USE OF SIMULATED HIGHWAY UNDERPASS CROSSING STRUCTURES BY FLAT-TAILED HORNED LIZARDS (*PHRYNOSOMA MCALLII*)

Final Report 594

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16. Abstract

The flat-tailed horned lizard (*Phrynosoma mcallii*) occupies a restricted range in the Lower Sonoran Desert of southwest Arizona, southeast California, and adjacent land in Mexico. Because they exhibit behavior patterns that include basking and remaining motionless when danger approaches, flat-tailed horned lizards are particularly susceptible to mortality on roads. Therefore, roads and new road construction are recognized as threats influencing the long-term persistence of this species. The propensity for flat-tailed horned lizards to use culverts as road crossing structures to avoid vehicle-caused mortality is unknown. From 2005-2006 we studied flat-tailed horned lizard use of a variety of simulated road crossing structures. The study objectives were to 1) determine if flat-tailed horned lizards will pass through culverts of sizes commonly used in road construction, and 2) compare and describe the characteristics of culverts used by flat-tailed horned lizards to those not used. We built a testing facility with six culverts of three dimensions and two interior lighting options. All culverts were 40 feet long; the three types included 24-inch diameter steel culverts, 36-inch diameter steel culverts, and 4-foot tall by 8-foot wide box culverts. One of each type of culvert was lit with skylights, and one of each type of culvert had only natural light from the ends. Light and temperature conditions in the culverts were evaluated during the study. Out of 54 flat-tailed horned lizards placed in the testing facility, we observed 12 complete crossings. The 36-inch diameter culvert without skylights was used five times. The 24-inch diameter culvert with skylights was not used, and other culvert designs were each used once or twice. Results indicated that flat-tailed horned lizards can use culverts as road crossing structures, but the evidence did not reveal a strong selection for or against any culvert type. Recommendations for employing appropriate road crossing structures are discussed.

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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm^2	mm^2	Square millimeters	0.0016	square inches	in^2
ft^2	square feet	0.093	square meters	m^2	m^2	Square meters	10.764	square feet	ft^2
yd^2	square yards	0.836	square meters	m^2	m^2	Square meters	1.195	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	square kilometers	km^2	km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	cubic meters	m^3	m^3	Cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	cubic meters	m^3	m^3	Cubic meters	1.308	cubic yards	yd^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.								
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")	mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION					**ILLUMINATION**		
fc	foot candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS					**FORCE AND PRESSURE OR STRESS**		
lbf	poundforce	4.45	newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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I. EXECUTIVE SUMMARY

The flat-tailed horned lizard (*Phrynosoma mcallii*) occupies a restricted range in the Lower Sonoran Desert of southwest Arizona, southeast California, and adjacent land in Mexico. Because they exhibit behavior patterns that include basking and remaining motionless when danger approaches, flat-tailed horned lizards are particularly susceptible to mortality on roads. More importantly, highways fragment areas of habitat and isolate segments of lizard populations. Depending on the size of the isolated habitat patches, these populations may be non-viable without connections to the larger population. Therefore, roads and new road construction are recognized as threats influencing the long-term persistence of this species.

The propensity for flat-tailed horned lizards to use culverts as road crossing structures to avoid vehicle-caused mortality is unknown. From 2005-2006, Arizona Game and Fish Department researchers studied flat-tailed horned lizard use of a variety of simulated road crossing structures. The study objectives were to 1) determine if flat-tailed horned lizards will pass through culverts of sizes commonly used in road construction, and 2) compare and describe the characteristics of culverts used by flat-tailed horned lizards to those not used. The research team built a testing facility south of Yuma, Arizona, with six culverts of three dimensions and two interior lighting options. All culverts were 40 feet long; the three types included 24-inch diameter steel culverts, 36-inch diameter steel culverts, and 4-foot tall by 8-foot wide box culverts. One of each type of culvert was lit with skylights, and one of each type of culvert had only natural light from the ends. Light and temperature conditions in the culverts were evaluated during the study. Out of 54 flat-tailed horned lizards placed in the testing facility, 12 complete crossings were observed. The 36-inch diameter culvert without skylights was used five times. The 24-inch diameter culvert with skylights was not used, and other culvert designs were each used once or twice. Results indicated that flat-tailed horned lizards can use culverts as road crossing structures, but the evidence did not reveal a strong selection for or against any culvert type.

Because the 24-inch diameter culverts were used less frequently than the larger culverts and they seemed more susceptible to movement of soil, the research team tentatively recommends against using these culverts as standard road crossing structures for flat-tailed horned lizards. While the 36-inch diameter and the 4-foot by 8-foot box culverts were not immune to movement of sandy soil, they were not as vulnerable as the smaller culverts. Although the 36-inch diameter culvert may be the best option, either of the larger styles could work as a crossing structure, as long as fencing is used to funnel animals toward the culvert, it remains passable, preferably holds some soil on the floor, and allows some daylight through its length.

Other issues to consider in designing appropriate road crossing structures include: regular maintenance (i.e., maintaining substrate in culverts and ready access to culvert entrances), how many to install, where to install them, position under the road, and topography of the crossing site. Although this study showed that in an experimental situation flat-tailed horned lizards are capable of moving through culverts, they may exhibit different reactions to culverts under normal circumstances in their own territories or during typical dispersal. To further test road crossing structures as a viable mitigation measure for flat-tailed horned lizards, use of actual culverts under roads (with exclusion fencing) should be documented for this species in situ.

II. INTRODUCTION

The flat-tailed horned lizard (*Phrynosoma mcallii*) is a small cryptic lizard restricted to the western Sonoran Desert in southeast California, southwest Arizona, and adjacent land in Mexico. It is commonly found below 820 feet in areas with flat to modest (< 3%) slopes. The flat-tailed horned lizard was proposed for threatened species listing by the U.S. Fish and Wildlife Service (Service) in 1993. The proposal was subsequently withdrawn in 1997 when it was determined that population trend estimates were ambiguous, and threats (i.e., habitat loss/degradation) to the species did not warrant listing. In 1997, flat-tailed horned lizards gained protective status on public lands under a conservation agreement signed by several state and federal agencies. This conservation agreement implements the *Flat-tailed Horned Lizard Rangewide Management Strategy* (Flat-tailed Horned Lizard Interagency Coordinating Committee 2003). On 7 December 2005 the Service announced reinstatement of the 1993 proposed rule, but again withdrew it on 28 June 2006 (71 FR 36745).

