Desert Tortoise (*Gopherus agassizii*) Monitoring

Project # 2005-UNR-585-P

Final Report

University of Nevada Reno

EXECUTIVE SUMMARY

The following report covers the five main themes addressed by 2005-UNR-585P—training field crews for annual desert tortoise density monitoring; electronic data collection and QA/QC, or collectively data management; initial calculation of range-wide density estimation using Distance; preliminary assessment of the distribution of threat indicators and desert tortoises, both live and dead; and preliminary predictive desert tortoise activity model.

Training including actual class room and field related activities to prepare field crews for approximately two months of intensive desert tortoise monitoring. Additionally, a monitoring handbook was developed covering topics relevant to monitoring. The final iteration of the 2008 handbook and its associated modules was a monumental development and greatly improved the overall training program.

The 2007 and 2008 databases contained approximately 19,000 and 23,000 records, respectively. Collection, management and QA/QC of data required extensive planning and documentation. Between 2007 and 2008 we redeveloped from scratch the electronic data collection system used by field crews to collect data in the field. This required redevelopment of contractor, intermediate and final QA/QC procedures and scripts. QA/QC was better documented, implemented, and corrected and recorded fewer errors in 2008 than in any year previous.

We calculated range-wide density estimates using program Distance for 2007 and 2008. Though we provided data collection and QA/QC assistance, the ultimate decision on what data to collect, how to collect it and where to collect it were the decisions of USFWS. Additionally, our density estimates are preliminary, final density estimation and trend analysis is the responsibility of USFWS. Based upon our initial analyses we offer suggestions for how to decrease bias and improve precision using an alternative method for calculation G_0 and a possible correction factor for the fact that tortoises are under-sampled in burrows, though we strongly encourage a more extensive look into the problem of under-sampling tortoises in burrows.

Using general linear models, and spatial general linear models, we explored the distribution of desert tortoise (either live or dead), and the encounter rates of live and dead tortoises along sampling transects, in relation to major highways, densities of roads and human population size, and habitat. Data were generated from range-wide monitoring of this species during 2001–2005 and 2007–2008. Our results indicate that tortoises are spatially aggregated on the landscape, and this aggregation is correlated with broad-scale habitat differences and anthropogenic impacts. The presence of tortoises on the landscape was largely positively related to better habitat, greater distances from highways, lower densities of dirt roads and lower human densities. The relationship between encounter rates, habitat, and anthropogenic measures was mixed.

Current methods to estimate population density for *Gopherus agassizii* require knowledge of the proportion of animals that are active during times when sampling is conducted. Assessing the proportion of animals that are active is both time consuming and expensive. We used bio-logging techniques (a new field that can be defined as the investigation of phenomena

in or around free-ranging organisms that are beyond the boundary of our visibility or experience) to measure the activity of 24 adult desert tortoises for 2 months in 2005 and 2006 during the times when range-wide monitoring for population density is typically conducted. Climate-derived variables were able to explain 84% of the daily activity of desert tortoises. Soil and air temperatures provided the greatest predictive inference, while measures of humidity and wind-speed provided little inference. We found that these simple biophysical models were not as accurate when predicting high levels of activity as they were at predicting low levels of activity, and tended to under-predict activity when true activity was high.

There were contracting delays for both UNR and USFWS in 2007. This delay limited are ability to coordinate, plan and implement in particular new training, handbook, QA/QC, and electronic database strategies. Nonetheless, progress was made in 2007. Full implementation and marked improvement were seen in 2008.

INTRODUCTION

Description of the Project

The work completed by 2005-UNR-585P continued and consolidated three previous projects:

1. Baseline density monitoring of desert tortoise populations;
2. Increasing effectiveness, and economy in monitoring of the desert tortoise; and
3. Development of a range-wide desert tortoise monitoring training program.

This project was jointly conducted in cooperation with USFWS (2005-USFWS-585A). The University of Nevada, Reno was responsible for or completed in cooperation with USFWS the following:

1. Training
    a. Training field crews
    b. Monitoring Handbook
2. Data Management
    a. Electronic data collection
    b. QA/QC
3. Range-wide density analysis using Distance
4. Preliminary assessment of distribution of threat indicators and tortoises
5. Preliminary predictive desert tortoise activity model.

Background and Need for the Project

After publication of the Desert Tortoise Recovery Plan in 1994 a workshop on Desert Tortoise monitoring, hosted by the University of Nevada, Reno (UNR) was held in February 1995 to start the planning effort for Desert Tortoise recovery. Tortoise biologists, statisticians and monitoring experts reviewed previous methods used to monitor tortoise populations and discussed possible methods to use in the future. At this workshop, the method of "Distance Sampling" (Buckland *et al.* 1993) was introduced as an alternative to permanent study plots

commonly used by the federal land managers to monitor tortoise populations. Identified problems with permanent study plots included low resolution of study plot data and inadequate sampling across the species' range (Anderson *et al.* 2001). In 1997, the Utah Division of Wildlife Resources instituted a monitoring program using transects to monitor tortoises and Program Distance to estimate densities at the Red Cliffs Desert Reserve within the Upper Virgin River Recovery Unit (McLuckie *et al.* 2002). Reserve-wide monitoring began in 1998.

In October 1998, Styrofoam tortoise models (styrotorts) were used in a workshop demonstration of distance sampling (Anderson *et al.* 2001). The federal and state land and resource manager's Management Oversight Group (MOG) chose distance sampling as the method that would be used on public lands to monitor Desert Tortoise populations, and this was formally endorsed by the MOG in June 1999.

In January 2001 a monitoring workshop was held in Las Vegas to explain the sampling techniques that would be used to conduct the first year of range-wide monitoring using Distance Sampling. In March 2001, a handbook was prepared by the United State Fish and Wildlife Service (USFWS) Desert Tortoise Coordinator to serve as a manual for field crews, and two four-day training workshops were conducted, each attended by approximately 40 people. These training workshops provided practice of the Distance Sampling techniques using styrotorts placed in natural habitats near Jean, Nevada. Finally, tortoise transects were sampled range-wide beginning in 2001 by consultants, The Mojave Preserve Preserve, Utah Division of Wildlife Resources, and University of Nevada-Reno personnel (USFWS 2006). Refinements to distance sampling techniques continue to be implemented (Tracy *et al.* 2004). In 2005 initial information was also collected on various habitat and threat variables. In 2006 monitoring did not occur and funding and contracting delays curtailed preparation for 2007 monitoring. These difficulties notwithstanding desert tortoise monitoring was implemented in 2007 in Clark County and range-wide using the revised methods adopted beginning in 2004 (USFWS 2006).

Management Actions Addressed

The research activities and conservation actions USFWS(11), BLM(9), BLM(7), NPS(3), and NPS(11) will be performed to reduce Species Threats 403, 501, 1101, and 1102, and Ecosystem/Habitat Threats 401, 403, 501, 1101, and 1102 in order to benefit *Gopherus agassizii* (desert tortoise), Mojave Desert Scrub Ecosystem, Blackbrush Ecosystem, Salt Desert Scrub Ecosystem, and Sagebrush Ecosystem within the following locations:

Gold Butte (Virgin Mountains):− BLM/BUREAU OF RECLAMATION
Gold Butte (Virgin Mountains):− BLM
Mormon Mesa (Mormon Mesa):− BLM/BUREAU OF RECLAMATION
Coyote Springs Valley (Hidden Valley − adjacent to Las Vegas Range &Arrow Canyon Range):− USFWS NATIONAL WILDLIFE REFUGE
Coyote Springs Valley (Coyote Springs Valley):− BLM
Coyote Springs Valley (Coyote Springs Valley):− USFWS NATIONAL WILDLIFE REFUGE
I−15 Corridor (Bird Spring Range):− BLM
I−15 Corridor (Ivanpah Valley − North):− BLM
Piute and Eldorado Valleys (Piute Valley):− BLM
Piute and Eldorado Valleys (Eldorado Valley):− BLM, and

Piute and Eldorado Valleys (El Dorado Mountains):− PRIVATE/NATIONAL RECREATION AREA

Goals and Objectives of the Project

The following goals are outlined in the Project SOW (E. Project Goals):

1. Baseline density monitoring will establish a statistical basis for determining population trends(s) and for evaluating management actions and threats.
2. Research into effectiveness monitoring will establish that current techniques cannot be improved on or will identify techniques that will improve effectiveness or reduce the cost of tortoise density monitoring.
3. Intensive, uniform training of tortoise monitors will result in an increase in accuracy and precision of density estimates as well as reduction in variance and observer (monitor) errors.

By achieving the above goals, the following will also be achieved:

1. Better (less biased, more precise) desert tortoise density estimates.
2. Better (less biased, more precise) description of distribution of desert tortoises in Clark County.
3. Preliminary description of correlations between threat indicators and desert tortoise distribution and abundance.

1.0 TRAINING

1.1 Methods and Materials

All persons who conducted LDS in 2007 and 2008 attended training in March, just before sampling began. The training sessions combined classroom work with field data collection. Lectures included an introduction to the theory of LDS, methods for collecting transect and ancillary data, and natural history and ecology of desert tortoises. The majority of the training, however, was devoted to conducting practice transects on 8 km of Styrofoam tortoise (styrotorts) training lines south of Las Vegas (USFWS 2006), adapted and expanded from the original training course described in Anderson et al. (2001). Analysis of the data collected during training was presented to the field crews in a debriefing session at the end of training. Workshop trainers identified deficiencies in data collection and suggested means to correct them. Participants provided valuable feedback on aspects of the methods that were not working well and made suggestions for improving these techniques. Personnel with serious deficiencies in data collection were provided additional training. The methods employed during training were the same used for actual data collection, although considerably fewer data were recorded during the initial training, (i.e. size and number of each model and its position on the transect).

