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Multiyear Monitoring (2007–2013) of Flat-tailed Horned Lizards (*Phrynosoma mcallii*)

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Abstract.—**Monitoring programs for species of conservation concern are notoriously flawed. Notably, many monitoring programs do not establish trigger points or a level of decline in population size that will result in management action. Here we report on the monitoring program for the Flat-tailed Horned Lizard (*Phrynosoma mcallii*) that has been established across its range throughout the United States by the Flat-tailed Horned Lizard Interagency Coordinating Committee (FTHL ICC). Importantly, we examine whether a trigger point of 30% decline was detected in these populations. Between 2007 and 2013, we detected 955 *P. mcallii* on 2,714 occupancy surveys and captured 715 individuals on 1,861 demographic surveys. Occupancy surveys have demonstrated that the species occurs throughout the management areas and occupancy estimates range from 0.25–0.89. Demographic surveys have demonstrated that population trends over time are correlated across all management areas; however, they are probably driven by factors at smaller geographic scales. During the study no population decline > 30% was detected after accounting for natural and stochastic fluctuations. Continued monitoring is called for to gain a greater understanding of what is driving the trends in populations both range-wide and at the scale of management areas.**

Key Words.—candidate species; conservation; demographic and occupancy monitoring; endangered species; Phrynosomatidae.

Introduction

Reptiles are experiencing alarming rates of decline globally (Gibbons et al. 2000). Common causes attributed to these declines are habitat loss and land conversion, habitat fragmentation (Gardner et al. 2007; Leavitt and Fitzgerald 2013), invasive species (Lovich 1995; Rosen and Schwalbe 2002; Treglia et al. 2013), environmental pollution (Hopkins et al. 1999), disease and parasitism (Allender et al. 2011; Clark et al. 2011), unsustainable use (Fitch et al. 1982), global climate change (Sinervo et al. 2010; Clark et al. 2011), and enigmatic decline (Gibbons et al. 2000, Hibbitts et al. 2009; Lindenmayer et al. 2013). Given this broad array of potential factors responsible for decline and unique ecological requirements for each species, these threats should be evaluated on a species-specific basis. Along this line, success in the management of sustainable populations requires forward thinking strategies and clear aggressive actions that will be taken when trigger point declines are detected (Yoccoz et al. 2001). Robust monitoring efforts to detect declines with high confidence are essential to these actions and strategies. Further, a recent review of monitoring programs identified a repeated list of critical factors essential to monitoring efforts to avoid extinction (Lindenmayer et al. 2013). The most critical factor identified is establishing biologically sound trigger points and biologically and logistically reasonable response actions.

Natural resource managers benefit from monitoring both the spatial and temporal dynamics of their targets by gaining a sense of the status of these entities (Guo et al. 2005). Often monitoring programs for wildlife focus on good habitat where a large sample will offer plentiful captures of the target species. However, these locations do not often represent the true density for the organism across its distribution (Whittaker and Goodman 1979). Here we analyze six consecutive years of monitoring data (2008–2013) for the Flat-tailed Horned Lizard (*Phrynosoma mcallii*) representing occupancy and demographic monitoring plots throughout the range of the species in the United States. The goal of monitoring is to use methods that are cost-effective, efficient to implement, and provide enough information to determine the status of the species through time, and to evaluate whether populations are stable, increasing, or decreasing.

Phrynosoma mcallii (Fig. 1) has the smallest range of any horned lizard in the United States (Sherbrooke 2003, Rorabaugh and Young 2009), and occurs from northern Sonora, Mexico to just north of the Salton Sea, California and enters the southwestern corner of Arizona south of the Gila River confluence with the Colorado River (Fig. 2). Much of the range of the species is also in Mexico; however, annual demographic and occupancy monitoring has only been conducted in the United States. *Phrynosoma mcallii* in the United States has experienced a significant range reduction (estimated 43–50%) due to urban and agricultural development in and around the Salton Sea (Rorabaugh and Young 2009). Multiple actions by stakeholders throughout the range of *P. mcallii* in the US and in Mexico have resulted in the creation of an interagency team, the Flat-tailed Horned Lizard Interagency Coordinating Committee (FTHL ICC), which is responsible for implementation of conservation and management strategies (FTHL ICC 1997, 2003, 2008). In 1997 the FTHL ICC, which includes stakeholders from both the US and Mexico created the Flat-tailed Horned Lizard Rangewide Management Strategy (FTHL ICC 1997, 2003) intended to maintain extant populations of the lizard in perpetuity. As a result, five management areas (MAs) and one research area (RA) were established to protect this species and to serve as long-term monitoring sites (Fig. 2). Further, the FTHL ICC determined that if a 30% decline is observed (after accounting for stochastic and natural causes), management action(s) will be determined and implemented to remedy the population decline. It should be noted the monitoring data presented herein is the largest and most compre-

