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Source: Copeia, 2012(2):222-228. 2012.

Published By: The American Society of Ichthyologists and Herpetologists

DOI: <http://dx.doi.org/10.1643/CE-11-102>

URL: <http://www.bioone.org/doi/full/10.1643/CE-11-102>

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Nesting Ecology of a Population of *Gopherus agassizii* at a Utility-Scale Wind Energy Facility in Southern California

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We investigated the annual nesting ecology of a population of Desert Tortoises (*Gopherus agassizii*) inhabiting a utility-scale renewable energy (USRE) facility in southern California and compared our results with populations inhabiting relatively undisturbed sites. In 2000, 15 radio-tracked females produced 29 clutches, and 24 nests were monitored to examine nest-site selection, nest predation, hatching success, date of emergence of hatchlings, and hatchling mass and carapace length. Overall, the nesting ecology of the population inhabiting the USRE facility was very similar to other populations of Desert Tortoises inhabiting relatively undisturbed habitats. Oviposition occurred from 12 May to 8 July, which was similar to other sites. Nest depths (11.1 cm), nest predation (12%), hatchling emergence date (7 August and 29 September), and hatchling morphometrics (i.e., MCL: 44.5 mm; mass: 23 g) were all within ranges reported in other populations. Unlike within other populations, we observed no relationship between hatchling size and either maternal body size or egg width. We found no evidence of females selecting for a particular burrow for oviposition of eggs based on environmental or anthropogenic variables. Most nests were located in or near burrows, and nest depth was greater for nests near the entrance than those deeper in the burrow. Although this study suggests that the nesting ecology of the Desert Tortoise population we studied was not adversely affected by the USRE facility, this relationship is only correlative because our study was not a before-after-control-impact (BACI) study, which would establish a cause and effect relationship. As pointed out in a recent review, BACI studies are critically needed to address the wildlife impacts of utility-scale renewable energy development.

ENERGY demand is rising concomitantly with increases in the human population, especially within and around the desert ecosystem of Southern California. With the increased popularity of alternative energy in the 1980s, numerous utility-scale renewable energy (USRE) facilities, especially wind farms, were built in southern California altering the landscape (Pearson, 1986; Wilshire and Prose, 1987). With California vowing to increase its renewable energy electrical sales from 12 to 33% by 2020 (State of California, 2005), numerous USRE developments (i.e., wind and solar facilities) are proposed for construction throughout southern California, including relatively intact Desert Tortoise (*Gopherus agassizii*) habitat (Lovich and Ennen, 2011).

Unlike volant vertebrate species (i.e., birds and bats), little is known about the effects of USRE facilities, in particular wind energy, on non-volant terrestrial species, such as *G. agassizii* (Lovich and Ennen, 2011). This is ironic because over 25 years ago, *G. agassizii* was identified as a significant impediment to the construction of USRE facilities (Pearson, 1986). Although this species is considered one of the most-studied turtle species in the United States (Ernst and Lovich, 2009), there is a scarcity of research focusing on the effects of USRE facilities on *G. agassizii* (but see Lovich and Daniels, 2000; Lovich et al., 2011a, 2011b, 2011c).

With renewed interest in renewable energy, large tracts of desert land will be altered for the development of USRE facilities, including habitat of *G. agassizii* (Lovich and Ennen, 2011). Habitat degradation and fragmentation associated with these facilities (i.e., roads, fencing, erosion, fire, and construction) are a potential concern to recovery of *G. agassizii*. Because the reproductive output of *G. agassizii* is

related to annual precipitation and food plant biomass (Turner et al., 1984, 1986; Lovich et al., 1999), habitat degradation and fragmentation could decrease resource availability, thus limiting reproductive output. Although the reproductive ecology of *G. agassizii* is well studied (reviewed by Ernst and Lovich, 2009), most of our knowledge is from natural sites without numerous anthropogenic structures or disturbances. Because of this and California's initiative to increase the construction of numerous USRE facilities in habitat for *G. agassizii*, we investigated the nesting ecology of tortoises at a wind energy facility in southern California and compared nest and nesting characteristics from the wind energy facility to those reported from other populations throughout the distribution of *G. agassizii* and the closely related *G. morafkai*.

