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# Pitfall Traps with Motion-activated Cameras in the Study of Terrestrial Lizards and Snakes

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*Abstract.*—**For understudied species, including many lizards and snakes, there is a need to develop new research techniques to understand basic aspects of their ecology and natural history. Traditional sampling methods for reptiles, such as pitfall traps, are labor-intensive and expensive, as they require frequent field visits and many personnel. We implemented traditional lizard pitfall traps with motion-activated cameras, allowing individuals to escape. We tested pitfall-camera traps in a Chihuahuan Desert habitat by comparing captures per trap day, diversity, and cost with a conventional pitfall trap array. Sampling with pitfall-camera traps resulted in an equivalent number of lizard captures per sampling block compared to traditional traps, increased diversity in species captured, and additional data in recording time of entry. All recordings also allowed proper identification and we were able to estimate snout-vent lengths of lizards. Pitfall-camera traps offer the ability to sample continuously at a lower economic cost and are potentially more ethical. Furthermore, pitfall-camera traps recorded the time of capture, allowing for the estimation of activity period of species captured, information that is typically lacking for reptiles. Our study suggests that implementing pitfall traps with cameras is an effective method for the survey of terrestrial lizards and snakes.**

*Key Words*.—activity; camera; ecology; ethical; herpetofauna; monitoring; whiptail lizards.

## Introduction

Developing effective research methods that provide ecological data from lizards and snakes is an emergent concern, as conservation strategies cannot be determined for many species with unknown aspects of their ecology and natural history (McDiarmid et al. 2012; Institutional Union for Conservation of Nature 2022). Cost-effective and non-intrusive methods for detecting lizards and snakes could improve ecological and conservation efforts (Elphick 2008). Current methods, including active searches, are labor intensive and require prolonged field visits, which can result in thousands of personnel hours (Garden et al. 2007; Christy et al. 2010; Silvy 2012). Researchers can be injured while searching and handling venomous snakes and large lizards (Beaupre and Greene 2012) and capturing and handling reptiles also causes stress, which can have long-term effects on the survival of some species (Langkilde and Shine 2006; Fauvel et al. 2012; Holding et al. 2014).

Currently, pitfall traps are a commonly used method for sampling lizards (Brown and Matthews 2016). Pitfall traps are open, buried containers covered with a board used to capture terrestrial organisms, with drift fences occasionally added to increase their efficacy (McDiarmid et al. 2012). Traps can be covered when not in use and then reopened in future research (Garden et al. 2007). Once opened, traps must be visited frequently to minimize the risk of temperature-induced mortality, and to decrease predation (Enge 2001; Karraker 2001; Ferguson et al. 2008; Ellis 2015). Although installation and maintenance of pitfall traps is labor intensive (Sung et al. 2011), they are effective at detecting species which other methods often fail to detect (i.e., nocturnal, fossorial, and cryptic species), but fail at capturing long-bodied snakes, large lizards, and other animals capable of escape (Thompson et al. 2005; Todd et al. 2007). Trapping animals also allows for collecting morphometric data of target species.

Technological advances have increased the use of motion-activated cameras in biological research, especially for mammals (Swann and Perkins 2014). Camera traps can effectively estimate abundance (Karanth et al. 2006), occupancy (O'Connell et al.

**Figure 1**. Study site used in the research conducted at Indio Mountains Research Station, Hudspeth County, Texas, USA. (Photographed by Guillermo Alvarez).

2006), activity patterns (de Almeida Jácomo et al. 2004), diet (Glen and Dickman 2003), and behavior (Bauer et al. 2005). While initial costs associated with cameras, memory cards, and batteries can be high, the continuous and concurrent data collection across sites can justify the costs (Swann and Perkins 2014). Additional advantages of camera traps include their ability to be deployed in most habitats and weather conditions (Swann and Perkins 2014), documentation of the date and time the animal is observed, and elimination of the need to trap the animal, thereby reducing the risk of temperature-induced mortality and predation (de Bondi et al. 2010; Swann and Perkins 2014). Despite advances, camera traps are not commonly used in reptile surveys (Cochran and Schmitt 2009; O'Connell et al. 2011; McCallum 2013); however, studies where cameras were used were able to record both large snakes (snout-vent lengths [SVL] of 1,500–2,000 mm) and small lizards (SVL 50 mm; Welbourne et al. 2015), and camera traps have been found more effective than active searches in some circumstances (McGrath et al. 2012). Camera traps were more effective at detecting diurnal than nocturnal species under certain conditions, and environments with a large thermal contrast between the animal and the background surface are recommended (Welbourne et al. 2015; Richardson et al. 2017).

