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RANGE-WIDE MONITORING OF THE MOJAVE POPULATION OF THE DESERT TORTOISE:

2007 ANNUAL REPORT

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EXECUTIVE SUMMARY

The recovery program for the Mojave population of the desert tortoise requires range-wide, long-term monitoring to determine whether recovery goals are met. Specifically, will population trends within recovery units remain stable for a period of 25 years? In 1999, the Desert Tortoise Management Oversight Group endorsed the use of line distance sampling (Buckland et al., 2001) as the method for estimating range-wide desert tortoise density. From 2001 to 2005, and again in 2007, desert tortoise populations in 5 of the 6 recovery units have been part of a coordinated, range-wide monitoring program using line distance sampling. (The Upper Virgin River Recovery Unit is monitored by Utah Division of Wildlife Resources.) The first 5 years of monitoring culminated in a summary report (USFWS, 2006) that included eleven recommendations, seven of which were tied to functioning of the monitoring program and are paraphrased here:

1. The range-wide monitoring program should continue under a formal study plan subject to scientific review.
2. Refine [line distance sampling] techniques to improve sampling efficiency and estimates of trends.
3. Evaluate the spatial scale of the monitoring program.
4. Improve training lines.
5. Evaluate the use of independent field teams in order to improve data consistency and quality.
6. Refine and formalize/document the QA/QC process.
7. Identify and assess options for securing continued funding for range-wide population monitoring.

When monitoring started again in 2007, the following steps were taken to implement these recommendations (numbers correspond to the recommendations above):

1. Parts of the original study plan (Anderson and Burnham, 1996) that had not been implemented originally were put in place. The resulting system for placement of transects under this plan was reviewed by spatial analysts with USGS.
2. Five sub-recommendations were made and three implemented within the program:
    a. Individual monitoring strata were used to stratify reanalysis of the 2001 to 2005 monitoring data. They were also used as recommended in Anderson and Burnham to stratify transect placement in 2007. The number of transects in each stratum was adjusted to target desired precision, based on 2001-2005 density estimates and as described in the original study plan.
    b. Estimates of detection probability were modified to reflect a balanced level of effort between teams. This approach to developing robust estimates has been published and implemented elsewhere. Examination of telemetry data was used to

    identify the consistent optimal monitoring period (April-May) when tortoises are predictably visible. This informed timing of monitoring in 2007 and selection of data to reanalyze from 2001 to 2005.
    c. A white paper was generated to guide the approach for estimating G_0 in 2007.
3. Data were collected for each assigned transect, describing access and completion issues so these can be addressed when the same transects are repeated in the future. Procedures were implemented to allow completion of transects in a non-standard way so that unsampled areas from earlier years could be surveyed.
4. Steps for improving training were taken in 2008, after the period of this report.
5. A second monitoring organization was contracted to provide field crews in 2007. Previous to this, some crews had organizational oversight, while others were contracted through a national hiring center, with all oversight and responsibility on the project planners.
6. The 2007 data management plan was drafted for the first time before the field season started.
7. No steps were taken to ensure stabilized funding for the annual monitoring effort.

This report describes the full set of quality assurance steps and final results for the 2007 monitoring effort. In 2007, the range-wide monitoring effort was partitioned among 17 sampling strata based primarily on critical habitat/Desert Wildlife Management Area/Area of Critical Environmental Concern boundaries. Data were collected by 20 field teams working with two different groups, Kiva Biological and Great Basin Institute. After an intensive, 1-week specialized training session, crews completed 557 transect surveys between 1 April and 20 May. In the course of these surveys, they walked 5936 kilometers of transects and reported 251 live tortoises.

Training is provided each year so that field crews are familiar with the specifics of distance sampling. Training also ensures consistency between the many crews collecting data. Inexperienced crews as well as those with prior experience participated in preseason training and testing provided by the University of Nevada, Reno, and by the U.S. Geological Survey. Inexperienced crews began training two weeks before the more specialized training was provided to the larger group. All of the experienced 2-person teams provided appropriate detection curves, detection proportion on the transect line, measurement accuracy from tortoise models to the transect line, and proportion detected by the leader and the "clean up" follower on the team. After training, it was determined that inexperienced crews averaged fewer tortoise models on the testing lines and were less precise in their distance measurements, so these skills will be a target of future training. Detection curves for each team were subjected to real-time evaluation in 2007, and on this basis, 8 of the 13 inexperienced teams were rebuilt with new pairings during training.

Four parameter estimates contribute to final reported tortoise densities in each monitoring stratum. The basis for distance sampling is the estimation of the number of tortoises detected at increasing distances from the walked transect. As the surveyors look farther from the transect centerline, they will detect fewer and fewer of the tortoises that are actually there, so describing the way detections decrease with distance allows for estimation of the proportion that were present but not detected within a given distance of the transect centerline. Second, an estimate is made of the proportion above ground or visible in their burrows and available to be detected on transects. Third, the first two estimates are combined with the number of tortoises encountered per kilometer walked to provide the actual density in each stratum. Finally, the proportion detected on the line must be estimated. Unless all tortoises were detected on the centerline, the density estimate must be adjusted to account for the occurrence of these additional tortoises.

In 2007, Kiva crews detected 49% of tortoises within 12m of the transect centerline, GBI detected 61%. The proportion of tortoises that were visible to be counted (G_0) varied in different parts of the range, which were also surveyed at different times during the spring season. Visibility varied from a high of 97% in MCAGCC during the second week in April to 77% at the Coyote Springs telemetry site, monitored during the last month of the field season. On average, crews walked 24km for each tortoise that was observed, but this number varied considerably from one monitoring stratum to the next. As usual, strata in the Northeastern Mojave Recovery Unit had the lowest densities (1.2 per km^2 in both the Gold Butte-Pakoon and the Beaver Dam Slope strata). The highest densities was reported on the Chocolate Mountain Air Gunnery Range (7.1 tortoises per km^2) and in the Ord-Rodman critical habitat unit (8.2 tortoises per km^2).

A priority for 2007 was to improve precision of density estimates. One large source of variance in density estimates has been the estimation of G_0. Analysis before the field season started indicated that much of the day-to-day variance in G_0 is due to monitoring over large spatial scales (where factors affecting tortoise activity may vary considerably) and over relatively large temporal scales (entire spring activity seasons) that describe activity over a period when the phenology of annual food plants changes considerably and when diurnal temperatures increase markedly.

For 2007, the study design was changed to minimize the variance of G_0. Each of six groups of telemetry sites and neighboring transect strata were completed in sequence to minimize the number of days required in the neighborhood of a given group and to more closely reflect only local conditions. Comparison of the 2005 with 2007 estimates of G_0 shows that in two of seven telemetry sites that were used both years, the precision of the estimate did not improve when fewer days were monitored, but the overall pattern indicates that this strategy will help improve the precision of the resulting density estimates. The method for calculating the variance of G_0 was also corrected this year.

By moving the final steps of the analysis out of Program DISTANCE, in 2007 I was able to utilize these regional estimates for G_0 as well as provide stratum-level density estimates. In many areas of the range in 2001 to 2005, a similar grouping approach had been used, completing local transects and monitoring telemetry sites in a short period of time. However, the previous method of analyzing data could only accommodate one G_0 estimate per year.

Estimates of density for 2007 are lower for all recovery units than the revised or original estimates for 2005. This change coincides with increasing efforts to sample from all of the areas managed for desert tortoises; the new areas of interest were excluded in the past as potentially low or no suitability to desert tortoises. Even if no change has occurred in population numbers, it is expected that estimates of overall tortoise densities will be lower if many of the areas added to the sampling frame contain lower densities of tortoises than the core areas sampled among all years.

To enable field crews to complete transects in some of these previously unsampled areas, a set of guidelines were developed at the beginning of the field season for completing transects in areas with rugged terrain or other obstacles (Appendix A). These rules did enable crews to sample entire strata in a more representative way; however, based on site visits with crews and visual (GIS) inspection of how these rules were applied on specific transects, guidelines were not applied consistently. During end-of-season debriefings, crew feedback also underscored that the rules were difficult to apply. A much-simplified, intensively instructed protocol for non-standard situations was developed for future years beginning in 2008.

Finally, the success of the range-wide monitoring program also depends on developing reliable, adequate, and consistent funding. Reanalysis of data from 2001 through 2005 clearly illustrated that sufficient effort (transects) in each stratum is needed to encounter several tortoises, otherwise estimates are not possible. In 2002, 2003, and 2004, sampling effort in one or more strata was insufficient to estimate density in at least one recovery unit. Effective implementation of this program requires stable funding so that monitoring effort matches planning requirements rather than funding limitations.

RANGE-WIDE DESERT TORTOISE POPULATION MONITORING
2007

INTRODUCTION

The Mojave Desert population of the desert tortoise (*Gopherus agassizii*) was listed as threatened under the Endangered Species Act in 1990. The initial recovery plan (USFWS, 1994) designated six recovery units to which decisions about continued listing should be applied. Both the 1994 recovery plan and the draft revised recovery plan (USFWS, 2008) specify that consideration of delisting should only proceed when population trends in each recovery unit are stable or increasing for at least one tortoise generation (25 years), and the only means to determine trend is by a rigorous program of long-term monitoring. Before the tortoise was listed, populations were monitored either using strip transects (Luckenbach, 1982) where indications of tortoise presence (live or dead tortoises, scats, burrows, or tracks) were converted to estimates of abundance based on transects conducted in areas of better-known tortoise density, or by using capture-recapture population estimates on a limited number of (usually) 1-mi^2 study plots (Berry, 1984). Although data have continued to be collected on transects and study plots in recent years, both methods suffer statistical deficiencies and logistical constraints that render them unsuited for monitoring trends in abundance applicable either range-wide or to individual recovery units (Corn, 1994; Anderson et al., 2001; Tracy et al., 2004). In 1999 the Desert Tortoise Management Oversight Group endorsed the use of line distance sampling (Buckland et al., 2001) for estimating range-wide desert tortoise density.