MATERIALS AND METHODS

Study site.—The study site is located (33°57'06"N, 116°40'02"W, WGS84) at what is known locally as the Mesa wind farm with 460 turbines, 51 electrical transformers, and an extensive network of access roads on land administered by the Bureau of Land Management (BLM) near Palm Springs, California. The site was developed for wind energy production starting in 1983, profoundly changing the landscape (Lovich and Daniels, 2000). Mesa is situated at the westernmost portion of the distribution of *G. agassizii* in the Sonoran Desert (Luckenbach, 1982; Patterson, 1982) and considered unusual habitat for this species due to steep topography, substantial rainfall (relative to other tortoise habitat), an unusual mix of plant communities (USFWS,

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Submitted: 21 July 2011. Accepted: 28 January 2012. Associate Editor: J. D. Litzgus.

© 2012 by the American Society of Ichthyologists and Herpetologists DOI: 10.1643/CE-11-102

1994), and a history of human disturbance from grazing, energy development, and fire (Lovich et al., 2011c). Detailed descriptions of Mesa are given in Lovich and Daniels (2000) and Lovich et al. (2011b).

X-radiography and tortoise reproduction.—From March to August 2000, we monitored the reproductive output of *G. agassizii* by outfitting adult females with radio-telemetry and using X-radiography. At the time of capture, midline carapace length (MCL) and mass were recorded for each individual. Females were located at approximately weekly intervals using radio-telemetry. The radios affixed to individuals weighed 50 g (model R1540, Advanced Telemetry Systems, Isanti, MN; Boarman et al., 1998). X-radiographs were taken using a portable X-ray machine (model HF60, Min-Xray, Northbrook, IL) at a dosage of 60 kilovolts for 0.10 seconds at a distance of 69.6 cm. X-radiographs were taken at approximately weekly intervals. This setting and the use of 3M's Imation Trimax Regular Rare Earth Cassettes subjected individuals to low levels of radiation exposure (Hinton et al., 1997).

Depending on the stage of shell development of eggs detected on the X-radiographs, thread-trailing devices (Claussen et al., 1997) were attached to the posterior end of the carapace. This procedure was conducted for the first and second clutches and only implemented on females expected to oviposit within seven days. Daily, we located and weighed each female to monitor weight loss, which would indicate that oviposition occurred (≈ 30 grams multiplied by the number of eggs). When weight loss occurred, we retraced the trail of thread and searched for the nest, concentrating on burrows that were occupied during the preceding days. After oviposition was confirmed, the thread trailing device was removed and was not reattached until a second clutch was detected on the X-radiograph.

At each potential nest site, we carefully excavated soil by hand to locate the nest. When a nest was located, we collected GPS data, the date of oviposition, depth to the top of the uppermost egg, and the distance from the lip of the upper burrow entrance to the closest egg. If the nest was not at a burrow, again we recorded depth but also recorded the distance to the nearest shrub, identified the shrub to species, and recorded the compass direction of vegetation from the nest. Each nest was carefully reburied with soil to the same depth as it was found. We recorded egg width from the X-radiographic images for each egg using digital calipers (Mitutoyo, Aurora, IL).

While following the thread trails, we collected several habitat variables at burrows occupied/visited by each female during the nesting season and burrows with nests. We only collected data at burrows and not pallets. At each burrow, including burrows with nests, we recorded GPS coordinates, elevation (m), slope aspect and angle, distance (m) to the nearest shrub and the species of shrub, orientation of burrow mouth, and distance to anthropogenic structures (i.e., roads, turbines, substations, and transformers) associated with the USRE facility. Slope aspect was estimated with a compass, and slope angle was estimated using an inclinometer. Also, burrow dimensions (i.e., length, width, and height) were recorded. Because we collected environmental and anthropogenic variables at all burrows visited by females during the reproductive season, we can establish female preference and nest-site selection by comparing

variables of burrows with nests and occupied burrows without nests. Also, we collected temperature data for Mesa using HOBO data loggers (HO8-001-02, Onset Computer Corporation, Bourne, MA) during the reproductively active months (April–August). We compared nest placement (i.e., depth and distance from burrow entrance) between Mesa and another population of *G. agassizii* at Fort Irwin, California reported by Baxter et al. (2008) and compared mean daily temperature between the two sites. Although Baxter et al. (2008) did not report temperature data from Fort Irwin, we obtained temperature data collected near Fort Irwin in Barstow, California at the Barstow–Daggett Airport (<http://mesowest.utah.edu/index.html>).