We evaluated the use of pitfall traps with motion-activated cameras to survey diurnal and nocturnal terrestrial lizards and snakes in a Chihuahuan Desert environment. We expected pitfall traps with cameras to be as efficient at capturing reptiles as traditional traps, with the additional benefits of lower effort and cost, and the ability to extract additional information in terms of activity data. Effectiveness was determined by comparing the number of sightings, total number of species detected, and overall costs.

## Materials and Methods

***Study site***.— We conducted the study at the Indio Mountains Research Station (IMRS; 30°46'37"N, 105°00'58"W), Hudspeth County, located southeast of Van Horn, Texas (https://www.utep.edu/indio/; Fig. 1). Vegetation at IMRS is typical of the Chihuahuan Desert (Johnson 2000; Worthington et al. 2018) consisting of dominant species such as Creosote Bush (*Larrea tridentata*), White-thorn Acacia (*Vachellia constricta*), Honey Mesquite (*Prosopis glandulosa*), Catclaw (*Senegalia greggii*), Engelmann's Prickly-pear (*Opuntia engelmannii*) and Desert Christmas Cactus (*Cylindropuntia leptocaulis*). Rocky slopes and outcrops are characterized by Pitaya (*Echinocereus enneacanthus*), Lechuguilla (*Agave lechuguilla*), Sotol (*Dasylirion leiophyllum*), Ocotillo (*Fouquiera splendens*), Eve's Needle (*Yucca faxoniana*), Torrey's Yucca (*Yucca treculeana*), and Purple Prickly-pear (*Opuntia macrocentra*). Grasses found in the area include Arizona Cottontop (*Digitaria californica*), Tanglehead (*Heteropogon contortus*), and Black Grama (*Bouteloua eriopoda*). Reptile diversity at IMRS includes 21 snake species and nine lizard species (Table 1).

***Traditional pitfall traps and pitfall-camera traps***.—We implemented one array of 30 traditional pitfall traps and one array of nine pitfall-camera traps (Fig. 2). We divided each array into three (150 × 50 m) blocks, with each block separated by a buffer zone of 100 m. In the traditional pitfall trap array, each block contained 10 traps, with each trap located a minimum distance of 20 m apart. In the pitfall-camera trap array, each block contained three traps with motion-activated cameras located a minimum of 50 m apart. Due to higher implementation costs, we used a smaller number of pitfall-camera traps in this array.

We surveyed pitfall traps from 17 May to 28 September 2018, and traps with cameras from 6 May to 2 November 2018. The traditional array was open to survey in the morning upon arrival, checked every 4 h, and closed prior to leaving. We continuously checked the pitfall-camera trap array throughout the season, with batteries and memory cards for cameras replaced four times. We sampled pitfall arrays across 136 d for a total of 4,050 effective trap days, while we checked pitfall-camera trap arrays continuously for

**Table 1.** Snake and lizard species documented at Indio Mountains Research Station, Hudspeth County, Texas, USA (Johnson 2000; Crother 2017).