In 2007 and 2008 a Desert Tortoise Monitoring Handbook was developed to document and standardize training of tortoise monitoring field crews. Due to funding and contracting delays the 2007 manual was largely based upon previous versions and expanded to a very limited degree. The 2008 handbook was created largely from scratch based upon a UNR/USFWS jointly developed curriculum (Heaton et al. 2008). Included in the 2008 manual were relevant topics required for successful implementation of desert tortoise population monitoring. In summary, the handbook included sections on topics relevant to distance theory, tortoise handling, data collection and QA/QC, and written and practical exercises. Five days of training were implemented in 2007. Based upon the new curriculum and handbook, as many as 15 days of training were administered to inexperienced field crews in 2008.

1.2 Results and Evidence of Results

Bias (i.e. mean proportion of estimated abundance different from known abundance of styrotorts) was reduced and detection probabilities of styrotorts within 3m of the transect centerline were largely improved in 2008 over 2007 (Table 1 and 2). There are some inconsistencies in the results, namely with small models, suggesting that there is still room for improvement.

The 2008 Training Manual was much improved over the 2007 manual. A testament to its usefulness is stated in the introduction to the 2009 Manual "The 2008 Desert Tortoise Population Monitoring Handbook presented a much more comprehensive set of material than its predecessors, and this version is built heavily on that 2008 edition." (USFWS 2009).
Based upon surveys administered by USFWS and presumably available from them, the USFWS Nevada subcontractor reported improvements in all categories questioned as related to training between 2007 and 2008.

Table 1. Results of 2007 line transect training. Bias is the mean proportion that estimated abundance differed from known abundance of Styrofoam tortoise models. The detection probability (p) is of tortoise models within 2m of the transect centerline.

Contractor	Dates	Number of teams	Large models		Small models	
			Bias	p	Bias	p
Kiva	27–28 Mar	8	0.05	0.93	−0.03	0.90
GBI	27–28 Mar	13	−0.07	0.69	−0.29	0.35
GBI retest	2 Apr	6	−0.05	0.80	0.01	0.97

Table 2. Results of 2008 line transect training. Bias is the mean proportion that estimated abundance differed from known abundance of Styrofoam tortoise models. The detection probability (p) is of tortoise models within 3m of the transect centerline. Six GBI teams were reconstituted and provided an extra day of training on 27 March.

Contractor	Dates	Number of teams	Large models		Small models	
			Bias	p	Bias	p
Kiva	26 Mar	6	0.11	0.88	−0.01	0.72
Kiva	27 Mar	6	−0.004	1.00	−0.18	0.93
GBI	14 Mar	18	−0.22	0.65	−0.32	0.35
GBI	17 Mar	16	−0.20	0.79	−0.33	0.46
GBI	21 Mar	18	−0.07	0.84	−0.19	0.82
GBI	24 Mar	17	−0.15	0.88	−0.13	0.75
GBI	27 Mar	6	−0.05	0.83	−0.09	0.65

1.3 Evaluations/Discussion of Results and 1.4 Conclusions

The desert tortoise range-wide monitoring program is a large and logistically complicated program to implement. Training has expanded from a few days primarily limited to styrotort data collection to a three week program covering distance theory, tortoise handling, data collection, QA/QC, etc. The training program has taken considerable criticism over the years, but that perspective of criticism often comes from single year participants or individuals involved in only a few years. The University of Nevada, Reno and its subcontractors have been involved with desert tortoise range-wide monitoring from its conceptual beginnings through to its implementation as scientist, analyst, trainers and trainees. We can unequivocally say that the training program has seen exponential levels of improvement over the years and that it will continue to benefit from improvements in years to come.

1.5 Recommendations

1.5.1 Training Lines

The following recommendations on training line refurbishment were developed primarily be Dr. Steve Corn, USGS. The current training lines at the north end of the LSTS have been in existence for nearly a decade and are in need a complete overhaul. Due to age there are problems with unreadable numbers, incorrect positions, and duplicate styrotort models (for a variety of reasons). There is also considerably more traffic on the Goodsprings Road (State Highway 161), creating a greater safety hazard for crossing the road and parking along it to access the lines. The

lines were designed before the use of electronic data collection (PDAs and Pendragon Forms), and the current setup is not ideally suited to rapid data analysis. For example, it is difficult to do much automated QA/QC on the training data to correct data entry errors. Finally, using the same training lines over and over creates the possibility that we are wearing semi-permanent paths onto the surface of the land that can assist trainees in finding the styrotorts and potentially bias the results. Rather than do a more thorough job of refurbishing the existing lines in the future, we recommend relocating the lines within LSTS. This would accompany a redesign of the training line configuration and changes to the training curriculum.

The example shown in Figure 1 includes 4km lines straddling the power line road that runs NW to SE through the north half of the LSTS. There are many other possible configurations, including those that don't require a 4-km straight line (the training lines are run in 1-km segments). Figure 2 shows the same amount of line distributed in 2 groups of 2-km lines. This 2nd configuration is advantageous in that none of the lines cross any roads, but it is slightly more complex to navigate.

These new lines would differ from the current lines in that they would center a strip 40-m wide (instead of 100 m currently) and would not have internal sub-lines (each line would be single and independent). These new lines would have the same density of styrotort models as the current lines ($400/km^2$) but would include 2 new sizes of models (see below). Each 1-km segment would include 16 styrotort models (4 of each size). Models would be distributed on the transect in the manner they are currently: evenly distributed perpendicular to the transect centerline and randomly placed along the length of the transect. New spatial distributions of the models will need to be generated. All models will be given unique numbers. Currently, the large and small models share many numbers, which creates errors and QA/QC difficulties if the size is recorded incorrectly.

To achieve sample sizes necessary to assess performance, the current training lines use an unrealistically high density of styrotort models ($400/km^2$). Also, the training transects are not conducted in the same manner as real transects. Crews establish a transect line between PVC posts spaced 100-m apart instead of attempting to follow a prescribed bearing. This is necessary to be able to test for ability to measure distance accurately and to keep crews from accidentally wandering outside the test area. A more realistic experience is desirable, which will provide training in conducting transects according to the actual protocol and also provide an opportunity to better assess the ability of field personnel to conduct accurate line-distance sampling. This strategy would include a 4-km^2 area (a training square) stocked with 400 models ($100/km^2$). This density is higher than most field crews currently encounter, but is at the top end of the range of local abundance of tortoises observed on some BLM permanent study plots. The area outlined in white in Figure 3 is the only part of the LSTS where a 4-km^2 area that does not have any roads inside the boundaries can be located (not having roads in the interior of the training square reduces the opportunities for vandalism of the models and simplifies their placement by not having to move models with assigned positions that would put them on a road).

The second feature of the training square, which is new to training, is that the size distribution of styrotort models will mimic that of live tortoises. In 2004 and 2005, of 785 tortoises with measured MCL between 161 and 320mm, 18.8% were between 160 and 200mm,

41.1% were between 201 and 240mm, 32.5% were between 241 and 280mm, and 7.5% were between 281 and 320mm. We recommend creating 2 new sizes of styrotort models with MCLs of 220 and 260mm, that will provide four models with 40 mm between sizes (30 mm for the 260 and 290mm sizes). These sizes would be apportioned among the 400 models according to the distribution of live tortoises above or similarly calculated across years. The models would be randomly distributed in the training square, and some (20–30%) would be placed in short, constructed burrows.

Each team would spend 3 days, running 9 E-W and 9 N-S lines (6 lines, or 12 km daily). Transects would be run with the same methods as actual transects (except that each transect would be a 2-km straight line), with waypoint data collected every 500m. The expected number of observations per team, given a 12-m transect half-width and 60% capture probability, would be about 50, sufficient to test each team's ability to collect accurate line-distance data. The training square could hold up to 18 teams simultaneously. At any given time, 9 teams would be doing EW lines and 9 teams would be doing N-S lines, and teams on parallel tracks would be spaced 220-m apart, so there would be few opportunities for a team to be helped by spotting models that another team has found.

Figure 1. Example new training line scenario using four 4-km lines straddling the power line road that runs NW to SE through the north half of the LSTS.

Figure 2. Example new training line scenario using four 4-km lines distributed in two groups of 2-km lines.

Figure 3. A more realistic training experience would include a 4-km^2 area (training square).

1.5.2. Overall Training Program

We believe the primary reason for the steady improvement of the training program over the years and most importantly the tremendous advancements in the program since 2007 are due in large part to the continued involvement of legacy individuals and the creation of the Desert Tortoise Recovery Office and dedicated Monitoring Coordinator.

More effort needs to be put into annual preventive maintenance of the training facilities. The PVC posts for the training lines need to be removed and stored at the end of each season. The styrotort models should be left in place, but there would be much less annual maintenance if they were protected from the elements (sun, ravens) when not being used for training. One possible solution would be to place them inside a pillowcase after training is finished. The

DTRO should maintain a more direct role in the training process, as was the case in 2009, and involve DTRO staff in the establishment and maintenance of the training facilities. This would be a means to provide the DTRO a better sense of "ownership" of the training process. Second, it would provide a bunch of field biologists turned bureaucrat a good opportunity for a couple of weeks away from their desks each year (even if it does involve wrangling Styrofoam instead of live tortoises).

Survey questions designed to gain feedback from field survey crews should undergo peer-review. "One special challenge for improving survey questions is that people with all manner of backgrounds, and no special training, write survey questions…Everyone thinks he or she can write good survey questions." (Fowler, 1995; pg vii).