Hatchling emergence.—After 70–76 d of incubation, we returned to the nests and installed a shaded neonate retaining enclosure (hardware cloth: diameter 30 cm, height 15 cm, 0.64 cm gauge) over each surviving nest. Nest enclosures were buried 3 cm deep into the soil to prevent hatchlings from escaping. Enclosures were checked daily for hatchlings after installation. Following emergence, each hatchling was measured (MCL and mass), the date was recorded, and they were released at their nest site.

Statistical analyses.—All data were tested for normality, and outliers were removed to meet the assumption of normality where appropriate. Data points were considered outliers if they were two standard deviations away from the mean and affected the assumption of normality. Due to repeated measures (i.e., multiple observations of an individual), all analysis of covariance (ANCOVA) and analysis of variance (ANOVA) tests were conducted as either incomplete or complete block designs with random effects (i.e., clutch number nested within individuals). Because maternal body size could influence nest depth, we divided nest depth by female MCL and used this measurement ratio as the dependent variable in an ANCOVA with clutch number as a factor, nest distance from the entrance of the burrow as a covariate, and an interaction term between clutch number and nest distance from the entrance of the burrow. Using only females that produced two clutches, we conducted a block design (i.e., clutch number nested within individuals) ANOVA with elevation (m) as the dependent variable and clutch number as the independent variable.

To determine if *G. agassizii* at Mesa displayed nest-site selection and because data did not conform to normality, we conducted a multi-response permutation procedure (MRPP; McCune and Grace, 2002). In this analysis, we used elevation, slope angle, distance to shrub, distance to disturbed area (i.e., anthropogenic features associated with wind energy) and burrow dimensions (i.e., length, width, and height) of occupied burrows and compared these data between burrows with nests and occupied burrows without nests. Because of the small sample size for both first and second clutches, we elected to combine clutch data in the MRPP for a more robust sample size. To account for independence issues of multiple burrows for each tortoise, we calculated mean values for each of the measured variables for burrows with and without nests and ran the MRPP using R statistical software (R Development Core Team, version 2.8.0, 2008). For circular variables recorded in degrees (i.e., slope aspect and burrow orientation), we used two Watson-Williams F-tests to determine if slope aspect and burrow orientation differed between occupied burrows

with nests and other occupied burrows without nests. However, both of these tests are affected by independence problems since an individual female had multiple burrows and nests. Therefore, an individual that utilized more burrows than another female might influence the statistical test disproportionately. Oriana software (Kovach Computing Services, Pentraeth, Isle of Anglesey, Wales, U.K.) was used for all circular statistics.

To determine if incubation time differed between first and second clutches, we conducted an incomplete block design ANOVA (i.e., clutch number nested within individual tortoises as a random factor) using incubation time as the dependent variable with clutch number as the factor. To test the influence of maternal body size and clutch number on hatchling MCL and mass, we conducted two incomplete block design ANCOVAs (i.e., clutch number nested within individual female as a random factor) with hatchling MCL or mass as the dependent variable using female MCL as a covariate to remove maternal effects, clutch number as a factor, and a clutch number by female MCL interaction term. To determine the influence of egg width and clutch number on hatchling size, two incomplete block design ANCOVAs (with individual female nested within clutch number as a random factor) were performed with clutch number as a fixed effect, egg width as a covariate, and an interaction term between either egg width or clutch number. Hatching success data did not meet the assumption of normality even after arcsine square root transformation. Therefore, to account for repeated measures in an analysis, we excluded two individuals that only produced first clutches and conducted a matched pair t-test to compare hatching success between first and second clutches. To compare temperature between Mesa and Fort Irwin, CA, we conducted a two-factor ANOVA. All univariate statistical analyses were performed using Jmp 8 (SAS Institute, Inc., Cary, NC).