| Snake Species | Lizard Species |
|---|---|
| Big Bend Patchnose Snake *(Salvadora deserticola*) | Checkered Whiptail (*Aspidoscelis tesselata*) |
| Black-necked Garter Snake *(Thamnophis cyrtopsis*) | Chihuahuan Spotted Whiptail (*Aspidoscelis exsanguis*) |
| Chihuahuan Desert Snake (*Trimorphodon wilkinsonii*) | Crevice Spiny Lizard (*Sceloporus poinsettii*) |
| Chihuahuan Night Snake *(Hypsiglena jani*) | Eastern Collared Lizard (*Crotaphytus collaris*) |
| Coachwhip Snake *(Masticophis flagellum*) | Four-lined Skink (*Plestiodon tetragrammus*) |
| Eastern Black-tailed Rattlesnake *(Crotalus ornatus*) | Great Plains Skink (*Pletiodon obsoletus*) |
| Glossy Snake *(Arizona elegans*) | Greater Earless Lizard (*Cophosaurus texanus*) |
| Gopher Snake *(Pituophis catenifer*) | Little Striped Whiptail (*Aspidoscelis inornata*) |
| Gray Banded Kingsnake *(Lampropeltis alterna*) | Marbled Whiptail (*Aspidoscelis marmorata*) |
| Long-nosed Snake *(Rhinocheilus lecontei*) | |
| Mountain Patchnose Snake (*Salvadora grahamiae*) | |
| Plains Black-headed Snake *(Tantilla nigriceps*) | |
| Ring-neck Snake *(Diadophis punctatus*) | |
| Rock Rattlesnake *(Crotalus lepidus*) | |
| Southwestern Black-headed Snake *(Tantilla hobartsmithi*) | |
| Trans-Pecos Rat Snake *(Bogertophis subocularis*) | |
| Trans-Pecos Threadsnake *(Rena segrega*) | |
| Western Diamondback Rattlesnake *(Crotalus atrox*) | |
| Western Hook-nosed Snake *(Gyalopion canum*) | |
| Trans-Pecos Rat Snake *(Bogertophis subocularis*) | |
| Whipsnake (*Masticophis taeniatus*) | |

181 d for a total of 1,629 effective trap days.

Traditional pitfall traps consisted of a buried 20-L plastic container with a coverboard positioned 4 cm above ground level; we did not employ drift fences in this study (Fig. 3). For water drainage, we drilled 20 holes (2 mm) into the bottom of each container. Traps with motion-activated cameras had a piece of hardware mesh (60 × 20 cm) attached to the inside container allowing organisms to climb and escape. We set each Game Spy 6MP Trail Camera (Moultrie, Alabaster, Alabama, USA; Fig. 3) with a 15 s delay between videos and we mounted cameras with the lens facing downward.

In the traditional pitfall trap array, we recorded species, sex, SVL, total length (TL), mass, date, and capture time (morning/evening) for all lizards. In the pitfall-camera trap array, we identified lizards and snakes observed in videos to species level, and whenever possible, sex was determined for sexually dimorphic species, for example in the Eastern Collared Lizard (*Crotaphytus collaris*) males display brighter coloration and wider heads (Degenhardt et al. 1996). For each observation, we recorded the exact times of entrance and exit of the trap using the time stamp feature of the camera. We also estimated SVL and TL measurements for lizards in video recordings with ImageJ® software (https://imagej.nih.gov/ij/.), using segments of the wire mesh in each trap as a known standard length. We compared SVL measured by hand from the pitfall traps to that estimated from camera footage for the most abundant lizard species. We prevented counting the same individual multiple times by implementing a 15 s camera delay and by not counting a second individual until a period of at least 10 min had elapsed on the camera timestamp from the initial observation.

***Statistical analyses***.—We compared the total number of lizard captures per block between the two separate arrays with a Wilcoxon Rank Sum Test considering only lizard captures from dates when both methods were concurrently deployed from May to September (23 d) to account for differences in sampling effort between methods. We calculated lizards/trap day for each block of 10 pitfall traps and three pitfall-camera traps. We compared the total number of individuals observed and the total number of species from each sampling method

