Pima County Ecological Monitoring Program

Sonoran Desert Tortoise (*Gopherus morafkai*) Monitoring Protocol

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Photo by Gerald Loew – Pima County

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Abstract

The Sonoran desert tortoise (*Gopherus morafkai*) is an iconic species ofthe Sonoran desert and is a species of conservation concern. Pima County's Multi-species Conservation Plan and Ecological Monitoring Plan define the County's requirement to monitor Sonoran desert tortoise on County conservation lands. County staff designed a long-term occupancy monitoring protocol on three County conservation properties in the Tucson Mountains, balancing concerns of cost-efficiency and travel time with a number of monitoring plots sufficient to generate meaningful results. Field sampling protocols were based on previously implemented occupancy monitoring efforts both on neighboring protected lands and throughout the state (Zylstra et al. 2010) to allow for comparison of monitoring results. Twenty monitoring plots were established in 2018, with subsequent monitoring planned every 2-3 years over the 30-year life of the permit. Overall percent area occupied was estimated at 0.62 (95% CI = 0.53 - 0.72) across all top-ranking models, and overall detection was estimated at 0.64 (95% CI = 0.59 - 0.70) across all sampling periods. The number of available shelter sites and the presence of an incised wash were the most predictive site-level covariates, while observer experience and air temperature were the most predictive survey-level covariates.

Acknowledgements

We would like to thank volunteers D. Turner, S. Mann, and K. Hefty for assistance with occupancy surveys. Mike List provided key GIS expertise and guidance for plot placement. Brian Powell provided important insight and guidance into all parts of planning and implementation of this protocol, as well as substantial amounts of legwork needed during property assessments for tortoise. We also acknowledge the expertise and assistance of Julia Fonseca, Taylor Edwards, Dale Turner, Phil Rosen, and Jeff Servoss, particularly during the project planning phase. We thank NRPR field staff for reporting tortoise observations on County lands. We also thank Pima County's Ecological Monitoring Program Science and Technical Advisory Team members for assistance with program design and protocol review.

Background & Objectives

The Sonoran desert tortoise (*Gopherus morafkai*) is a well-loved, iconic species in Sonoran desert ecosystems. The species is known to occur broadly across much of western and southern Arizona, as well as parts of northwestern Mexico, in upper and lower Sonoran Desert ecosystems. It ranges in elevation from near sea level at the Colorado River to over 1,500 m in southeastern Arizona. Pima County's Sonoran Desert Conservation Plan identified the Sonoran desert tortoise as a species of conservation concern due to its ecological significance. Additionally, the U.S. Fish and Wildlife Service (USFWS) recently decided that federal protections for this species was not warranted (USFWS 2015), in part due to the strong and long-standing commitments that land managers have invested and continue to invest in the study and management of this species. The County's Multi-species Conservation Plan (MSCP) ensures that the County remains in compliance with its Section 10 incidental take permit that it has been issued from the U.S. Fish and Wildlife Service. As part of the MSCP, Pima County has agreed to monitor Sonoran Desert tortoise (hereafter tortoise) populations on County conservation lands.

Pima County's tortoise monitoring objective is to detect biologically meaningful changes in tortoise populations and where possible, to support other monitoring efforts at spatial scales beyond Pima County lands. Pima County staff efforts before monitoring began (2016-2018) focused on improving our understanding of where tortoises occurred across County open space lands. These efforts found that tortoises occur widely across County preserves, including known higher density populations in the Tucson Mountains, Tortolita Mountains, and along the east side of the Santa Catalina Mountains outside of the San Pedro River floodplain (Fig. 1). However, the goals of this monitoring protocol do not simply include inventorying locations where tortoises were observed, but to be able to produce robust and meaningful estimates of tortoise population trends across the 30 year duration of the County's MSCP.

Spatial Sampling Design

Many of these areas require extensive travel time to visit, which thereby limits the amount of time staff can allocate towards implementing the monitoring effort. Additionally, reduced travel time allows for increased number of monitoring plots to be established thereby potentially increasing the power of monitoring results.

After developing a greater understanding of the tradeoffs between area of inference of monitoring results and logistical considerations, Office of Sustainability and Conservation (OSC) staff determined to concentrate surveys at three properties in the Tucson Mountains, 1) the Tucson Mountain Park, 2) Sweetwater Preserve, and 3) Painted Hills Preserve (Fig. 2). These properties are in close proximity to both County offices and metro Tucson, thereby both reducing travel time and allowing for additional questions to be asked such as potentially addressing impacts experienced by tortoise populations that are related to urbanization and encroachment. Importantly, implementing the protocol in a single, easily accessible area allows

for increased probability of change detection over the lifetime of the permit as staff can budget for more plots and site visits as compared to a remote site.

Monitoring Parameter: Occupancy

County staff considered both density and occupancy metrics for the tortoise monitoring protocol. Occupancy is an accepted metric for monitoring wildlife populations, and is less expensive and more time economical as compared to using population density as a monitoring parameter. Occupancy models were developed in the mid-2000s to account for the issue of imperfect detectability, an important issue during wildlife surveys (MacKenzie et al. 2002). Repeated surveys at a series of monitoring plots are used to survey for a species within a specified study area. However, surveys may fail to detect a species, when in fact it is present. The probability of detection of that species on each survey may vary as a function of both landscape level and survey-specific factors, including, vegetation structure, observer experience, and local weather conditions. A site is considered "occupied" when a live animal is observed during that survey. The number and timing of positive detections are then used to estimate the probability of occupancy by site as well as the probability of detecting the species and the overall proportion of area used by the target species within the study area.

Other natural resource managers in Arizona, including the National Park Service and Arizona Game and Fish Department, have in the past, are currently, or are anticipating in the future monitoring desert tortoise using an occupancy-based metric, including in areas nearby Pima County properties in the Tucson Mountains. By following the same protocol, the results of our monitoring effort will be comparable to those of partner agencies.

This document outlines the plot selection criteria and methods, field sampling protocol, and data analysis approach implemented by Pima County staff to monitor Sonoran desert tortoise occupancy on County lands in the Tucson Mountains.