In response to increasing transportation demands in southwestern Arizona, the Arizona Department of Transportation (ADOT) is developing plans to build new highways and improve existing highways within flat-tailed horned lizard habitat. The Rangewide Management Strategy recognizes roads and new road construction as threats influencing the long-term persistence of this species. Since flat-tailed horned lizards exhibit behaviors that include basking and remaining motionless when danger approaches, they are particularly susceptible to mortality on roads (Flat-tailed Horned Lizard Interagency Coordinating Committee 2003). More importantly, highways fragment areas of habitat and isolate segments of wildlife populations. Depending on the size of the isolated habitat patches, these populations may be non-viable without connections to the larger population (Trombulak and Frissell 2000). The Rangewide Management Strategy stipulates the installation of effective culverts to mitigate road effects and maintain connectivity between flat-tailed horned lizard populations bisected by paved roads proposed or authorized by signatories to the conservation agreement. It also states that the Flat-tailed Horned Lizard Interagency Coordinating Committee shall provide a culvert design. To date, there has been little information to guide this effort.

Highway crossing structures can mitigate some roadway effects on wildlife, but only if the target species use them (Ng et al. 2004). Road permeability can be improved for lizards and other wildlife by installing culverts as crossing structures (Yanes et al. 1995, Ascensão and Mira 2007). Culverts accompanied by proper exclusion fencing further improve connectivity between road-fragmented habitat patches and decrease roadway mortality (Dodd et al. 2004, Aresco 2005). Some animals exhibit aversion to certain types of crossing structures and may not use a culvert if it is not suitably designed (Rodriguez et al. 1996, Ng et al. 2004). Use may be influenced by the culvert's internal temperature, lighting, or overall width (Ruediger 2001).

The propensity for flat-tailed horned lizards to use culverts as road crossing structures is unknown. To determine if culverts can mitigate road effects on flat-tailed horned lizards, it is imperative to determine crossing structure parameters that are suitable for the species. The purpose of this study was to test flat-tailed horned lizard use of several different simulated road-crossing structures, and assist decisions regarding mitigation of highway construction and maintenance within flat-tailed horned lizard habitats.

This project was designed to test flat-tailed horned lizard use of commonly employed road crossing structures and provide information that can be applied to road design and maintenance questions. The project addressed the following objectives:

- Determine if flat-tailed horned lizards will pass through culverts of sizes commonly used in road construction.
- Compare and describe the characteristics of culverts used by flat-tailed horned lizards to those not used.

III. METHODS

A. STUDY SITE

The study site was located approximately 10 miles south of Yuma, Arizona on the Barry M. Goldwater Range (Figure 1). The biotic community is classified as the Lower Colorado River Valley subdivision of the Sonoran Desert. Dominant vegetation includes creosote bush (*Larrea tridentata*), white bursage (*Ambrosia dumosa*), and big galleta (*Pleuraphis rigida*). Topography is gently rolling with broad dunes of sandy loam, and elevation ranges from 100-400 feet above sea level (Brown 1994). Mean summer (June-September) temperature and rainfall are 90 degrees Fahrenheit and 3/10 inches, respectively (TWC 2007).

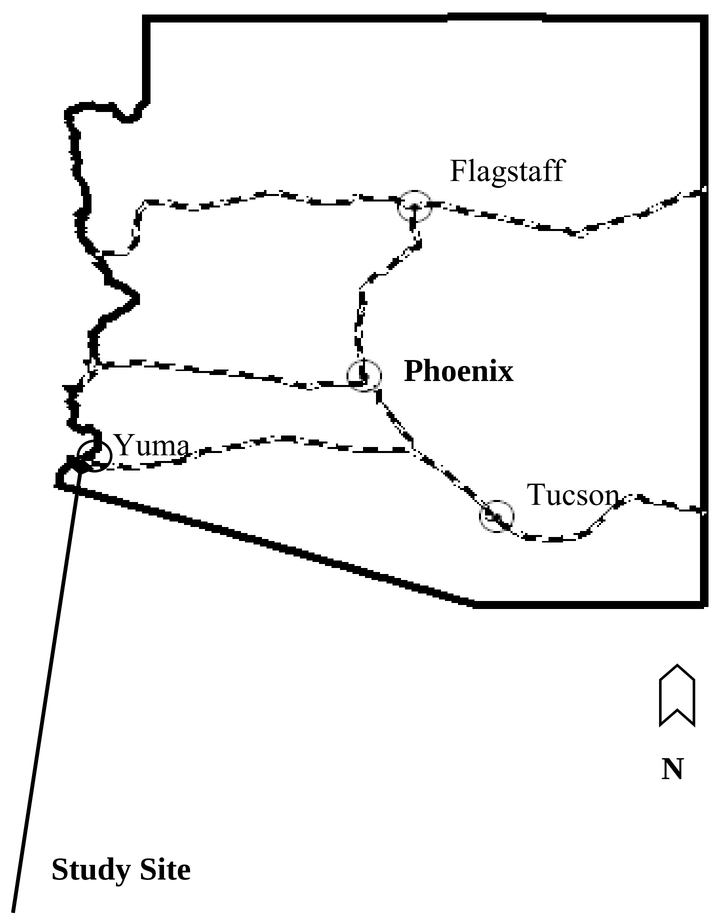

Figure 1. Flat-tailed horned lizard study site from 2005-2006

B. FACILITY CONSTRUCTION

In 2005 the research team built a facility to test potential use of highway culverts currently used by ADOT to control water flow and erosion. The testing facility (Figure 2) was designed as a hexagon (100 feet/side, 6/10 acre) constructed with ¼-inch mesh hardware cloth 36 inches tall, buried 6 inches and held up by ¼-inch rebar. Midway on each side of the hexagon, we installed a 40-foot long culvert connected to a 10-foot by 10-foot hardware cloth peripheral enclosure. Ground inside the fenced area was not disturbed to preserve natural characteristics of the vegetation and soil. The length of culverts used in this study was similar to that of culverts used under typical two-lane roads. Four-lane roads typically have an open median between the opposing traffic directions. To maintain even substrate conditions throughout the testing facility, sand was distributed inside each culvert to thoroughly cover the floor 1-3 inches deep (Figure 3). The R-value (insulation coefficient) of a road (asphalt and gravel fill) was estimated to be approximately 22, so each culvert was covered with approximately 18-24 inches of soil and/or rigid foam insulation (R-Tech expanded polystyrene; Insulfoam, Tacoma, Washington, USA) to simulate thermal properties of an actual culvert under a road.