RESULTS

Nesting ecology.—Fifteen females were monitored from 23 March to 30 July 2000, and they produced a total of 125 eggs in 29 clutches. Of those 15 females, 13 produced second clutches and one produced a third clutch. Clutch size ranged from 1–8 eggs, and the mean clutch size was 4.3 eggs (SD = 1.37). First (\bar{x} = 4.2, SD = 1.6, n = 15) and second clutch sizes (\bar{x} = 4.5, SD = 1.8, n = 13) did not differ significantly (F = 0.17, df = 1,26, P = 0.69). Mean egg width was 38.6 mm (SD = 2.8, n = 29). The earliest date of oviposition occurred on 12 May while the latest clutch that was monitored was oviposited on 8 July. Thirteen females were thread-trailed to locate 23 of 25 nests oviposited. Additionally, we located one nest without thread (maternity known) for a total of 24 nests monitored. All clutches were oviposited in association with a burrow except for one clutch, which was oviposited in a road berm under a Creosote Bush (*Larrea tridentata*). For a given female, all first and second clutches were in different burrows, on average 227.3 m (SD = 36.1, n = 24) apart from each other, and no burrow had multiple clutches associated with it during the nesting season. For females that oviposited two clutches, there was no significant elevation difference (F = 0.09, df = 1,10, P = 0.77) between first (\bar{x} = 756.3 m, SD = 45.1, n = 11) and second (\bar{x} = 758.4 m, SD = 41.3, n = 11) clutches.

Unknown predators depredated three nests (12%), all of which were second clutches and accounted for 31.4% of

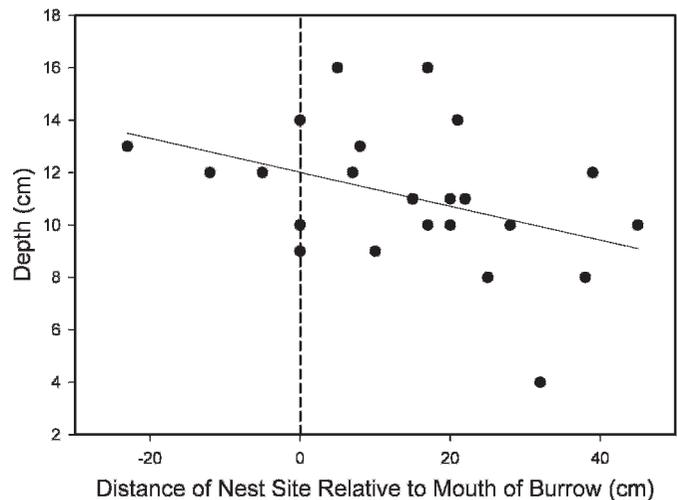


Fig. 1. Depth and distance relative to the burrow entrance of nests from a population of *Gopherus agassizii* inhabiting a wind energy farm in Riverside County, California showed a negative relationship. The dashed line represents the mouth of the burrow and positive distances represent nest within a burrow.

eggs in second clutches and 15.0% of all eggs produced. Only three nests (12%) had evidence of a female voiding, and none of these nests were destroyed. Although three nests were located on burrow aprons and three were deposited directly beneath the mouth of the burrow, most (i.e., 17 nests) were located inside burrows. Mean distance from the burrow mouth was 13.3 cm (SD = 13.1, n = 20) with a mean depth of 11.1 cm (SD = 2.47, n = 20). Mean distance from the burrow mouth and mean depth did not significantly differ among first and second clutches with regard to the interaction term (depth vs. distance; F = 1.45, df = 1,19, P = 0.24) or did depth as a factor in the ANCOVA (F = 1.08, df = 1,19, P = 0.31). However, there was a relationship between nest distance from the burrow entrance and depth (F = 4.42, df = 1,19, P = 0.05; Fig. 1), which produced a depth and distance continuum where nests outside the burrow and farther away from the entrance of the burrow were oviposited deeper and nests inside the burrow and farther away from the entrance were oviposited shallower. During the nesting season, mean daily temperatures at Mesa (\bar{x} = 24.4°C, SD = 5.7) were consistently lower (F = 71.3, df = 4,4, P < 0.0001) than Ft. Irwin, CA (\bar{x} = 28.4°C, SD = 5.7).

Nest selection.—*Gopherus agassizii* did not exhibit nest-site selection as shown by MRPP using the non-circular variables (Δ_o = 462.4, Δ_e = 449.5, P = 0.93), or using the circular variables to compare slope aspect and burrow orientation between nest burrows and other burrows used by the females (aspect: F = 1.21, df = 1, P = 0.275; orientation: F = 1.87, df = 1, P = 0.175).