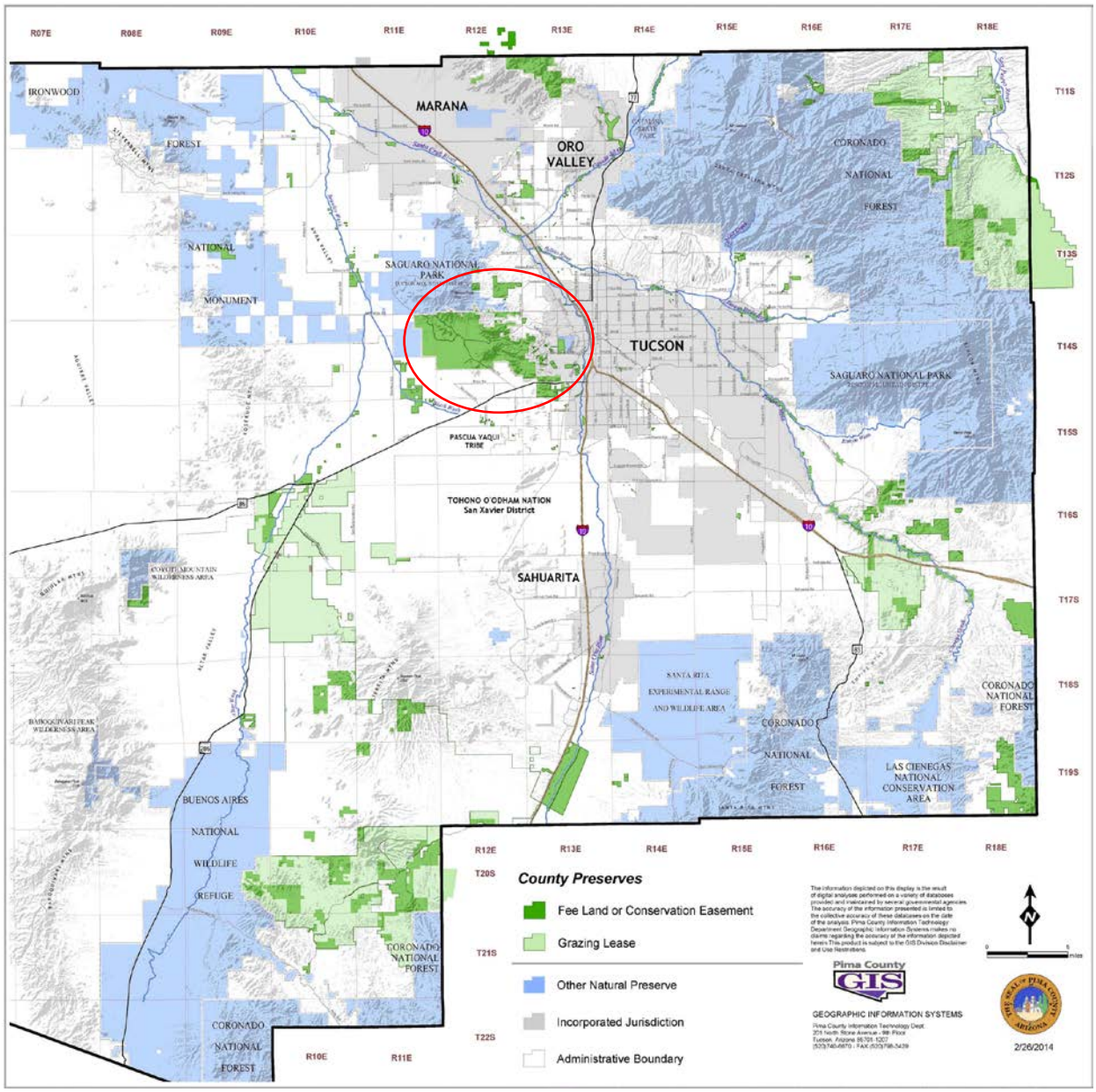


Figure 1. Map of Pima County Conservation Lands (dark and light green), with Tucson Mountain Conservation Properties circled in red.

Monitoring Plot Locations

Plot Generation

We defined plot selection criteria based on prior published recommendations (Zylstra et al. 2010) while incorporating the unique topography, areas of development, and proximity to private property associated with the selected Pima County properties in the Tucson Mountains (Table 1). These criteria included that all plots had to be at least 100 meters from the County property boundary as well as from any roads. Additionally, plots could not be within 50 m of a trail, and were required to be within a one hour hike from the closest access point (i.e., a trailhead or roadside). Occupancy plots also had to be on slopes that were less than 35° and that were within 500 m of a 5° slope. We then utilized the Reversed Randomized Quadrant-Recursive Raster (RRQRR) approach (Theobald et al. 2007) to generate 50 potential monitoring plot locations across the three selected properties that constituted the sampling frame for this monitoring effort (Fig. 2). These plots were spatially balanced, so that if a plot were to be dropped due to severe topography (i.e., not evident in the GIS layer for slope) or a lack of suitable shelter sites (see below) the replacement would still represent the sampling frame as a whole.

Table 1. Sonoran desert tortoise occupancy plot selection criteria.

Criteria	***Range/Buffer***	***Data Source***
Slope	*< 35° slope, within 500m of > 5° slope*	*Pima Co. 10ft DEM*
Property boundaries	*100 m buffer*	*Pima County Preserves*
Roads	*100 m buffer*	*County roads layer*
Designated trails	*50 m buffer*	*NRPR TMP Trails layer*
Hike time	*< 1hr from access points*	*Calculated – distance from nearest road*

Plots were 3 hectare squares, or 170 m on a side (Zylstra et al. 2010). The entire boundary of each plot must have occurred fully within the sampling frame boundary to be included. We selected the first 25 plots locations (20 primary plots with 5 alternates) to be visited during the first round of surveys, with additional alternate plots available if necessary.

Plot Validation

We performed an aerial image and field validation process to identify potential monitoring plots that did not meet sampling criteria. These criteria included the presence of landscape features that were not detected during the initial RRQRR plot generation process, and that would have been grounds for eliminating a plot such as terrain deemed unsafe. Additionally, we removed any plot that had less than two potential tortoise shelters as ascertained by the first field visit (Rubke et al. 2016). We immediately discarded two primary plots and one alternate due to the identification of high social trail density or old livestock watering features during the aerial imagery review. Three alternates were used in place of these discarded plots. Two additional plots were not revisited after the first round of surveys due to containing fewer than

two potential shelter sites. Replacements for these two plots were added and surveyed at the end of the first survey period to maintain consistent sampling effort across all plots (i.e., all plots had one survey in each of three survey periods).

To facilitate ease of field surveys and to ensure adequate survey coverage at each plot, we generated transect lines for each survey plot (Fig. 3). These allowed surveyors to quickly determine whether they were on bearing and maintaining an appropriate distance from other surveyors. Transects were 170 m long, placed 10 m apart, and inset 5 m edges of the plot, for a total of 17 transects per plot. The transects were meant to provide general guidance to ensure that all of each plot was covered, and surveyors were responsible for surveying up to 5 m to either side of each transect. Plots were rotated so that transects ran perpendicular to the prevailing slope for increased safety and efficiency, and were pre-loaded on GPS-enabled field tablets (Panasonic Toughpad FZ-M1 and Garmin Oregon 450).

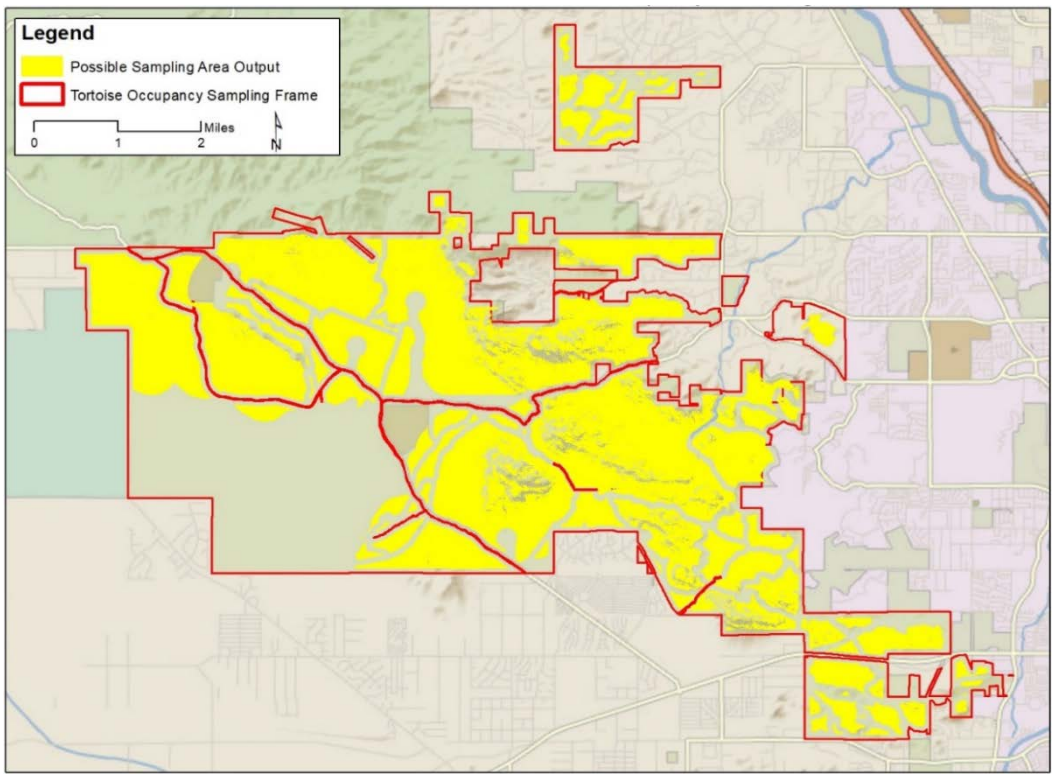


Figure 2. Occupancy monitoring sampling frame in the Tucson Mountains, based on plot selection criteria (Table 1). A large part of the southwestern region of the sampling frame is gently sloping bajada that does not meet the slope criteria.

