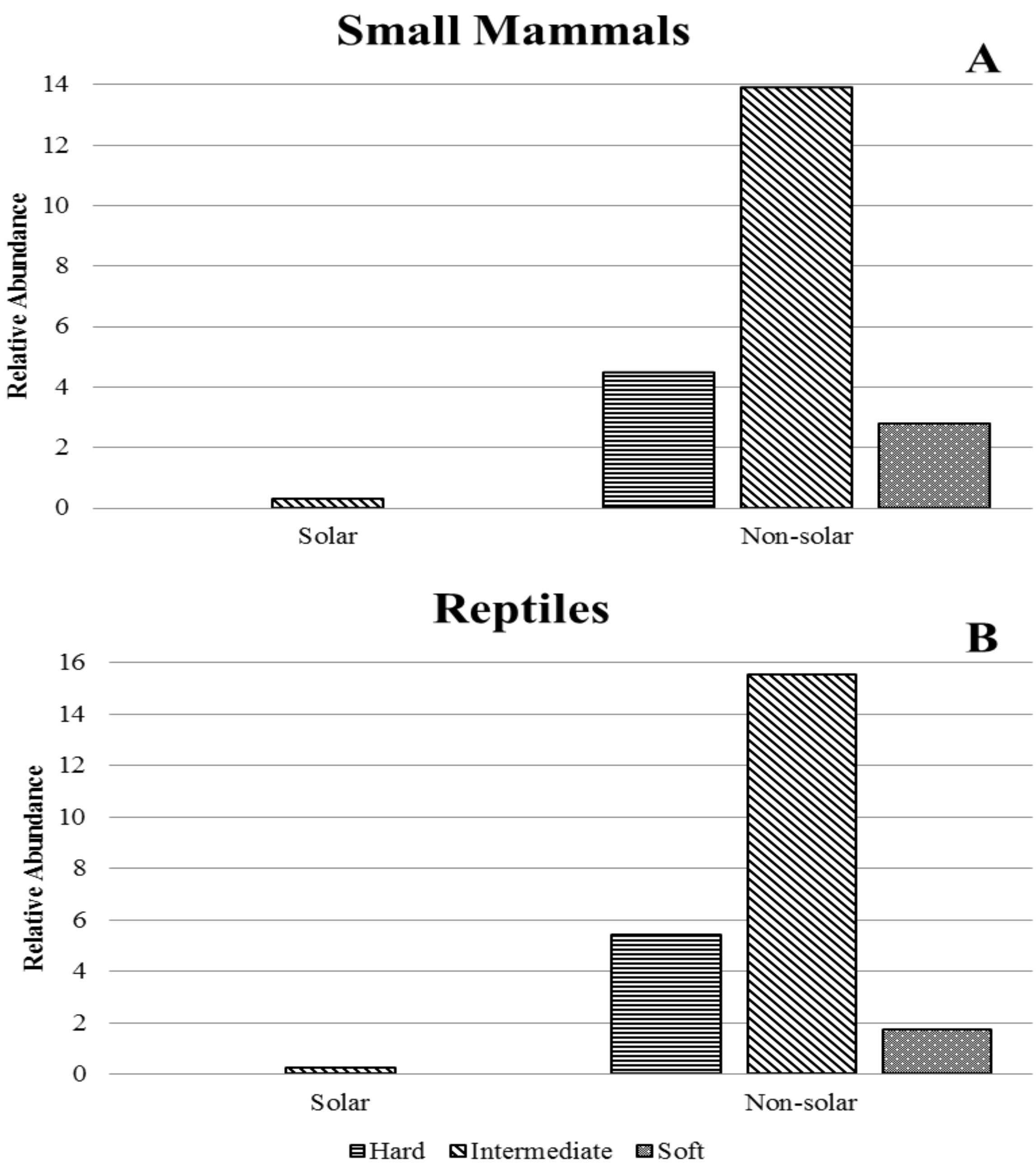


Figure 9. Comparison of captured individuals between traps located within the solar array and those beyond the solar array in three Desert Southwest military installations, 2014-2015. Relative abundance was measured as the average number of individuals captured per footprint type.