Emergence and hatchling.—The first hatchling emerged on 7 August, 85 days after oviposition. The last hatchling to emerge was on 29 September, 81 days after oviposition. Incubation time varied from 74–100 d (\bar{x} = 84.6 d, SD = 6.4, n = 20) and was significantly different between first (\bar{x} = 87.9, SD = 5.4, n = 12) and second (\bar{x} = 80.6, SD = 5.2, n = 8) clutches (F = 18.6, df = 1,18, P = 0.0005). Hatching success for non-predated nests was greater for second clutches (\bar{x} = 82.2%, SD = 18.1%, n = 8) than first clutches

Table 1. A Comparison between Hatching Success among Clutches and Overall Hatching Success from a Population of *Gopherus agassizii* Inhabiting a Wind Farm Facility in Southern California. Hatching success (% Succ.) was calculated for each monitored clutch by dividing the number of successfully hatched eggs by the total number of eggs oviposited but excluding nest which experienced nest predation. Hatching success incorporating nest predation (% Succ. pred.) included the nest predation within the calculation.

Female ID number	First clutches			Second clutches			Both combined	
	# Eggs	# Hatch	% Succ.	# Eggs	# Hatch	% Succ.	% Succ.	% Succ. pred.
3	4	3	75.0%	5	5	100.0%	87.5%	87.5%
6	1	0	0.0%	3	2	66.7%	33.3%	33.3%
8	4	3	75.0%	8	0 ^a	0.0%	75.0%	37.5%
10	6	5	83.3%	4	3	75.0%	79.2%	79.2%
16	3	2	66.7%	5	5	100.0%	83.3%	83.3%
20	4	3	75.0%	2	0 ^a	0.0%	75.0%	37.5%
23	4	4	100.0%		NA ^b		100.0%	100.0%
32	8	8	100.0%	7	6	85.7%	92.9%	92.9%
35	5	5	100.0%	6	0 ^a	0.0%	100.0%	50.0%
36	4	2	50.0%	4	4	100.0%	75.0%	75.0%
49	3	1	33.3%				33.3%	33.3%
61	5	4	80.0%	2	1	50.0%	65.0%	65.0%
69	5	4	80.0%	5	4	80.0%	80.0%	80.0%
Overall nest success			70.6 ± 29.8%			82.2 ± 18.1%	75.3 ± 21.2%	65.7 ± 24.3%

^a Nest predation

^b Nest not found

(\bar{x} = 70.6%, SD = 29.8%, n = 12; Table 1), but was not significantly different (t -ratio = 1.28, df = 7, P = 0.24). When nest predation was incorporated in the calculation of hatching success, hatching success was not significantly different between first (\bar{x} = 70.6%, SD = 29.8%, n = 12) and second clutches (\bar{x} = 65.7%, SD = 38.2%, n = 11; t -ratio = -0.71, df = 10, P = 0.50). Of 20 nests that produced hatchlings, 74 hatchlings (including two deformed/trapped nestlings) were produced. Seventeen eggs from multiple nests (n = 14) did not hatch, and when nests were excavated, eggs were found in various stages of development ranging from no visible embryo development (five eggs) to fully developed embryos (four eggs) that died. Most of the eggs that did not hatch had early stage embryos (eight eggs). First clutches contained 12 non-viable eggs, and second clutches contained five non-viable eggs. Of the 72 hatchlings that were able to emerge from the nest chamber, two (0.03%) showed some degree of deformity.

Mean hatchling MCL was 4.45 cm (SD = 0.19; range 3.61–4.97), and mean hatchling mass was 23.0 grams (SD = 3.9; range 12.7–30.0). Hatchling MCL was not significantly different between first (\bar{x} = 4.46, SD = 0.28, n = 12) and second clutches (\bar{x} = 4.39 cm, SD = 0.20, n = 8; Table 2). Also, hatchling mass was not significantly different between first (\bar{x} = 23.32, SD = 4.22, n = 12) and second (\bar{x} = 21.80, SD = 3.40, n = 8; Table 2) clutches. In all the ANCOVAs, maternal MCL and egg width had no significant relationship with hatchling MCL or mass (Table 2). Likewise, all the interaction terms were not significantly different either.

DISCUSSION

Nesting ecology at Mesa appears to be similar to populations in more natural areas as reported in other reproductive studies of *G. agassizii* (Turner et al., 1986; McLuckie and Fridell, 2002). For example, oviposition of first clutches at Mesa occurred in May–June while oviposition of second

clutches occurred in June–July. However, when third clutches were present at another California site, oviposition occurred in June and July (Turner et al., 1986); whereas at Mesa, oviposition of third clutches occurred only in July (Lovich et al., 1999; this study). Also compared to other *G. agassizii* studies, we found a similar percentage of nests being depredated. For example, Mesa nest depredation was within the range (i.e., 12.0–70.0%) reported at other sites in the Mojave Desert (Hampton, 1981; Roberson et al., 1985; Bjurlin and Bissonette, 2004).