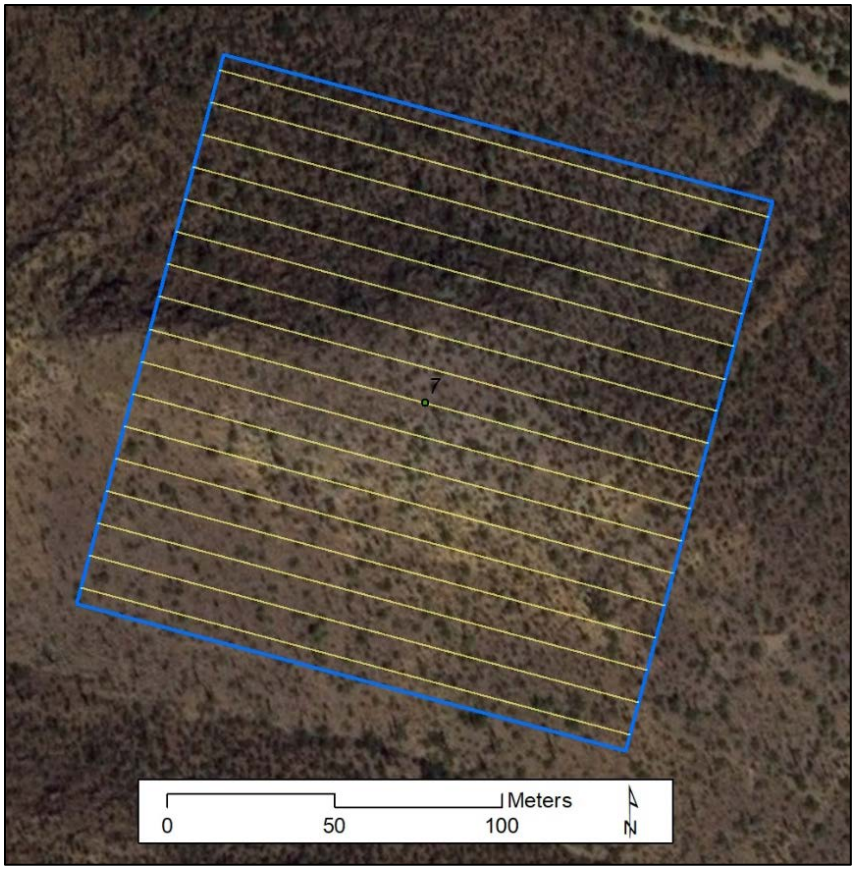
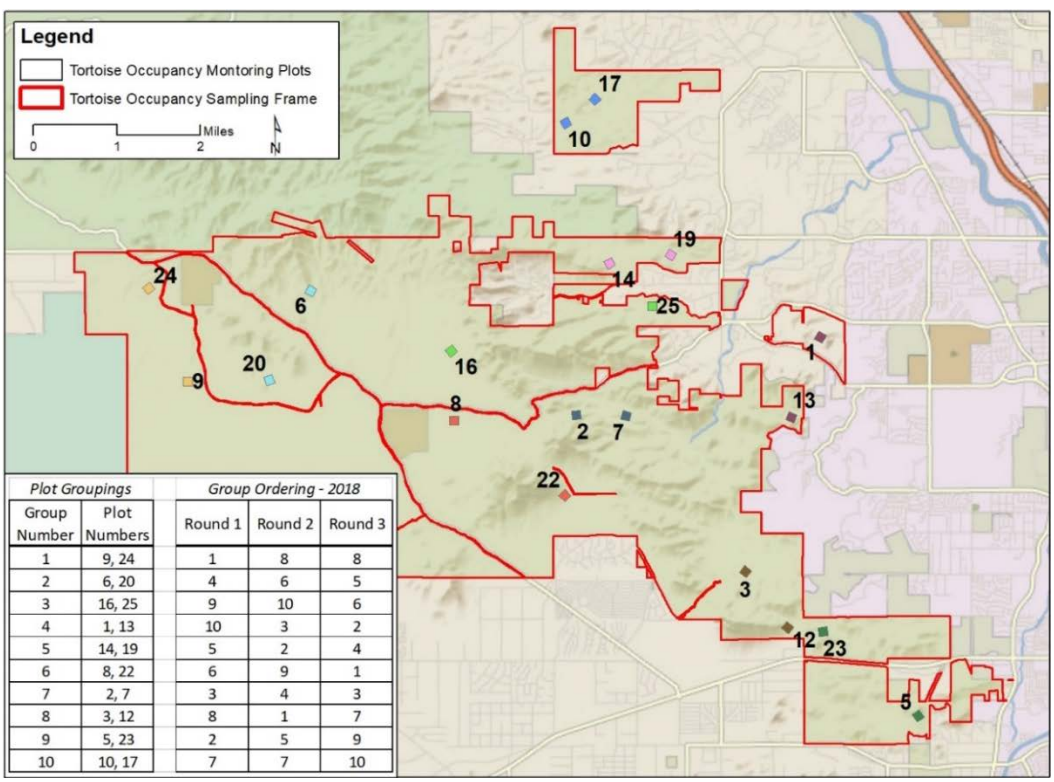


Figure 3. Example plot boundary (blue) and survey transects (yellow).



Plot Groupings		Group Ordering - 2018		
Group Number	Plot Numbers	Round 1	Round 2	Round 3
1	9, 24	1	8	8
2	6, 20	4	6	5
3	16, 25	9	10	6
4	1, 13	10	3	2
5	14, 19	5	2	4
6	8, 22	6	9	1
7	2, 7	3	4	3
8	3, 12	8	1	7
9	5, 23	2	5	9
10	10, 17	7	7	10

Figure 4. Sampling plot locations, plot groupings are shown in different colors.

Field Sampling Protocol

Field Surveys

We grouped the plots into 10 pairs based on their locations (Fig. 4) to minimize drive/hike time between plots, and increase the likelihood of being able to sample at least two plots per day before temperatures became prohibitively hot. We randomized the order of pairs for each of three sampling periods, and alternated which of the members of a pair we visited first on a given field day (i.e., one plot sampled first during the first survey period, second plot sampled first during the second period). We started surveys between 0600 and 0700 h based on travel time to the plot and length of daylight. Surveyors first navigated to one of the downhill corners of the plot and recorded plot information and starting weather conditions (measured 1 cm above ground in the shade: air temperature, relative humidity, barometric pressure, and cloud cover) using a Kestrel 3500 handheld weather meter (See Appendix A).

Surveyors generally followed the center line of transects while surveying up to 5 m on either side of the line. The goal was to view the entire plot, accounting for the density of vegetation, the complexity of rock features, or the prevailing slope. This meant that if a plot contained dense vegetation or rough topography, surveyors would walk at a much slower pace compared to plots that had sparser vegetation or more simple topography. Surveyors would veer off the transect line to inspect behind or under vegetation or rock outcrops, as relevant, before returning to the center line to continue onward. If a shelter was observed, the surveyor would inspect it for tortoise sign or presence, which may have required utilizing a flashlight to illuminate deep shelters or an implement to clear packrat midden debris out of the shelter. Transects were typically walked starting at the downhill side of the plot and working uphill. If multiple surveyors were present, transects were walked in parallel with surveyors adjacent to one another and walking in the same direction.

Evidence of tortoise sign or shelter sites were recorded only within the bounds of the plot. (Tortoises or their sign located outside of the plot boundaries were noted as incidental observations, but not included in occupancy analyses.) Recorded sign were carcasses, scat, tracks, and egg shells, while shelter types were caliche caves, dirt burrows, rock shelters, middens, and pallets. A single observation could include both sign and shelter type (i.e. scat inside a rock shelter). The relative age of sign/shelter (< 1 year, > 1 year, or unknown) was also recorded when possible to differentiate current from previous years' sign. Tortoise scats that were < 1 year old were those that were dark in coloration and well formed. We assumed that any rock shelter that could approximately contain an adult tortoise and that was at least one body length deep was a potential tortoise shelter site. Recent tortoise shelters were those that had clear evidence of shaping and scuffing by tortoises, or that contained recent scats or tracks. Lastly, shelters that were unconfirmed as being used by tortoises (i.e., dimensions were such that they were capable of accommodating an adult tortoise, but had no direct evidence of use) were only marked as potential (See Appendix B).