DISCUSSION

Sustaining and conserving suitable habitats and resources for sensitive species allow military installations to manage potential risk and maintain compliance with Federal regulations such as the Endangered Species Act (ESA). In addition, a memorandum of understanding between the Department of Defense (DoD) and the International Association of Fish and Wildlife Agencies directs the management of natural resources on military installations under provisions of the Sikes Act (USC 1960). Although many small mammal and reptile species on military lands are not currently protected under the ESA, they represent species that could affect DoD actions in the future. Meeting Federal compliance is vital to mission implementation and to maintaining military training activities across installations. Therefore, the impacts to small mammal and reptile communities presented by renewable energy development on DoD lands must be identified to avoid conflicts between wildlife at risk and military operations.

This study was designed to determine the impacts solar development has on species at risk in the Sonoran and Mohave deserts on DoD lands. We used small mammal and reptile communities to estimate the impact of three solar developments on at risk species. Our results suggest that the wildlife communities within the solar facility developments were displaced almost completely as hypothesized by previous researchers (Lovich and Ennen 2011; Northrup and Wittemyer 2013). Our findings indicate that communities of these two taxa disperse into the nearest available habitat around the facility. We detected increased diversity and abundance in these taxa at 300-400m from the solar array. These results suggest that the physical footprint regardless of intensity (Hard, Intermediate or Soft) displaces the wildlife community completely. Our findings also indicate that the displacement of the wildlife community results in a halo of increased diversity and abundance at 300-400m from the solar facility. These results can inform wildlife management decisions while maintaining military missions. Developing highly disturbed areas for solar development may cause the least impact to existing wildlife communities (Stoms et al. 2013) with minimal displacement of existing animals. For this reason we encourage installations to assess existing disturbed lands for solar development which will reduce displacement risk to both small mammal and reptile communities.

While we detected consistent trends in species richness, diversity, and abundance across the three solar arrays, data patterns may have been driven by site related conditions. At EAFB, a severe drought (Herbst and Kumazawa 2013; EAFB 2014; EAFB 2015) likely contributed to low captures and possible extirpation events as documented during other severe droughts (Ehrlich et al. 1980). The presence of only two small mammal species across all trapping grids suggests that current climatic conditions are a stronger driver on these communities than the presence of the solar array thus altering community dynamics (Dale et al. 2001) on a scale larger than our sampling efforts could detect. We also documented a common raven (*Corvus corax*) that raided five Sherman traps with small mammals and successfully mutilated the specimens beyond recognition or flew off with them. This occurred on the first trap-day only. At Davis-Monthan Air Force Base (DMAFB), we had a unique situation of habitat alteration both inside and outside of the physical footprint of the solar array from "hydro-seeding" (slurry combination of seed and mulch) in addition to invasive plant encroachment primarily by buffelgrass (*Pennisetum ciliare*). This provided the only habitat available to Arizona cotton rats (*Sigmodon arizonae*; Gwinn et al.

2011). These unique conditions may have contributed to the site specific results on these bases. We explain the specific findings and patterns for each objective below.

Objective 1. Quantify differences in reptile and small mammal diversity and abundance between solar development sites and un-impacted sites on DoD installations.

We report on three different aspects of species composition; species richness, diversity and abundance. We used these three aspects to evaluate the impact of solar development to establish community assemblages of small mammals and reptiles. Our results concerning the solar array versus our control sites indicate that solar development eliminates area as potential habitat for small mammals and reptiles. Our findings also indicate that species richness, diversity and abundance of these two taxa were negatively correlated with the presence of the solar array. These findings also provide a baseline that can be used to compare richness, diversity and species abundance across time (Bejder et al. 2006). Our extensive trapping efforts detected so few individuals within the solar array that our species richness, diversity, and abundance estimates were functionally zero. Given that these three solar arrays have been established for several years (multiple species generations) enough time has passed to allow for recolonization if the habitat was suitable, yet no recolonization has occurred. These findings suggest that the development of these solar arrays lead to the loss of the site as wildlife habitat and quantify similar to observations by Lovich and Ennen (2011).

Objective 2. Identify the spatial extent of solar development impacts on wildlife communities with application to Species at Risk.

Our results suggest that both small mammals and reptiles avoided these solar arrays. In addition, species richness, diversity and abundance increased with distance from the solar array. This pattern is similar to the response of these taxa to road development (Findlay and Houlahan 1997; Fahrig and Rytwinski 2009) and land conversion (Findlay and Houlahan 1997). While, this pattern of response to development was observed by Lovich and Ennen (2011), other researchers found no consistent response of small mammals to anthropogenic disturbance (Rosa and Bissonette 2007). We found a consistent bell-shaped curve distribution across distance for species richness, diversity, and abundance for all three DoD installations. The tails of this curve occurred at the solar array and at the control. The peak of species richness, diversity and abundance was observed at an intermediate distance (300 to 400m) from the solar array (Table 6, Figures 6 and 8). This was likely due to displacement and subsequent dispersal of these two taxa (Lidicker 1975) into the surrounding landscape. This halo of increased species richness, diversity and abundance at 300 to 400m from the solar array suggests that disturbance from the construction of the solar arrays has altered the potential carrying capacity (Robbins 1973) in the adjacent landscape.