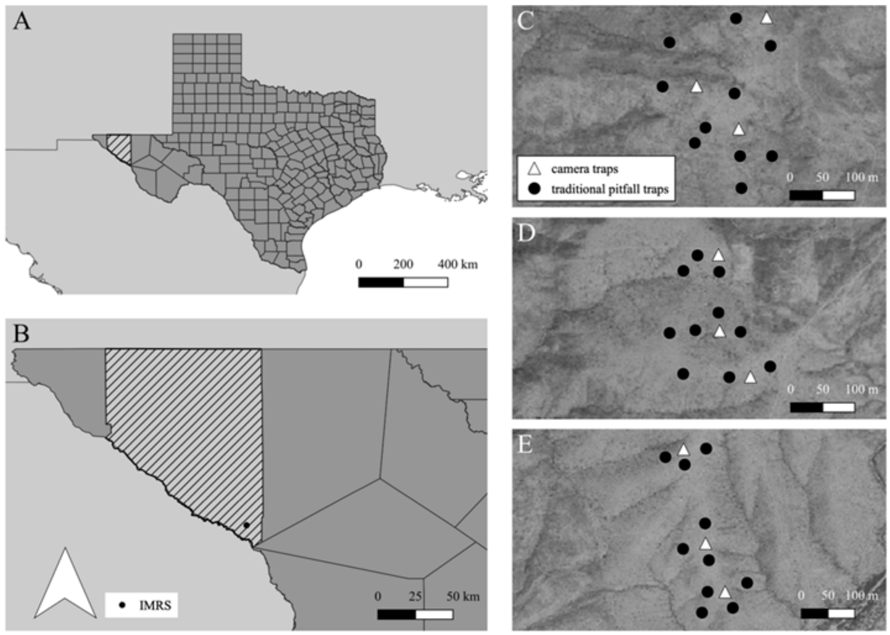


**Figure 2**. (A and B) Map of study site at the Indio Mountains Research Station (IMRS) in Hudspeth County, Texas, USA. (C, D, E) Traps were organized in three arrays 100 m from each other. We used 30 traditional pitfall traps and 10 camera traps. (Topography maps provided by U.S. Geological Survey Imagery: basemap.nationalmap.gov).

using Shannon's Diversity Index (Shannon and Weaver 1963). Further observation comparisons were limited due to differences in sampling methods.

**Figure 3**. (A) Outside view of a traditional pitfall trap with no drift fences used in the study in Hudspeth County, Texas, USA. (B, C) Inside views of a traditional pitfall trap equipped with a motion-activated camera (Moultrie® Game Spy 6MP Trail Camera) and hardware mesh allowing organisms to escape. (Photographed by Guillermo Alvarez).

Using time of entrance provided by the pitfall-camera traps, we estimated the diurnal activity of the three most frequently observed species. We used Fisher's Exact Test to determine whether the two most numerous lizard species captured by pitfall-camera traps were active at significantly different times, restricting data to lizards captured between 0600 and 1759 and dividing time into periods of three-hour blocks. We used $\alpha = 0.05$ for all statistical tests. We conducted all tests using the statistical software R (R Development Core Team, 2021). At a minimum, we identified non-target species such as invertebrates and rodents to order level. Direct comparisons between methodologies were restricted to using array blocks as the sampling unit, as the low sample size of camera-traps (n = 9) prevented statistically rigorous comparison between individual traps. In addition, these comparisons only used capture data from dates when both methods were concurrently running.

## Results

***Quality of images obtained using pitfall-camera traps***.—Overall, the motion-activated cameras provided sufficient footage of lizards and snakes to allow identification to species level and to determine the sex for sexually dimorphic species. All images were time-stamped, allowing for comparison of captures between species. We could not determine the sex of snakes and non-sexually dimorphic species. The 10-s length of the videos, which often recorded multiple videos of the same organism, and the short distance between the lens and the subject resulted in 100% of the videos used in SVL estimations for lizards. The average SVL (± standard deviation) estimated from video recordings (74.03 ± 10.31 mm) of the Marbled Whiptail (*Aspidoscelis marmorata*), the most frequently recorded species observed in both sampling methods, and measurements taken from captured individuals (73.67 ± 8.73 mm) did not significantly differ ($t$ = 0.888, df = 57, $P$ = 0.674). We performed no measurement comparisons of additional species due to low sample sizes in one or both sampling methods.

***Total images and trap captures***.—Pitfall-camera traps required a low number of field visits (four) to change batteries and memory cards, while the array of 30 traditional pitfall traps required a higher number of field visits (14). Pitfall-camera traps detected a higher number of individual observations and total number of species per trap compared to traditional methods (Table 2). Sampling using pitfall-camera traps detected 98 squamate observations (87 lizards, 11 snakes). In contrast, we caught 72 individuals from the traditional pitfall trap array (70 lizards, two snakes; Table 2). The number of lizard observations per a given block of either trap type did not differ significantly (W = 8.0, $P$ > 0.05). Per block, pitfall traps captured 0.097 ± (standard deviation) 0.041 lizards per trap day and pitfall-camera traps captured 0.043 ± 0.029 lizards per trap day, despite sampling blocks of camera traps containing fewer traps. Overall, traditional pitfall traps recorded 42.9% of lizard and 9.5% of snake species previously documented at IMRS, while pitfall-cameras documented 57.1% and 28.6%, respectively.