Tortoise Processing

Live tortoises were processed both within the bounds of the plot and within a reasonable proximity of the plot (~200 m; tortoises beyond this distance were not weighed, measured, and marked, but their location noted as an incidental observation). We processed tortoises that were close to, but not on the plots because these individuals could potentially be recaptured on plot during a subsequent plot visit. However, tortoises had to have been found within the boundaries of a plot to be included in subsequent occupancy analyses. Animals were not processed if air temperature exceeded 35˚C. Information on environmental conditions, tortoise location and behavior, shelter site, identification, general health, and disease were recorded for each detected individual (Appendix C).

We permanently marked tortoises in order to track the number of distinct individuals per plot and to gather potential demographic, survival, and movement data if animals were recaptured in subsequent survey periods or years. Animals were marked using a unique ID number (224-290) that was coordinated with AZGFD and Saguaro National Park staff so as not to overlap with known ID numbers for other tortoises that had been marked in the surrounding area (i.e., Saguaro National Park - Tucson Mountain District) during prior monitoring efforts. Individuals were marked with both a "license plate" and marginal scute notches. The "license plate" consisted of applying a small amount of Bic wite-out quick dry correction fluid to the fifth vertebral scute, writing the tortoise's assigned ID number in permanent marker, and applying fast-drying epoxy with a single use popsicle stick (J-B Weld MinuteWeld Instant-Setting epoxy) to cover and protect the entire area (Fig. 5). Care was taken to not allow epoxy to run across the seams between scutes which could potentially impact the growth of juveniles. Individuals were notched along the marginal scutes using the AZGFD A marking system (Cristina Jones, AZGFD, personal communication; Averill-Murray 2000) and a Nicholson 6" slim taper triangular file (Figs. 5 & 6). Care was taken to make notches deep enough to be permanent but not too deep to cause harm to the tortoise (i.e., notching deep enough to expose bone and cause bleeding). Additionally, bridge scutes (sides of the carapace) were avoided on small individuals as they can potentially cause irreversible damage as animals grow. We did not notch the scutes on very small juveniles (< 100 mm MCL), and for three juveniles < 75 mm MCL, we placed a dab of epoxy-covered wite-out on the 5th vertebral scute without including a number.

We used Pesola scales (5 kg, 2.5 kg, 1 kg, 0.1 kg) to record tortoise mass by using a single use, plastic grocery shopping bag as a sling. We recorded tortoise middle carapace length (MCL) with a 45 cm metal ruler. We made a conscious effort to handle all tortoises with slow and steady movements, keeping them low to the ground (not lifting them high in the air), and did not turn them upside down. We did not handle any animals that we had already marked and processed during previous plot visits, unless the wite-out or permanent marker needed to be touched up. All animals were handled with disposable nitrile gloves; rulers, files, and other equipment that came into contact with a tortoise were all disinfected after each use with a 20% bleach solution to prevent potential disease transmission between individuals.

Figure 5. Marked tortoise with license plate and scute notch shown.

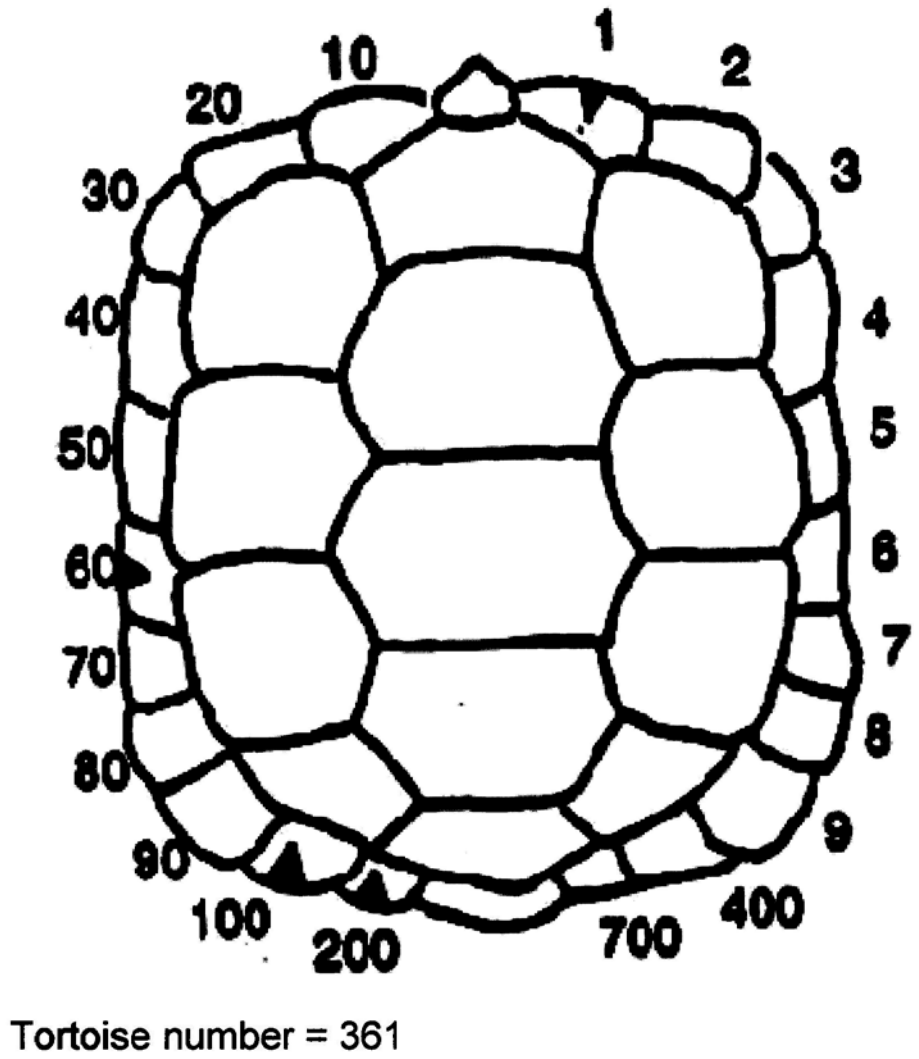


Figure 6. AZGFD Tortoise Marking System A (Averill-Murray 2000).

Data Analysis

We summarized all sign, shelter sites, and live tortoise observation data by plot and visit number. We used all tortoise detections, both juvenile and adult, in our analyses of occupancy. The number of shelter site observations were averaged across all three sampling periods, by plot, to account for potential differences in detection probabilities and observer experience. We extracted three groups of plot-level covariates used to calculate the probability of occupancy (Ψ): 1) topography, 2) geomorphology, 3) land/vegetation cover (consistent with Zylstra et al 2010). We also extracted covariates associated with each survey date used to calculate probability of detection (p). All covariates are described in detail with units and data sources in Table 2.

We used program PRESENCE (MacKenzie et al. 2017) to analyze desert tortoise occupancy. We followed the three steps for fitting single-season occupancy models with both site-level and detection-level covariates as outlined by MacKenzie (2006) and as followed by Zylstra et al. (2010). Those steps are 1) create models for each covariate group affecting ψ, with all possible combinations of covariates, while keeping a static, basic set of covariates for *p*, 2) create models for all possible combinations of covariates affecting *p*, using all covariates represented in top-ranking models from step 1, and 3) create a set of final candidate models with all possible combinations of top-ranking Ψ and *p c*ovariates derived from steps 1 and 2. In all steps, models were ranked according to their Akaike information criterion (AIC) scores, and only those candidate models with ΔAIC values ≤ 2.0 were included in the final. Model goodness-of-fit was assessed using c-hat (ĉ) (Mackenzie & Bailey 2004). This method uses a parametric bootstrap approach by running 100 iterations of the selected model, calculating the c-hat test statistic, a measure of overdispersion in the data also called the variance inflation factor. C-hat values of ~1 suggest that the model is appropriate to describe the data (i.e., the data are not overdispersed), where values >1 suggests that there is a lack of model fit (variance > mean) and that the standard errors of the parameters should be adjusted by the square root of c-hat (i.e., inflated). A c-hat of <1, or underdispersion, is generally considered acceptable with no need to adjust parameter metrics.