2.0 DATA MANAGEMENT

2.1 Materials and Methods

Data management included four phases largely developed by UNR:
1. Data collection. UNR was responsible for developing the Collection database schema and its associated forms and checks according to USFWS specifications. The Survey Contractors were responsible for collecting the field data on paper and electronic data collection devices (RDAs) and running hotsync operations (developed by UNR) to integrate data collected on each individual RDA.
2. First Level Contractor QA/QC. UNR was responsible for developing scripts to import the populated Collection database into the Contractor database, developing scripts to automate some of the Contractor QA/QC checks, and for performing weekly assessment of each contractor's populated Collection database. The contractors were responsible for running the UNR developed import script to import records from the Collection database into the Contractor database, running checks on the Contractor database, correcting errors, and delivering a complete, corrected Contractor database, along with their completed paper datasheets.
3. Second Level QA/QC. This level was completed by a USFWS collaborator. Though UNR was not directly responsible for this collaborator, we worked with them and developed the QA/QC plan that was to be followed by the collaborator.
4. Final QA/QC. UNR subcontractor, Topoworks, was responsible for performing the Final QA/QC, which included developing scripts; performing checks; reviewing records that violated checks, making corrections, and documenting the checks, violations of checks and corrections. Also included final standardization of the LDS and G_0 databases and delivery of final internal user products to USFWS and Clark County.

The 2007 electronic field data collection database was implemented with minor modification from the 2005 database. Delayed contract start prevented us from making major changes. Nonetheless, we implemented the database in the latest version of Pendragon and on new electronic field data collection hardware. New hardware included a ruggedized PDA and Bluetooth GPS. The 2008 electronic field data collection system was built from scratch…transect, G_0, and training databases, as well as contractor and final QA/QC scripts. In

short, data collected in the Collection database were constrained to a logical range of values. If the values were not within the range then the user was prompted to enter the correct value. Additionally, there were a number of required fields, if not filled out, the form would not save until the user completed all fields. Contractor QA/QC scripts checked for inconsistencies between two or more fields and identified missing values. In both 2007 and 2008 regular, near weekly QA/QC feedback was provided to contractors by UNR.

Records violating final database rules were identified during QA/QC, and either resolved with a correction or allowed to remain as an exception to the rule. Many violations represent errors in the database, but not all. Some violations flagged unusual conditions because they were potential errors. In these cases, the paper datasheets and associated records were reviewed to see if a correction was needed. If not, the data were allowed to remain in the database as an exception to the rule. In addition some violations flagged data that violated rules because they needed to be processed and modified for the final database product, but were not errors. Each violation was reviewed to make the best determination possible as to whether it represented an error, an allowed exception, or a QA/QC processing step. Some database errors found during QA/QC can be corrected, while some cannot.

2.2 Results and Evidence of Results

QA/QC procedures have seen steady improvement over the years of the monitoring program. In the years prior to 2007 QA/QC was retroactive in the worst case (2001-2003) and only preliminarily considered in other years (2004-2005). In 2007, though only just before the field season began because of contracting delays, and in 2008 months in advance of the field season, a Data Management Plan and QA/QC Plan were developed. It is impossible to compare 2001-2005 QA/QC with 2007-2008. QA/QC was retrospective for 2001-2005 and we cannot be sure that all records were systematically checked nor that corrections were systematically recorded. Nonetheless, we have very little doubt that QA/QC improved from 2007-2008 over 2001-2005 if for no other reason than records were checked, errors recorded and errors corrected systematically based upon a detailed QA/QC plan.

We can compare 2007 and 2008. Because of the difference in the total number of records contained within the two databases percentages are provided (2007 = 19,001 and 2008 = 22,979 database records). The percentage of database violations reported in 2007 and 2008 were 8.7% and 5.6% respectively. That is a reduction by 1/3 the number of violations in just one year. In 2007 39% of the violations were corrected and 61% were allowed to remain as exceptions in the database. In 2008 73% of the violations were corrected and 27% were allowed to remain as exceptions. The reduction in exceptions was significant, and suggest the completely redesigned 2008 electronic data collection database was better suited to the monitoring program data collection needs and more user friend for field crew.

2.3 Evaluation/Discussion of Results and 2.4 Conclusions

In 2007 as part of our end of season assessment we discovered and reported some inconsistencies in walked and unwalked transects by the Nevada USFWS subcontractor. Based upon a thorough assessment of the field data submitted by the subcontractor and our own field

reconnaissance we believe that transects were reported as Unwalkable or Inaccessible when in reality they were Walkable or Accessible, that portions of started transects were reported as Unwalkable when in fact they were Walkable and that multiple truncated transects were walked in a single day when protocol would have dictated a single full length transect to be walked. These inconsistencies were restricted to the last week and possibly week and a half of the field season. We found no evidence that crews falsely reported transects or tortoise observations, only that they inflated the number of attempted transects and transects walked by walking several short transects in one day. We found no inconsistencies in the 2008 database regarding transect Walkability or Accessibility.

2.5 Recommendations

Formalized electronic data collection, Data Management and QA/QC procedures have greatly enhanced the quality of the data collected for tortoise monitoring. Future years should emphasize revamping the training collection database, management and QA/QC procedures. The training database was the one database that was not redeveloped from scratch for this project.

Transect planning and QA/QC have involved three parties over the years, USFWS, a USFWS non-contracted third party collaborator, and UNR. The addition of a non-contracted third party has complicated coordination and timely delivery of products. In the absence of a contractual obligation by this third party there is no incentive to follow QA/QC plans or meet deadlines that affect contractually obligated parties. The process from transect planning and placement through to final QA/QC needs further streamlining.

The limited nature of the inconsistencies in Walked, Unwalked, Accessible and Unaccessible transects, due primarily to the fact that they occurred over a very short time window, have relevance only to planning in future years. In other words, decisions regarding the Walkability or Accessibility of a transect for future years should not rely on data collected in 2007 regarding Walkability or Accessibility. In 2008 the Walkability and Accessibility of transects were collected via a transect "standardness" field and formally captured in the electronic database. In addition, USFWS provided more detailed training on Walkability and Accessibility. We found no inconsistencies in the 2008 database regarding transect standardness. Formal capture of data on transect "standardness" and training should continue into the future. Transect "standardness" was not captured in 2001-2005. However, a retrospective analysis of transect lines walked in those years may provide a first step insight into an areas walkability if no other information is available.

Starting in 2007 transects were selected randomly from a nested grid developed by USFWS (USFWS 2008). Transects selected from a nested grid, versus complete spatial randomness, have a much higher probability of being selected for sampling in future years. In other words, there are fewer possible transects within a reasonable nested grid (i.e. it is not reasonable to nest the grid beyond some minimum distance between start points). This process and its implications with respect to distance analysis should be peer reviewed.

3.0 DESERT TORTOISE DENSITY ESTIMATION

3.1 Materials and Methods

"The first priority of planning for each field season is to determine the location and number of transects" to be sampled for tortoise monitoring (USFWS 2009 Clark County Final Report; 2005_USFWS_585A_P_Final Project Report_D9). The identification, shape and size of monitoring strata, transect placement strategy and ultimately the number and location of transects were decisions made by USFWS in 2007 and 2008 and were not under our direct control. We analyzed the data provided to us.

Transects were conducted by 2-person crews using the method adopted beginning in 2004 (USFWS 2006). Transects are walked in a continuous fashion, with the lead crew member walking a straight line on a specified compass bearing, trailing about 25m of line, and the second crew member following at the end of the line. This technique involves little lateral searching (other than by eye). Use of two observers allows testing of the assumption that all tortoises on the transect centerline are recorded ($g(0) = 1$). The capture probability for tortoises within 1m of the transect centerline was estimated as for a 2-pass removal estimator (White et al. 1982): $\hat{p} = 1 - (\text{follow/lead})$, where lead = the number of tortoises first seen by the observer in the leading position and follow = the number of tortoises seen by the observer in the follower position. Capture probabilities were estimated separately for all observations, observations in burrows, and observations on the surface. The multipliers used in DISTANCE were calculated as: $\hat{g}(0) = 1 - (1 - \hat{p})^2$, and the variance of $\hat{p}$ was estimated as for G_0, above, where n = the total number of tortoises recorded within 1 m of the transect centerline, and the variance of $\hat{g}(0)$ was estimated as twice the variance of $\hat{p}$.

Not all tortoises in a population can be detected by transects, even if they are on the center of the transect line. Typically, these are either undetectable in deep burrows or well hidden in dense vegetation. The existence of a portion of the population that is "invisible" to sampling will bias the density estimates derived from LDS, but if the proportion of the population available for sampling can be estimated, then DISTANCE uses this parameter (G_0) to correct the bias. Estimation of G_0 was conducted using cohorts of focal tortoises in at least one of the sampling areas in each RU. The focal animals are equipped with radio transmitters and observed daily while transects are being sampled in that area.

Each time a focal tortoise was observed, it was determined if the tortoise would have been visible to an observer conducting a line transect (yes or no), and its position was recorded, either below ground (in burrow) or above ground (at mouth of burrow, under vegetation, or in the open). For each day, we calculated the proportion of observations where the tortoise was visible for four categories: (1) all observations, (2) observations below the surface only, (3) observations above the surface only, and (4) above the surface (all observations). We calculated G_0 statistics for RUs as the mean of the daily proportion visible. The variance of G_0 was estimated using the formula for a binomial proportion (Snedecor and Cochran 1967): $\hat{var} = [G_0 \cdot (1 - G_0)]/n$, where n = the number of days of observation.

We used Program DISTANCE, Version 5, Release 2 (Thomas et al., 2006), to estimate density of tortoises. We compared detection-function models (uniform, half normal, and hazard-

rate) and key function/series expansions (none, cosine, simple polynomial, hermite polynomial) recommended by Buckland et al. (2001). We truncated observations to improve model fit (Buckland et al., 2001). We chose the model with the lowest Akaike Information Criterion (AIC) as the best fitting model.