The testing facility included three types of culverts and two interior lighting options. Culvert types included 24-inch diameter galvanized steel culverts, 36-inch diameter galvanized steel culverts, and 4-foot tall by 8-foot wide box culverts. The steel culverts were the same as those in use by ADOT. The box culverts were constructed of ¾-inch plywood and framed with 2-inch by 4-inch wood posts (Figure 4). Box culverts were designed to mimic those made of concrete in use by ADOT. Each culvert received one of two lighting options: light or dark. The "light" culverts were lit inside with skylights; the "dark" culverts received only natural light from the ends. For the skylight option, at least one 12-inch tubular skylight was installed midway into one of each type of culvert. Because the 24-inch and 36-inch culverts were much darker than the box culverts, they were fitted with two additional skylights. In 2005, sunlight was directed into the mouth of these crossing structures with 22-inch flexible tubular skylights suspended from the top half of the culvert openings. These terminal skylights reduced the entrance diameter of these culverts by one-third to one-half. Interior lighting conditions were improved in 2006 by removing the terminal skylights, and installing two 10-inch tubular skylights, 10 feet away on either side of the midway skylight (Figure 5).

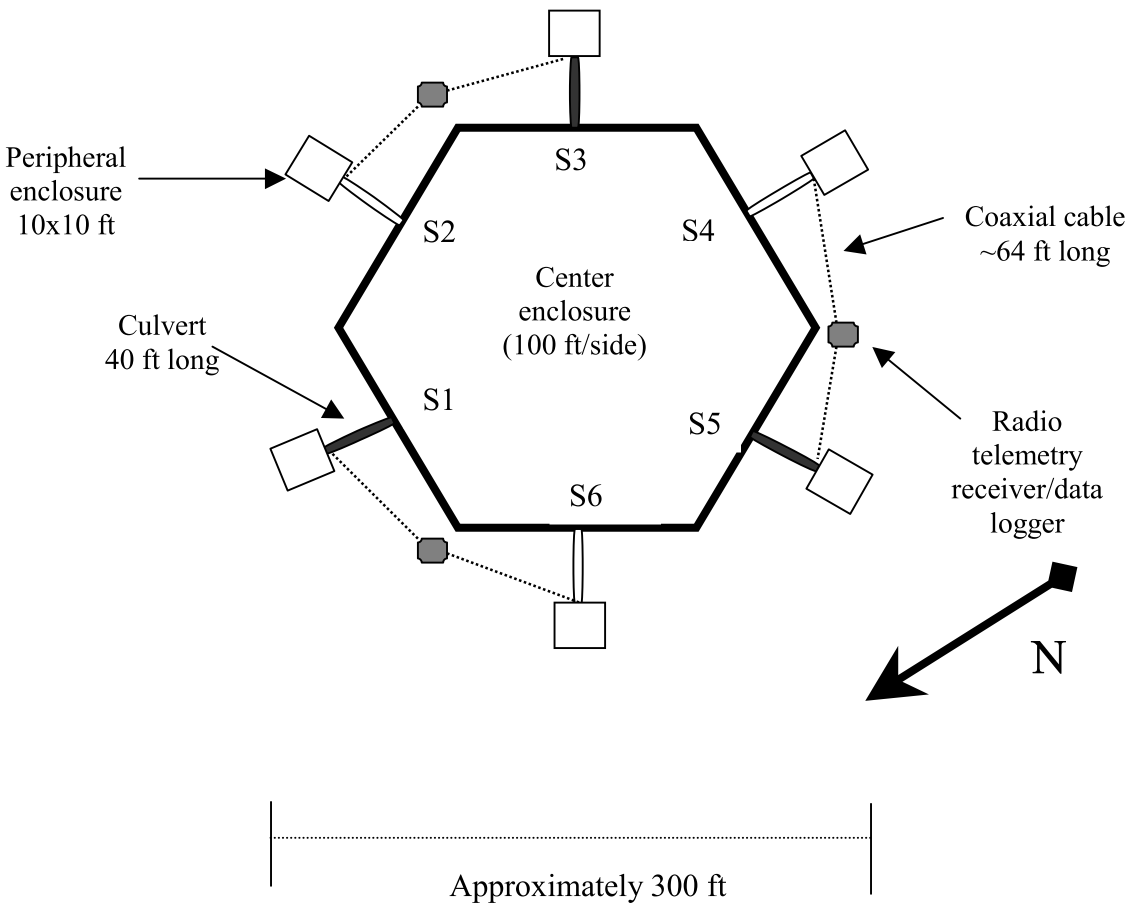

Figure 2. Layout of the testing facility (not to scale)

Notes: Total dimensions of the facility were approximately 300 feet by 300 feet. Each enclosure was constructed of 36-inch hardware cloth buried approximately 6 inches and held up by 1/4-inch rebar. The crossing structures (S1 –S6) were constructed as follows: S2 and S5 were 24-inch culvert piping; S3 and S6 were 36-inch culvert piping; and S1 and S4 were 4-foot tall by 8-foot wide simulated box culvert (constructed of 3/4-inch plywood). S2, S4, and S6 had skylights illuminating the crossing structures internally. All culverts had approximately 18-24 inches of soil or comparable insulation covering each structure. Three radio telemetry receiver-data loggers each operated two antennas of coaxial cable.

Figure 3. Soil from the site distributed through the 36-in diameter culvert without skylights.

Figure 4. Entrance of the 4-ft by 8-ft box culvert with a skylight (upper right) and headwalls (dark brown).

Figure 5. Skylights positioned on a 24-in diameter culvert.

Notes: In the background is the main enclosure. In the left foreground is the small peripheral pen that prevents flat-tailed horned lizards from escaping if they walk though the culvert. Plywood headwalls minimize sand loss at the ends.