Distance sampling methods use measurements taken from the center of the transect lines to tortoises to model detection as a function of distance from the walked path; tortoises farther from the travelled path have a lower probability of detection. In order to anchor the curve and estimate the number of tortoises within a given distance from the center of the transect, the assumption is applied that all tortoises are detected on the transect center line (Anderson et al., 2001; Buckland et al., 2001). There are minimal additional assumptions in distance analysis – that distance is measured to the point where the animal was first detected and that distance is measured accurately – but these are easily satisfied in line distance sampling of desert tortoises. The assumption that detection at the center line of the transect is perfect, however, can be violated during line distance sampling of tortoises, but the use of two observers minimizes these violations of the assumption and provides a correction factor in the form of an estimate of the number of tortoises on the line that were missed (USFWS, 2006).

Distance methods have been used to estimate abundance of Desert Tortoises in the Sonoran Desert in Arizona (Swann et al., 2002; Averill-Murray and Averill-Murray, 2005) and in the Upper Virgin River Recovery Unit in Utah since 1998 (McLuckie et al., 2008). The USFWS used line distance sampling to estimate abundance of tortoises in the remaining five recovery units in Utah, Arizona, Nevada, and California starting in 2001 (USFWS, 2006). This report includes further evaluation of data from the first 5 years of the study, describes the sampling design adopted for 2007 to address some of these results, reports on the results of training exercises for field crews, presents the analysis of desert tortoise density in 2007, and uses the refined approaches to reanalyze data from 2001 through 2005.

METHODS

Study areas and transect locations

Long-term monitoring strata will be used over the life of the project to describe population trends in areas managed to conserve tortoises. Figure 1 depicts these strata as well as 2 more that were added for 2007 only. Strata were created for Newberry Springs and Pinto Mountains 2 to create density estimates for relatively large contiguous areas of public land located near other areas managed for desert tortoises. Density estimates for these single-year strata are not included in annual recovery-unit-level estimates that are assessed for long-term trends.

Modification of previous procedures

Monitoring strata encompass large areas with variable geography and topography. It is expected that tortoises will not occupy any one stratum at a uniform density; some local areas will support higher numbers of tortoises than others. In addition, some of the terrain is so rugged that it would not be safe to complete transects there. From 2001 to 2003, these considerations led planners to mask out some areas of each stratum from sampling (USFWS, 2006). The excluded areas changed in each of these years, however, and for purposes of estimating densities in these strata, more extensive and consistent sampling was desirable. In 2004 and 2005, transects were placed at random on the landscape, with crews able to remove or “slide” transects based on safety considerations (USFWS, 2006). Examination of completed transects after the field season indicated that local areas had not been sampled and many transects were moved for reasons that were unclear – in part because field crews had not documented their decision-making process.

In 2007, standard 12-km transects were walked using the same protocols as in 2004 and 2005 (USFWS, 2006), with up to 25% alternate transects provided to replace any unwalkable assigned transects. A new set of guidelines were provided to crews to give them options for completing transects without moving them away from the basic assigned location; from 2004 and 2005, crews were instructed in how to move transects to areas more likely to hold tortoises and/or areas that were less difficult for humans to traverse. The 2007 guidelines (Appendix A) were developed after training to set conditions under which non-standard transects would be created by 1) deflecting transects inward, or 2) creating rectangular transects along obstacles associated with human infrastructure (large roads, private inholdings, etc.). In rugged terrain, 3) transects could be shortened to enable completion before 4pm each day.

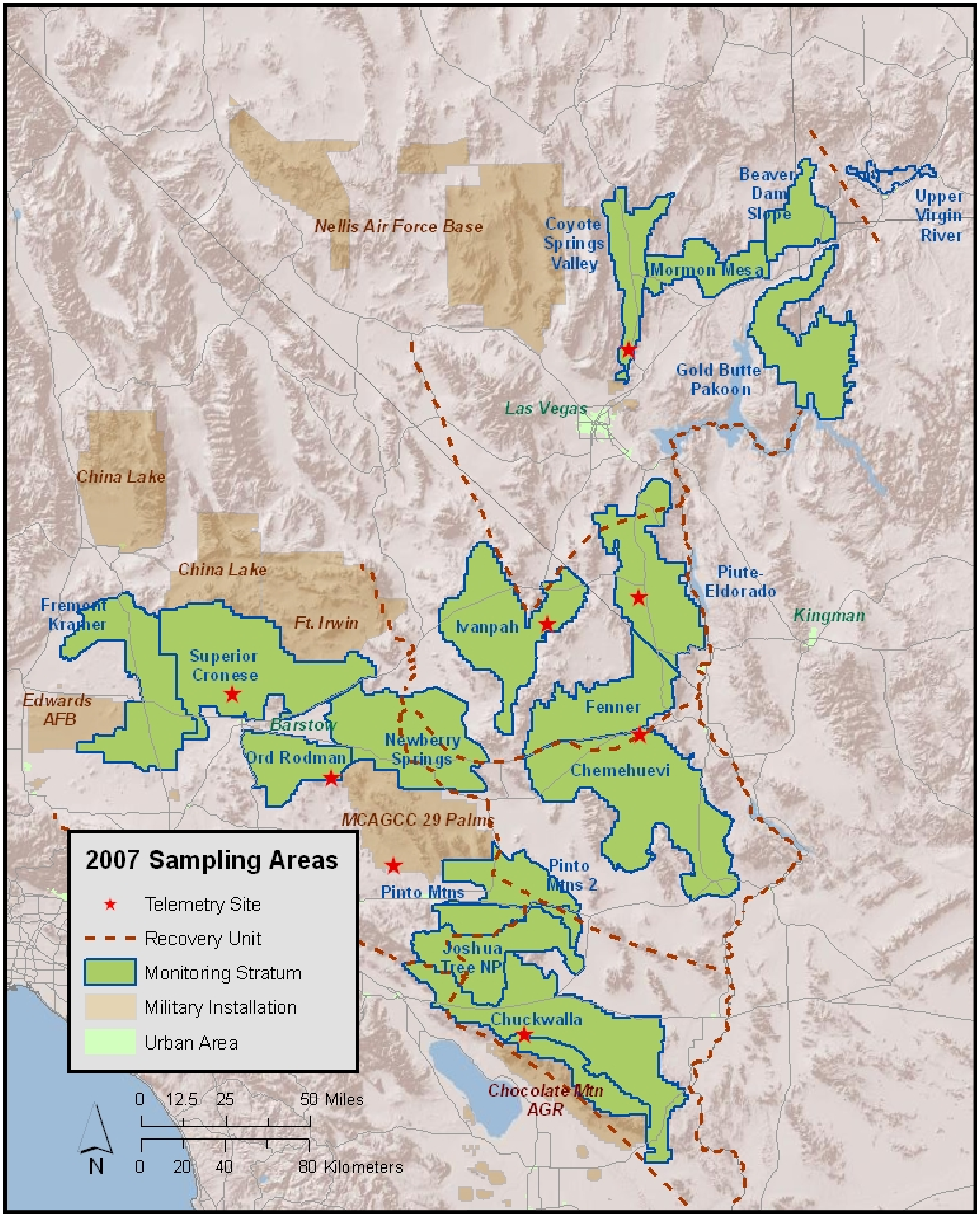

Figure 1. Range of tortoises in the Mojave population (USFWS 1994). Monitoring strata fall within recovery units. For 2007 only, the Newberry Springs and Pinto Mountains 2 strata were surveyed along with the long-term monitoring strata.

The optimal number of transects in a monitoring stratum was determined by evaluating how these samples would contribute to the precision of the annual density estimate for a given recovery unit. Anderson and Burnham (1996) prepared a power analysis to guide this sort of evaluation for the long-term desert tortoise monitoring project. The power to detect an increasing population size is a function of 1) the magnitude of the increasing trend, 2) the "background noise" against which the trend operates, and 3) the length of time the trend is followed (even a small annual population increase will result in a noticeably larger population size if the increase continues for many years). Using readily accessible software (TRENDS; Gerrodette, 1987), Anderson and Burnham (1996) considered a number of possible scenarios (Table 1).

Table 1. Scenarios explored in Anderson and Burnham (1996) and associated power for a one-tailed test.

Actual annual change in abundance	CV	α	Years between first and last survey	Years between consecutive surveys	Power
-0.12	0.15	0.15	4	1	0.78
-0.12	0.15	0.15	5	1	0.97
+0.02	0.15	0.15	25	1	1.00
+0.01	0.15	0.15	25	1	0.86
+0.02	0.35	0.15	25	1	0.72
+0.02	0.15	0.15	25	2	0.99
+0.02	0.15	0.15	25	3	0.92
+0.02	0.15	0.15	25	4	0.83

The magnitude of the population trend is a function of recovery activities and the population dynamics of the tortoise – neither of these elements are affected by monitoring design and sample size. The second contributor to the power to detect a trend – the level of background variability in the density estimates – is directly affected by the number, length, and placement of transects in the monitoring strata. Anderson and Burnham (1996) recommended that transect number and length be assigned to target precision reflected in a coefficient of variation (CV) of 10-15% for the estimate of importance. The CV describes the standard deviation (a measure of variability) as a proportion of the mean. It is often converted to a percentage. Since recovery criteria target trends within recovery units (USFWS, 1994), precision in that density estimate was the focus. The target CV is achieved based on the number of tortoises that might be encountered there (some strata currently have higher densities than others), as well as the area of the stratum – its proportional contribution to the recovery unit density estimate (Buckland et al., 2001).