3.2 Results and Evidence of Results

3.2.1 2007

G_0 statistics were computed from 3500 observations of 99 telemetered tortoises on a total of 100 days. The G_0 statistics are the mean daily proportions of all focal tortoise observations that were visible for each RU or RU segment for which abundance was estimated. Overall, 2874 observations (0.821) were visible, and area G_0s varied between 0.769 (Beaver Dam region of the Northeast Mojave RU and 0.972 (Joshua Tree/Pinto Mountain region of the Western Mojave RU). The analysis of abundance also employed a multiplier for g(0) < 1. For 31 detections of tortoises within 1m of the transect centerline, 24 were found by the observer in the lead position and 7 by the follower, resulting in $\hat{p} = 0.708$, and $\hat{g}(0) = 0.915$ (SE = 0.077).

The contractors completed 557 transects totaling 5935.7 km (Table 3). Sampling began on 1 April and ended on 30 May. A total of 251 live tortoises were recorded, including 235 with MCL ≥ 180mm. Of the adult-sized tortoises, 126 were found on the surface and 109 in burrows. There were also 657 tortoise remains recorded, including 185 intact shells.

The detection function with the lowest AIC was the half-normal key function with 2nd order cosine adjustment (Figure 5). Observations were truncated at 15 m, resulting in discarding of 11 observations. The detection probability = 0.418 (SE = 0.032) and the half strip width = 6.27 m (SE = 0.47). The distribution of detections showed evidence of heaping at 1–2 m. This may result from the apparent failure to find about 9 % of tortoises within 1 m of the transect centerline.

Table 3. Estimated abundance of desert tortoises in the Mojave Desert in 2007.

Recovery Unit	Area (km^2)	Tran-sects	n	G_0	Density (/km^2)	SE	95% CI	CV %
Northeast Mojave (all)	4917	240	50	–	2.30	0.42		18.4
Northeast Mojave (Coyote Springs, Gold Butte Pakoon, Mormon Mesa)	4089	187	42	.805	2.47	0.49	1.68–3.63	19.7
Northeast Mojave (Beaver Dam Slope)	828	53	6	.769	1.42	0.69	0.57–3.56	48.3
Eastern Mojave	6681	76	43	.792	5.88	1.10	4.08–8.49	18.7
Eastern Colorado	4263	100	63	.880	5.42	1.15	3.58–8.20	21.3
Northern Colorado	4038	15	7	.618	5.48	2.06	2.56–11.8	37.5
Western Mojave (all)	13092	126	63	–	4.50	0.83		18.4
Western Mojave (Fremont-Kramer,	9716	90	51	.972	5.17	1.07	3.45–7.74	20.7

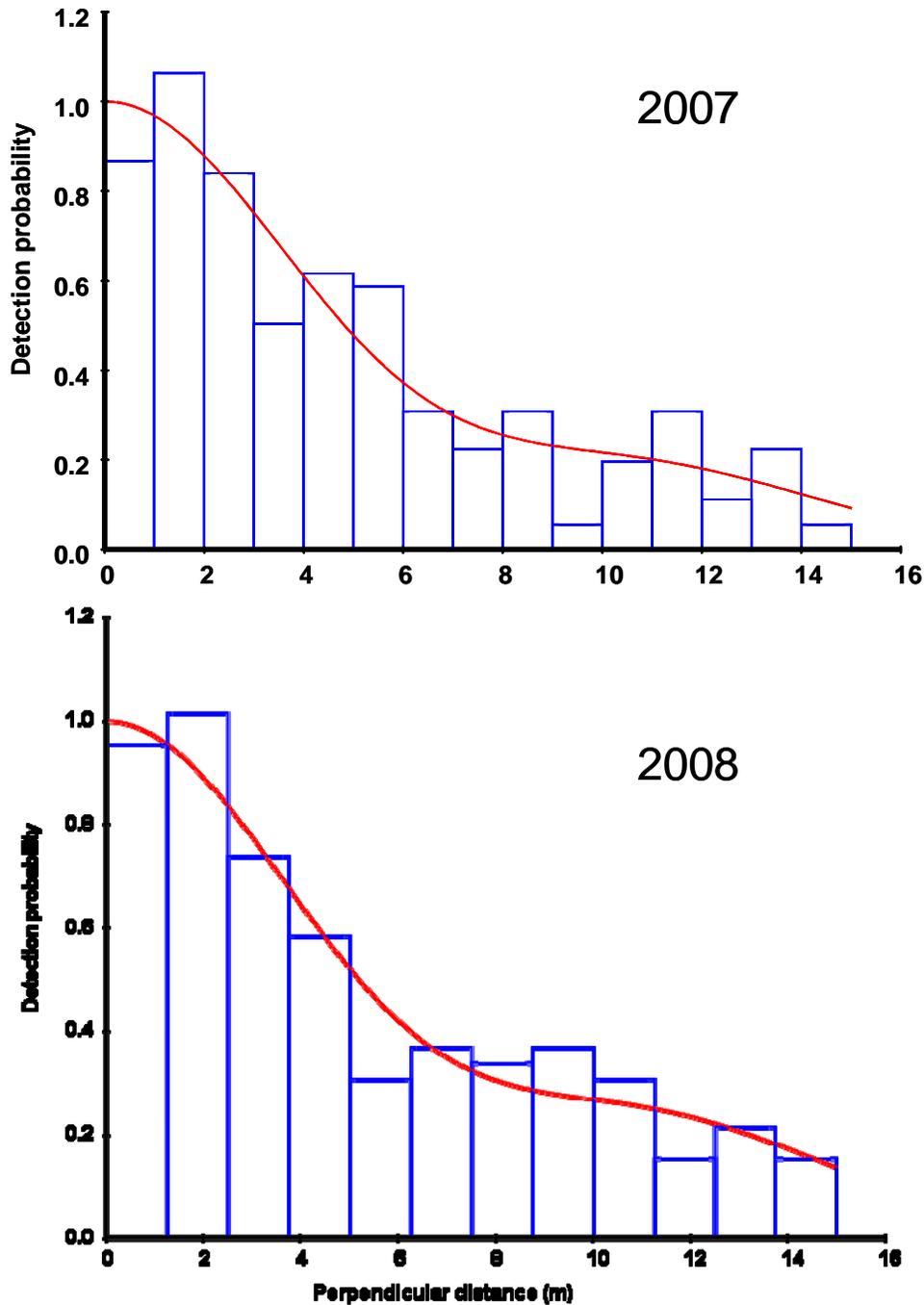|							
Newberry Springs, Ord-Rodman, Superior-Cronese)							
Western Mojave (Joshua Tree, Pinto Mtn)	3376	36	12	.805	2.59	0.94	1.28–5.25	36.2

Figure 4. Detection functions for live adult tortoises in 2007 and 2008.

3.2.2 2008

G$_0$ statistics were computed from 4129 observations of 79 telemetered tortoises on a total of 61 days. The G$_0$ statistics are the mean daily proportions of all focal tortoise observations that were visible for each RU or RU segment for which abundance was estimated. Overall, 3116 observations (0.755) were visible, and area G$_0$s varied between 0.556 (Eastern Colorado RU) and

0.817 (Northeast Mojave RU). The analysis of abundance also employed a multiplier for $g(0) < 1$. For 28 detections of adult tortoises within 1m of the transect centerline, 25 were found by the observer in the lead position and 3 by the follower, resulting in $\hat{p} = 0.88$, and $\hat{g}(0) = 0.986$ (SE = 0.104).

The contractors completed 737 transects totaling 7439.5 km (Table 4). Sampling began on 31 March and ended on 30 May. Live tortoises recorded totaled 232, including 36 with MCL < 180mm, 179 with MCL ≥ 180mm, and 17 with undetermined MCL, which were treated as adults in the analysis. Of the adult-sized tortoises, 155 were found on the surface and 41 in burrows. There were also 525 tortoise remains recorded, including 138 intact shells.

The detection function was modeled with observations truncated at 15 m, resulting in discarding of 17 observations (Figure 4). The detection function with the lowest AIC was the hazard rate function, but half-normal key function with 2nd order cosine adjustment had nearly identical support and was selected because the detection probability was slightly greater with smaller error. The detection probability = 0.458 (SE = 0.042) and the half strip width = 6.88 m (SE = 0.63).

Table 4. Estimated abundance of desert tortoises in the Mojave Desert in 2008.

Recovery Unit	Area (km^2)	Tran-sects	n	G_0	Density (/km^2)	SE	95% CI	CV %
Northeast Mojave (Coyote Springs, Gold Butte Pakoon, Mormon Mesa, Beaver Dam Slope)	6334	362	47	0.817	1.25	0.259	0.83–1.86	20.8
Northeast Mojave (Pahrump)	2178	123	36	0.643	3.12	0.796	1.91–5.12	25.5
Eastern Mojave	6763	153	61	0.752	3.76	0.791	2.50–5.66	21.0
Eastern Colorado	4263	25	10	0.751	4.92	1.709	2.48–9.75	34.8
Northern Colorado	4038	7	4	0.556	4.68	2.523	1.42–15.5	53.9
Western Mojave (all)	9351	67	21	0.732	2.74	0.904	1.45–5.18	33.0

3.2.3 Potential Bias from Under-sampling Tortoises in Burrows

We have long known that line transect methods under-sampled tortoises in burrows, based on a comparison between transect observations and focal tortoise observations of the proportion of observations below the surface. However, our estimate that this bias was relatively small (~5%) was based on data from pilot studies in 2000 before range-wide sampling was begun. We revisited this question by examining all data from range-wide sampling in 2001–2008 and found a larger potential bias but with considerable inter-annual variation. By assuming that the proportion of observations of tortoises in burrows and on the surface during transects should be the same as observed for the visible focal G_0 tortoises, number of expected observations of transect tortoises in burrows, $B_{Te} = S_T \cdot (p_{fB}/p_{fS})$, where S_T = the number of surface observations on transects, p_{fB} = the proportion of visible focal observations in burrows, and p_{fS} = the proportion of visible focal observations on the surface. The number of tortoises "missed" during transects is estimated as $B_{Te} - B_T$ (the number of transect observations in burrows), and varied

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between 122 in 2001 to 9 in 2007, with corresponding under-sampling bias in total observations of 22.8–3.5% (Table 5).