Figure 1. The Flat-tailed Horned Lizard (*Phrynosoma mcallii*) from El Golfo, Sonora, Mexico. (Photographed by Robert Lovich).

hensive on the species geographically, and < 1% of the land in the management areas have been disturbed since the creation of the Rangewide Management Strategy in 1997. Declines such as those documented in the highly fragmented and heavily urbanized Coachella Valley to the north (Barrows et al. 2008) have not been witnessed in the management areas surveyed for this study. In 2008, the FTHL ICC established a monitoring plan that evaluates both demography and occupancy of *P. mcallii* using the same methods for consistency across MAs (FTHL ICC 2008). Finally, monitoring methods account for imperfect detection probabilities by having either multiple temporal or spatial replicates within each MA. This issue is critical to the precision of these estimates of abundance, occupancy, and population dynamics for this species (Grant and Doherty 2007, 2009; Royle and Young 2008; Barrows and Allen 2009). Herein we provide an assessment of monitoring data to assess the current status of *P. mcallii* within these MAs and RA. Given that no current rangewide demographic baseline exists for comparison, we compare results necessarily to those of other similar efforts for this species at smaller geographic scales within the US range of the species.

Materials and Methods

Monitoring efforts for *P. mcallii* have varied over the years as a result of development and evaluation of appropriate, accurate, and efficient methodologies by individual stakeholders of the FTHL ICC (Grant and Doherty 2007; Royle and Young 2008). In 2008, the FTHL ICC established a monitoring plan to be implemented by all stakeholders and in each MA (FTHL ICC 2008). The resulting plan consists of both occupancy and demographic monitoring thereby accounting for the spatial and temporal dynamics of this species population.

Occupancy monitoring.—We selected occupancy plots randomly from the MAs in a probabilistic manner (randomly). We surveyed rectangular 2-ha plots multiple times during the active season for *P. mcallii* (May - October) between 2011 and 2013 at three MAs. Fifteen minutes prior to sunrise, two surveyors walked these plots searching the ground for lizards and