The actual number of transects assigned in each stratum was a function of the optimal numbers described above, as well as on available funding. Even in cases where funding was not directly available from the associated land management agency, a smaller number of transects were nonetheless placed in each long-term monitoring stratum so that year-to-year recovery unit estimates would be based on the same monitoring areas. This approach to optimizing transect numbers in each stratum differed from that in previous years, when transects numbers were assigned in proportion to sample area, and strata without dedicated funding were not sampled.

Once the number of transects in a stratum was determined, these were laid out systematically across strata, with a random origin for the lattice that separated the transects. In strata with more transects, nested lattices with smaller spacing (3km) were used to ensure sufficient transects. In strata with fewer transects, lattices with wider spacing (9- or 27-km spacing) were used. Use of systematic placement provided more even coverage of the entire stratum, something that may not occur when a strictly random placement of transects is used. In both cases, transects are located at random with respect to the location of desert tortoises.

Systematic placement of transects was recommended by Anderson and Burnham (1996) but had not been used in previous years. In those years, strictly random placement of transects was adopted.

Field observer training

In 2007, two sets of field observers participated. Kiva Biological (Kiva) supplied crews for monitoring in California. Great Basin Institute (GBI) supplied crews for monitoring in Nevada, Arizona, and Utah. The former crew was composed almost entirely of teams with previous years of experience, whereas the latter crew had only one experienced member. The GBI crews were therefore provided with 2 weeks of preparatory training before a single week of joint training with the experienced Kiva crew (Table 2). The goal of the final (joint) week was to standardize the protocols used by crews range-wide. A single evaluation was given to each paired team, based on performance on a field arena outfitted with a high density of polystyrene tortoise models placed in measured locations (Anderson et al., 2001). Crews were evaluated on 1) ability to detect all tortoises within 1m of the centerline, 2) shape of the team's detection function indicating appropriate search technique, 3) leader detecting close to 80% of the tortoise models (related to above requirement for the pair to detect all tortoises on the centerline), and 4) ability to correctly report the distance of each model from the transect centerline.

In 2008, UNR was contracted through USFWS and Clark County, Nevada, to provide not only the specialized line distance sampling training, but also training to bridge the gap between a general biology education and the specialized skills needed for line distance sampling (March 12 to 22).

Table 2. Training schedule for 2007

Date[a]	Activity	Location[b]	Trainer(s)
Monday, 12 March	Tortoise handling in small groups Developing tortoise search image	DTCC	Marlow (UNR), Nussear (USGS), Medica (USGS)
Tuesday, 13 March	--		
Wednesday, 14 March	Compass and pacing exercise	LSTS	Marlow, Nussear, Medica
Thursday, 15 March	Practice transects (start with 400m, end with 12km)	LSTS	Marlow, Nussear, Medica
Friday, 16 March			
Monday, 19 March	Practice transects	LSTS	Kahn (GBI)
Tuesday, 20 March	Tortoise handling in small groups	Field station	Marlow, Medica
	Transect Methods Lecture (incl. data collection)	Field station	Kipke (NDOW)
Wednesday, 21 March	Practice transects – teams of 5, with electronic and paper data collection	LSTS	Medica, Kahn
Thursday, 22 March			
Monday, 26 March	Desert Tortoise Recovery & Monitoring Program	USGS	Allison (FWS)
	Introduction to Line Distance Sampling		Corn (USGS)
	Tortoise natural history		Woodman (Kiva)
	Electronic data collection forms		Heaton (UNR)
	Preparation for training lines		Corn
Tuesday, 27 March	Training Lines (evaluation, 8km) RDA data download	LSTS	Corn/Heaton
Wednesday, 28 March	Training Lines (evaluation, 8km) RDA data download	LSTS	Corn
Thursday 29 March	Practice transects (8km)	LSTS	
Friday, 30 March	Training line debriefing Quality control feedback on training data	USGS	Corn Heaton
Monday, 2 April	Training Lines (evaluation, 8km)	LSTS	

[a] The first two weeks were attended by inexperienced (GBI) field crews; the final week provided joint training for GBI and Kiva crews with previous experience at desert tortoise line distance sampling.

[b] Locations: DTCC=Desert Tortoise Conservation Center, Las Vegas; LSTS=Large Scale Translocation Site near Jean, NV; Field Station=facility maintained by UNR in Henderson, NV; USGS=USGS Henderson, NV facility

Proportion of tortoises detected at varying distances from the transect centerline
Polystyrene models of desert tortoises ("models") are placed on the training course using the same placement instructions (vegetation or open placement, distance along training line, and distance perpendicular from training line) each year. This course is used to determine whether 1) individual teams are able to detect all models on the transect center line, 2) whether their survey techniques yield useful detection functions, and 3) whether they can accurately report the distance of each model from the transect centerline. For each purpose, many opportunities must be provided, so the course is populated at a very high density of models (410/km^2).

Crews are sent on transects and training lines as paired, independent observers. That is, the follower is 25m behind the leader, with the opportunity to detect models not found by the leader. If the leader detects 80% of all tortoises that are found, the assumption is that the follower detects 80% of the tortoises that are missed by the leader. If this assumption is true, in this example, the pair together will detect 0.80 + (0.80 X (1 – 0.80)) = 0.96 of all tortoises on the center line. Because the location of all models is known, data from training lines can also be used to 1) assess the dual-observer assumption that all models are equally detectable (detections attributed to the follower occur at the same rate as original detection rate by leader), and 2) to estimate the detection rate using this technique for tortoises elsewhere in the Mojave Desert.

Tortoise encounter rate and development of detection functions
The number of tortoises seen in each stratum and their distances from the line are used to estimate the encounter rate (tortoises seen per kilometer walked), the detection rate (proportion of available tortoises that are detected out to a certain distance from the transect centerline), and their respective variances. Detection function estimation is "pooling robust" under most conditions (Buckland et al., 2001). This property holds as long as factors that cause variability in the curve shape are represented proportionately (Marques et al., 2007). Factors that can affect curve shape include vegetation that differentially obscures vision with distance, or different detection protocols used by individual crews. All crews in the California crew (Kiva in 2007) walked the same number of transects (days), and all crews in Nevada/Arizona/Utah (GBI in 2007) also had equal effort, but funding differences for the two associated parts of the tortoise range resulted in more transects per team (more effort) for GBI. For this reason, I estimated detection functions separately for GBI- and Kiva-monitored strata. The encounter rate is much less sensitive to small sample sizes, so it was estimated for each stratum separately.

I used Program DISTANCE, Version 5, Release 2 (Thomas et al., 2006) to fit appropriate detection functions, to estimate the encounter rate of tortoises in each stratum, and to calculate the associated variances. One record was created for each transect, with additional records for each additional tortoise on that transect. Analysis was only applied to live tortoises with midline carapace length (MCL) greater than 180mm. Transects were packaged into monitoring strata ("regions" in Program DISTANCE).

I truncated observations to improve model fit as judged by the simplicity (reasonableness) of the resulting detection function estimate (Buckland et al., 2001**.** Using truncated data, I used the Akaike Information Criterion (AIC) to compare detection-function models (uniform, half normal, and hazard-rate) and key function/series expansions (none, cosine, simple polynomial, hermite polynomial) recommended in Buckland et al. (2001).

Proportion of tortoises that are available for detection by line distance sampling, G_0

Not all tortoises in a population can be detected on 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 downward the density estimates derived from line distance sampling, but if the proportion of the population available for sampling can be estimated, then this parameter (G_0) can be used to correct the bias. Estimation of G_0 was conducted using focal tortoises in 10 sites located throughout the monitoring area (Fig. 1). At these telemetry sites, the focal animals are equipped with radio transmitters and observed daily while transects are sampled in the associated strata.

Each time a transmittered tortoise was observed, it was determined if the tortoise would have been visible to an observer conducting a line transect (yes or no). Through careful coordination, observers at telemetry sites monitored visibility during the same time period when field crews were walking transects. After visiting all of the focal animals one time, observers visited focal animals as many times as possible during the allotted time, recording visibility each time. Bootstrapped estimates of G_0 started by selecting one visibility record at random for each day that a tortoise was seen. The average visibility of all tortoise observations at a site on a given day was calculated and used to estimate the mean and variance of G_0 at that site. When there was more than one site in a given area, G_0 statistics were calculated for each G_0 group of sites as the grand mean of all G_0 sites in the group. One thousand bootstrap samples were generated in SPSS (release 16.0.2; SPSS, 2008) to estimate G_0 and its standard error.

Modification of previous procedures

Density estimates are based on 3 other estimates, each with their own variance. The total variance of density is the sum of the 3 components, so the relative importance of a particular component can be estimated by its contribution to the variance of the density estimate. In analyses before 2007 (USFWS, 2006), the standard error for the estimate of G_0 was calculated to be on the order of 0.002, contributing less than 2% of the total variance in density estimates.

During planning for the 2007 field season, errors were discovered in past calculations of both G_0 and its standard error. In the past, the standard error for a given year was incorrectly adjusted by the total number of tortoises tracked that year. In USFWS (2006), it was originally estimated as:

$$SE(G_0) = \sqrt{\frac{\mathrm{var}(G_0)}{n}}$$

Where *n* was the number of tortoises that were tracked during the 2-month period. However, the standard error for describing availability of the population for monitoring should be invariant to the number of tortoises used to estimate G_0. From 2001 through 2005, approximately 100 tortoises were tracked each year, so the correct standard error should have been about ten-fold greater than the reported estimate, decreasing the precision of the density estimate:

$$SE(G_0) = \sqrt{\mathrm{var}(G_0)}$$

Further, G_0 was originally computed as the mean of all tortoise observations over all days at all sites over the field season. Using this original approach, sites with more tortoises (and tortoises with more observations) are more influential in the estimate of global tortoise activity patterns, although these sites really only provide more information for transects in the same region. The approach implemented for this report instead gives each tortoise in a site equal weight and each site is given equal weight when calculating the local G_0.