Overall, pitfall-camera traps captured a higher diversity than traditional pitfall traps. Traditional pitfall traps detected six lizard and two snake species, while pitfall-camera traps detected eight lizard and seven snake species (Table 2). Notably, pitfall-camera traps recorded the large *C. collaris* and several snake species that were undetected in the traditional pitfall traps. The Shannon Diversity Index was higher for the pitfall-camera traps array compared to the array of traditional pitfall traps (Table 2). Traditional traps recorded a higher frequency of Little Striped Whiptails (*A. inornata*) and recorded one snake species undetected in pitfall-camera traps (Table 3). Sampling of the traditional pitfall trap array resulted in 91 non-target observations composed of 82 invertebrates and nine rodents. Sampling using pitfall-camera traps resulted in 95 non-target observations, with 87 invertebrate sightings and eight rodents.

In addition, we calculated the average number of lizard and snake captures per trap day per block of pitfall-camera traps across the entire period that pitfall-camera traps were active (n = 118 d). We restricted captures to those between May and August (n = 74 lizards, nine snakes), which we considered the active period for reptiles, with few observations recorded between September and 2 November (n = 13 lizards, two snakes). The mean number of lizards per trap day per block was 0.0819 ± (standard deviation) 0.026, and the mean number of snakes per trap day per block was 0.010 ± 0.002.

***Activity patterns***.—Using the exact time of entry provided by the pitfall-camera traps, the diurnal activity of the three most frequently observed lizard species varied considerably (Fig. 4). The activity peaks of *A. marmorata* and the Greater Earless Lizard (*Cophosaurus texanus*) were bimodal and unimodal, respectively, and distributed at different times of the day for each species (Fig. 4). The third most frequently recorded species, the Round-tailed Horned Lizard (*Phrynosoma modestum*) did not appear to have a pronounced daily activity peak (Fig. 4). The two most numerous lizard species captured by pitfall-camera traps were active at significantly different times with the proportions of *A. marmorata* and *C. texanus* captures not equally distributed throughout the day, which were significantly different only between 1200–1459 (Fisher's Exact Test, $P$ < 0.05), when *C. texanus* captures were more abundant (Fig. 5). As data collection using traditional pitfalls was restricted to morning and evening collections, fine-scale analysis of activity period could not be conducted on data using this capture method.

**Table 2**. Comparison of Pitfall Trap (n = 4,050 trap days) and Pitfall-camera Trap (n = 1,629 trap days) methods for capturing lizards and snakes at Indio Mountains Research Station, Hudspeth County, Texas, USA.

| | Sampling Method | |
|---|---|---|
| | Pitfall Traps | Pitfall-camera Traps |
| Individual Lizards | 70 | 87 |
| Individual Snakes | 2 | 11 |
| Number of Lizard Species | 6 | 8 |
| Number of Snake Species | 2 | 7 |
| Shannon's Diversity Index (*H*) | 2.079 | 2.565 |

***Cost-effectiveness***.—Cost for fuel and materials was $868.30 USD for the traditional trap array and $797.80 USD for the pitfall-camera trap array. We estimated costs associated with fuel at $33.45 USD per round trip to the field station. Establishing and visiting the pitfall-camera trap array to replace batteries and memory cards required four visits ($133.80 USD) while establishing, opening, and closing traps at the traditional array required 14 visits ($468.30 USD). Cost of materials used to create the pitfall-camera trap array totaled $464.00 USD (cameras, buckets, boards, and hardware), and consumables for one season was approximately $200.00 USD (batteries and memory cards). The approximate cost of the materials used in the traditional trap array was $400.00 USD (buckets, boards, and hardware).

**Table 3**. Total number of snake and lizard captures by species recorded by pitfall and pitfall-camera traps at Indio Mountains Research Station, Hudspeth County, Texas, USA