Table 5. Estimation of bias from under-sampling tortoises in burrows.

	Focal Tortoises Visible Observations (proportion)		Transect Tortoise Observations			Predicted		Number "missed"	% of predicted total
Year	In Burrow	On Surface	In Burrow	On Surface	Total	In Burrow	Total		
2001	1138 (0.474)	1265 (0.526)	131	281	412	253	534	122	22.8
2002	706 (0.581)	509 (0.419)	177	170	347	236	406	59	14.5
2003	449 (0.356)	813 (0.644)	114	393	507	217	610	103	16.9
2004	499 (0.323)	1048 (0.677)	128	484	612	231	715	103	14.4
2005	785 (0.348)	1468 (0.652)	169	458	627	244	702	75	10.7
2007	1393 (0.485)	1481 (0.515)	117	134	251	126	260	9	3.5
2008	1058 (0.340)	2058 (0.660)	41	155	196	80	235	39	16.6

The 2007 results suggest little bias in the estimate of the abundance of tortoises in burrows, but that season may have been anomalous. The bias in 2008 was similar to the estimates for 2001–2005. So far, no analysis has attempted to correct for this bias, but any comparisons among years will need to address the issue of under-sampling tortoises in burrows. While we think the bias from under-sampling tortoises in burrows is real, it needs more thought before altering the analysis. This must be addressed by individuals continuing to work on range-wide monitoring.

3.3 Evaluation/Discussion of Results

Density estimates in 2007 show relatively uniform abundance of 5–6 adult tortoises per km^2 in most RUs except for the lower abundance in the Northeast Mojave. Density estimates were lower in 2008 compared to 2007 in all RUs. Part of this may be due to a larger apparent bias in 2008 from under-sampling tortoises in burrows. Density estimates have not been adjusted to account for this potential bias. The large confidence intervals of the abundance estimates make interpretation of the results of a given year or two difficult. Tortoise densities appear to continue to decline since the beginning of range-wide monitoring, but earlier results need to be re-examined from a number of different aspects.

3.4 Conclusions

The detection probability and half strip width were slightly higher in 2008 compared to 2007, but the shape of the detection function was essentially the same in both years. This suggests that sampling was conducted similarly in both years, and that a pooled detection function may be appropriate in future analyses.

3.5 Recommendations

The large amount of variation in the potential bias due to under-sampling of tortoises in burrows complicates potential solutions. Two potential solutions for dealing with this bias are to estimate abundance using only observations where tortoises were recorded above ground, or estimate abundance separately for tortoises observed above and below the surface and combine these to estimate total abundance. Using only surface observations to estimate abundance may impose an unacceptable decrease in sample size in dry years, such as 2002 and 2008 when surface activity was low and more than half of the observations on transects were of tortoises in burrows. However, the justification for estimating abundance separately for tortoises above and below ground assumes that tortoises above and below ground have different detection functions (e.g., detection of burrows declines more with distance than detections of tortoises above ground), but that detection of burrows on the transect centerline satisfies the condition that $g(0) = 1$. If a significant proportion of burrows on or near the transect centerline are missed, then the combined estimate will still have negative bias. The simplest means to account for any bias from under-sampling tortoises in burrows is to use the estimated bias (Table 5) as a correction factor when estimating abundance. However, this will decrease the precision of the abundance estimates. Correction factors would also need to be estimated individually for each Recovery Unit, similar to G_0, instead of using the global estimates in Table 5.

Comparisons with data from 2001–2005 (USFWS 2006) and trend analysis cannot be done until the earlier data are reanalyzed. These analyses were done using a single estimate of G_0; the data need to be reanalyzed using G_0 statistics specific to each RU. In addition, the earlier estimates may be biased due to under-sampling of tortoises in burrows. Reanalysis of the 2001–2005 data and biases associated with under-sampling of tortoises in burrows will need to be further considered and data reanalyzed, both of which are outside the scope of this contract.

4.0 THREATS MODELING

4.1 Methods and Materials

Using general linear models, and spatial general linear models, we explored the distribution of desert tortoise (either live or dead), and the encounter rates of live and dead tortoises along sampling transects, in relation to major highways, densities of roads and human population size, and habitat. Data were generated from range-wide monitoring of this species during 2001–2005 and 2007–2008. The following hypotheses were tested.

1) The presence of live tortoises and tortoise carcasses (hereafter referred to only as tortoises) is positively correlated with search effort (transect length), habitat quality, distance from highway, and negatively correlated with road density and human populations.
2) Encounter rates of tortoises (live tortoises in this case) are positively correlated with habitat quality, distance from highways, and negatively correlated with road density and human population size.

3) Encounter rates of dead tortoises are positively correlated with road density, human population size, habitat quality, and negatively correlated with distance from major highways.

4.2 Results and Evidence of Results

The presence of tortoises are generally positively correlated with greater habitat quality, greater distances from highways, fewer dirt roads, and fewer humans, and spatially aggregated on the landscape. Whereas predicting the presence of tortoises was straightforward using habitat, roads, highways, and human population size, predicting encounter rates was not straightforward. Rates of encounter of live and carcass tortoise along monitoring transects were not similar within and among geographic areas with respect to the covariates analyzed. This may be due to the patchy spatial distribution of tortoises on the landscape, or due to the survey methods employed. Regardless, the encounter rates of carcasses exceeded rates of encounter of live in all cases except the Northeastern Mojave, which also had the highest cumulative sampling effort.

4.3 Evaluation/Discussion of Results

Data used here were part of a range-wide monitoring program that began in 2001; and the sampling strategy and design have changed over the years. Transect length and placement progressed from relatively short (1.4km) transects, randomly placed within a very restricted area in 2001-2003, to relatively long (10-12km) transects more uniformly distributed across the landscape in 2004-2008 (USFWS 2006; USFWS 2008). Tortoises were neither randomly nor uniformly distributed across the landscape, and as a result, there were large expanses of habitat that were intensively surveyed, but may not have been occupied. This caused some areas to be over-, or under-sampled relative to their occupancy, and influenced the resulting encounter rates for live or dead tortoises. For example, much of the Northeastern Mojave analysis unit had low detection of tortoises (live or dead) on transects. Nevertheless year after year transects continued to be walked where there was little or no probability of encountering animals. This drove down the overall live and carcass encounter rates for the entire analysis unit.

4.4 Conclusions

Spatially aggregated populations present problems to researchers trying to assess population parameters such as density or abundance (Seber 1986; Levin 1992, McDonald 2004). Many conventional methods have been shown to yield poor estimates of abundance when populations are spatially aggregated (Thompson 1990; Christman 2000; Pollard et al. 2002). The method employed by U.S. Fish and Wildlife Service for range-wide population density monitoring is Distance Sampling, which can be very effective even for animals that are sparsely distributed and that have low populations (Buckland et al. 2001; Anderson et al. 2001). Tortoises appear to be patchily distributed across the landscape; as a consequence standard distance sampling techniques may yield a low number of detections and high variance (Pollard and Buckland 2004).

4.5 Recommendations

Desert tortoises have a patchy distribution across the landscape that is correlated with and likely affected by habitat potential, road density, distance to major highways, and human population size and desert tortoise range-wide monitoring strategies should take this into account. Adaptive sampling strategies are required to produce unbiased estimators of population density when populations are patchily distributed (Pollard and Buckland 2004); at present adaptive sampling strategies are not employed for desert tortoise range-wide population monitoring.

Where statistically significant correlation exist between desert tortoise (live and dead) distributions and threats the scientific and management community should strive to better understand the relationships between them and investigate causative and mechanistic relationships. This can only be done with detailed on the ground studies designed to address the specific threat-tortoise distribution relationship.

Since reporting our preliminary assessment of the distribution of desert tortoises in relationship to threats we found two additional statistical analysis techniques that will allow us to more rigorously explore 1) the distribution of live to dead desert tortoises and 2) the relationship of these two distributions to threats. First, though we have compared through various roundabout ways the distribution of live versus dead desert tortoises were unaware of a means to compare statistically the two distributions. That is no longer the case. We believe we can use the method proposed by Syrjala (1996) to statistically compare the difference between the spatial distribution of these two "populations". Second, though we utilized statistical methods to explore the relationship between the distribution of live and dead tortoises with threats we believe we have found a more direct and robust set of methods as proposed by Perry and Smith (1994). This method tests the null hypothesis of a random association between distribution and variable, in our case tortoise distribution and threats. In both cases, these statistical techniques must be further explored before publishing our work on the distribution of desert tortoises in relationship to threats.