Objective 3. Evaluate the mitigation value of "soft-footprint" solar development when compared to standard "hard-footprint" development.

Comparison of "soft" and "hard" footprint designs does not generally suggest measureable differences. However, we conclude that in all cases species richness is ≤ to surrounding species richness (Tables 5 and 6), but we do not suggest direct comparisons due to the unique species composition at each facility. Figure 8 indicates that relative abundance is nearly non-existent as compared to the surrounding landscape in all cases. This contradicts previously held perceptions of “soft” footprint design and potential benefits for at risk species such as the Mohave ground squirrel (*Xerospermophilus mohavensis*; Gatlin 2012). It is possible that due to the construction of these solar arrays in these environments, the disturbance and displacement impacts may be permanent regardless of the surface maintenance. There are examples of small mammals avoiding areas of high soil compaction (Malizia et al. 1991; Ignacio et al. 2007) likely due to high energy costs adversely affecting thermoregulation (Vleck 1991). Considering that each of these sites was within either Mohave or Sonoran deserts, this may well be the case in our different footprint types. This has been laboratory tested with some species suggesting that high soil compaction results in little to no burrowing activity (Ducey et al. 1993). This question of soil compaction should be explored further to assess potential mitigation alternatives for this type of disturbance during the construction of solar arrays.

Objective 4. Provide management recommendation to mitigate and monitor impacts of current and future solar development projects on DoD installations in the desert southwest.

Natural resource management recommendations associated to the successful development, operation, and maintenance of renewable energy sources are paramount to become a net-zero energy military installation. Although each installation is unique in their missions, there are some general patterns we derived from the data collected in this project that can help guide environmentally responsible solar energy generation across all solar developments on military installations. It is important to note that our management recommendations are specific to photo-voltaic solar arrays and may not be applicable to other types of solar energy generation technology such as concentrated solar power technology or heliostat power plants (a.k.a. power towers).

1. It is our recommendation to prioritize proposed development of solar arrays towards disturbed or previously disturbed areas. Prioritizing solar development on disturbed lands will likely expedite the process by reducing time associated with ordinance clearances, cultural sites, and environmental compliance including potential impact to species at risk.
2. We recommend that an initial survey be conducted on proposed site developments to identify any potential at risk species identified in an installation’s INRMPs. This should include identifying features that may attract or concentrate small mammals and/or reptiles.
3. If at risk species are identified during an initial survey, monitor the immediate and adjacent areas (up to 400 m for the proposed solar development) to determine if any mitigation measures are warranted.
4. We recommend having a wildlife biologist document any active burrows within the proposed solar development. If active burrows are identified, we recommend attempting to trap and relocate those individuals at least 400 m outside of the immediate impact area immediately prior to construction to reduce collapsing active burrows on existing wildlife. This will also reduce the level of dispersal into the adjacent landscape thus reducing stress on already limited resources.
5. As most solar arrays are typically fenced (chain-linked) for security purposes, we recommend installing low to the ground openings (during construction) to allow wildlife

to move through the fence rather than digging under the fence. This can help maintain the integrity of the fence for a longer duration.

We conclude that the development and operations of a solar array does not produce “edge” as defined by Murcia (1995). However, the effect of this type of development on existing small mammal and reptile communities has measurable impacts. This effect is primarily observed as displacement where the area physically developed for the solar array is generally considered non-habitat or low-quality habitat for these communities as measured by three metrics: species richness, species diversity, and relative abundance. On open desert landscapes, the development of solar arrays will likely create islands of non- or low-quality habitat increasing heterogeneity in the landscape. Furthermore, the increase in abundance adjacent to solar arrays may unbalance the equilibrium of that habitat beyond its carrying capacity. The results presented in the report will need to be considered as solar generation continues to scale up and solar arrays become a more prominent on military landscapes to balance military missions such as net-zero energy mandate (Booth et al. 2010) with natural resource missions such as installation-specific Integrated Natural Resource Management Plans (INRMPs).

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