| Species | Pitfall Trap | Pitfall-Camera Trap |
|---|---|---|
| Big Bend Patchnose Snake (*Salvadora deserticola)* | 0 | 2 |
| Checkered Whiptail (*Aspidoscelis tesselata)* | 2 | 1 |
| Chihuahuan Night Snake (*Hypsiglena jani)* | 0 | 1 |
| Coachwhip Snake (*Masticophis flagellum)* | 0 | 1 |
| Eastern Collared Lizard (*Crotaphytus collaris)* | 0 | 7 |
| Greater Earless Lizard (*Cophosaurus texanus)* | 6 | 26 |
| Ground Snake (*Sonora semiannulata)* | 1 | 0 |
| Little Striped Whiptail (*Aspidoscelis inornata)* | 29 | 5 |
| Long-nosed Snake (*Rhinocheilus lecontei)* | 1 | 0 |
| Marbled Whiptail (*Aspidoscelis marmorata)* | 24 | 35 |
| Round-tailed Horned Lizard (*Phrynosoma modestum)* | 7 | 10 |
| Texas Banded Gecko (*Coleonyx brevis)* | 2 | 2 |
| Trans-Pecos Ratsnake (*Bogertophis subocularis)* | 0 | 2 |
| Tree Lizard (*Urosaurus ornatus)* | 0 | 1 |
| Western Diamondback Rattlesnake (*Crotalus atrox)* | 0 | 2 |
| Whipsnake (*Masticophis taeniatus)* | 0 | 3 |
| Total | 72 | 98 |

## Discussion

***Detection efficiency of lizards and snakes***.—Pitfall-camera traps were effective at detecting small and large organisms, as well as diurnal and nocturnal species. This method could eliminate the negative effects of chasing, capturing, and handling animals (Langkilde and Shine 2006). The use of pitfall-camera traps does not require searching, capturing, or handling large or venomous snakes, also decreasing risks for researchers (Beaupre and Greene 2012). Success in detecting ectothermic species such as reptiles may rely on the type of camera used, as a sufficient temperature contrast must exist between the background surface and the organism for the sensor to trigger the camera (Welbourne et al. 2016). To overcome this issue, Welbourne (2013) developed the Camera Overhead Augmented Temperature (COAT) protocol, using a heat-gaining substrate to create a temperature differential between the reptile and the background. Due to this required temperature differential, using camera traps in other environments has been less effective especially in the detection of nocturnal reptiles (Welbourne et al. 2016; Richardson et al. 2017). In our Chihuahuan Desert study, it was possible to detect small and nocturnal species (geckos) despite the smaller thermal signature of these smaller species (Swann and Perkins 2014), likely due to a sufficient thermal contrast between the background surface and the organisms due to the bottom of the container being shielded from the sun and in contact with soil at 60 cm below the surface. In addition, the camera sensor was located close to the background surface, allowing detection of small organisms.

***Monitoring lizards and snakes using pitfall-camera traps***.—In our study, pitfall-camera traps yielded a similar number of lizard observations and more snake observations compared to traditional pitfall traps, indicating greater effectiveness than pitfall traps alone. The total number of lizard observations per trap day was similar between the two methods, but overall higher diversity was observed with pitfall-camera traps. Pitfall-camera traps sampled a broader spectrum of fauna, including large lizards, snakes, and invertebrates that usually escape pitfall traps (Michael et al. 2012; Silvy 2012) potentially eliminating the need for separate surveys for taxa previously excluded (Garden et al. 2007). Pitfall-camera traps had the ability to remotely capture SVL, TL, and exact times of capture continuously