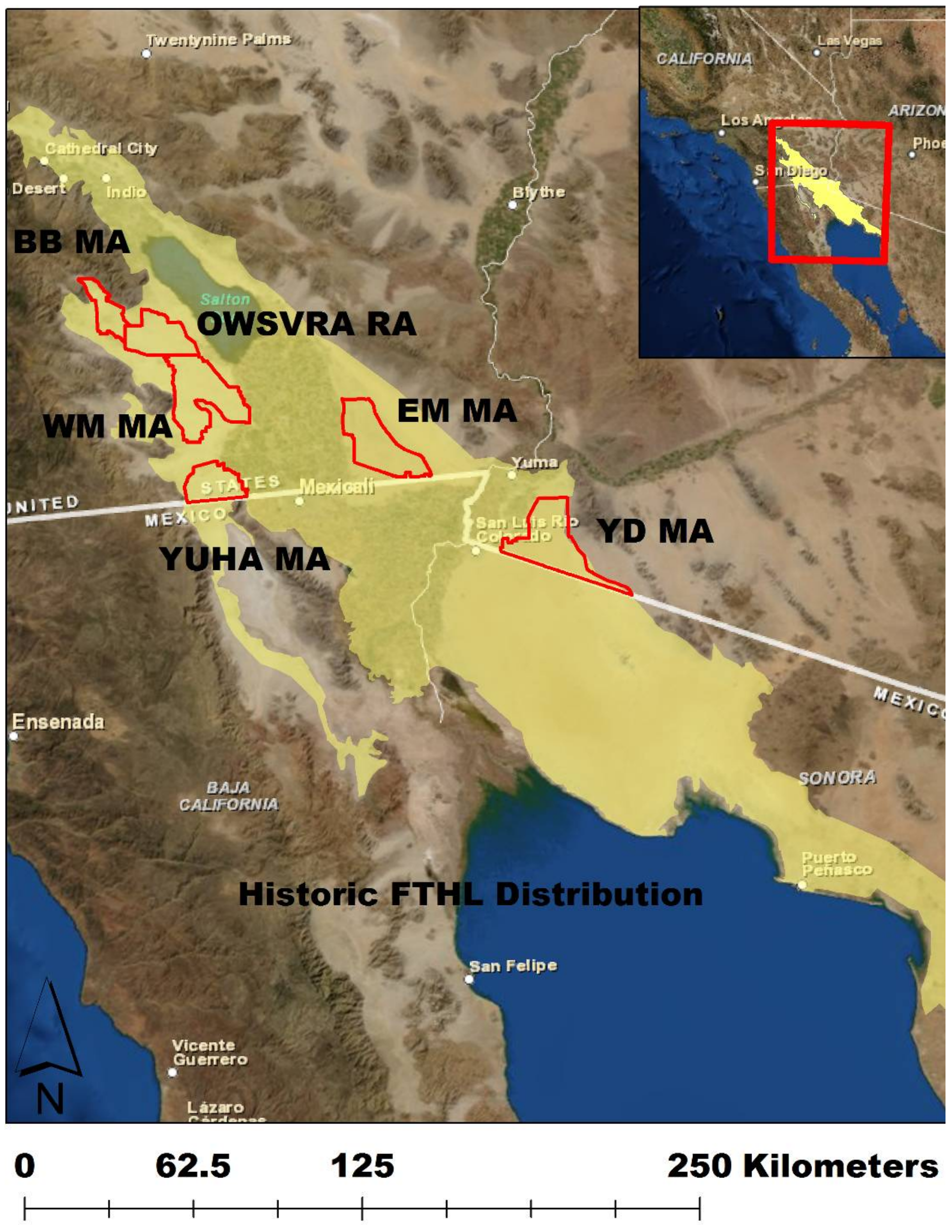

FIGURE 2. Historic distribution of the Flat-tailed Horned Lizard (*Phrynosoma mcallii*) and current location of five management areas and one research area in southwestern Arizona and southeastern California, USA.

lizard sign (tracks and scat). To fit within an occupancy framework, we conducted multiple revisits. Our goal was to sample 100–200 plots per MA six times each summer. We marked all *P. mcallii* encountered on the ventral surface with unique characters using felt-tipped markers for rapid visual identification. When we observed a horned lizard, we considered the plot occupied and surveyors moved to a new randomly selected plot.

***Demographic monitoring.*—**We selected a series of demographic plots (9-ha each) based on perceived habitat quality and ease of access in each MA and surveyed them from 2008 to 2013. On demographic plots, we surveyed entire plots every week-day for two weeks, thus we conducted 10 capture occasions per year. During the surveys, our teams were composed of five to seven surveyors total per year with two teams of two to four observers covering 4.5 ha per capture occasion (half the 9-ha survey plot). We surveyed plots on foot by spacing observers 18–25 m apart while walking in a serpentine fashion along transects for the length of the plot. We repeated this until the entire plot was searched. While walking, we investigated habitat features such as burrows, clumps of vegetation, sand mounds, and ant colonies for *P. mcallii* sign and presence. We followed *P. mcallii* tracks until a lizard was found, or the trail became too degraded to follow. We rotated team starting positions each day so that transect areas were searched at different times during the course of survey. During each survey session, our survey teams also alternated search areas between the east and west halves of the plot to minimize surveyor bias. We conducted surveys approximately 15 min before sunrise or when there was enough light for tracking. Daily survey duration was variable depending on tracking conditions and the number of *P. mcallii* found and processed and a typical survey effort lasted 3–4 h. In addition to temporary marking with a felt-tipped pen, we permanently marked *P. mcallii* measuring ≥ 45 mm snout-vent length (SVL) by inserting Passive Integrated Transponders (PIT) tags into the body cavity for permanent identification. We did not insert PIT tags in juveniles or small individuals (< 45mm SVL) due to perceived risk of internal injury. We documented capture locations for each lizard using hand-held GPS units.