After applying the correct calculation methods, I explored the effect of this decrease in precision for the standard error of G_0 on the density estimates that had been used in 2001 through 2005 (Appendix B), and determined that G_0 estimation now contributed about 60% of the variance in density. Daily variance within sites was the most important contributor to the total variance in G_0. This is not surprising, because over the 2-month field season, conditions such as temperatures and flowering plant availability are expected to change considerably, which should result in highly variable tortoise activity.

I used these assessments to change the sampling design in 2007 so that G_0 for a given set of transects would be estimated only at the nearest G_0 site(s), and transects in the area of one G_0 group would be completed in as short a time as possible. In past years, the sampling design was also sometimes set up to provide localized visibility estimates for transects in a given area, and sometimes these transects and the telemetry site were monitored intensively and completed in a small window of time. However, even when the nearby telemetry sites were monitored on the same days as the local transects were completed, these dates were usually spread over most of the field season, interspersed with visits to other monitoring strata and their telemetry sites. The design from 2001 to 2005 reflected the intention to estimate a single representative G_0 each year.

In the process of optimizing the analysis for 2007, I also recalculated density estimates for 2001 through 2005 using separate G_0 and SE(G_0) estimates based on transmittered tortoises observed in neighboring areas on the same dates that transects were walked. The use of standard deviation uncorrected for number of tortoises observed was expected to increase the coefficient of variation (CV) and decrease apparent precision, while the use of estimates reflecting a shorter activity period was expected to decrease CV and increase precision of the density estimate. The updated G_0 estimates, as well as stratum and recovery unit density estimates for 2001 through 2005 are provided in Appendix C. The changes from USFWS (2006) in reported density estimates for those first years of monitoring are reported in Appendix D.

Proportion of available tortoises detected on the transect centerline, *g(0)*

Transects were conducted by 2-person crews using the method adopted beginning in 2004 (USFWS, 2006). Transects were 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 movement off the transect center line, where attention is focused. Use of two observers allows “removal” type mark-recapture estimation of the proportion of tortoises detected on the line; this is a test of the assumption is that all tortoises on the transect centerline are recorded ($g(0) = 1$). The capture probability (p) for tortoises within increasing distances from the transect centerline was estimated as for a 2-pass removal estimator (White et al., 1982): p = (lead–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. The corresponding proportion detected on the line by two observers was estimated by $1 - q^2$, where $q = 1 - p$. Figure 2 graphs the relationship between the single-observer detection rate (p) and the dual-observer detection rate ($g(x)$). The guideline at $g(x) = 0.9$ represents an arbitrary standard for the proportion of these cryptic animals occurring right along the transect centerline that should be detected by each team. The actual proportion detected can be estimated and adjusted for, but the target should be at least 90%. The guideline intercepts the curve, indicating that the leader should be detecting at least 70% of all tortoises on the centerline in order to meet this standard. This is the basis for one of the training metrics (see Table 3).

Few or no tortoises are located exactly on the line, and even examining a small interval – 1m on each side of the transect line – results in few observations to precisely estimate *g(0)*. Instead, my test of the assumption involves examination of the *g(0)* estimate starting with larger intervals from the line, getting smaller and smaller. As the intervals get smaller, more observations are near the center line, so the estimates should converge on $g(0) = 1.0$.

If the test does not indicate that all tortoises were seen on the transect centerline, the variance of p can be estimated as the binomial variance = $q(1 + q)/np$ (White et al., 1982), where n = the estimated number of tortoises within 1 m of the transect centerline, and the variance of *g(0)* is estimated as twice the variance of p.

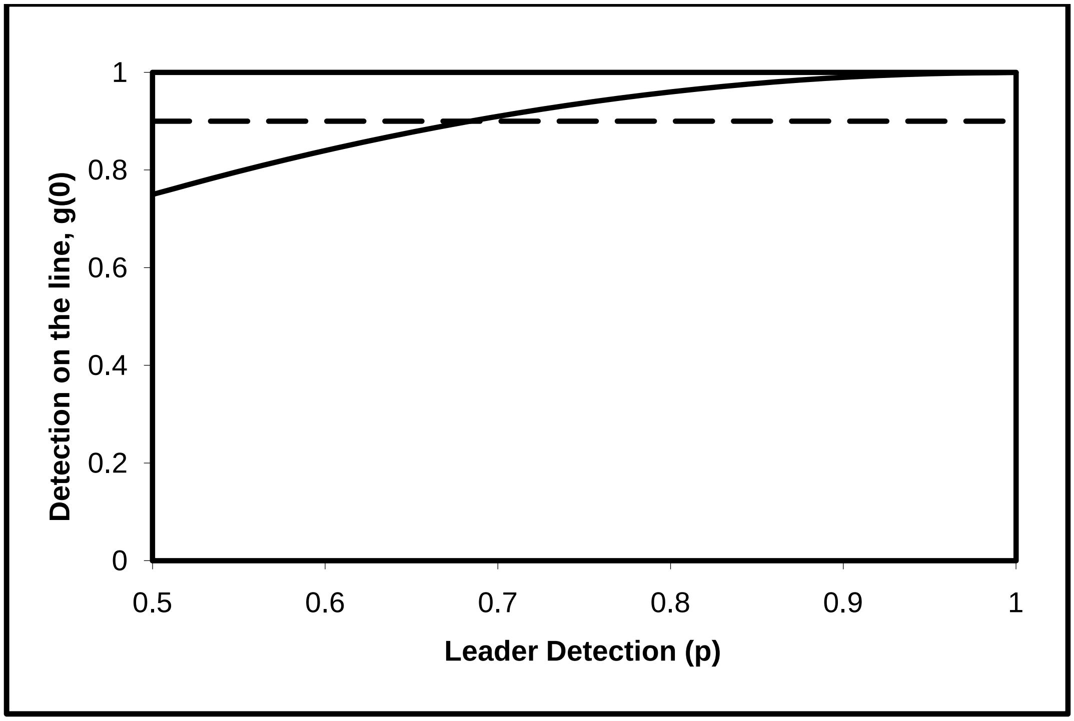

Figure 2. Relationship between single-observer detections (by the leader) and dual-observer (team) detections.

Estimates of tortoise density

Each year, the density of tortoises is estimated at the level of the recovery unit. The calculation of these densities starts with estimates of the density of tortoises in each stratum from Program DISTANCE, as well as their variance estimates:

$$D = \frac{n}{2wLP_a G_0 g(0)},$$

where L is the total length of kilometers walked in each stratum and w is the distance to which observations are truncated, so $2wL$ is the area searched in each stratum. This is a known quantity (not estimated). P_a is the proportion of desert tortoises detected within w meters of the transect centerline and was estimated using detection curves in Program DISTANCE. The encounter rate (n/L) and its variance were estimated in Program DISTANCE for each stratum. Calculation of D requires estimation of n/L, P_a, G_0, and $g(0)$. This means that the variance of D depends on the variance of these quantities as well.

For desert tortoise densities, the encounter rate (n/L) is estimated independently for each stratum ("unpooled"), whereas proportion of available tortoises and proportion of available tortoises detected on the transect center line are estimated jointly for all strata ($g(0)$) or for all strata in the recovery unit (G_0). The detection function, which comes into the above equation as P_a, may be estimated jointly or separately, depending on the number and quality of observations. In 2007, separate detection curves were created for each field team (GBI or Kiva), pooled across all strata surveyed by that team. A schematic of the process leading to density estimates is given in Fig. 3. Density estimates for each stratum result on the right by combining the parts from the left. These stratum-level estimates can be combined to generate recovery unit density estimates, although estimates from Newberry Springs and the additional Pinto Mountains strata are not part of the long-term monitoring project and are not used to develop annual recovery-unit-level density estimates.

Tortoise encounter rate	**Proportion that are visible, G_0**	**Detection rate, P_a**	**Proportion seen on the line, $g(0)$**	**Density**	**Density**
Stratum	*Neighboring G_0 sites*	*Data collection group*	*Overall*	*Stratum*	*Recovery unit*
AG	Chuckwalla	Kiva	Full set of tortoise observations	AG	Eastern Colorado
CK				CK	
JT	MCAGCC + Superior Cronese + Ord Rodman			JT	Western Mojave
PT				PT	
FK				FK	
OR				OR	
SC				SC	
PT2				PT2	
NS				NS	
CM	Chemehuevi + Ivanpah + Piute			CM	Northern Colorado
FE				FE	Eastern Mojave
IV				IV	
PI		GBI		PI	
BD	Coyote Springs			BD	Northeastern Mojave
CS				CS	
GB				GB	
MM				MM	

Figure 3. Process for developing density estimates in 2007. For each type of estimate needed, the full set of data was subdivided appropriately. Contributing estimates in the four left-hand columns are listed with the subsets of the data on which they are based. These estimates combined from left to right to generate stratum and recovery unit density estimates.