We utilized the integrated model averaging function within program PRESENCE to calculate estimated percent area occupied (in our case likely the percent area used) across the monitoring seasons and detection both by survey period and across all survey periods. Estimates of Ψ and *p* were averaged across all top candidate models (according to model weight) within each monitoring site, and then averaged across all monitoring sites to generate global estimates for percent area occupied and detection (Mackenzie & Bailey 2004). Values were reported with the model estimate and 95% confidence interval. Beta values for all covariates in the top-ranking candidate models were averaged to determine the relative level of influence on predicting either Ψ or *p*.

We then used linear regression to interpret the relationship between individual predictor covariates and either Ψ or *p*.

Results

Field Surveys

We surveyed all 20 monitoring plots three times each during the 2018 monsoon season (July 8 – September 20), with varying lengths of time between successive visits for a given plot (maximum = 45 days, minimum = 13 days, mean = 25 days). We observed live tortoises on 12 of 20 plots (60%) and during 25 of 60 surveys (41.7%). We observed 0-7 live tortoises per survey with an average of 0.783 live tortoises (SE = 0.175) per survey. We observed 49 tortoises (≥42 unique individuals) across all surveys, including 11 females, 16 males, and 13 juveniles. Four

tortoises were detected but not marked or processed due to temperatures that we considered too warm to safely extricate them from burrows or rock shelters.

Female and male adult tortoises did not differ in mass or MCL (Fig. 7). Consequently, mean adult mass was 2410 ± 101 g and mean adult MCL was 220 ± 4 mm. On average, juvenile (individuals < 180 mm MCL) mass was 624 ± 131 g and MCL was 126 ± 11 mm. Eight of the 40 tortoises voided during processing (4 males, 1 female, and 1 juvenile). Two adult tortoises, on two different plots had overt symptoms of a respiratory infection including wheezing and/or wet, crackly sounding breathing; however, only one of these individuals had obvious nasal discharge. An additional nine tortoises showed mild swelling of the eyelids (sometimes with inflamed conjunctiva), but these individuals were generally otherwise healthy in appearance with no other evident symptoms of illness. Sixteen individuals had scute or shell anomalies, which primarily consisted of extra or missing marginal scutes; however, several individuals had more extreme anomalies with numerous extra vertebral or costal scutes (Fig. 8).

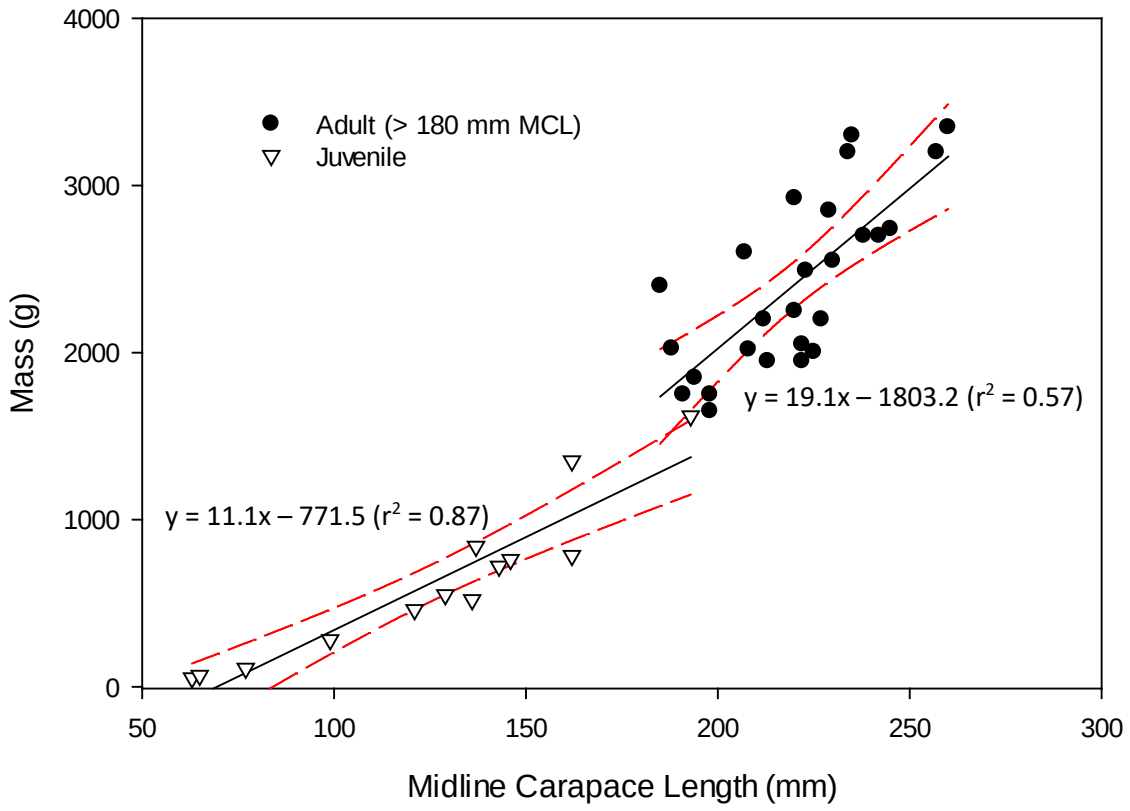


Figure 7. Plotted 95% Confidence intervals on relationship between length and mass for juvenile (< 180 mm MCL) and adult tortoises. Note that we could not sex one individual > 180 mm MCL.

Figure 8. Two tortoises with extreme scute anomalies, including five costal scutes (normally four) and nine vertebral scutes (normally five) on both animals.

Occupancy

Candidate models included covariates from all three tested groups. Top models within the topography group included elevation and slope, and vegetation included average vegetation cover and height; however, all of these individual models had higher AIC values as compared to a model with no defined covariates (i.e., the null model). Top covariates in the geomorphology group were number of available shelter sites and presence of an incised wash; the model with both of these covariates present was the only one to have a lower AIC value than the null model. Observer experience and weather variables (temperature, relative humidity) were the strongest predictors of detection. After assessing the strong correlation between temperature and relative humidity, we decided to use only temperature in final candidate models.

We considered 6 of 33 top-ranking candidate models for analysis (Table 2). Naive occupancy (ψ) for the 2018 monitoring season was 0.6. We estimated overall percent area occupied to be 0.62 (95% CI = 0.53 - 0.72) across all top-ranking models. Goodness of fit for our top-ranking model was acceptable (χ^2 = 4.78, p = 0.95), suggesting moderate under-dispersion relative to expected values. The top-ranking model included number of available shelter sites and presence of an incised wash as predictors for occupancy and observer experience and air temperature for detection. Three of the candidate models included one additional parameter (5 versus 4; Table 2) compared to the top-ranking model (i.e., within 2 AIC units of the top-ranking model),

however the negative log likelihood did not appreciably change. This suggests that the additional parameter in these models is an uninformative parameter without ecological basis, and we report them but do not assess the impact from those covariates on either ψ or *p* (Arnold 2010). The number of potential shelter sites was strongly positively associated with occupancy (β = 3.27, SE = 2.45) and was present in all top-ranking models (Fig. 9). Presence of an incised wash was present in one model and was moderately associated with occupancy (β = 2.04, SE = 1.48), while average percent vegetative cover was also present in one model but minimally associated with occupancy (β = 0.02, SE = 0.02). Additionally, these covariates were only additive to a model with the number of available shelter sites. Lastly, elevation was present in three additional top-ranking models (not shown in Table 2), however all three models failed to converge so these were not included in the final suite of six candidate models. Elevation differed only slightly between plots (775 – 950 m), and is unlikely to have a substantial impact on tortoise occupancy, in this case. All of the evaluated top-ranked candidate models are shown in Appendix D.