***Analysis of multiple-season occupancy.*—**For MAs where multiple years of occupancy data have been collected (Yuma Desert MA [YD MA], Borrego Badlands MA [BB MA], and Ocotillo Wells State Vehicular Recreation Area RA [OWSVRA RA]; Fig. 2), we used a robust design multi-season occupancy model to estimate detection probability (ρ), occupancy probability (Ψ), and extinction (ε) from 2011–2013 (MacKenzie et al. 2003). Robust design multi-season models assume local seasonal closure for Ψ and allow trends to be evaluated across multiple MAs where missing sites or surveys may exist. We compared a set of 62 models in a multi-model likelihood framework that estimated Ψ and ε either by MA or as constant values and we considered models with MA, seasonal, yearly, and pass specific effects on ρ. We evaluated occupancy models with multiple-season and robust-design in program MARK (White and Burnam 1999). Missing values for locations and years were coded as "." and not all MAs were evenly sampled resulting in larger standard error around the parameter estimates. We ranked all models according to their Akaike's Information Criterion (AIC; Akaike 1973) and we corrected for small sample size (AICc; Burnham and Anderson 2002). To account for model selection uncertainty, we averaged parameter estimates across all candidate models based upon resulting model weights (i.e., parameter estimates from models with higher model weights contributed more strongly to final estimates than models with lower model weights (Burnham and Anderson 2002). Occupancy data from previous years for MAs without multiple years of data were

Table 1. Four top candidate models of demographic parameters used to estimate Flat-tailed Horned Lizards (*Phrynosoma mcallii*) abundance across all the management areas in California and Arizona 2011–2013. Acronyms and symbols are for parameters (Par), management area (MA), yearly estimates (year), and model constant (.).

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	No. of Par	Deviance
Ψ(MA*t)γ"(.)γ'(.)	10,056.77	0.00	0.80	1.00	44	8,214.80
Ψ(MA*t)γ"(.)γ'(MA)	10,060.86	4.09	0.10	0.13	48	8,210.47
Ψ(MA*t)γ"(MA)γ'(.)	10,061.21	4.45	0.09	0.11	48	8,210.83
Ψ(MA*t)γ"(MA)γ'(MA)	10,065.95	9.18	< 0.01	0.01	51	8,209.23

reported by Frary (unpubl. report), and we incorporate those values to this assessment for comparison.

Robust-design demographic models.—We used robust-design demographic models (Kendall 2011) to derive population size (N) in program MARK (White and Burnam 1999). These models are designed to allow for immigration, emigration, births, and deaths between primary occasions. We assumed that the demographic plots were closed during the 10-d capture session (secondary occasions). For this analysis we examined estimates of survivorship (φ) by MA, over time, with a MA × time interaction and as a constant. Our estimates of changes in availability (γ' and γ") were either by MA or as a constant and all estimates of capture probability (ρ) and recapture probability (c) were set as constants per year. Data analysis was performed on the data available on adults (> 45 mm SVL) from both sexes. The sites used in this analysis were East Mesa MA plot 1 (EM1), West Mesa MA plot 1 (WM1), Yuma Desert MA plot1 (YD1), Yuma Desert MA plot 2 (YD2), and Yuha Basin MA plot 1 (YU1; Fig. 2). All models were ranked according to their Akaike's Information Criterion (AIC; Akaike 1973) and were corrected for small sample size (AICc; Burnham and Anderson 2002). To account for model selection uncertainty, parameter estimates were averaged across all candidate models based upon resulting model weights (i.e., parameter estimates from models with higher model weights contributed more strongly to final estimates than models with lower model weights (Burnham and Anderson 2002).

Results

Analysis of multiple-season occupancy.— Between 2011 and 2013 we conducted 2,714 occupancy surveys on 217 separate plots in three MAs. We observed 955 *P. mcallii* on 150 plots leaving 67 plots unoccupied during the course of this survey. Naïve estimates of occupancy over this time were 0.21 for BB MA, 0.89 for YD MA, and 0.88 for OWSVRA RA. The top four models for multiple-season occupancy incorporating imperfect detection accounted for 99.9% of the total AICc weights (Table 1). Of these, the top model accounted for 77.0% of the AICc weight and estimated Ψ by MA, φ by MA, and ρ by year and MA (Table 1). Model-averaged occupancy estimates were highest at OWSVRA RA (0.89 ± 0.04) and YD MA (0.85 ± 0.04) and lowest at BB MA (0.25 ± 0.09). Estimates of local extinction were higher in 2011–2012 than in 2012–2013 at all MAs (Fig 3). None of the extinction rates are predicted to be higher than the target value, 0.30, required for management action. However, inconsistencies in data collection (many missing surveys) at BB MA resulted in wide confidence intervals for that MA.