C. MONITORING FLAT-TAILED HORNED LIZARD USE OF EXPERIMENTAL CULVERTS

From September through October 2005 and June to September 2006, flat-tailed horned lizards were captured from approved locations on the Barry M. Goldwater Range and adjoining Bureau of Reclamation land. The research team recorded capture coordinates (UTM, NAD 1927), sex, and length (2005, total length; 2006 snout-to-vent length) for each individual. Only lizards ≥ 1 year old were used in the study. Either a 0.36-gram or a 0.77-gram radio transmitter (models LB-2N or BD-2, respectively; Holohil Systems Ltd., Carp, Ontario, Canada) was affixed on the back of each individual with Dap brand silicon aquarium sealant. After covering the tags with sealant, they were dusted with sand for camouflage. Each individual also received a unique identification mark on the belly and tail with black permanent marker. To ensure attachment and tag performance, tags were activated and affixed the night before releasing the flat-tailed horned lizards into the testing facility (Figures 6 and 7).

Figure 6. Flat-tailed horned lizard with a radio telemetry transmitter attached.

Notes: The larger rod on the left side of the lizard's back is a radio frequency identification transponder that we tested unsuccessfully in 2005. The traditional radio telemetry transmitter (Holohil model LB-2N) is on the right side of the lizards back, with the thin wire projecting posteriorly. Most lizards only carried the telemetry transmitter.

Figure 7. Flat-tailed horned lizard exhibiting typical hiding behavior while carrying a radio telemetry transmitter.

Anywhere from six to eight flat-tailed horned lizards were in the testing facility at any one time. In 2005 the research team experimented with radio frequency identification (RFID) transponders, but the system failed to work at the study site (Painter and Ingraldi 2005). In 2006 only traditional radio telemetry equipment was used to monitor lizard movements.

All flat-tailed horned lizards were released in the morning, in the center of the main enclosure where all six culverts were equally available for selection. Because the testing facility contained several active ant nests, supplemental food was not provided. The research team monitored movement (i.e., use of each crossing structure) of each individual lizard for 10 days. After 10 days, or death of an individual in the testing facility, animals were replaced with new individuals. General location and status of each animal was determined with handheld receivers at least every third day. If an animal was lost, circumstances of the loss were noted. After 10 days in the testing facility, surviving individuals were taken out, their tags removed, and released at their point of capture. Animals originally found on a road were released approximately 100 yards from their capture point.

Because the RFID remote detection system failed to work during 2005, location and status of each animal was determined with handheld receivers once every day. If an animal was found in a terminal pen, the type of culvert was noted and that event counted as one crossing. In 2006, the research team used radio telemetry equipment with stationary scanning receiver-data loggers (model R4500S; Advanced Telemetry Systems, Inc., Isanti, Minnesota, USA) to remotely detect and record flat-tailed horned lizard movement through the culverts, in addition to checking lizard status approximately every third day with handheld receivers. At the rim of the exit (i.e., distal end) of each crossing structure, a radio telemetry antenna was buried just under the sand to detect flat-tailed horned lizards as they passed out of the culvert. Each receiver monitored two culverts. When a receiver detected a signal, it logged the antenna, time, frequency, and signal strength. Data were downloaded to a laptop computer in the field.

D. MEASURING TEMPERATURE AND LIGHT INTENSITY

In 2005 one data logger (Hobo® pendant temp/light data logger; Onset Computer Corporation, Bourne, Massachusetts, USA) was placed on the floor about 15 feet inside the distal end of each crossing structure to measure light intensity and temperature inside the culverts every 15 minutes. In 2006 temperature and light intensity data collection was modified by placing a data logger on the floor midway inside each culvert to take readings inside the culverts every 60 minutes. In both years, one data logger was placed outside the culverts to record ambient environmental conditions. These data loggers were in place for the duration of the field season. To compare conditions between the simulated crossing structures and culverts actually installed under roadways by ADOT, temperatures outside and inside three real culverts similar to those in the testing facility were also sampled in 2006 (Table 1). Sampled culverts were located under highway US-95, approximately 23 miles north of the study site. Real culverts installed for water flow typically passed under the road at an angle, were installed as a pair, and/or were located down in a wash. For general comparison, the research team found such dissimilarities acceptable. Samples were collected over a 24-hour period at each of the three real culverts. Data loggers were checked to ensure they measured within 2 degrees Fahrenheit of each other.

Table 1. Description of real road culverts selected for temperature comparison to simulated road crossing structures.

Culvert Width	24-in diameter	36-in diameter	4-ft tall x 8-ft wide
Date placed	9/12/2006	9/14/2006	9/16/2006
Time placed	14:00	16:40	11:50
Date retrieved	9/14/2006	9/16/2006	9/18/2006
Time retrieved	16:14	11:13	07:30
Approximate length (ft)	68	89	36
Alignment	E-W	NW-SE	E-W
Mean temperature difference (°F ± SD)	−2.9 ± 7.1	−2.6 ± 8.1	−5.9 ± 8.2
Comments	Logger placed on sand in metal culvert; mouth a bit elevated above the ground outside; not in a wash and hasn't seen water in a long time.	Two metal culverts in a shallow wash, side by side with about 12 inches of dirt between; logger placed on sand and rocks inside north pipe; it funnels water but was mostly dry at the time.	Double side-by-side concrete box culvert in a shallow wash; logger placed on sandy gravel in the north box; box funnels water, but it was dry at the time.

Notes: By subtracting culvert temperature from ambient temperature, mean temperature difference and range were determined for comparison with simulated culverts.

E. ANALYSIS

Flat-tailed horned lizard use of each of the six culvert types was summarized as a count of the number of times a lizard crossed through to a terminal pen. The number of crossings confirmed visually added to the number of likely crossings detected only by the remote telemetry units. For a description of what the research team considered a "likely crossing," see Appendix A. Low numbers of observations precluded reliable statistical analysis of lizard crossings.

After the 2005 field season, it was discovered that the 24-inch and 36-inch diameter culverts did not mimic real culvert conditions because the bulky skylights attached to the ends blocked more light than they directed into the culvert interior (Painter and Ingraldi 2005). Because interior lighting and probably airflow in these culverts likely did not accurately mimic real culvert conditions, 2005 light intensity and temperature data were dropped from final analyses.