We found no evidence of nest sites being associated with any anthropogenic structures or any other variables collected at Mesa. This finding was interesting because burrows of *Gopherus agassizii* were found to be non-randomly dispersed throughout Mesa and were in close proximity to turbines, concrete pads, and roads (Lovich and Daniels, 2000), and nests are usually constructed in the burrow or in association with a burrow (e.g., on the apron; Hampton, 1981; Bjurlin, 2001; Baxter et al., 2008; this study). Other nest characteristics comparisons, such as depth, between Mesa and other populations of *G. agassizii* were very similar. Mesa's nests were constructed at depths (11.1 cm, SD = 2.5) within the reported range (10–25 cm; Nichols, 1953; Hampton, 1981). When comparing nest depths (8–10 cm) and placement relative to the burrow entrance (70 cm) together to a population at Fort Irwin, CA (Baxter et al., 2008), the nests at Mesa were slightly deeper, but closer to the entrance of burrow (13.3 cm, SD = 13.1). These differences may be associated with temperature differences among the two sites (Mesa and Fort Irwin, CA), where Mesa has consistently lower temperatures from May–August. Because Mesa was cooler, depositing eggs closer to the burrow entrance could allow eggs to experience warmer incubation conditions (Baxter et al., 2008).

Hatchling success in *Gopherus agassizii* varies somewhat throughout its range (Turner et al., 1986; McLuckie and Fridell, 2002). Mesa's hatching success rates (75%) were

Table 2. Statistical Results from Four ANCOVAs Investigating Differences between Hatchling Morphometrics (e.g., Midline Carapace Length [MCL] and Mass) and Clutch Number (Clutch no.) in a Population of *Gopherus agassizii* Inhabiting a Wind Energy Facility in Southern California. Female MCL (\varnothing MCL) and egg width (EW) were used as individual covariates.

Parameter	Clutch no.	Covariate	Covariate*clutch no.
Hatchling MCL	$F_{1,17} = 2.50$; $P = 0.13$	\varnothing MCL: $F_{1,17} = 0.18$; $P = 0.67$	$F_{1,17} = 0.48$; $P = 0.50$
Hatchling MCL	$F_{1,15} = 0.32$; $P = 0.58$	EW: $F_{1,15} = 2.27$; $P = 0.16$	$F_{1,15} = 0.54$; $P = 0.47$
Hatchling mass	$F_{1,17} = 2.58$; $P = 0.13$	\varnothing MCL: $F_{1,17} = 0.07$; $P = 0.80$	$F_{1,17} = 1.10$; $P = 0.31$
Hatchling mass	$F_{1,15} = 0.24$; $P = 0.63$	EW: $F_{1,15} = 2.62$; $P = 0.13$	$F_{1,15} = 0.48$; $P = 0.50$

within the range (73–82.5%) reported in other populations of *G. agassizii* (McLuckie and Fridell, 2002; Bjurlin and Bissonette, 2004). Elsewhere in California, Turner et al. (1986) reported a much lower hatching success of 45.6%; however, this was for eggs that had been removed to artificial nests, and it is unclear if the movement or potential difference in the artificial nest environment caused the lower hatching success.