Robust design-derived abundance

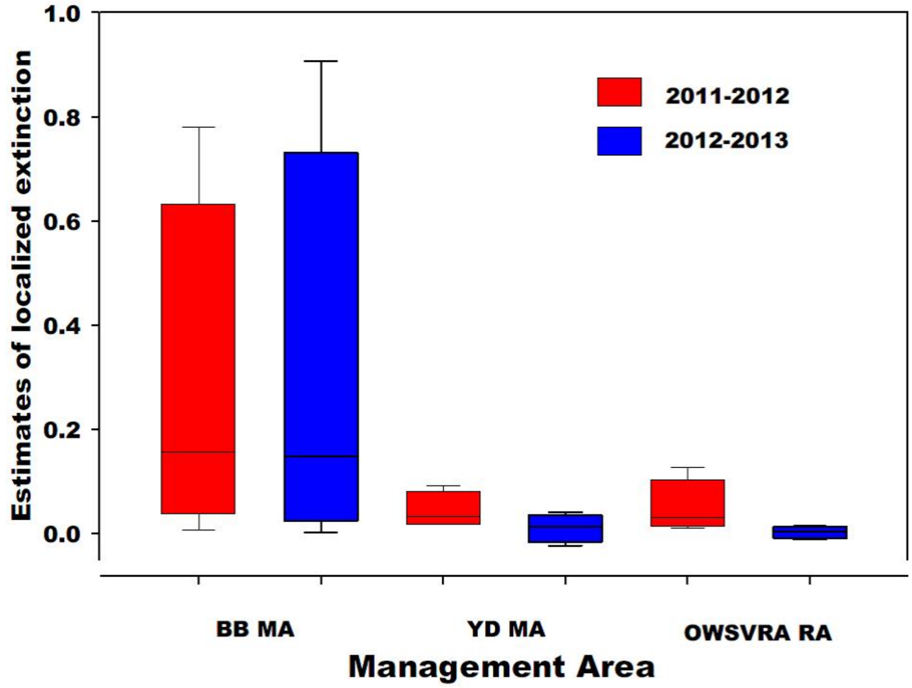

Figure 3. Extinction rate estimates (median, second and third quartile, and range of the estimate) as modeled from a multiple-season occupancy model of three Flat-tailed Horned Lizard (*Phrynosoma mcallii*) management areas in Arizona and California between 2011 and 2013.

***estimates.*—**Between 2007 and 2013, we captured 715 individual *P. mcallii* on 1,861 separate occasions at the five MAs. The model with the most support for *P. mcallii* demographics captured 80% of all the model weights and estimated a MA x time interaction on φ and estimated a constant value for γ" and γ' (Table 2). None of the competing models were well supported by the data (i.e., all models had model weights lower than 10%). Abundance of adult *P. mcallii* were similar or higher in 2012 to those in 2008 at WM1, EM1, YD2 and YU1 (Fig. 4), whereas there appeared to be a decrease at YD1. Population abundances gradually increased at all MAs in either 2010 or 2011 and then decreased thereafter (Fig 4; Table 3).

The plots at YD MA (1 and 2) have been visited since 2008; however, due to an increased abundance of *Bouteloua aristoides* (Needle Grama) on the YD1 in 2013 (Fig. 5), very few captures occurred there despite this area being very active for *P. mcallii* earlier in the year during occupancy monitoring activities (pers. obs.). As a result, the apparent population size from our model estimate is much lower. The estimates of N for the nearest plot (YD2) from 2008 to 2013 suggest a spike in growth in 2010 and a continued leveling out through 2013 (Fig. 4).