In 2006, mean light intensity measurements were compared among all culverts and ambient values. Temperature measurements were used to calculate the disparity between ambient and internal culvert temperature, and then the season-long means from the six simulated culverts were compared. A subset of the temperature discrepancies from the simulated culverts was also compared to that of the real culverts under highway AZ-95. The subset was determined by including only measurements from the simulated culverts that were taken in the same 24-hour period as that of the real culverts. Each test was conducted with a one-way ANOVA, and because equal variances could not be assumed, multiple comparisons were conducted with a Games-Howell post hoc test. All tests were considered significant at $\alpha = 0.05$ (SPSS for Windows, Version 11.5, 2002).

There was one problem with light and temperature data collection in 2006; the data logger in the simulated 24-inch diameter dark culvert was buried by windblown sand at some point in the field season. This situation was not discovered until the end of the season. Light intensity recordings indicated that it was mostly covered by 11 July 2006, so that data set was truncated, and mean temperature difference of the simulated 24-inch diameter dark culvert was not compared to that of the real 24-inch diameter culvert.

IV. RESULTS

A. FLAT-TAILED HORNED LIZARD USE OF EXPERIMENTAL CULVERTS

Arizona Game and Fish Department biologists monitored movements of 54 flat-tailed horned lizards (34 males and 20 females) in the testing facility and observed 12 complete crossings (Table 2). Proportionally, there was little difference in use between the sexes; 23% (eight) of the males used culverts and 20% (four) of the females used culverts. All crossing structures except the 24-inch diameter culvert with a skylight were used at least once (Table 3). Dark culverts were used more frequently (nine crossings) than culverts with skylights (three crossings). The 36-inch diameter culverts were used most frequently (six crossings), and the 24-inch diameter culverts were used least frequently (two crossings). No individual flat-tailed horned lizard used more than one culvert.

From September through October 2005, at least two of 12 flat-tailed horned lizards made complete crossings through culverts. From June through September 2006, 42 flat-tailed horned lizards were monitored in the testing facility. The research team visually confirmed that six individuals used culverts, and remote telemetry data indicated another four individuals likely used culverts. During both years, tracks of other species were found in the culverts, including snakes, ground squirrels, beetles, roadrunners, passerines, and lizards with long tails.

Not all flat-tailed horned lizards survived 10 days. In 2005, one individual shed its skin with the transmitter and was lost in the testing facility; a raptor killed another individual. In 2006 predation in the testing facility became a problem. Predators (e.g., ground squirrels, roadrunners, shrikes, or raptors) killed at least 20 flat-tailed horned lizards. Telemetry signals of another 15 individuals were lost, which was likely a result of raptors carrying the lizards far away. One individual died of exposure when its transmitter wire snagged on a stick. Approximate end dates and apparent fates are listed in Appendix B. Exact survival times were not measured, because the majority of animals were not visually checked every day.

Table 2. Information on each flat-tailed horned lizard used in the simulated road crossing structure experiment (2005-2006).

ID #	Sex	Release date	Culvert use	Culvert width and lighting	Detection method
A	M	22-Sep-05	Yes	4-ft x 8-ft light	Visual
B	M	22-Sep-05	Unknown		
C	M	22-Sep-05	Yes	24-in dark	Visual
D	M	22-Sep-05	Unknown		
E	M	22-Sep-05	Unknown		
F	M	22-Sep-05	Unknown		
2A	M	11-Oct-05	Inside 36D		
2B	M	11-Oct-05	Unknown		
2C	F	11-Oct-05	Unknown		
2D	M	11-Oct-05	Unknown		
2E	F	11-Oct-05	Unknown		
2F	M	11-Oct-05	Unknown		
A1	M	10-Jun-06	Unlikely		
A2	M	10-Jun-06	Unlikely		
A3	F	10-Jun-06	Unlikely		
A4	F	10-Jun-06	Unlikely		
A5	F	10-Jun-06	Unlikely		
A6	F	10-Jun-06	Unlikely		
2B	F	12-Jul-06	Unlikely		
4B	M	12-Jul-06	Unlikely		
MC1	M	12-Jul-06	Unlikely		
MC3	M	12-Jul-06	Unlikely		
MC5	M	12-Jul-06	Yes	4-ft x 8-ft light	Remote receiver
MC13	F	14-Jul-06	Unlikely		
MC27	M	5-Aug-06	Unlikely		
MC28	M	5-Aug-06	Unlikely		
MC26	F	5-Aug-06	Unlikely		
MC29	F	5-Aug-06	Unlikely		
MC30	F	6-Aug-06	Yes	36-in dark	Visual & remote receiver
MC33	F	8-Aug-06	Yes	36-in dark	Remote receiver
MC47	M	18-Aug-06	Unlikely		
MC42	M	18-Aug-06	Unlikely		
MC46	F	18-Aug-06	Unlikely		
MC45	M	18-Aug-06	Unlikely		
MC43	M	18-Aug-06	Unlikely		
MC44	M	18-Aug-06	Yes	24-in dark	Visual & remote receiver
MC48	M	30-Aug-06	Yes	4-ft x 8-ft dark	Visual & remote receiver
MC49	M	30-Aug-06	Unlikely		
MC50	F	30-Aug-06	Yes	36-in dark	Remote receiver
MC54	M	30-Aug-06	Unlikely		
MC51	M	30-Aug-06	Yes	36-in dark	Remote receiver

Continued.

Table 2 (continued).

ID #	Sex	Release date	Culvert use	Culvert width and lighting	Detection method
MC55	M	30-Aug-06	Unlikely		
MC52	F	30-Aug-06	Unlikely		
MC53	M	30-Aug-06	Unlikely		
MC56	M	4-Sep-06	Unlikely		
MC57	F	4-Sep-06	Unlikely		
MC58	M	4-Sep-06	Yes	4-ft x 8-ft dark	Visual & remote receiver
MC59	F	5-Sep-06	Unlikely		
MC60	F	7-Sep-06	Unlikely		
MC61	F	7-Sep-06	Yes	36-in dark	Visual & remote receiver
MC62	M	7-Sep-06	Yes	36-in light	Visual & remote receiver
MC63	M	11-Sep-06	Unlikely		
MC64	F	11-Sep-06	Unlikely		
MC65	M	11-Sep-06	Unlikely		

Notes: Release Date: date the animal was released in the testing facility.