Whereas the number of tortoises in the set of strata representing a recovery unit can be simply added together, the variance must be arrived at by accounting for whether this involves pooled or unpooled estimates. As described above, three of the four estimates that contribute to calculating density in a stratum were based on data “pooled” from other strata as well, so when data from these strata are combined, the correlated nature of the variances has to be accounted for. Specifically, the method described in Buckland et al. (2001:89) was used to combine density variances correctly and arrive at the variance (and confidence intervals and CV) for the recovery unit. Pooled and unpooled variance estimates cannot currently be combined as needed in

Program DISTANCE, so final construction of density mean and variance estimates from the above components was completed without specialized software.

Modification of previous procedures

In previous analyses (USFWS, 2006), a single detection curve was developed for all tortoise observations range-wide. No estimate was made of the proportion of tortoises undetected on the line (*g(0)*), which was assumed to be negligible based on training data (USFWS, 2006:25) and use of the dual observer technique since 2004. A single G_0 was used, reflecting the fact that transects were completed over the entire season, so a single G_0 capturing all spatial and temporal variability was used. Finally, because stratum-level density estimates were not required, a single annual analysis was generated in Program DISTANCE, providing recovery-unit estimates of density.

To provide more appropriate detection curves (one each for GBI and Kiva), to correct density estimates using G_0 values that are more relevant to local conditions when transects were walked, and to provide stratum-level density estimates that must be correctly combined into density estimates for recovery units, the current analysis relies on Program DISTANCE for fewer steps of the process. This separation of the analysis from this software was called for in Tracy et al. (2004), and USFWS (2006) noted limitations of exclusive reliance on the software, recommending an unspecified change in procedures to allow refined analysis.

Debriefing to describe strengths and weaknesses of project preparation and execution

At the end of the field season, a debriefing meeting was held to review tasks and responsibilities, strengths and weaknesses of the program, and to plan for the next field season. Field crew members were surveyed prior to the end of the field season to identify areas to target for improvement. As a result, separate debriefings were held to address topics in data management and field season preparation.

RESULTS

Field observer training

Crew trials were conducted on 27 and 28 March (Table 2). Some first-year crews were rematched after testing to build more consistent teams and were given a further 8km trial before the field season. Figures 4 and 5 are for crews that were not rematched, and indicate well-shaped curves that nonetheless vary between crews. Strikingly different detection curves represent different detection probabilities (P_a). Detection curves that fall more rapidly after the first few meters generally indicate more appropriate search patterns, with more attention near the transect centerline. Distance sampling and development of a single detection curve from many observers is nonetheless robust to the effects of pooling these differences, as long as the observers contribute proportionally to the overall pattern (Marques et al., 2007).

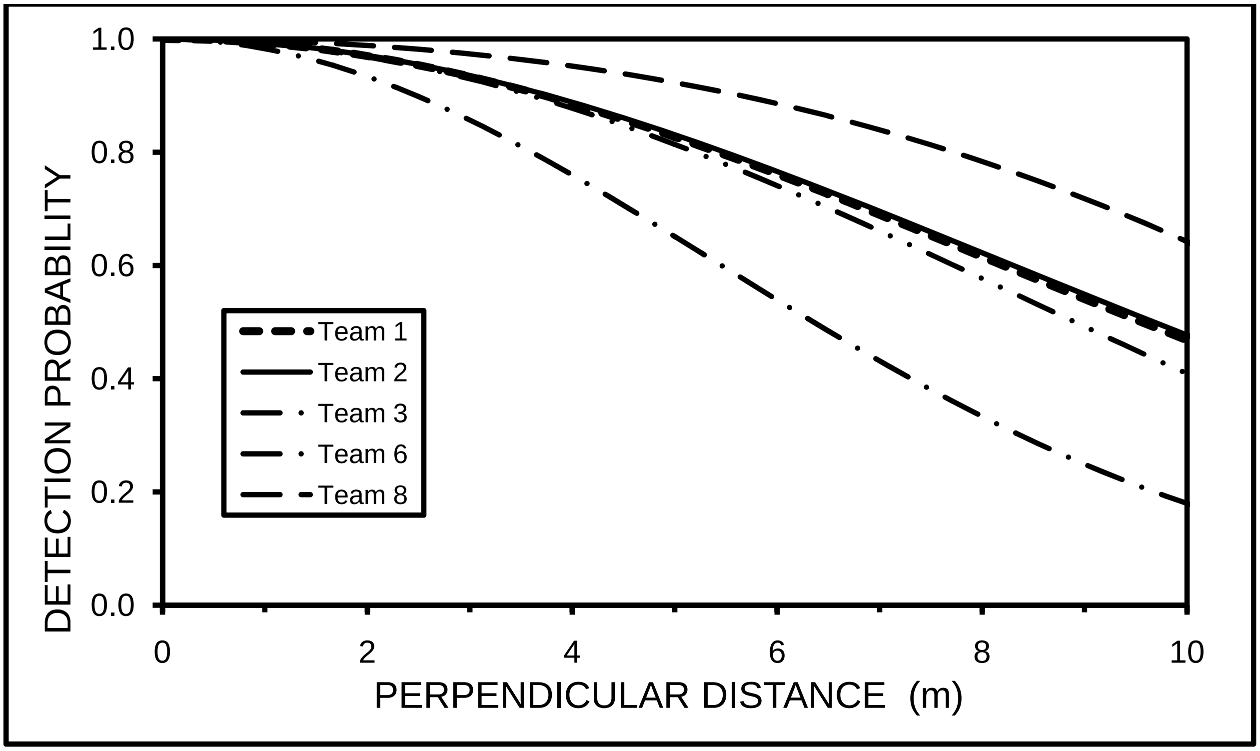

Figure 4. Detection curves for each of the 2007 trainee teams that returned after at least one year of monitoring experience. Curves are based on 16km trials.

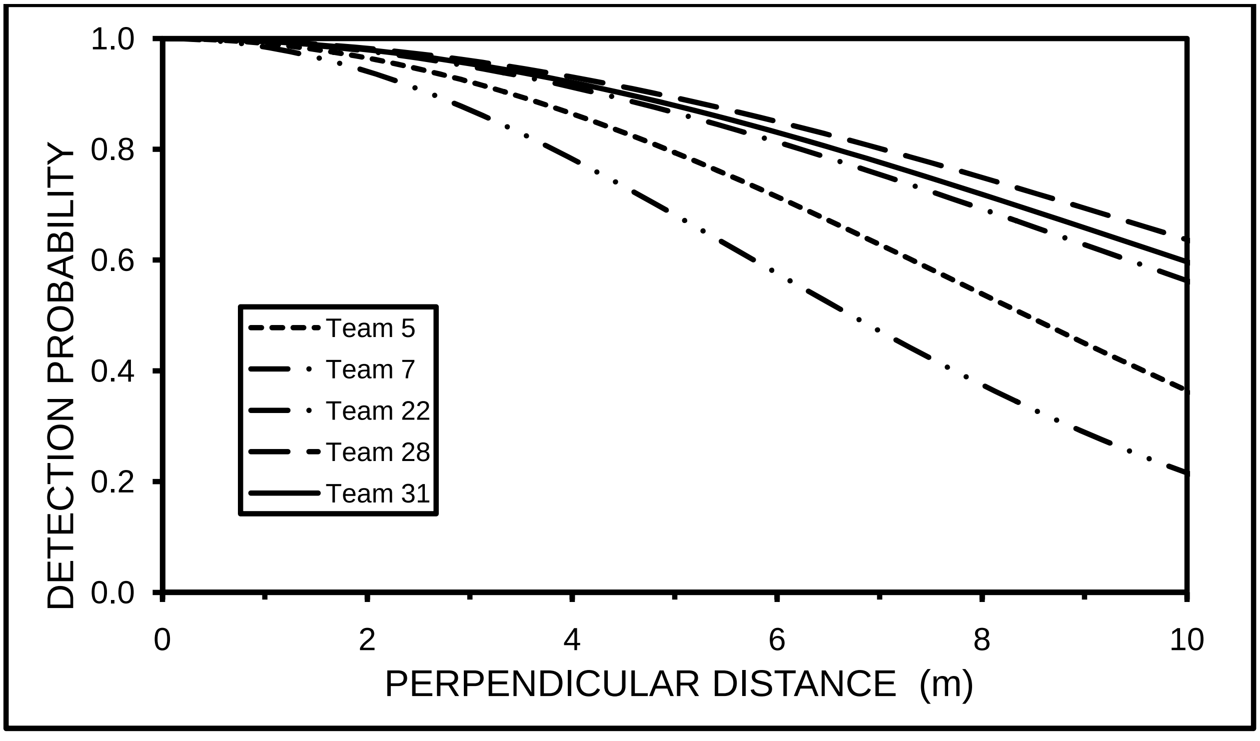

Figure 5. Detection curves for each of the 2007 first-year teams that were kept together throughout training. Curves are based on 16km trials.