At Mesa, the emergence dates and morphometrics of hatchling of *Gopherus agassizii* were similar to those in other studies. Mesa hatchlings emerged from the nest from 7 August to 29 September, which was comparable to other reported periods of emergence (McLuckie and Fridell, 2002). However, it is possible that some hatchlings overwinter (Gibbons and Nelson, 1978) at Mesa. We found a 4.9 cm MCL tortoise at Mesa on 6 May 2010 that was just within the range of MCL observed for hatchlings at our site in 2000. Overwintering behavior was reported by Grant (1936) for *G. agassizii* and suggested for *G. morafkai* by Averill-Murray et al. (2002). First clutches had a significantly longer incubation period than second clutches at Mesa. The difference was mostly likely associated with higher temperatures experienced by the second clutch relative to the first clutch. There was little difference in the mean incubation time between Mesa (84.56 d) and a population of *G. agassizii* in Utah (McLuckie and Fridell, 2002; 89.7 ± 3.25 d). At Mesa, hatchling MCL (44.3 mm) was very similar to other studies of *G. agassizii* (MCL: 45.0 ± 0.33 mm, McLuckie and Fridell, 2002; 43.8 ± 2.15 mm, Bjurlin and Bissonette, 2004). Although maternal influences, such as body size, on reproductive traits appear to be the norm for *G. agassizii* (i.e., egg dimensions: Wallis et al., 1999; McLuckie and Fridell, 2002; clutch size: Turner et al., 1986; Mueller et al., 1998; Wallis et al., 1999; McLuckie and Fridell, 2002; clutch frequency: Turner et al., 1986; Wallis et al., 1999; McLuckie and Fridell, 2002; annual egg production: Mueller et al., 1998; Wallis et al., 1999; McLuckie and Fridell, 2002), we found no support for maternal body size or egg dimensions influencing hatchling size (MCL and mass). Conversely, McLuckie and Fridell (2002) found maternal body size to positively influence hatchling MCL, but similar to our findings, found that hatchling MCL was not influenced by egg dimensions. The lack of maternal influence on hatchling size at Mesa could be explained by the size of the monitored females. Because the monitored females at Mesa were all relatively large (\bar{x} = 25.1 cm, SD = 1.5, range = 21.6–27), our sample probably did not include enough small individuals needed to detect this trend if it existed.

Knowledge of population demography, in particular reproduction, is crucial for understanding population-level trends and patterns. Although not as important as adult survivorship in population viability of *Gopherus agassizii* (Doak et al., 1994), reproductive output directly influences population demography, through its influence on recruitment. For example, Congdon et al. (1993), based on life-history tables, suggested that any life history parameter that was chronically and negatively affected could cause population declines in Blanding's Turtles, a species with similar age at maturity and longevity to desert tortoises. Therefore, any chronic perturbation to a population could have significant effects on the persistence of that population. Undoubtedly, USRE facilities leave enormous footprints within the desert ecosystem and a particular site (Pearson, 1986; Wilshire and Prose, 1987). Because egg production of *G. agassizii* has been correlated with annual plant biomass (Turner et al., 1984, 1986; Lovich et al., 1999), the alteration of a site due to construction and maintenance (i.e., roads, turbines, solar panels, mirrors, and electrical transformers) could negatively influence plant biomass and diversity (Lovich and Ennen, 2011), which in turn could adversely impact tortoise reproduction. It appears that the tortoise population at Mesa is stable (Lovich et al., 2011b), but additional research is needed to investigate the potential interactions between habitat modification and reproductive output in desert tortoises.

The results of this study suggest that the nesting ecology of a population of *Gopherus agassizii* at Mesa was not adversely affected by the long-term operation of a USRE wind farm when compared to other populations. However, without baseline data on nesting ecology before the construction of the wind energy farm this study cannot evaluate the actual effect of the facility on that population of *G. agassizii*. Our study does not represent a before-after-control-impact (BACI) study which is needed to elucidate a causal relationship between presence and operation of this particular USRE wind farm and their effects on the nesting ecology of *G. agassizii*. Because site-specific differences in habitat and environmental variables vary widely in the Desert Southwest, more studies, in particular BACI studies, would further our understanding of the effects of USRE on terrestrial wildlife, including *G. agassizii*. Until then, we know relatively little about the effects of renewable energy development on terrestrial wildlife (Lovich and Ennen, 2011), despite a societal rush to embrace that technology in the Desert Southwest and elsewhere.

ACKNOWLEDGMENTS

Many people assisted us during the course of this study. Field support for this project was provided by interns from the Student Conservation Association and volunteers too numerous to list. Special thanks to R. Daniels, R. Griese, M. Massar, and G. Wright for their long commitment to the support of our project. Dr. M. Westbrooks allowed us to use his veterinary facilities to process X-radiographs. Research was supported by the California Energy Commission (Research Development and Demonstration Division, Public Interest Energy Research program [contract #500-09-020]), California Desert District Office of the Bureau of Land Management (BLM), the Palm Springs–South Coast Field Office of BLM, and Joshua Tree National Park. M. Agha assisted with temperature data collection. We thank K. Nussear of the U.S. Geological Survey for his helpful comments on an earlier version of this manuscript. Research was conducted under permits from the U.S. Fish and Wildlife Service, California Department of Fish and Game, and the BLM. Special thanks to A. Muth for providing accommodations at the Philip L. Boyd Deep Canyon Research Center of the University of California, Riverside, during the development of the manuscript. Use of product trade names does not constitute U.S. Geological Survey endorsement of any product.

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