Discussion

These results provide the first assessment of *P. mcallii* populations throughout their range in the US since Grant and Doherty (2007) provided estimates for a few MAs in California. Our data expand on Grant and Doherty's data (2007) by incorporating three additional locations (including Arizona) and providing an assessment of the spatial distribution of this species within the MAs. We found no evidence of a population decline greater than 30% during the monitoring period after accounting for natural and stochastic pop-

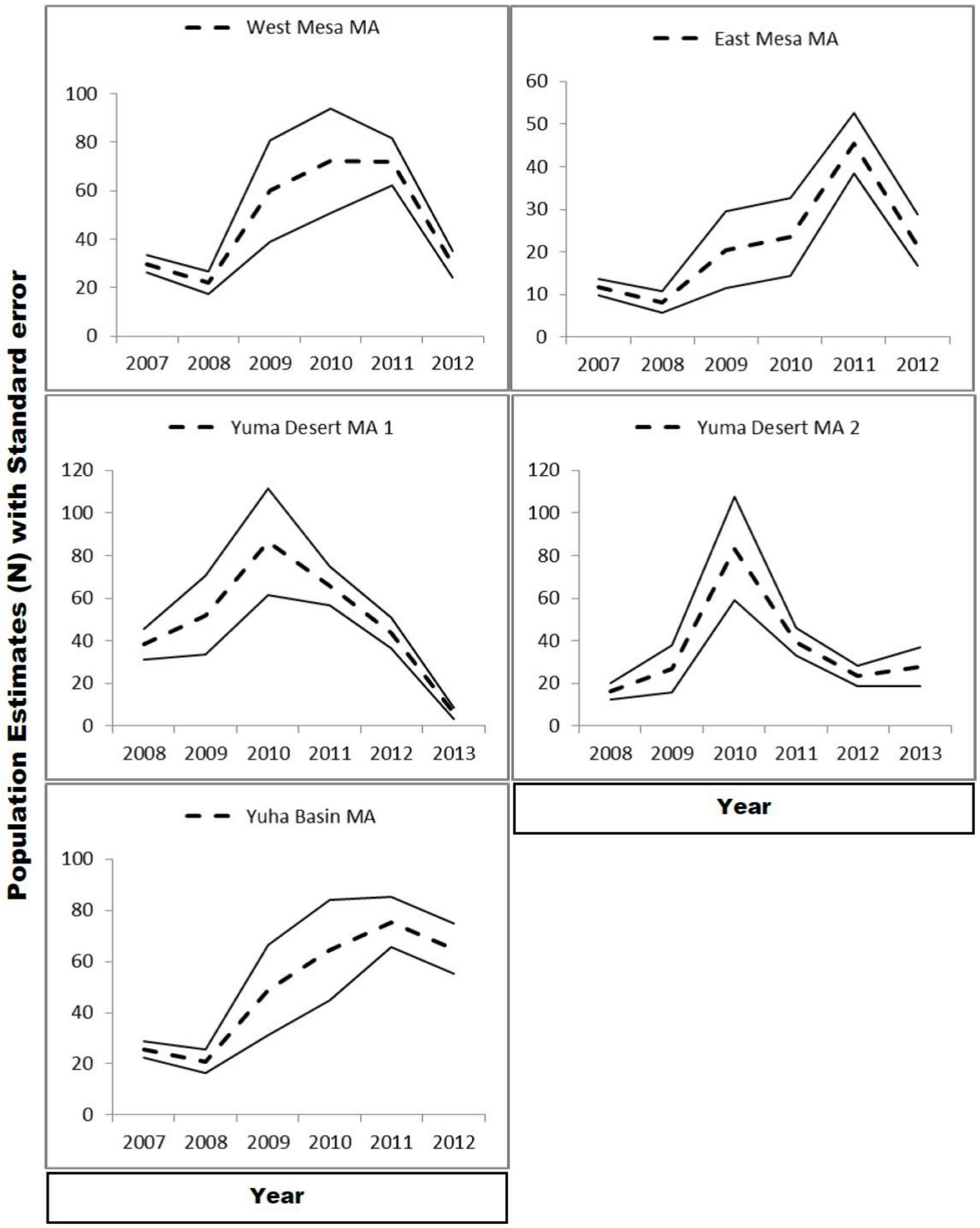

Figure 4. Population abundance estimates derived from model averaging for all Flat-tailed Horned Lizard (*Phrynosoma mcallii*) management areas in Arizona and California, USA, between 2007 and 2013.