Proportion of tortoises detected at varying distances from the transect centerline
Table 3 reports statistics for each team after collecting data on 16km on the evaluation lines. Measurement accuracy reported in Table 3 gives the average absolute difference between the expected and measured perpendicular distances from the model to the walked line. All measurements for all models during the 2-day trial are used for this estimate, and capture inaccuracies from 1) using a compass and measuring tape to record distances to the models, plus 2) inaccurately following the trajectory of the transect. The latter source of error does not occur on monitoring transects, because the walked transect is the true transect. On training lines, error in measurements is increased if crews do not walk on exactly the measured line that was used to place the models. The "Detected by Leader" column reports the proportion of all models found by crews that were found first by the leader. During training, this number is easily calculated and is used to identify crews in which one of the observers is not finding at least 80% of all detected

Table 3. Diagnostics for individual teams after training

Team	Detected by leader	Measured v. exact model distance (m)	Estimated abundance	95% confidence interval	
				Lower limit	Upper limit
1	0.79	0.82	415	345.2	499.4
2	0.77	0.81	398	331.7	477.4
3	0.81	1.03	485	406.5	578.8
4	0.76	0.97	359	268.3	479.1
5	0.87	1.09	386	307.9	483.9
6	0.82	0.74	394	319.4	484.9
7	0.83	0.91	415	317.3	542.9
8	0.95	0.82	410	317.6	528.7
21	0.67	1.66	320	259.4	395.4
22	0.79	1.18	314	263.6	374.4
23	0.64	0.97	312	264.1	369.7
24	0.68	1.21	442	334.2	584.5
25	0.71	1.29	296	234.7	373.3
26	0.70	1.55	445	239.0	827.0
27	0.70	1.39	316	259.6	385.3
28	0.73	2.61	389	314.8	479.6
29	0.79	0.91	401	301.4	534.8
30	0.81	0.93	282	206.9	385.4
31	0.79	1.01	386	313.5	476.2
32	0.62	1.78	269	218.8	331.1
Target	**>0.70**	**0**	**410**		
Returning crews	**0.83**	**0.84**	**420.3**		
First-year crews	**0.73**	**1.35**	**351.8**		
Overall	**0.76**	**1.18**	**371.7**		

models. With a 70% success rate for the leader, a 91% detection rate is expected for the team.After this training, in part on the basis of lower performance on detection at 1m and on "Detected by Leader," Teams 21, 23, 24, 25, 26, 27, 30, and 32 were split and new teams constructed. New teams are retested for a single day (instead of 2) to be sure they meet standards before beginning field work.

Table 4 reports the proportion of models that were available and were detected by each team at 1-, 2-, and 5-meters from the transect centerline. Teams were tested before and after the field season (pre- and post-season, respectively) and were given new team identification numbers for new pairings. Detection on the centerline was expected to be 100%, but with the returning crews

Table 4. Proportion of tortoise models detected within 1-, 2-, or 5-m of the transect center line.

	Pre-Season Detection Probabilities			Post-Season Detection Probabilities		
Team	1m	2m	5m	1m	2m	5m
1	1.00	0.84	0.84	0.67	0.75	0.75
2	0.90	0.92	0.84	0.50	0.73	0.70
3	0.90	0.88	0.90	0.67	0.75	0.72
4	0.91	0.84	0.79			
5	0.82	0.80	0.73	1.00	0.86	0.78
6	0.91	0.89	0.87	0.50	0.67	0.63
7	0.91	0.81	0.69			
8	0.82	0.77	0.71	0.67	0.75	0.66
21	1.00	0.75	0.64	0.57	0.64	0.59
22	0.69	0.79	0.68	0.25	0.36	0.50
23	0.83	0.74	0.66			
24	0.75	0.63	0.65			
25	0.75	0.62	0.63			
26	0.55	0.58	0.60			
27	0.90	0.73	0.77			
28	0.67	0.58	0.58			
29	0.82	0.83	0.77			
30	0.60	0.60	0.64			
31	0.64	0.65	0.72			
32	0.82	0.63	0.59			
33				0.75	0.36	0.41
34				0.60	0.50	0.55
35				1.00	0.77	0.70
36				1.00	0.67	0.55
Returning crews	**0.91**	**0.86**	**0.83**	**0.60**	**0.73**	**0.69**
First-year crews	**0.76**	**0.68**	**0.66**	**0.74**	**0.59**	**0.58**
Overall	**0.81**	**0.74**	**0.72**	**0.68**	**0.65**	**0.63**

averaged 91%. First-year trainees did not perform as well, and the overall average on the line was only 81% before the start of the field season. Overall averages in the final row of the table show lower detection rates after the field season than before. The basis for this is not clear, but similar results were seen in previous years. The preseason training lines are used to acclimate and evaluate teams on their overall search and detection pattern. If detection curves describing the field season effort indicate an appropriate search pattern, poor detection patterns while searching for models after the field season may reflect 1) lack of motivation, 2) acquired search pattern for live tortoises and their burrows, or 3) any number of other issues. Since the training lines with models bear only sufficient resemblance to field season transects, and the original purpose of these post-season detection curves is unclear, future effort will be directed at scrutinizing weekly data during the field season against troubling patterns rather than working on improving post-season polystyrene model detection.

Table 5 reports the observed detection rate within varying distances of the transect centerline, as well as the expected detection rate if tortoises detected by the leader and follower are seen with the same probability. Observed detection rates in the 6th column better match those in the 8th than in the 7th column, indicating that models that the first observer missed were also more likely to be missed by the second observer. Particular models were inherently more difficult to see, a violation of the assumption of equal detectability. This assumption is the basis for calculating the proportion of tortoises on the centerline that are detected during the field season, *g(0)* (see *Estimates of Tortoise Abundance*, below). The equivalent estimate on the training lines (the proportion of models within a meter of the centerline that were detected) is 0.81, but is not comparable to transect detections for many reasons. For instance, live tortoises are often detected in proximity to burrows, but no models are placed in burrows for training. The probability of detecting a burrow (leading to detection of tortoises) might also be different from the probability of detecting a tortoise on the surface, so the general concern that detection probabilities are likely to be heterogeneous will lead to future examination of factors that influence heterogeneous detection walking actual transects. These factors may affect detection on the surface as well as detection of burrows (Krzysik, 2002).

Table 5 also reports the proportion of models detected each year within 5m of the transect centerline by the leader only (column 5). This number is relatively consistent between years (mean=0.63, variance=0.011), and is one approximation of the proportion of tortoises that are expected to be found using a centerline-scanning approach to detect tortoises.

Table 5. Proportion of tortoise models that were detected by the leader (single-observer) or leader-follower team (dual-observer) following training, 2004-2007.

				Observed proportion detected		Expected proportion detected by the team[b]	
Within *x* m of centerline	Time period[a]	Year	# of Teams	Single observer (std. dev.)	Dual observer (std. dev.)	Under the assumption of equal detectability	If some models were more concealed than others[c]
1	Pre-field season	2004	20	0.63 (0.117)	0.74 (0.118)	0.86	0.74
		2005	24	0.82 (0.102)	0.90 (0.085)	0.97	0.89
		2007	20	0.72 (0.146)	0.81 (0.157)	0.92	0.81
1	Post-field season	2004	17	0.62 (0.219)	0.73 (0.216)	0.85	0.72
		2005	23	0.67 (0.181)	0.76 (0.164)	0.89	0.77
		2007	15	0.60 (0.219)	0.68 (0.220)	0.84	0.70
2	Pre-field season	2004	20	0.62 (0.110)	0.73 (0.104)	0.86	0.73
		2005	24	0.73 (0.100)	0.83 (0.085)	0.93	0.82
		2007	20	0.66 (0.140)	0.74 (0.111)	0.89	0.76
2	Post-field season	2004	17	0.62 (0.128)	0.74 (0.128)	0.86	0.73
		2005	23	0.60 (0.128)	0.7 (0.125)	0.84	0.71
		2007	15	0.56 (0.162)	0.61 (0.159)	0.80	0.67
5	Pre-field season	2004	20	0.60 (0.113)	0.73 (0.103)	0.84	0.71
		2005	24	0.67 (0.075)	0.79 (0.071)	0.89	0.77
		2007	20	0.60 (0.130)	0.72 (0.097)	0.84	0.71
5	Post-field season	2004	17	0.60 (0.136)	0.72 (0.144)	0.84	0.71
		2005	23	0.53 (0.112)	0.65 (0.101)	0.78	0.65
		2007	15	0.51 (0.129)	0.6 (0.117)	0.76	0.62

[a] Teams were tested immediately after training/before the field season, and then again after the field season.

[b] The proportion a team is expected to detect is based on the assumptions that the models are all equally detectable and the follower detects the same proportion as that leader. Based on the proportion seen by the leader (column 5), under the above assumptions, it is expected that a greater proportion of the models will be reported by the teams – note that column 7 is consistently higher than column 6. In the last column of this table, the proportion of models that are actually detectable was reduced until the expected proportion seen by the team closely matched the observed proportion (compare columns 6 and 8).

[c] The best fit between observed (column 6) and expected (column 8) occurred when it was assumed that 45% of the models overlooked by the leader were also undetectable by the follower.

Transect completion

Figures 6 through 9 show locations of transects and observations of live tortoises. Table 6 reports the number of assigned and completed transects in each stratum. The number completed in California closely approximated the planned (assigned) number (98% completion) and was purposely trimmed during the field season when all anticipated funds did not materialize. However, only 89% of transects assigned to the other field crew were completed. A small set of issues prevented completion of more transects by GBI.

The Union Pacific Railroad gated the primary access road through the center of the Mormon Mesa stratum. This action alone prevented access to 24 transects in that stratum. Identifying the shifting set of access routes characterized a larger issue for the GBI crews and was partially responsible for unwalked transects that were not in rugged terrain (last column of Table 6). The late initiation of their agreement precluded much logistic planning, and access routes were sometimes not found into parts of the monitoring strata.

The basic completion percentages do not describe the most important issue that remained to be addressed. Only a proportion of assigned transects could be completed in the planned way: a 12km square transect, 3km on a side (Table 6). Various obstacles affected transect completion. Some obstacles, such as uncrossable highways and private inholdings, could be addressed by "reflecting" the corner of the transect inward to avoid the obstacle (Buckland et al. 2001, Appendix A) or by elongating the transect in one direction. This modification was not expected to move the transect into a different landform, a change that would affect the probability of encountering tortoises on the transect. However, other obstacles were more difficult to address. The jurisdictional boundaries of the monitoring strata include terrain that may be navigable by tortoises, but is not safe for humans. However, if a transect is reflected around rugged terrain, keeping the transect in flatter topography, this is expected to impact the probability of encountering a tortoise.