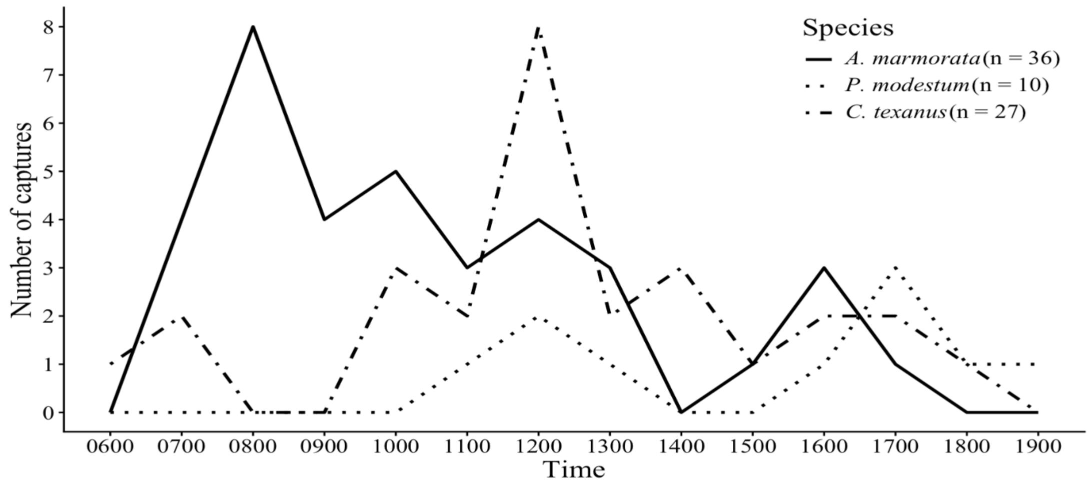


**Figure 4**. Frequency of captures in Hudspeth County, Texas, USA, by time period of the most abundant lizard species: Marbled Whiptail (*Aspidoscelis marmorata*); Round-tailed Horned Lizard (*Phrynosoma modestum*); and Greater Earless Lizard (*Cophosaurus texanus*). Other species were not included due to low sample sizes.

across sites, while information that could not be gained from pitfall-camera traps included sex for some species, gravidity in females, identification of unique markings, and weight of the organism. The ability to also record data without physical capture may make pitfall-camera traps less invasive to species compared to traditional pitfall traps (Putman 1995). The collection of more precise activity data will especially yield greater information in estimating daily and seasonal activity patterns. Future advances in camera technology may provide better image resolution to allow individual identification for more ethical mark-recapture studies of reptiles (Perera and Perez-Mellado 2004; Edwards and Gardner 2010). All videos collected allowed accurate and relatively easy species identification, and all videos of lizards contained a frame from which an estimated SVL measurement could be estimated.

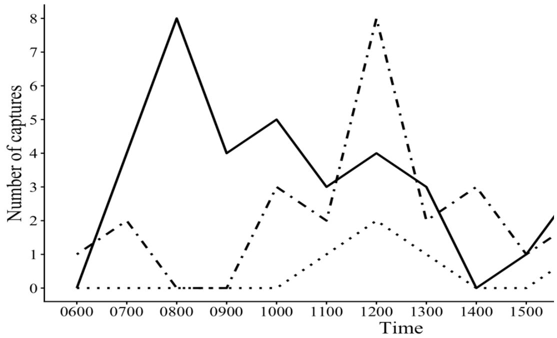


**Figure 5**. Proportion of diurnal captures of Marbled Whiptail (*Aspidoscelis marmorata*) and Greater Earless Lizard (*Cophosaurus texanus*) in Hudspeth County, Texas, USA. Time periods beyond 1800 h contained one or fewer captures and were not analyzed. The asterisk (*) indicates significance difference at the 0.05 level.

***Cost effectiveness***.—Overall, pitfall-camera traps were more cost-effective than the surveys conducted using traditional pitfall traps as it required fewer field visits, fewer personnel, and continuous sampling with minimal effort. Surveys using the traditional array also required overnight stay at the study site and the assistance of multiple individuals to operate traps, thus resulting in increased costs in labor, food, and lodging. We found that a block of three pitfall-camera traps was equivalent in number of lizard captures to a block of 10 pitfall traps, in addition to increasing the capture of large species as well as documenting activity period.

***Conclusion***.—In species typically captured with traditional pitfalls (small- to medium-sized lizards), pitfall-camera traps were efficient in capturing similar numbers of observations with minimal researcher input. In addition, pitfall-camera traps captured species outside the normal range of capture by pitfall traps, such as large lizards and snakes. Pitfall-camera traps also gather more information than pitfall traps alone in recording time of entry. Activity periods for reptiles are typically estimated broadly, lacking fine scale resolution, and use of pitfall-camera traps would resolve this useful ecological data, additionally allowing standardized comparisons between species and sites. Overall, we recommend the use of pitfall-camera traps in reptile monitoring as a more efficient method for surveys when the aim is to document species at a site.

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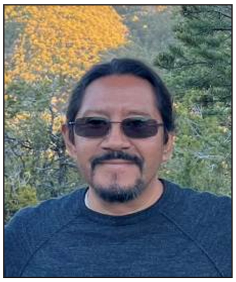

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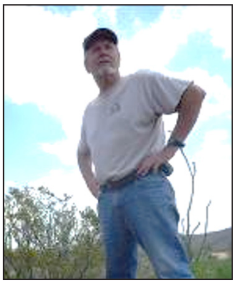

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