FIGURE 5. Typical (left) and abnormal (right) summer vegetation on the Yuma Desert Management Area plot 2, in Arizona, USA.

ulation fluctuations. It is of interest to note that the highest occupancy was at an off-road vehicle recreation location (OWSVRA). Expectation of habitat disturbance and alteration as being negative for FTHL occupation may be more complex than a priori assumptions (Grant and Doherty 2009). While the FTHL ICC recognizes the benefits of incorporating other methods to monitor these populations, implementation of additional techniques has been prohibitively expensive. Therefore we did not try to extend our estimates to rangewide densities as has been done by others (Grant and Doherty 2007). Many of our demographic plots do not represent any typical or common condition found throughout the range of *P. mcallii*. We selected demographic plots due to their expected large sample size, thus any estimates of MA population size would greatly overestimate the true value.

Prior to 2008, stakeholders did not use common protocols for annual demographic and occupancy monitoring. Since that time we have had the benefit of using the same protocols (FTHL ICC 2008), with the benefits of rangewide comparability over the long term to detect trends, and to establish baseline information regarding the species. From our analysis of all annual survey data since 2008, we see clear and well-supported trends emerging. Notably, these populations appear to be increasing, and decreasing in concert. In accordance with our management strategy (FTHL ICC 2003) the FTHL ICC has, thus far, maintained a close watch on the fluctuations of FTHL populations and distributions to formulate an appropriate response if a 30% decline is detected or imminent. In the coming years as more monitoring data are collected and analyzed, the FTHL ICC will be prepared to respond if a population decline of that size occurs. As monitoring data sets grow, the potential accuracy for modeling future population trends will increase.