From 2001 through 2003, planners for the monitoring project eliminated such areas from sampling, but each year saw changes to the filter they used, so the conclusions from the resulting data could not be compared between years or applied to the entire DWMA. In 2004 and 2005, the planners put transects out at random, but allowed field crews to "slide" transects away from such obstacles; however, this resulted in transects that were still not representative and in modifications that were not documented.

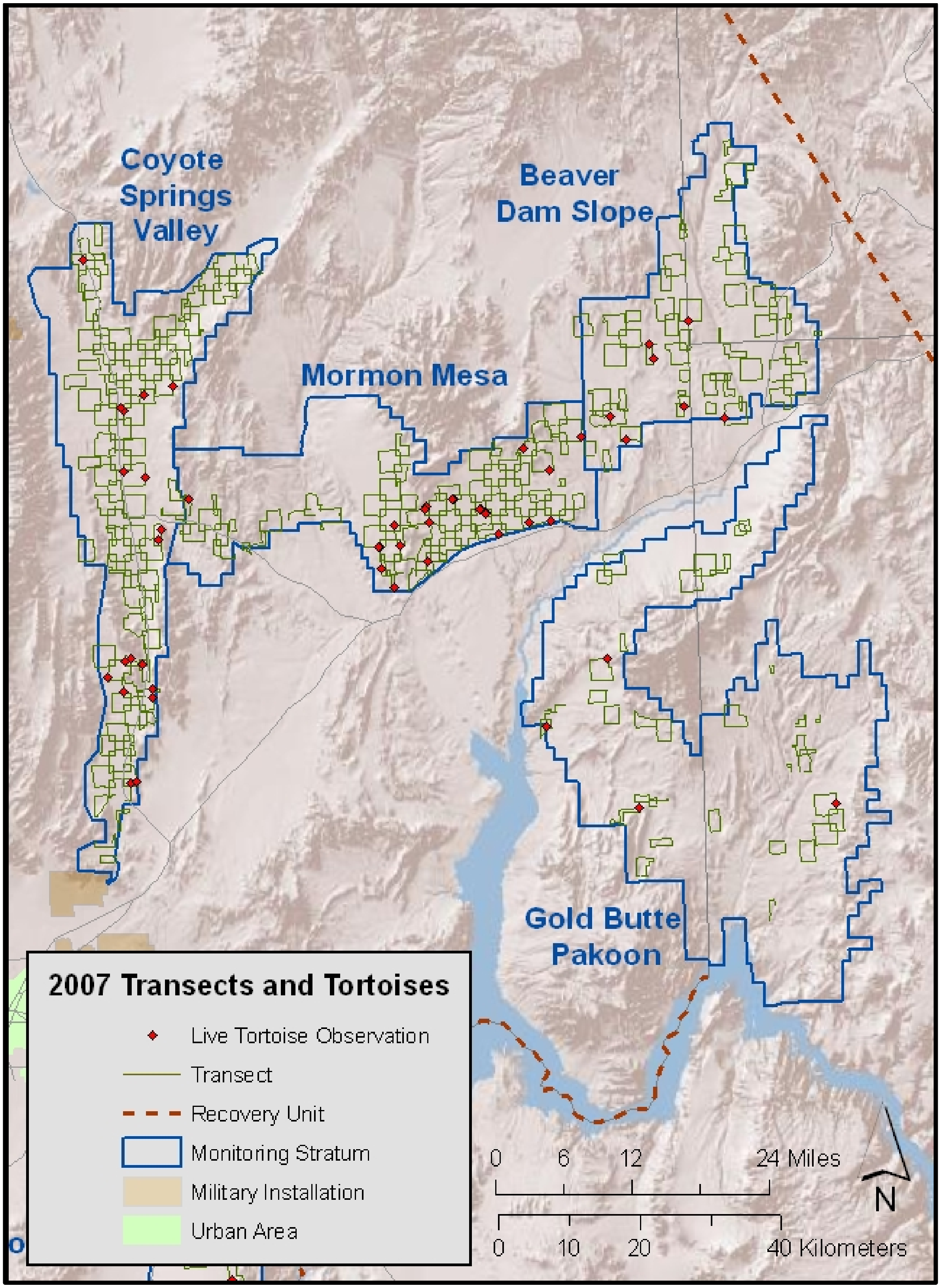

Figure 6. Distribution of distance sampling transects and live tortoise observations in the Coyote Springs Valley, Mormon Mesa, Beaver Dam Slope, and Gold Butte-Pakoon monitoring strata.

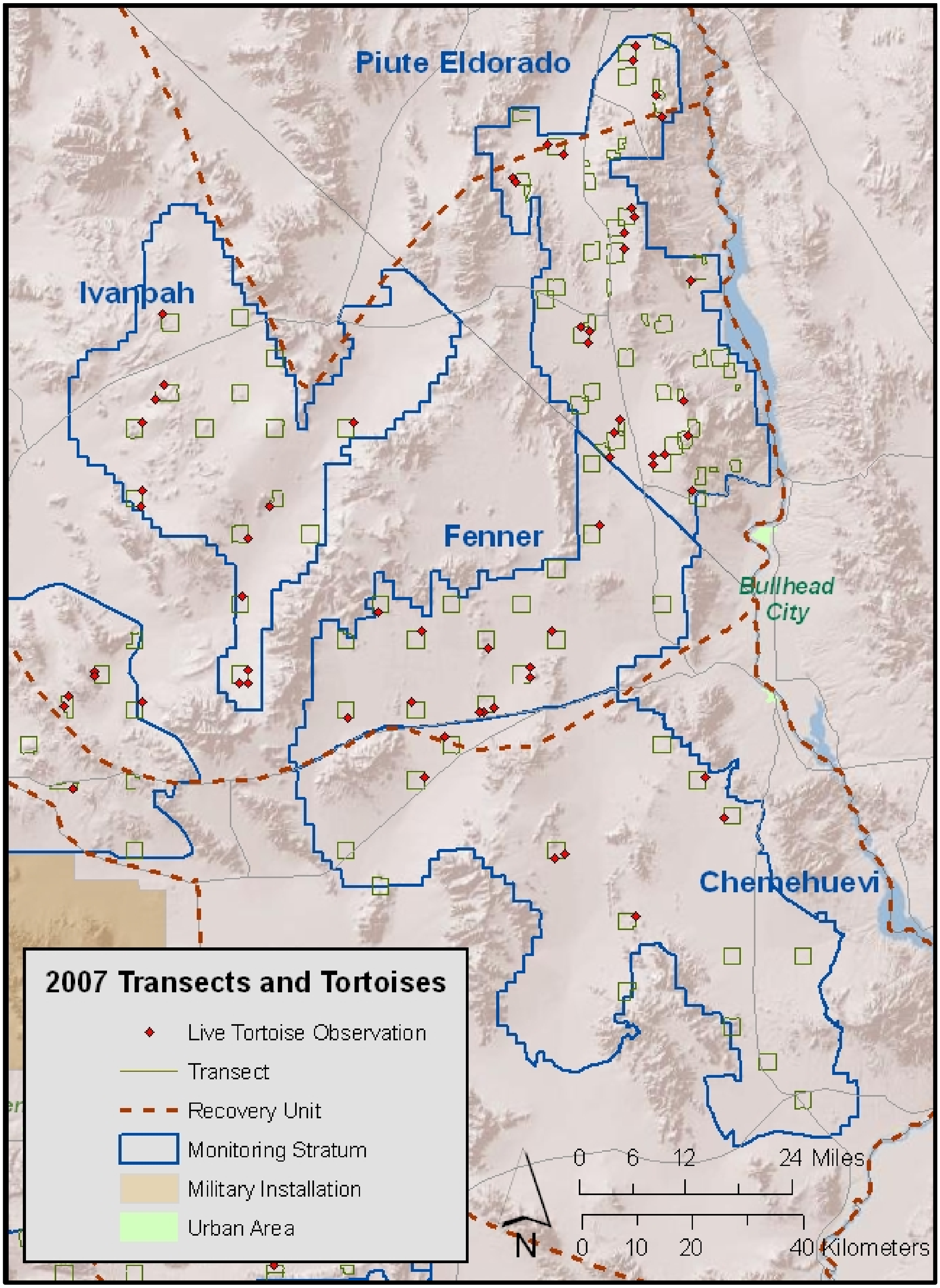

Figure 7. Distribution of distance sampling transects and live tortoise observations in the Piute-Eldorado Valleys, Ivanpah, Fenner, and Chemehuevi monitoring strata.