Culvert Use: Yes = crossed all the way through a culvert, Unknown = never observed using a culvert, Unlikely = probably did not use any culverts because the remote telemetry detection system did not record a strong signal from their transmitter, or Inside 36D = found inside the 36-in diameter dark culvert.

Detection methods: Visual = lizard visually observed in the terminal pen of a culvert, Remote receiver = remote receiver detected a crossing, or Visual & remote receiver = lizard was visually observed in terminal pen and the remote receiver detected the crossing.

Table 3. Summary of flat-tailed horned lizard use of simulated road crossing structures (2005-2006).

Culvert width and lighting	2005 visual detections	2006 remote detections only	2006 remote detections verified visually	Total crossings
24-in dark	1	0	1	2
24-in light	0	0	0	0
36-in dark	0	3	2	5
36-in light	0	0	1	1
4-ft x 8-ft dark	0	0	2	2
4-ft x 8-ft light	1	1	0	2
Sum	2	4	6	12

Notes: In 2005, only visual observations of crossings were noted. In 2006, some crossings were detected only with remote telemetry receivers; some were also verified with visual observations.

B. TEMPERATURE AND LIGHT INTENSITY

For all simulated culverts, light intensity inside was considerably dimmer than ambient light intensity (Table 4). Of the two lighting options at the testing facility, the interior of all culverts with skylights was brighter than the interior of all culverts without skylights. Each culvert differed from ambient light intensity and that inside all other culverts (ANOVA: $F_{6, 8158} = 583.42$, $P \leq 0.001$; post hoc: all $P \leq 0.017$).

Among the simulated culvert temperature discrepancies (Table 4), within same-size pairs generally did not differ, but among-size comparisons were generally significantly different ($F_{5, 12700} = 97.73$, $P \leq 0.001$). The only exception was the 24-inch dark culvert, which differed from its same-size partner, and did not differ from either of the 4-foot by 8-foot box culverts (Tables 4 and 5).

Table 4. Light intensity and temperature discrepancies at the testing facility (Jun-Sep).

Culvert width and lighting	Mean light intensity (Lumens/square foot ± SD)	Mean temperature discrepancy (°F ± SD)
Ambient	2549.8 ± 3437.8	-
24-in dark	1.2 ± 0.5	* 3.4 ± 8.3
24-in light	85.5 ± 104.7	−0.2 ± 6.6
36-in dark	14.9 ± 95.3	1.5 ± 6.6
36-in light	100.1 ± 121.7	1.5 ± 5.8
4-ft x 8-ft dark	34.1 ±14.4	3.0 ± 4.5
4-ft x 8-ft light	116.8 ± 76.5	2.7 ± 5.1

Notes: SD stands for 'Standard Deviation. Light intensity was averaged over all daylight hours. Mean temperature discrepancy and range was determined by subtracting culvert temperature from ambient temperature. * Conditions inside the 24-inch dark culvert were only averaged through 11 July 2006, because the data logger was likely buried by windblown sand after that point.

Table 5. Games-Howell test results (P-values) of multiple comparisons among temperature discrepancies recorded at simulated culverts.

Culvert width and lighting	24-in light	36-in dark	36-in light	4-ft x 8-ft dark	4-ft x 8-ft light
24-in dark	0.000	0.000	0.000	**0.830**	**0.264**
24-in light	------	0.000	0.000	0.000	0.000
36-in dark	------	------	**1.000**	0.000	0.000
36-in light	------	------	------	0.000	0.000
4-ft x 8-ft dark	------	------	------	------	**0.311**

Notes: Bold text denotes a significant difference between means ($\alpha = 0.05$). The notable comparison here is the two 24-inch culverts differed from one another, while the other same-size pairs did not. Even in a separate comparison between the 24-inch culverts using data from both sets through 11 July 2006, the means differed ($F_{1, 1500} = 21$, $P \leq 0.001$).

Temperature discrepancy comparisons between real and simulated culverts during a 24-hour period showed few differences ($F_{7, 745} = 4.76$; $P \leq 0.001$). On average, the temperature discrepancy of the 4-foot by 8-foot real concrete box culvert was 2-4 degrees Fahrenheit more than that of other culverts. Mean temperature discrepancy of the 4-foot by 8-foot real concrete box culvert differed significantly from that of the simulated dark box culvert ($P \leq 0.001$), the simulated light box culvert ($P = 0.001$), the simulated 24-inch light culvert ($P = 0.001$), the real 24-inch culvert ($P = 0.004$), and the real 36-inch culvert ($P = 0.005$). Mean temperature discrepancy among all other real and simulated culverts did not differ (all $P \geq 0.129$).

V. CONCLUSIONS

Although natural conditions inside the testing facility were preserved as much as possible, the research team acknowledges that the response of each flat-tailed horned lizard to being placed in a foreign environment likely influenced their behavior. Normal daily home range movements, migration, dispersal, or breeding behavior may affect an animal's propensity to use culverts as actual road crossing structures. The observed low crossing rate could have been affected by each individual's reaction to unfamiliar surroundings, the high density of animals inside the testing facility, presence of predators, or other factors we did not measure. As the purpose of this study was not focused on absolute crossing rates, but rather on whether flat-tailed horned lizards would use culverts and if so what types, the research team agrees that the collected data met the defined objectives.

Flat-tailed horned lizards can use culverts as road crossing structures, but the evidence did not reveal a strong selection for or against any culvert type because each size of culvert was used and both lighting options were used (Table 3). However, the 36-inch culverts were used slightly more often than the other sizes, and we observed no use of the 24-inch culvert with skylights. It is possible that more crossings occurred undetected, especially in 2005 when we relied solely on periodic visual monitoring. Lizards may prefer to use culverts of an intermediate size. Smith (2003) found that herpetofauna in Florida used culverts most frequently when they were ≥ 59 inches wide and 23-59 inches high.