Detection (*p*) decreased slightly as the season progressed, with estimated detection by survey period to be p_1 = 0.71, p_2 = 0.67, and p_3 = 0.55. Overall detection was estimated at 0.64 (95% CI = 0.59 - 0.70) across all three sampling periods. Observer experience was strongly negatively associated with detection (β = -5.67, SE = 2.67, Fig. 10A). This is counterintuitive to the expected result, but this finding may be related to how we estimated surveyor experience, which was calculated as the proportion of surveyors who had had any prior tortoise monitoring experience. In our case, all plots at a minimum, were surveyed by someone with prior experience, and only some surveys included larger teams, some of whom had had no prior tortoise experience. The relationship between numb of observers and detection showed a slight positive relationship (Fig. 10B). Surveyors fatigue throughout the course of the day, and having more surveyors present can allow for more overlap in area surveyed and the potential that another observer might detect any given tortoise. Temperature also slightly positively influenced associated with detection (β = 0.20, SE = 0.08), suggesting that individuals were more visible during hotter periods of the day (Fig. 11). We however suggest that there is a likely a quadratic relationship, where there is an optimal temperature at which tortoises are detectible, however the quadratic relationship did not come out as significant in any of our top models.

Table 2. Top-ranking candidate occupancy model results.

Model	AIC	ΔAIC	AIC weight	Model Likelihood	# Par.	neg2*Log Likelihood
psi(shelter, wash), p(obs, temp)	67.32	0	0.2261	1	4	59.32
psi(shelter, wash, disturb), p(obs, temp)*	68.29	0.97	0.1392	0.6157	5	58.29
psi(shelter, vegcov), p(obs, temp)	68.83	1.51	0.1063	0.47	4	60.83
psi(shelter), p(obs, temp)	69.21	1.89	0.0879	0.3887	3	63.21
psi(shelter, disturb, vegcov), p(obs, temp)*	69.23	1.91	0.087	0.3848	5	59.23
psi(shelter, wash, vegcov), p(obs, temp)*	69.32	2	0.0832	0.3679	5	59.32

* Models were not considered in final parameter estimates due to increased number of parameters but no change in log-likelihood values.

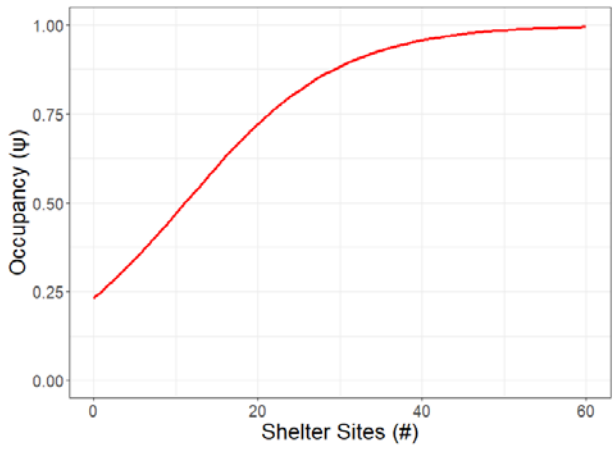


Figure 9. Logistic regression between number of available shelter sites and occupancy.

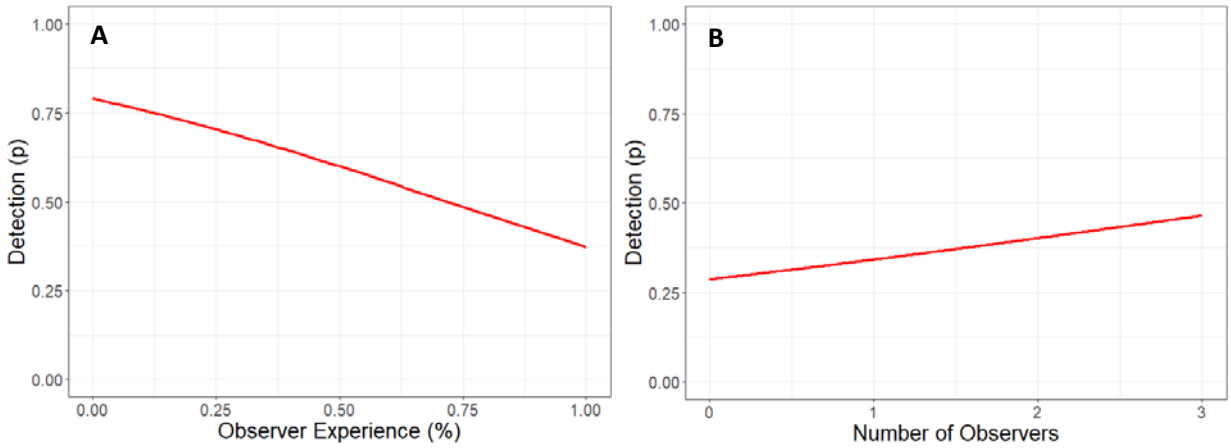


Figure 10. Relationship between A) observer team experience and B) number of observers and detection.

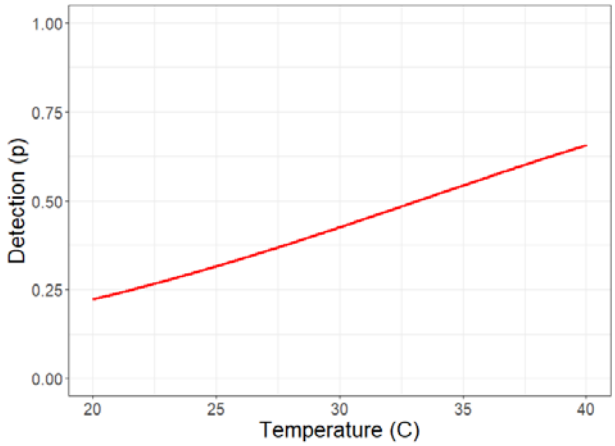


Figure 11. Relationship between survey air temperature and detection.

2018 Monitoring Season Summary

County staff were successful in establishing and monitoring 20 plots in the Tucson Mountains during the 2018 season. Our estimate of occupancy (ψ) was 0.62 (95% CI = 0.53 - 0.72), which is not different from the estimate of 0.72 (95% CI = 0.56 - 0.89) found in a comparable study (Zylstra et al. 2010). However, our overall estimate of detection (*p*) at 0.64 (95% CI = 0.59 - 0.70) was considerably higher than the estimate of 0.43 (95% CI = 0.33 - 0.52) found in the same study (Zylstra et al. 2010). Estimates from Zylstra et al. 2010 were pooled across all monitoring sites in Saguaro National Park East and West units, potentially allowing for increased estimates of ψ due to incorporation of known high density tortoise populations in the Rincon Mountains. Additionally, that study utilized many more surveyors with varying levels of experience and monitoring sites varied more considerably in landscape position and vegetative structure as compared to our Tucson Mountain sites, potentially allowing for our considerably increased estimate of *p*. This monitoring effort establishes a baseline for tortoise populations on County lands in the Tucson Mountains and through subsequent monitoring efforts will allow staff to assess, through changes in occupancy, the status of tortoise populations on these properties over time.

Literature Cited

Arnold, T.W., 2010. Uninformative parameters and model selection using Akaike's Information Criterion. The Journal of Wildlife Management, 74:1175-1178.

Averill-Murray, R.C. 2000. Survey Protocol for Sonoran Desert Tortoise Monitoring Plots: Reviewed and Revised. Arizona Interagency Desert Tortoise Team.

Hines, J. E. 2014. PRESENCE 12.24. Software to estimate patch occupancy and related parameters. U.S. Geological Survey–Patuxent Wildlife Research Center, Laurel, Maryland. Available: http://www.mbr-pwrc.usgs.gov/software/presence.shtml (accessed 8 Oct 2018).

LANDFIRE, 2014, Existing Vegetation Cover Layer, LANDFIRE 1.1.0, U.S. Department of the Interior, Geological Survey. Accessed 11 October 2018 at http://landfire.cr.usgs.gov/viewer/.

LANDFIRE, 2014, Existing Vegetation Height Layer, LANDFIRE 1.1.0, U.S. Department of the Interior, Geological Survey. Accessed 11 October 2018 at http://landfire.cr.usgs.gov/viewer/.

LANDFIRE, 2014, Existing Vegetation Type Layer, LANDFIRE 1.1.0, U.S. Department of the Interior, Geological Survey. Accessed 11 October 2018 at http://landfire.cr.usgs.gov/viewer/.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83: 2248-2255.

MacKenzie, D.I., J. D. Nichols, J. E. Hines, M. G. Knutson and A. B. Franklin. 2003. Estimating site occupancy, colonization and local extinction probabilities when a species is detected imperfectly. Ecology 84: 2200-2207.