Notably our methods are different from those

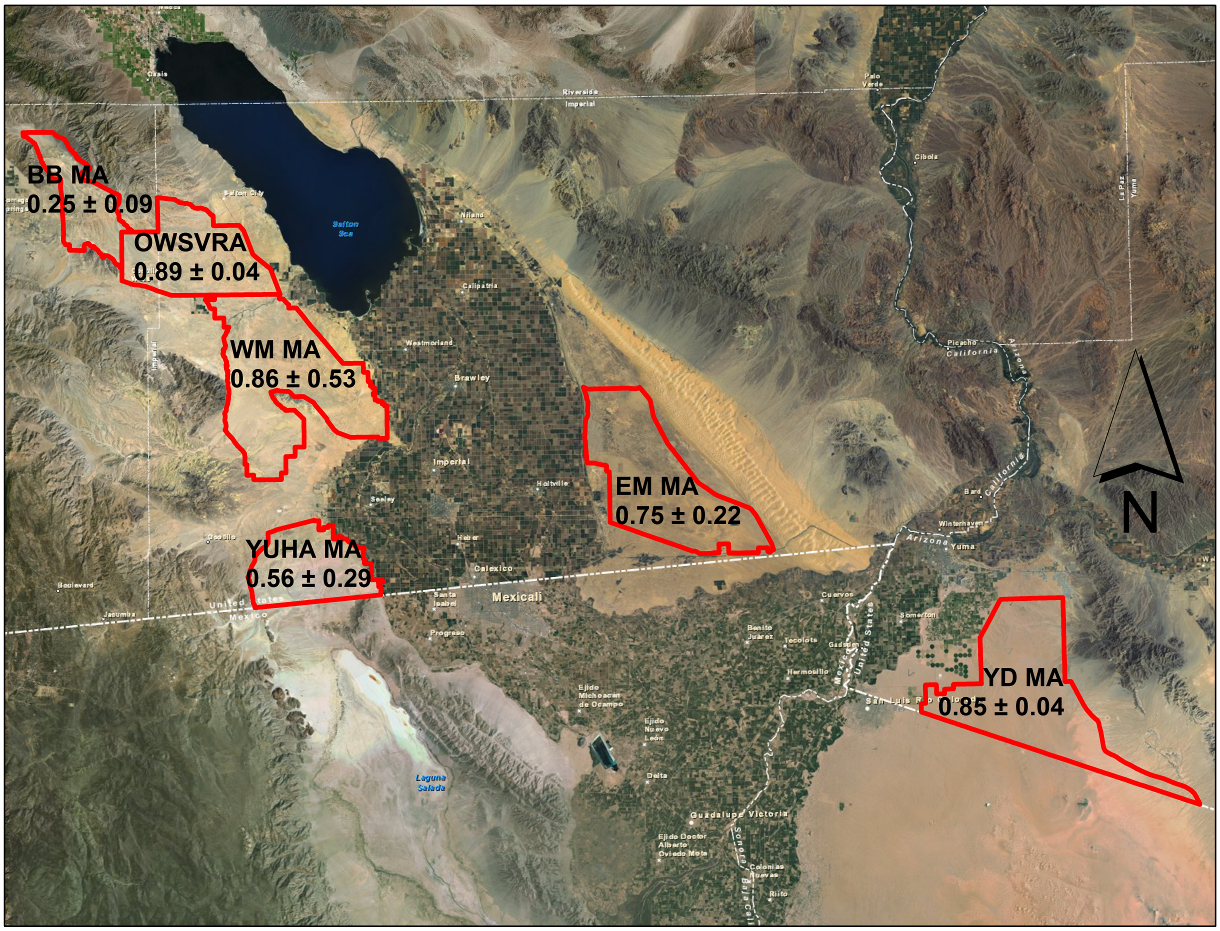

Figure 6. Estimates of occupancy for Flat-tailed Horned Lizard (*Phrynosoma mcallii*) within management areas in Arizona and California, USA, taken from the last year of assessment.

Table 2. Four top candidate models of multiple-season occupancy for Flat-tailed Horned Lizards (*Phrynosoma mcallii*) across all the management areas in California and Arizona 2011–2013. Acronyms and symbols are for parameters (Par), management area (MA), yearly estimates (year), and model constant (.).

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	No. of Par	Deviance
Ψ(MA)ϵ(year)ρ2011(MA)ρ2012(MA)ρ2013(MA)	2,686.81	0.00	0.77	1.00	13	2,660.09
Ψ(MA)ϵ(MA)ρ2011(MA)ρ2012(MA)ρ2013(MA)	2,689.49	2.68	0.20	0.26	13	2,662.77
Ψ(MA)ϵ(.)ρ2011(MA)ρ2012(MA)ρ2013(MA)	2,693.07	6.26	0.03	0.04	13	2,666.35
Ψ(.)ϵ(MA*year)ρ2011(MA)ρ2012(MA)ρ2013(MA)	2,701.26	14.45	< 0.01	< 0.01	13	2,674.54

Table 3. Correlation coefficients derived for population estimates between Flat-tailed Horned Lizard (*Phrynosoma mcallii*) management areas in California and Arizona 2007–2013. Management areas are West Mesa (WM), East Mesa (EM), Yuma Desert 1 (YD1), Yuma Desert 2 (YD2), Yuha Desert (YUD).

	WM	EM	YD1	YD2	YUD
WM	1.00				
EM	0.76	1.00			
YD1	0.86	0.50	1.00		
YD2	0.72	0.30	0.74	1.00	
YUD	0.72	0.84	0.60	0.49	1.00

used in other investigations of *P. mcallii*. In the Coachella Valley region of California, populations have been monitored by using smaller plots, animal tracks and sign, and within the context of monitoring the entire biological community (Barrows et al. 2008, Barrows and Allen 2009). The Coachella Valley is a heavily fragmented ecosystem with little remaining habitat for *P. mcallii* (Barrows et al. 2008; Barrows and Allen 2009) and therefore makes for a challenging comparison of population parameters. In contrast, the majority of the lands within the FTHL ICC MAs are relatively intact and undisturbed. Moreover, fiscal realities result in limited funds for annual monitoring. Thus, collection efforts are maximized towards capturing data on *P. mcallii* using direct observations versus ecosystem monitoring. While not perfect, the FTHL ICC and its MOG are using peer-reviewed protocols and monitoring strategies for *P. mcallii* that address problems created by imperfect detection probability, and protocols have been standardized across most of the range of the species in the US.

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Linden Piest, Daniel J. Leavitt, Nicholas B. Heatwole, Robert E. Lovich, Robert J. Powell, Erica Stewart, Kevin Ponce, and Jack Crayon (from left to right) at the Flat-tailed Horned Lizard Interagency Coordinating Committee (FTHL ICC) meeting, Bureau of Reclamation Office, Yuma, Arizona, 11 February 2015. Not shown in the photo are **Jimmie Collins, Cat Crawford, Tyler J. Grant, Eric V. Hollenbeck, Michael F. Ingraldi, Aimee Roach, Abigail Rosenberg, Felicia Sirchia, Andrew Trouette, Joyce Schlachter, and Daniel M. Steward**. As members of the FTHL ICC, they collaboratively implement the Rangewide Management Strategy for the FTHL to manage the species in perpetuity on the five management areas. (Photographed by Craig Fisher).