Although mean temperature discrepancy was not the same among all culverts, they were reasonably close, and all averaged less than 5 degrees Fahrenheit different from ambient conditions. Unless temperature inside a culvert is drastically different from that outside, the research team foresees no issues with temperature dissuading flat-tailed horned lizard use. Lighting inside the 40-foot long experimental culverts may not have affected lizard selection of culverts, but dark culverts were used slightly more than culverts with skylights. Culverts longer than 40 feet were not tested in this study, so poor lighting could be a problem with extremely long culverts, where the center of a small diameter culvert would be very dark.

Flat-tailed horned lizards did not seem averse to entering culverts. In 2005, at the end of the summer when lizards were starting to spend more time underground, one individual was found buried in the sand and mildly torpid a few feet inside the entrance of the 36-inch diameter dark culvert. In 2006, three flat-tailed horned lizards (MC44, MC50, and MC51) were found lingering inside either the 24-inch diameter dark culvert or the 36-inch diameter dark culvert several hours before passing all the way through. Lizards may also use culverts as thermoregulatory microhabitat or hiding cover since they provide vertical structure (e.g., Rodriguez et al., 1996).

Although we did not test whether substrate inside a culvert affects selection, it may be important for encouraging use, especially in corrugated metal culverts that are slick and uneven and very different from natural sand or rock. Lesbarreres et al. (2004) found that amphibians select culverts lined with soil as opposed to those of bare concrete. The same idea of substrate influence may be true for flat-tailed horned lizards.

Characteristics of some culverts changed as time passed. Although light intensity and visibility from entrance to exit was excellent in the box culverts, strong winds inevitably swept the sandy soil away from the ends of the culverts, revealing the smooth wood beneath. If the box culverts had been built 1 or 2 feet into the ground and leveled with soil, they may have resisted the scouring action of the wind. The real concrete box culvert also had no soil at the ends, but this was likely due to effects of water flow instead of wind. The 24-inch diameter culverts seemed particularly susceptible to movement of the sandy soil. They began filling in with sand quicker than the other culverts, restricting visibility from entrance to exit. At the real 24-inch diameter culvert, soil had eroded away from around the ends, leaving the openings above ground level, rendering it useless as a crossing structure for flat-tailed horned lizards.

VI. RECOMMENDATIONS

Because the 24-inch diameter culverts were used less frequently than the larger culverts and they seemed more susceptible to movement of soil, the research team tentatively recommends against using these culverts as standard road crossing structures for flat-tailed horned lizards. While the 36-inch diameter and the 4-foot by 8-foot box culverts were not immune to movement of sandy soil, they were not as vulnerable as the smaller culverts. Although the 36-diameter culvert may be the best option, either of the larger styles could work as a crossing structure, as long as fencing is used to funnel animals toward the culvert, it remains passable, preferably holds some soil on the floor, and allows some daylight through its length.

Other issues to consider in designing appropriate road crossing structures include: regular maintenance (i.e., maintaining substrate in culverts and ready access to culvert entrances), how many to install, where to install them, position under the road, and topography of the crossing site. Although this study showed that in an experimental situation flat-tailed horned lizards are capable of moving through culverts, they may exhibit different reactions to culverts under normal circumstances in their own territories or during typical dispersal. To further test road crossing structures as a viable mitigation measure for flat-tailed horned lizards, use of actual culverts under roads (with exclusion fencing) should be documented for this species in situ.

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APPENDIX A. RECORDS AND INTERPRETATION OF FLAT-TAILED HORNED LIZARD REMOTE TELEMETRY DATA

Appendix A lists the guidelines used in determining if remote telemetry data indicated a flat-tailed horned lizard crossed through a simulated road crossing structure. The complete set of remote telemetry data is on file at the Arizona Game and Fish Department, and is available upon request (Research Branch, AGFD, 2221 W. Greenway Rd., Phoenix, AZ 85023; 602-942-3000).

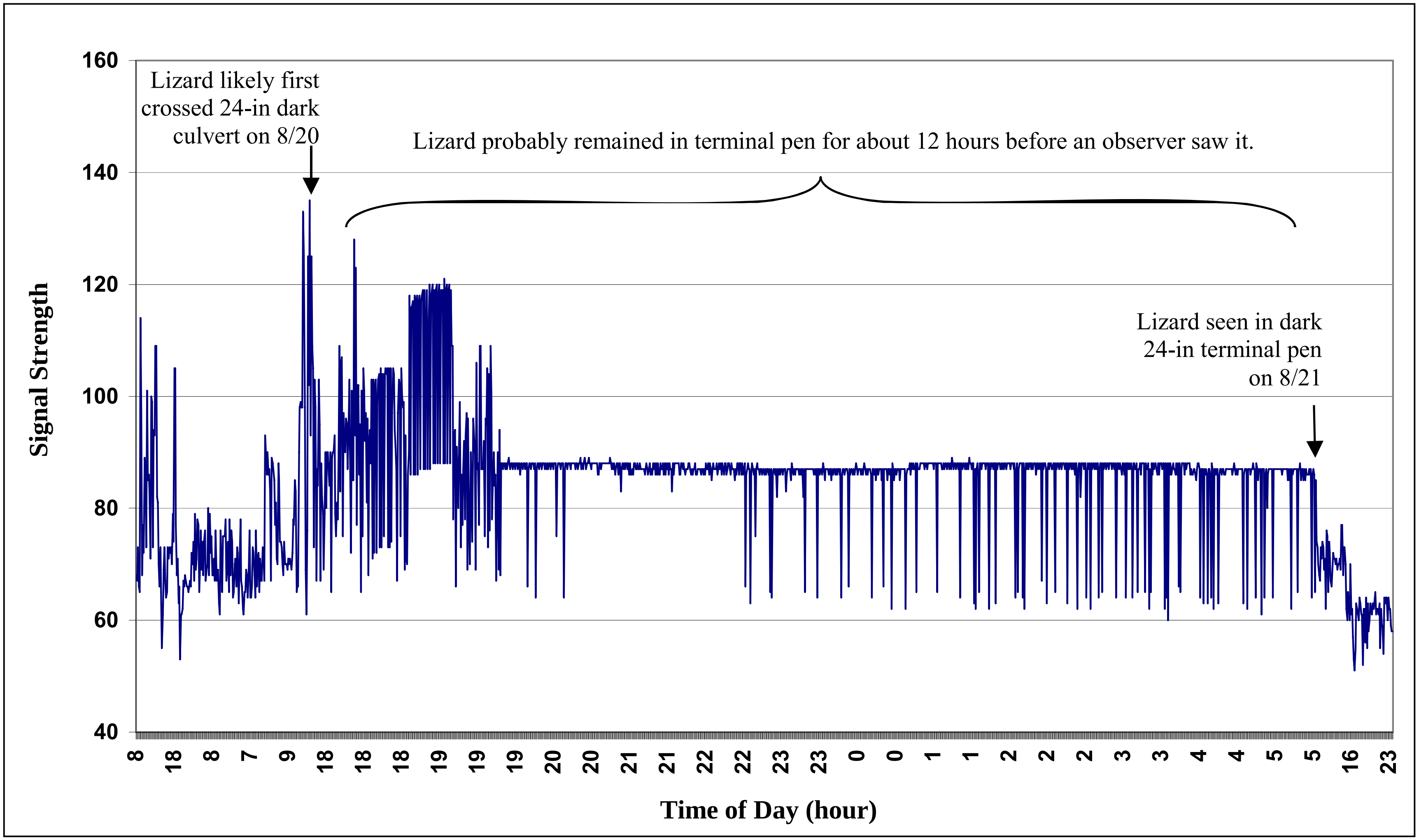
We established basic guidelines for interpreting remote telemetry data by evaluating the signal patterns recorded during visually confirmed crossing events. An example is presented on the next page. If a flat-tailed horned lizard successfully crossed through a culvert to the terminal pen, the following general patterns were usually (but not always) evident in the antenna and signal strength data:

- The data file had several hundred to a few thousand detections for a single frequency.

- The data file had many (e.g., > 40 or 50) detections at an identified antenna within a few minutes or hours. Detections without an identified antenna were not convincing.

- A dominant antenna was identified repeatedly in the section where lots of detections were recorded in a few minutes or hours. The dominant antenna was the one with a signal strength >>100, at the same time the subordinate antennas recorded a signal strength <<100 (if at all).

- The increase/decrease in signal strength was more or less steady over time as the lizard walked past the antenna. A convincing signal pattern would not jump instantly or repeatedly from a weak signal (e.g., 60-70) to a strong signal (e.g., >115).



Appendix A (contd). Example of signal strength recorded by a remote telemetry receiver (Flat-tailed horned lizard Male MC44). This example includes all the detections of frequency 150.410-411 on receiver R2678, which monitored the dark 24-in diameter metal culvert and the lit 4-ft x 8-ft box culvert from 18-30 August 2006. The strong signals from the 24-in culvert dominate and cluster at the top of the line. After the lizard was seen in the terminal pen, he was moved back to the main pen, and the signal faded accordingly.

APPENDIX B. SURVIVAL DATA AND FATE OF FLAT-TAILED HORNED LIZARDS

ID #	Release date	Approximate end date	Apparent fate
A	22-Sep-05	2-Oct-05	Lived
B	22-Sep-05	2-Oct-05	Lived
C	22-Sep-05	2-Oct-05	Lived
D	22-Sep-05	2-Oct-05	Lived
E	22-Sep-05	23-Sep-05	Shed transmitter
F	22-Sep-05	2-Oct-05	Lived
2A	11-Oct-05	22-Oct-05	Lived
2B	11-Oct-05	15-Oct-05	Predator
2C	11-Oct-05	22-Oct-05	Lived
2D	11-Oct-05	22-Oct-05	Lived
2E	11-Oct-05	22-Oct-05	Lived
2F	11-Oct-05	22-Oct-05	Lived
A1	10-Jun-06	< 21-Jun-06	Predator
A2	10-Jun-06	< 21-Jun-06	Predator
A3	10-Jun-06	20-Jun-06	Predator
A4	10-Jun-06	< 21-Jun-06	Predator
A5	10-Jun-06	< 21-Jun-06	Predator
A6	10-Jun-06	< 21-Jun-06	Predator
2B	12-Jul-06	14-Jul-06	Predator
4B	12-Jul-06	14-Jul-06	No signal
MC1	12-Jul-06	14-Jul-06	No signal
MC3	12-Jul-06	23-Jul-06	Lived
MC5	12-Jul-06	21-Jul-06	No signal
MC13	14-Jul-06	18-Jul-06	Predator
MC26	5-Aug-06	17-Aug-06	Lived
MC27	5-Aug-06	7-Aug-06	No signal
MC28	5-Aug-06	16-Aug-06	Died intact
MC29	5-Aug-06	7-Aug-06	No signal
MC30	6-Aug-06	14-Aug-06	Predator
MC33	8-Aug-06	9-Aug-06	Predator
MC42	18-Aug-06	20-Aug-06	Predator
MC43	18-Aug-06	22-Aug-06	No signal
MC44	18-Aug-06	22-Aug-06	Predator
MC45	18-Aug-06	22-Aug-06	Predator
MC46	18-Aug-06	19-Aug-06	No signal
MC47	18-Aug-06	20-Aug-06	No signal
MC48	30-Aug-06	1-Sep-06	No signal
MC49	30-Aug-06	1-Sep-06	Predator
MC50	30-Aug-06	8-Sep-06	Lived
MC51	30-Aug-06	1-Sep-06	No signal

Continued.

Appendix B (contd).

ID #	Release date	Likely end date	Fate
MC52	30-Aug-06	1-Sep-06	Predator
MC53	30-Aug-06	1-Sep-06	Predator
MC54	30-Aug-06	2-Sep-06	No signal
MC55	30-Aug-06	31-Aug-06	Predator
MC56	4-Sep-06	6-Sep-06	No signal
MC57	4-Sep-06	5-Sep-06	Predator
MC58	4-Sep-06	13-Sep-06	Lived
MC59	5-Sep-06	14-Sep-06	Lived
MC60	7-Sep-06	16-Sep-06	Lived
MC61	7-Sep-06	13-Sep-06	Predator
MC62	7-Sep-06	13-Sep-06	No signal
MC63	11-Sep-06	13-Sep-06	No signal
MC64	11-Sep-06	12-Sep-06	Predator
MC65	11-Sep-06	12-Sep-06	No signal