The implications of 1) above, a robust statistical means to compare the distribution of live and dead tortoises is extremely significant. Comparison between the distribution of live and dead desert tortoises was initially begun in the DTRPAC report (Tracy et al. 2004). Specifically, they identified areas within the three critical habitat units within the West Mojave Recovery Unit (Fremont-Kramer; Superior-Cronese; and Ord-Rodman) plus the Desert Tortoise Natural Area (also in the West Mojave Recovery Unit and attached to Fremont-Kramer) that had increased probabilities of encountering dead rather than live animals, and extensive regions where there were statistically significant clusters of carcasses but no clusters of live animals. We were restricted by data and analysis limitations in 2004 that are largely overcome now. We have more data across portions of the range that were limited previously and we have a robust statistical method that will allow us to statistically compare the distribution of these two populations of tortoises – live and dead. The identification of areas where there are carcasses and few to no live animals, equal numbers of carcass and live animals and areas dominated by live animals should be used to inform management actions, scientific research and populations monitoring.

5.0 ACTIVITY MODELING

5.1 Methods and Materials

5.1.1 - Field Methods: Study Area

A total of twenty-four adult tortoises were fitted with VHF radio transmitters (Model RI-2B, Holohil Systems Ltd, Ontario, Canada) using standard protocols (Boarman and Goodlett 1998) and studied in their natural environments in April and May of 2005 and 2006. The study area was located in Piute Valley, Nevada, west and south of Searchlight, Nevada. The sex, body mass, and mean carapace length (MCL) for each animal were measured prior to affixing transmitters. In addition to radio-transmitters, small microloggers (MLOG_RTL, Sigma Delta Technologies, Floreat, Western Australia) capable of measuring and storing data of nanoclimate conditions were affixed to each animal. The microloggers measured light (mW·cm^{-2}), temperature (°C), and relative humidity (%), and recorded data every 15 minutes. Each micrologger was encapsulated in silicone sealant and enclosed in a hard plastic case to protect it from water and abrasion. The data from the first 24 hours after animals were released were not included in analyses to eliminate any unusual behavior associated with handling the animals.

Animals were tracked and observed two to six times every other day from 23 April to 01 June in 2005 and 01 April to 01 June in 2006. Tracking and observations occurred throughout each day during the spring activity season for tortoises. At each observation, an animal's location, microhabitat position ("in the open away from vegetation", "in a burrow", "in the mouth of a burrow", or "under vegetation"), and behavior (resting, walking, feeding, drinking, mating, or fighting) were recorded, resulting in approximately 130 visual observations for each animal over the two-year period. Animals that were observed above ground were considered active. At the conclusion of the study, all microloggers were removed and their data were downloaded.

5.1.2 - Climate Measurements

Weather stations were installed at the north and south end of the study site to record climate data. Data from both weather stations were pooled to create a single climate dataset. Where possible, data from the northern site were used, as this site contained the majority of animals. Missing data were filled in from the southern site when needed. The location of each weather station was representative of the area contained in the study site with respect to topography and vegetation. Each weather station consisted of a Campbell Scientific (Logan UT) CR10x datalogger that recorded multiple meteorological parameters including wind speed (R.M. Young, Traverse City MI, Wind Sentry Anemometer; m·s^{-1}), solar insolation (LI-COR, Lincoln NE, Silicon Pyranometer; W·m^{-2}), precipitation (Texas Electronics, Dallas TX, 8" Rain Gauge; mm); all measured at 1 m above the surface. Air temperatures (°C) were measured using shielded (Christian and Tracy 1985b) 24 AWG type K thermocouples (Omega Scientific, Stamford CT) at three different heights aboveground (10 cm, 20 cm, and 40 cm). Soil temperatures were similarly measured at four depths below the surface (0 cm, 10 cm, 30 cm, 70 cm). At each weather station, temperatures were measured in direct sunlight and under the shade of a Joshua tree (approximately 3.5 meters tall) to capture both the shaded and unshaded temperatures that a tortoise might experience. Weather parameters were recorded at 15-minute intervals. Rainfall data were collected daily. In addition to the weather station, a micrologger similar to that used on the animals was placed on the substratum surface near the weather station at each site to compare

the nanoclimate measured by the microloggers on the animals to the climate measured by the weather stations.

In addition to measuring climate variables, we estimated the aboveground surface operative temperature (T_e) for an unshaded location using a modeled relationship between T_e and several climate variables. This relationship was derived from aluminum cast models of desert tortoises (Zimmerman et al. 1992) using a simple linear regression containing four variables from a weather station in Las Vegas, NV in 1997 (Nussear unpublished data) where:

$$T_e = -7.534 + 0.008 * (SI) + 0.757 * (WS) + 1.223 * (T_{a(sun)}) + 0.335 * (T_{a(sun)} - T_{a(shade)})^2$$

and SI = solar insolation ($W \bullet m^{-2}$), WS = wind speed ($m \bullet s^{-1}$), and $T_{a(sun)}$ and $T_{a(shade)}$ are air temperatures (°C) at 10 cm above the surface in a sunny and shaded location, respectively.

All climate variables (including T_e, excluding precipitation) were averaged for each day during the hours that range wide monitoring for density has been conducted, namely from sunrise to 3PM (Fish and Wildlife Service 2006). Separately, the number of continuous hours between sunrise and 3PM where the surface operative temperature was below 40 C was estimated and used as a proxy for the length of the potential activity time during the morning of each day given observations from previous research (Zimmerman et al. 1994).

5.1.3 - Classifying Activity

We used the nanoclimate data recorded by each animal's micrologger to predict the microhabitat occupied by an animal for each 15-minute interval and its subsequent activity (defined as above or below ground) with logistic regression. This was done with two logistic regression models, one for the daylight hours (where solar insolation was above 800 $W \cdot m^{-2}$) and a second for the morning and evening (where solar radiation was between 50 and 800 $W \cdot m^{-2}$). The model used for each period of the day was selected from a series of competing models using stepwise selection comparing the Akaike Information Criterion (AIC) scores among models (Anderson and Burnham 2002, Burnham and Anderson 2002). A random selection of 15% of the observations was withheld during the model selection process to test each model with a confusion matrix for accuracy, using Cohen's Kappa to assess its overall performance (Fielding and Bell 1997). Fitted values from the selected model for each period (morning/evening and daylight) were combined into a complete account of each study animal's microhabitat position throughout the sampling season.

Daily estimates of the g_0 parameter were calculated by taking the proportion of the fitted activity values of all study animals for each day that were above ground and active. This daily index of population activity included 23 April to 01 June in 2005, and 01 April to 01 June in 2006. FWS methods to estimate range wide density conduct sampling during the months of April and May (USFWS 2006), however, due to logistics, our study did not start until the 23rd of April in 2005, thus limiting the first year of data to the mid and end of the range wide sampling season. Additionally, range wide sampling is typically terminated by 3PM each day, and therefore we limited our fitted values (which are analogous to behavioral observations used by FWS) to sunrise to 3PM of each day. Differences among years in the daily estimates of activity were assessed using repeated measures ANOVA.

5.1.4 - Predicting Activity

We modeled activity for desert tortoises with a suite of environmental variables to identify any that could predict the g_0 parameter at a daily time scale. Operative temperatures on the substratum surface, air and soil temperatures, solar insolation, humidity, wind speed, precipitation and seasonality (using the proxy of soil temperature at 70 cm below the surface and length of morning potential activity time) were hypothesized to have possible influences on desert tortoise activity. Linear regression with beta error distributions (using package betareg 1.2 in R 2.8.1, Alexandre de Bustamante Simas 2009, Ferrari & Cribari-Neto 2004, R Development Core Team 2007) was used to identify combinations of meteorological variables that best described the proportion of aboveground observations for each day. The meteorological variables used to model T_e were not included in any model also containing T_e due to the inherent dependence of T_e on certain meteorological variables. Very low levels of activity (< 0.2) accounted for nearly 50% of tortoise daily activity values. Because current implementations of linear regression using beta distributions in the betareg software package do not include the ability to use weighted regression, we resampled the daily index of activity using a weighted thinning method to reduce the sample size of low activity values. We divided the index of activity into 20 equally spaced subsets of activity from 0 to 1 in intervals of 0.05. Subsets with low activity generally had higher sample sizes than did subsets with high activity. A random sample of 5 from each subset was used to create the training dataset, which had a possible n of 100. This process was repeated 30 times, yielding separate training datasets of activity. Each dataset was used to train a suite of models from which we used multi-model inference with AIC (Burnham and Anderson 2002, Link and Barker 2006) and pseudo-R^2 (Ferrari & Cribari-neto 2004) to address questions about desert tortoise activity and climate.

Prior to modeling, the response variable was rescaled to remove any zeros or unities following the procedure described by Smithson and Verkuilen (2006). Pseudo-R^2 measures were calculated as the square of the sample correlation coefficient of the fitted and observed values (Ferrari & Cribari-neto 2004). Models with non-significant parameter estimates were not considered, and models with DAIC of less than 2 were considered to be nearly equal in model fit and performance. The median DAIC from the 30 training datasets is reported, and models that performed well on all 30 training datasets were considered candidates for the prediction models. The AIC weighted coefficients from each parameter in the candidate models were used to define the final prediction model, and the median pseudo-R^2 for each model was used as an index of overall fit (Ferrari & Cribari-Neto 2004).

Comparisons of the precision of our modeled daily g_0, as well as a daily g_0 (referred to as the Focal Method) derived from field observations (24 tortoises observed twice per day) were made against the fitted activity values derived from the dataloggers in 2005 and 2006. We calculated the mean and confidence interval for each method of estimation for high ($0.73 > m > 1.0$), medium ($0.39 > m > 0.49$) and low ($0 > m > 0.21$) levels of activity. The range for each level was picked to ensure a maximum of 10 daily activity values in each level, though the range for high activity was larger than either of the other levels due to the scarcity of high activity during the dates of the study. From our model that predicted a daily g_0, we selected 10 days for which the activity (measured from dataloggers) was within the defined range of each level. We calculated the mean of the confidence intervals ($a = 0.05$) for the modeled g_0 values among the 10 days selected. The second method used field observations of our study animals. Here we

randomly selected two of our field observations of each of our study animals from the same 10 days selected above. This equated to approximately 48 observations for each level of activity. We calculated the average of the binary activity assessments and its confidence interval, similar to what is done in the FWS monitoring program to estimate sampling availability (Fish and Wildlife Service 2006). We assumed either method (modeled g_0 or field observations) to be sufficient for predicting all three levels of activity if the confidence intervals from the selected 10 days of either method overlapped the true mean of activity for the same 10 days.