MacKenzie, D.I., and L.L. Bailey, 2004. Assessing the fit of site-occupancy models. Journal of Agricultural, Biological, and Environmental Statistics 9:300-318.

MacKenzie, D.I., L. L. Bailey and J. D. Nichols. 2004. Investigating species co-occurrence patterns when species are detected imperfectly. Journal of Animal Ecology 73:546-555.

MacKenzie, D.I. 2006. Modeling the probability of resource use: the effect of, and dealing with, detecting a species imperfectly. Journal of Wildlife Management 70:367-374.

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey, and Hines, J.E. 2017. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Elsevier.

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, accessed 27 Sept 2018.

Rubke, C. A., H. A. Hoffman, and D. J. Leavitt. 2016. Sonoran Desert Tortoise (Gopherus Morafkai) occupancy monitoring at the Organ Pipe Cactus National Monument. Arizona Game and Fish Department, Phoenix, Arizona, USA.

Theobald, D.M., D.L. Stevens, Jr., D. White, N.S. Urquhart, A.R. Olsen, & J.B. Norman. 2007. Using GIS to generate spatially-balanced random survey designs for natural resource applications. Environmental Management, 40(1): 134-146.

US Fish & Wildlife Service (USFWS). 2015. Federal Register: Endangered and threatened Wildlife and Plants; 12-Month Finding on a Petition to List Sonoran Desert Tortoise as an Endangered or Threatened Species. URL: https://www.fws.gov/southwest/es/arizona/Documents/SpeciesDocs/SonoranTort/FR_SonoranTort_Final_Oct6.pdf

Zylstra, E.R., Steidl, R.J., & Swann, D.E. 2010. Evaluating survey methods for monitoring a rare vertebrate, the Sonoran desert tortoise. The Journal of Wildlife Management, 74(6), 1311-1318.

Appendix A: Plot and Weather Information Data Sheet

Pima County EMP - Desert Tortoise Occupancy Monitoring

Plot & Weather Information

GENERAL INFORMATION

Plot Number	Date	Observers	Season Visit Number	Pass
			1	AM
			2	PM
			3	

WEATHER AND PLOT DATA

Start data:

Process Start Time:	Rel Humidity Start:	Temperature (1cm) shaded (C):	Cloud cover Start (%):
			None
			0-25%
			25-50%
			50-75%
			75-100%

End data:

Process End Time:	Rel Humidity End:	Temperature (1cm) shaded (C):	Cloud cover End (%):	Rainfall During Survey?
			None	Yes
			0-25%	No
			25-50%	
			50-75%	
			75-100%	

TORTOISE DETECTION DATA

Live tortoise detected:	Total # live tortoises:	Total tortoise processing time
Yes		
No		

TORTOISE SIGN DATA

Sign detected:	Total # carcasses:	Total # scat:	Total # tracks:
Yes			
No			

SHELTER SITE DATA

Total # caliche caves:	Total # burrows:	Total # middens:	Total # boulder piles:	Total # rock shelter:

OTHER OBSERVATIONS

Recent Human activity?	Photo #s:	total area of buffelgrass (m)
Yes		
No		

Notes:

Appendix B: Sign and Shelter Data Sheet

Pima County EMP - Desert Tortoise Occupancy Monitoring
Sign & Shelter Observations

GENERAL INFORMATION

Date: **Plot Number:** **Visit Number:** **Observer:**

Waypoint	Type of Obs	Sign Type	Shelter Type	Depth inside shelter	Age of sign	Photo #

Sign Type:	Shelter Type:	Age of Sign
Carcass	Caliche cave	<1 year
Carcass piece	Dirt burrow	>1 year
Scat	Rock shelter	
Tracks	Midden	
Egg	Pallet	
shells	N/A	
N/A		

Appendix C: Plot and Weather Information Data Sheet

Pima County EMP - Desert Tortoise Occupancy Monitoring

Live Tortoise Observation

GENERAL INFORMATION

Date:	Plot Number	Visit Number:	Waypoint Number:	Observer:	Process Start Time:	Process End Time:

ENVIRONMENTAL INFORMATION

shaded 1cm air temperature (°C)	relative humidity (%)

LOCATION AND BEHAVIOR INFORMATION

Tortoise Location	Tortoise Behavior
In open	Resting
Under vegetation	Basking
Palle	Walking
Burrow	Feeding
Rock shelter	Digging
Caliche cave	Asleep

SHELTER SITE INFORMATION

Substrate above:	Substrate below:	Depth inside	Other tortoises
Rock	Rock	<0.5m	Yes
Soil	Soil	0.5-1.0m	No
Caliche	Caliche	>1.0m	
Vegetation	Unknown	Unknown	

TORTOISE IDENTIFICATION INFORMATION

Tortoise ID:	Capture type:	Sex:	MCL (mm):	Weight (g):	Scute anomalies?
	1st capture	M			Yes (notes in comments)
	Recapture	F			No
	Unknown	Unknown			

Notched today?	Expoxied today:	L Posterior Scutes:	R Posterior	L Marginal	R Marginal Scutes:
Yes	Yes	100	400	10	1
No	No	200	700	20	2
Previously done	Previously done			30	3
Touched up	Touched up			40	4
				50	5
				60	6
				70	7
				80	8
				90	9

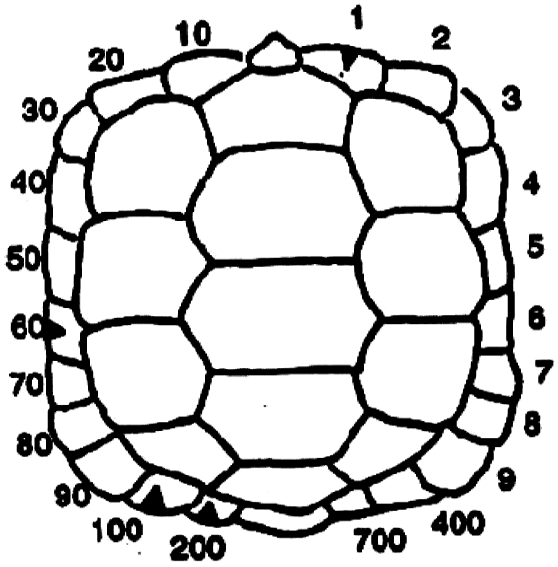
GENERAL HEALTH INFORMATION

Breathing:	Nasal discharge:	Beak/Nares:	Exudate:	Nares Occluded:	Eyes:	Eyelids:
Smooth	Yes	Dry	None	Neither	Bright	Swollen
Wheezing	No	Damp	Clea	Righ	Cloudy	Wet
Rasping/clicking		Wet	Cloudy	Left	Sunken	Discolore
			White	Both		Normal
			Yellow			

Oral	Posture:	Shell closure:	Chin glands:	Integument:	Parasites?	Voided?
Discharg	Alert	Tight	Swollen	Dull	Yes	Yes
Pink	Lethargic	Limp	Draining	Glossy	No	No
White			Normal	Normal		
Plaque				Peeling		
Unknow						
n						
Volume of Void (ml):	**During:**	**Urine**				

SHELL/BONE DISEASE INFORMATION

Shell anomolies/irregularities:	Shell	Shell pitting:	Shell wear	Scute	Fungus/necrosi	Evidence of trauma (select all
Yes	None	Yes	1	Yes	Yes	Head
No	Present	No	2	No	No	Forelimbs
	Active		3			Hindlimbs
	Healed		4			Gular
			5			Carapace
			6			Plastron
			7			Bone/scute replacement