To estimate the utility of our predictive model of g_0, we assessed model performance by predicting the activity of a large population of desert tortoises in the Bird Spring Valley near Las Vegas, NV during the years of 1997, 1998, and 1999 (Nusser and Tracy 2007). Activity data from the Bird Spring Valley Site were similarly truncated to April and May from sunrise to 3PM, and limited to days where at least 9 total observations were recorded. Model utility was assessed with standard linear regression and R^2.

5.2 Results and Evidence of the Results

5.2.1 - General Climate Descriptions

Mean daily air temperatures (T_a) at 10 cm above the ground ranged from 12 to 46 °C, although temperatures as low as 0 °C were recorded in the April. Soil temperatures at 30 cm (shallow = T_{s-30}) and 70 cm (deep = T_{s-70}) below the surface did not vary as much throughout each day, though they increased nearly linearly throughout the season. Deep soil temperature (70 cm) increased more linearly than did shallow soil temperature (30 cm), and was used as an index for the progression of season in both years. Both T_a and T_{s-30} were significantly different among years with 2006 being the hotter year. Precipitation tended to occur as short isolated rain events, and overall, was not different among years. Surface T_e ranged from -16 to 66 °C, and was highly correlated with T_a (Pearson's r = 0.97, p > 0.0001). In general, the length of the morning potential activity time decreased throughout the study each year, with a maximum near 8 hours in early April and a minimum of 1.5 hours at the end of May.

5.2.2 - Classifying Activity

An individual's position within the environment (above or below ground) was best modeled with three independent variables from the microloggers and weather stations. These were differences between (1) temperature, (2) relative humidity, between an individual's nanoclimate and the ground surface, and (3) a categorical variable (*light*) representing the difference between the amount of light an animal experienced and the amount of light available at the substratum surface. The model classifying logger data into an individual's microhabitat position during morning and evening hours (50 < solar insolation < 800 W·m^{-2}) did better than the model for the mid-day (solar insolation > 800 W·m^{-2}), with a Kappa of 0.69 and 85% of the aboveground and belowground predictions being correct (Table 1).

5.2.3 - Trends in Activity

In general, the daily activity of tortoises was higher in April than in May in both 2005 (Figure 5, top) and 2006 (Figure 5, bottom). While there was no overall difference in the mean

daily activity of individuals between 2005 and 2006 ($F_{1,90} = 2.91$, p > 0.09) there was more variability in daily activity in 2006 than in 2005, especially later in the activity season (Figure 5).

Table 6 - Each diel time period was modeled with a separate logistic regression. Model performance was assessed with the % correct for each of the two possible microhabitat positions (above or below ground).

DAYLIGHT

Actual	Predicted		Total	Percent correct
	Above ground	Below ground		
Above ground	53	13	66	0.80
Below ground	13	61	74	0.82
total	66	74	140	
Kappa	0.63			

MORNING/EVENING

Actual	Predicted		Total	Percent correct
	Above ground	Below ground		
Above Ground	153	28	181	0.85
Below Ground	34	193	227	0.85
total	187	221	408	
Kappa	0.69			

Figure 5. Daily activity (proportion of animals aboveground) for each day during the range wide monitoring period season (01 April – 01 June) of 2005 (top) and 2006 (bottom). The later year saw increased activity on a few days at the end of may, likely due to the increase in precipitation that occurred in on those days. Confidence intervals (a = 0.05) are represented with dots when they are too small for plotting.
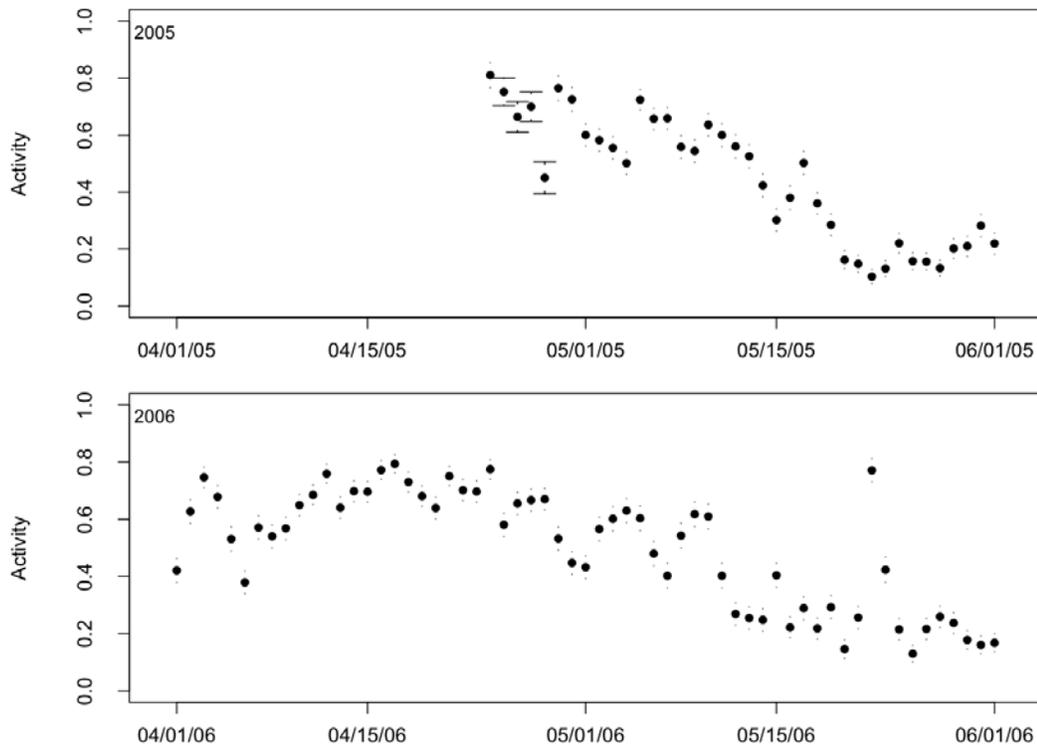
5.2.4 - Predicting Activity

Two models had DAIC scores of less than two and these were selected to predict the daily g_0 parameter. Each model contained deep soil temperature (T_{s-70}), air temperature (T_a) and the interaction of T_{s-70} and T_a. Additionally, the 2nd model contained a term for the length of the morning potential activity period. The model coefficients were similar among the two top models, where T_{s-70} was positive, T_a was positive, and the interaction of T_a and T_{s-70} was negative, and $T_e{}^{40}Hrs$ was positive.

The model predicting daily activity explained approximately 84% of the variance in the observed daily activity of our study animals in both years combined, and explained 86% and 84% in 2005 and 2006 respectively. In general, we observed more consistent behavior in 2005 than in 2006. This model of g_0 did not accurately predict the high level of activity, with a predicted value near the lower confidence limit of the focal observations. The mean confidence intervals from the predictive climate model for the three levels of activity: high (m = 0.77), medium (m = 0.43) and low (m = 0.15) were 0.01, 0.08, and 0.04, respectively. In contrast, the field observation method (Fish and Wildlife Service 2006) to estimate activity did show sufficient accuracy to predict all three levels of activity (as determined by the comparison of the Logger and Observation data), but showed lower precision than did our model (Figure 6) at all three levels of activity. The mean confidence intervals from the field observation method for each of the levels of activity: high (m = 0.77), medium (m = 0.43) and low (m = 0.15) were 0.14, 0.13, and 0.08, respectively.

Figure 6. Predicted activity from the climate model (white) and current field observation methods (dark grey, see Fish and Wildlife Service 2006) for 10 days where daily activity was high (0.73 < m < 1.0), medium (0.39 < m < 0.49) and low (between 0 < m < 0.21). Observed activity derived from the dataloggers (light grey) provided the reference from which the two other methods were compared. Confidence intervals (a = 0.05) are shown.
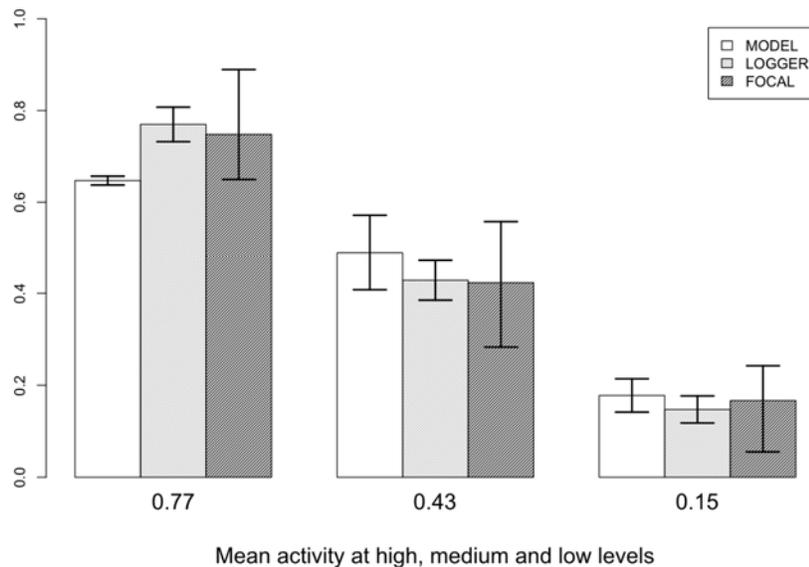
When applied to the independent testing dataset from Bird Spring Valley, our model showed a mean R^2 of 0.42, and a highly significant slope coefficient ($t_{1,32}$, p < 0.001) across the three years where behavioral observations were available (1997, 1998, and 1999). Our model did

not predict equally well among years, with R^2 values of 0.61, 0.69, and 0.16 for the three years of 1997, 1998 and 1999, respectively. Drought conditions that likely suppressed tortoise activity in some years. Additionally, our model did not yield a significant slope coefficient for the 1999 drought year ($t_{1,6}$, p > 0.3), although 1997 ($t_{1,10}$, p < 0.001) and 1998 ($t_{1,12}$, p < 0.001) were both highly significant. Unfortunately, the sample size in 1999 was substantially smaller (40%) than in 1997 or 1998, which likely contributed to our inability to accurately predict tortoise activity in that year. Soil temperature in Bird Spring Valley was generally lower than at our study site, though air temperature was similar.

5.3 Evaluation/Discussion of Results

Quantifying the variation in activity of animals is important to many monitoring protocols; as the availability of animals to be censused is a critical aspect to estimating population densities using distance sampling (Bayliss and Giles 1985, Hill et al. 1985, Anderson et al. 2001, Jachmann 2002, Skaug et al. 2004, Gómez de Segura et al. 2006, Nussear and Tracy 2007). Desert tortoises have been the focus of recent research identifying the need for the application of tortoise activity and sampling availability to distance sampling methods (g_0, Anderson el al. 2001). Subsequent research has highlighted the importance of identifying additional sources of undocumented variation that require an in-depth look at how sampling availability and activity are quantified (Nussear and Tracy 2007, Inman et al. *In Review*).

The methods currently used to estimate sampling availability (Fish and Wildlife Service 2006) use small populations of transmitter equipped tortoises that are intensively monitored for their activity (i.e. 2-3 observations per tortoise per day) during the sampling period. The tortoises are also monitoring and maintained throughout the year, adding additional cost. In addition, the monitoring program for desert tortoises uses a single estimate of activity to account for the influence of sampling availability on estimates of density for the entire sampling season (Fish and Wildlife Service 2006, Nussear and Tracy 2007, Inman et al. *In Review*). If it was possible to model sampling availability (g_0) with sufficient precision to include in estimates of density, a significant cost savings could be realized. More importantly, modeled estimates of daily activity could be incorporated into the density estimate, which could potentially improve the precision of the density estimate, as we show behavior to vary a great deal throughout the season (Figure 5).

The model predicting daily activity throughout the activity season used deep soil temperature (T_{s-70}) and the length of time where surface operative temperature was below 40 °C as an index of the progression of the activity season. The model also contained air temperature (T_a) and the interaction of air temperature and deep soil temperature. The influence of deep soil temperature was positive, suggesting that activity increases as soil temperature increases. However, it is important to note that this study was designed to model the daily activity of tortoises at a population level (g_0) and therefore did not evaluate tortoise behavior after 01 June in either year, nor in the hours outside of the typical sampling day. Thus, any inferences made about the relationships of climate variables and tortoise behavior can only be relevant during these times. Similarly, the coefficient for T_a was positive, suggesting that as the daily average of air temperature increased, activity did as well. The influence of air temperature was slightly smaller than that of soil temperature. The negative coefficient for the interaction of T_a and T_{s-70} suggests that when as deep soil temperature increases, the positive effect of air temperature is

reduced. Biophysical models that incorporate operative temperature models have proven important for understanding the interactions of organisms with their environments, and have led to predictions of behavior for many terrestrial ectotherms (Waldschmidt and Tracy 1983, Christian and Tracy 1985a, Tracy and Christian 1986, Grant and Porter 1992, Zimmerman et al. 1994). In our model, the coefficient for $T_e^{40}Hrs$ was positive, indicating that an increase in the amount of time in the morning that surface operative temperatures were not near lethal conditions equated to an increase in the activity of tortoises. This is consistent with biophysical predictive influences of operative temperature and its potential influence on behavior (Zimmerman et al. 1994).

Previous efforts to model patterns of tortoise activity were only able to explain 42% of the variation in the daily activity of a large population of desert tortoises (Nussear and Tracy 2007). We found that modeling activity using automated observations obtained by bio-logging (Rutz and Hays 2009) an individual's nanoclimate for extended periods of time during the sampling season resulted in a model that nearly doubled the explanatory power over previous efforts (R^2 = 84%), though when applied to an independent dataset from different years, our among year R^2 was only 0.42 overall, but with higher performance in more typical years (e.g. R^2 = 61% and 69%). This reduced explanatory power is likely due to the differences in deep soil temperature between the Bird Spring Valley site and our study site near Searchlight, NV during the period in which sampling is conducted. The Bird Spring Valley site is located approximately 97 km (60 miles) north of our study site, and showed cooler soil temperatures, yet air temperatures were very similar. This difference caused our models to over-predict activity when activity was low, and under-predict when activity was high. This was likely due to the significant interaction of soil and air temperature, wherein the cooler soil temperatures reduced the effect of air temperature, causing a reduction in predicted activity when air temperatures were in fact warm enough for activity. Similarly, the reduced effect of air temperature caused the model to over-predict activity when air temperatures were hot enough to cause individuals to seek thermal refugia.

Our greatest prediction accuracy occurred when activity was lowest because even during times of peak activity, some individuals exhibited little or no activity. Low levels of activity (exhibited by most or all animals in the population) may be due to physiological constraints on activity, such as when only extreme (high or low) operative temperatures are possible. Low levels of activity (exhibited by a few animals) during otherwise hospitable conditions may be due to factors un-related to temperature or the environment. For example, even if the above ground climate is hospitable, an individual may have no need to emerge from its burrow as it may have satiated its need for food or mating. Thus, it appears that tortoises are remarkably unpredictable in many aspects of their behavior, especially during periods when the environment is unlikely to constrain activity. In summary, it is far easier to predict when desert tortoises *cannot* be active than it is to explain when desert tortoises *are* active.

5.4 Conclusions

We have demonstrated that it is possible to model daily activity of desert tortoises with sufficient precision to reflect the precision of what is likely obtainable using repeated field observations of small focal populations of animals, but not a similar accuracy at high levels of

activity. For example, 24 tortoises observed 2 times each day could only attain a confidence interval of 0.14 when 70% of the animals were active, and a confidence interval of 0.08 when less than 20% of the animals were active. In contrast, our model showed a confidence interval of 0.01 and 0.04 for high and low levels of accuracy. The activity models shown here give predictions that are substantially lower than actual activity when activity is high, though more important, these models give accurate and precise estimates when activity is low, which has a greater effect on the precision of estimates of density (Inman et al. *In Review*).

The clear limitation of the models presented here is that they are not per se mechanistic, and have been derived from the time of day and time of year when range wide monitoring occurs, instead of the transitional periods during the late afternoon and late season when population activity declines. Furthermore, additional models that describe the behavior of individuals at different times of the day will help shed light on what governs the behavior desert tortoises, and will ultimately allow building more robust models than will the empirical approach taken here, which is site and season specific. Regardless, a modeling approach should be considered as an alternative for predicting behavior of animals, with the caveats given here.

5.5 Recommendations

The results of this study reveal several limitations to monitoring desert tortoise population density. Differences in activity among years, and during the season within a year cause the use of single constants representing tortoise availability to be monitored to be naïve and unreliable. Thus, the recommendation is to conduct all activity monitoring only in years in which activity is high and this would help reduce variance among samples (years) in estimates of density. Reducing this variance could increase power to detect trends in population density. Second, reducing the affect of season in activity monitoring would be helpful. Thus, conducting all monitoring in the three weeks surrounding May 1 would be optimal. This would require huge numbers of crews working simultaneously during a very short monitoring season, but monitoring in weeks outside of this time frame will decrease the reliability of the estimate of density. Finally, it would be better to get an estimate of the abilities of crews to see tortoises during transect censuses, and to use these estimates of abilities as an adjustment on all data from each crew according to their abilities. This approach requires keeping crews together during monitoring, and keeping their abilities as a variable in the overall estimate of population density. This allows the variance in activities to be revealed independent of the variance caused by observers.

It is important to assess the extent to which the statistical models created to predict activity (such as those created in our research) are or are not, generalizable among sites to be monitored. Thus, it should be asked if the model predictions will work in other locations? We simply do not know how much location influences model predictions of activity as there are differences in vegetation and meteorology among sites. Thus, this potential problem of the ability to model density needs further study. If the models are generalizable, then they could be used instead of focal-animal populations to assess tortoise activity. The fact is that a focal population of twenty tortoises only has a precision of 95% (as a single tortoise acting strangely translates into a 5% error). Thus, models such as those produced in this research can eliminate imprecision naturally occurring in use of focal animal populations.

The limitations of monitoring desert tortoise with distance models are formidable. The Desert Tortoise Recovery Plan Assessment Team (Tracy et al. 2004) noted these limitations and recommended that monitoring desert tortoise should use stratified metrics that recognize information about the efficacy of management actions at several levels of integration. In particular, the DTRPAC felt that there would be information at landscape levels as distribution of presence and absence could be put into a GIS model to assess gains and losses of filled habitat. We felt that vital rates important to population levels could reflect management, so birth and death rates could be monitored in well-replicated study sites. The DTRPAC also felt that information at the individual level could be valuable. Thus, assessing health and stress metrics of individuals could show gains and losses in respect to management. Collectively these three levels could yield a principal component that could be a recovery metric that would be more valuable than simple density measurements, which cannot be accomplished at needed resolutions to be of much value.

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