Tortoise number = 361

Appendix D: 2018 Occupancy Monitoring Data & Results

Table D1. Site and detection-level covariates used in occupancy analysis

Variable Name	Description	Units	Data Source
Site Variables			
Topography			
Elevation	Elevation of plot center	Meters	3 m Digital Elevation Model
Slope	Average slope - 100 random locations / plot	Degrees	3 m Digital Elevation Model -
Average Aspect	Mean zonal aspect for each plot	Degrees	3 m Digital Elevation Model - CalcZonalMeanAspect (https://community.esri.com/thread/47864)
Percent North Aspect	Percent of plot facing north, 315-45 degrees	Percent	3 m Digital Elevation Model
Percent East Aspect	Percent of plot facing east, 45-135 degrees	Percent	3 m Digital Elevation Model
Percent South Aspect	Percent of plot facing south, 135-225 degrees	Percent	3 m Digital Elevation Model
Topographic Ruggedness Index	Topographic ruggedness index	N/A	3 m Digital Elevation Model – TRI ArcGIS tool (https://www.arcgis.com/home/item.html?id=334346db638844039dc1c4abf5dd8d00)
Precipitation	30-year normal annual precipitation	Millimeters	PRISM Climate Group – 800 m resolution data product
Geomorphology			
No. of Shelter Sites	Number of total possible/confirmed shelters averaged across all visits	Count	Field observation
Soil Type	Dominant soil type: Anklam-Cellar-Rock outcrop complex, 15 to 55 % slope	Presence	NRCS SSURGO
Soil Type	Dominant soil type: Pinaleno-Stagecoach complex, 5 to 16 percent slope	Presence	NRCS SSURGO
Soil Type	Dominant soil type: Pinaleno very cobbly sandy loam, 1 to 8 percent slope	Presence	NRCS SSURGO
Soil Type	Dominant soil type: Pantano-Granolite complex, 5 to 25 percent slope	Presence	NRCS SSURGO

Presence of Incised Wash	Presence of incised wash on plot	Presence	Field observation / aerial imagery
Vegetation			
Avg. Percent Vegetation Cover	Average vegetation percent cover, middle value of each bin was taken per cell (i.e., 10-20% =15%)	Percent cover	Landfire 2014 Existing Vegetation Cover dataset, 30 m resolution
Avg. Vegetation Height	Average vegetation height middle value of each bin was taken per cell (i.e., 1-2 m = 1.5 m)	Meters	Landfire 2014 Existing Vegetation Height dataset, 30 m resolution
Percent Riparian Vegetation	Percent of plot classified as riparian vegetation	Percent	Landfire 2014 Existing Vegetation Type dataset, 30 m resolution
Percent Upland Vegetation	Percent of plot classified as upland vegetation	Percent	Landfire 2014 Existing Vegetation Type dataset, 30 m resolution
Bufflegrass	Number of buffelgrass bunches per plot	Count	Field observation
Distance to Development	Straight-line distance from center of plot to nearest development outside of the Pima County property	Meters	National Land Cover Dataset and Aerial imagery

Detection Variables	
Survey Period	Survey period
Order First	Plot survey completed first during field day (y/n)
Order Second	Plot survey completed second or third during a field day (y/n)
Avg. Relative Humidity	Average relative humidity between start/end of survey (%)
Avg. Temperature	Average temperature between start/end of survey (° C)
Rain During Survey	Rain during survey (y/n)
Avg. Cloud Cover	Average visually estimated cloud cover between start/end of survey, (bins: None, 0-25%, 25-50%, 50-75%, >75%)
Experience Level	Percent of team with experience surveying for desert tortoises (%)

Table D2. Land cover (vegetation) covariates model selection results (percent cover, average height, percent riparian vegetation, distance to development).

Model	AIC	ΔAIC	AIC weight	Model Likelihood	# Par.	neg2*Log Likelihood
psi(cov),p(stand)	77.12	0	0.1685	1	3	71.12
psi(height),p(stand)	77.19	0.07	0.1627	0.9656	3	71.19
psi(develop),p(stand)	77.98	0.86	0.1096	0.6505	3	71.98
psi(riparian),p(stand)	78.3	1.18	0.0934	0.5543	3	72.3
psi(cov,develop),p(stand)	78.47	1.35	0.0858	0.5092	4	70.47
psi(height,develop),p(stand)	78.58	1.46	0.0812	0.4819	4	70.58
psi(cov,height),p(stand)	79.1	1.98	0.0626	0.3716	4	71.1
psi(cov,riparian),p(stand)	79.12	2	0.062	0.3679	4	71.12
psi(riparian,develop),p(stand)	79.81	2.69	0.0439	0.2605	4	71.81
psi(cov,height,develop),p(stand)	80.39	3.27	0.0328	0.195	5	70.39
psi(cov,riparian,develop),p(stand)	80.44	3.32	0.032	0.1901	5	70.44
psi(height,riparian,develop),p(stand)	80.54	3.42	0.0305	0.1809	5	70.54
psi(cov,height,riparian),p(stand)	81.1	3.98	0.023	0.1367	5	71.1
psi(cov,height,riparian,develop),p(stand)	82.38	5.26	0.0121	0.0721	6	70.38

Table D3. Topographical covariates model selection results (elevation, slope, aspect).

Model	AIC	ΔAIC	AIC weight	Model Likelihood	# Par.	neg2*Log Likelihood
psi(elev),p(stand)	77.81	0	0.173	1	3	71.81
psi(slope),p(stand)	77.93	0.12	0.1629	0.9418	3	71.93
psi(aspect-s),p(stand)	78.26	0.45	0.1381	0.7985	3	72.26
psi(elev,aspect-e),p(stand)	79.28	1.47	0.083	0.4795	4	71.28
psi(slope,aspect-s),p(stand)	79.29	1.48	0.0825	0.4771	4	71.29
psi(elev,aspect-s),p(stand)	79.3	1.49	0.0821	0.4747	4	71.3
psi(slope,aspect-e),p(stand)	79.48	1.67	0.0751	0.4339	4	71.48
psi(elev,slope),p(stand)	79.65	1.84	0.0689	0.3985	4	71.65
psi(aspect-e/s),p(stand)	79.69	1.88	0.0676	0.3906	4	71.69
psi(elev,slope,aspect-s),p(stand)2	80.99	3.18	0.0353	0.2039	5	70.99
psi(elev,slope,aspect-e),p(stand)	81.22	3.41	0.0314	0.1818	5	71.22

Table D4. Geomorphological covariates model selection results (# shelter sites, presence of incised wash, soil type).

Model	AIC	ΔAIC	AIC weight	Model Likelihood	# Par.	neg2*Log Likelihood
psi(shelter,wash),p(stand)	73.16	0	0.4509	1	4	65.16
psi(shelter,wash,soil),p(stand)	75.16	2	0.1659	0.3679	5	65.16
psi(shelter),p(stand)	75.46	2.3	0.1428	0.3166	3	69.46
psi(shelter,soil),p(stand)	75.54	2.38	0.1372	0.3042	4	67.54
psi(soil),p(stand)	77.67	4.51	0.0473	0.1049	3	71.67
psi(wash),p(stand)	78.09	4.93	0.0383	0.085	3	72.09
psi(wash,soil),p(stand)	79.64	6.48	0.0177	0.0392	4	71.64

Table D5. Top-ranking candidate models.

Model	AIC	ΔAIC	AIC weight	Model Likelihood	# Par.	neg2*Log Likelihood
*psi(shelter,wash,elev),p(obs,temp)	63.8	0	0.4354	1	5	53.8
*psi(shelter,wash,elev),p(obs,temp)	65.8	2	0.1602	0.3679	6	53.8
*psi(shelter,wash,aspect-s),p(obs,temp)	65.8	2	0.1602	0.3679	6	53.8
psi(shelter,wash),p(obs,temp)	67.32	3.52	0.0749	0.172	4	59.32
psi(shelter,wash,disturb),p(obs,temp)	68.29	4.49	0.0461	0.1059	5	58.29
psi(shelter,vegcov),p(obs,temp)	68.83	5.03	0.0352	0.0809	4	60.83
psi(shelter),p(obs,temp)	69.21	5.41	0.0291	0.0669	3	63.21
psi(shelter,disturb,vegcov),p(obs,temp)	69.23	5.43	0.0288	0.0662	5	59.23
psi(shelter,wash,vegcov),p(obs,temp)	69.32	5.52	0.0276	0.0633	5	59.32
1 group, Constant P	74.46	10.66	0.0021	0.0048	2	70.46
1 group, Survey-specific P	78.21	14.41	0.0003	0.0007	4	70.21

* Models estimates did not converge to significant digits greater than 3, these models were not included in analysis.