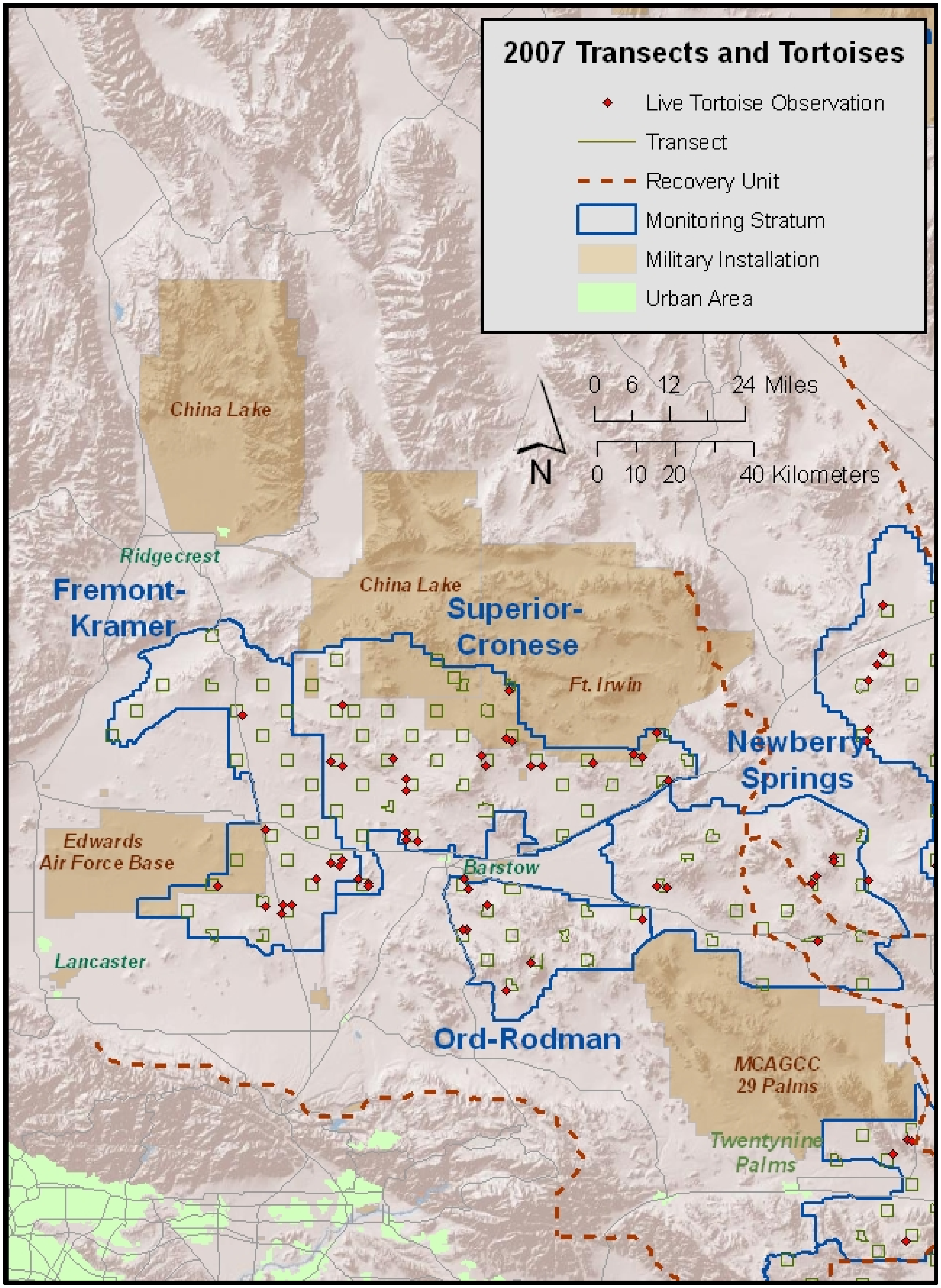

Figure 8. Distribution of distance sampling transects and live tortoise observations in the Fremont-Kramer, Superior-Cronese, Ord-Rodman, and Newberry Springs monitoring strata

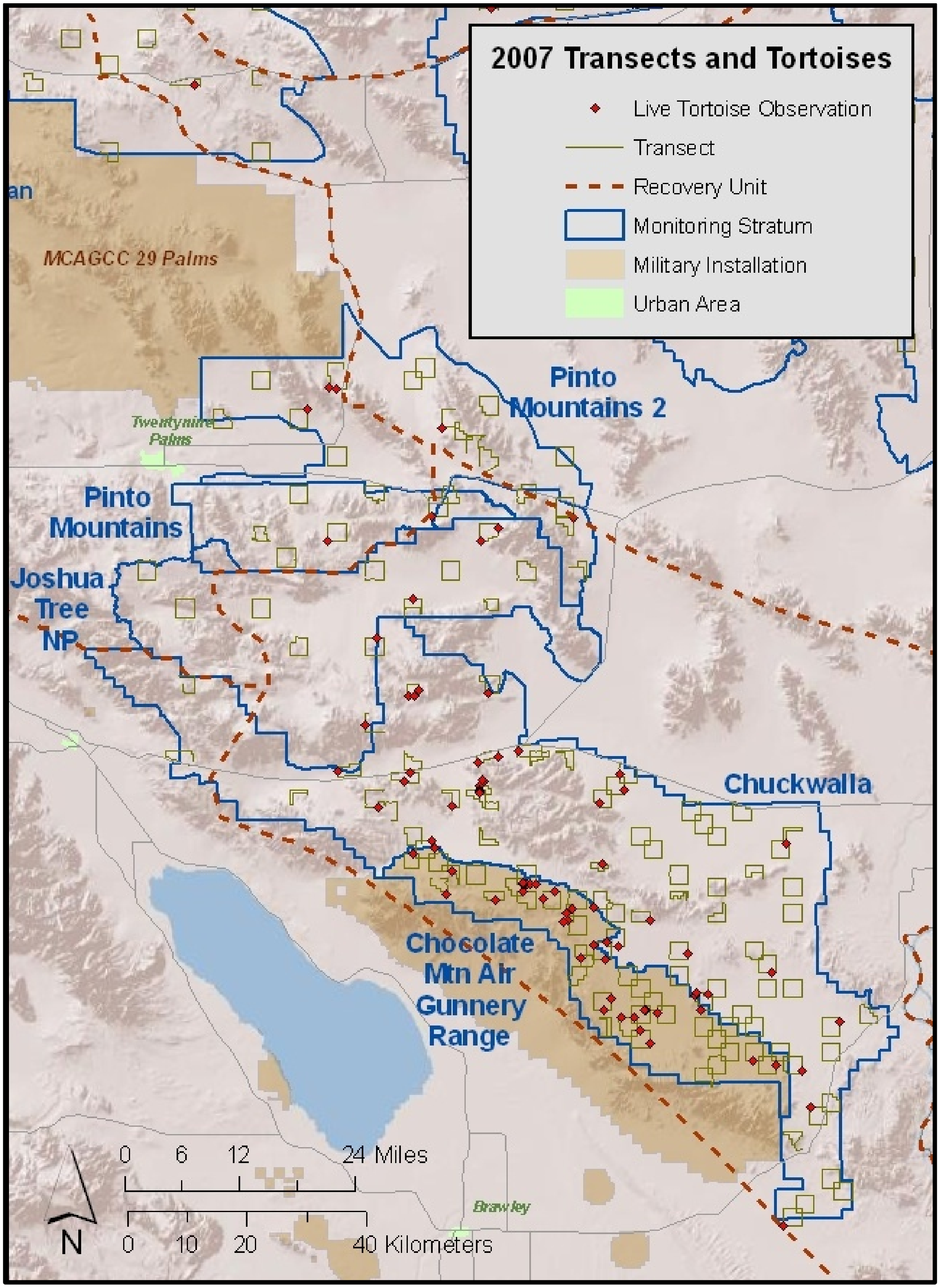

Figure 9. Distribution of distance sampling transects and live tortoise observations in the Pinto Mountains, Pinto Mountains 2, Joshua Tree National Park, Chuckwalla, and Chocolate Mountain AGR monitoring strata.

In 2007, crews were instructed to keep the transects centered in the assigned location, but to reflect as needed around obstacles. The expectation was that most of the rugged terrain would be sampled this way, and the transect locations would be representative, not purposefully in better areas for encountering tortoises. However, accommodation of rugged terrain resulted in modification of a high percentage of assigned transects (Table 6; average 32%, minimum 0%, maximum 60%), indicating that a more formal approach will be needed. Crews also applied variable interpretations of the guidelines for when and how to reflect transects. Although coverage in all strata was more even than in 2004 and 2005, when entire strata were also included in the sampling frame, these transects still oversample low-relief areas.

Table 6. Number and type of transects in each stratum.

Stratum	Assigned	Assigned and alternate transects completed*	Assigned, completed 12k square	Assigned, completed by reflecting around non-terrain obstacle	Assigned, completed by moving around terrain obstacle	Walkable assigned transects that were not walked*
AG	37	35	17	3	9	3
CK	68	65	23	6	24	0
BD	40	53	5	0	30	0
CS	99	88	28	2	44	15
GB	43	37	5	0	22	2
MM	93	62	17	6	31	11
PI	46	46	14	2	23	2
FE	15	15	10	1	0	4
IV	15	15	8	1	3	3
CM	15	15	12	0	0	1
FK	25	25	16	2	2	4
OR	12	12	3	4	3	0
SC	38	38	23	4	3	3
NS	15	15	2	2	7	0
JT	11	12	5	0	4	1
PT	12	11	4	0	4	0
PT2	13	13	6	0	5	0
Total	597	557				
Total in long-term strata	569	529				

*Assigned transects that were not walked were generally replaced by alternates.

Tortoise encounter rates and detection functions

Based on detection function behavior, all observations out to 12m (*w*) from the transect center line were used. Detection curves were estimated separately for each of the monitoring field teams (GBI and Kiva). For GBI (n=60), a uniform curve with simple cosine adjustment was selected; for Kiva (n=132), a uniform curve with second-order cosine adjustment was selected. Figures 10 and 11 are histograms of the observed number of tortoises seen at increasing distance from the transect centerline. These observations were used to model detection curves, overlaid in the same figures. The area below these curves is the proportion of tortoises that were detected out to 12m from the line, P_a. Based on these curves, GBI detected 61% of the visible tortoises within 12m of the centerline. The corresponding estimate of P_a for strata surveyed by Kiva was 0.49. Coincidently, estimates for both teams had the same CV(P_a)=0.086. No attempt was made to create detection functions for individual strata, where there were insufficient tortoise observations to develop detection histograms.

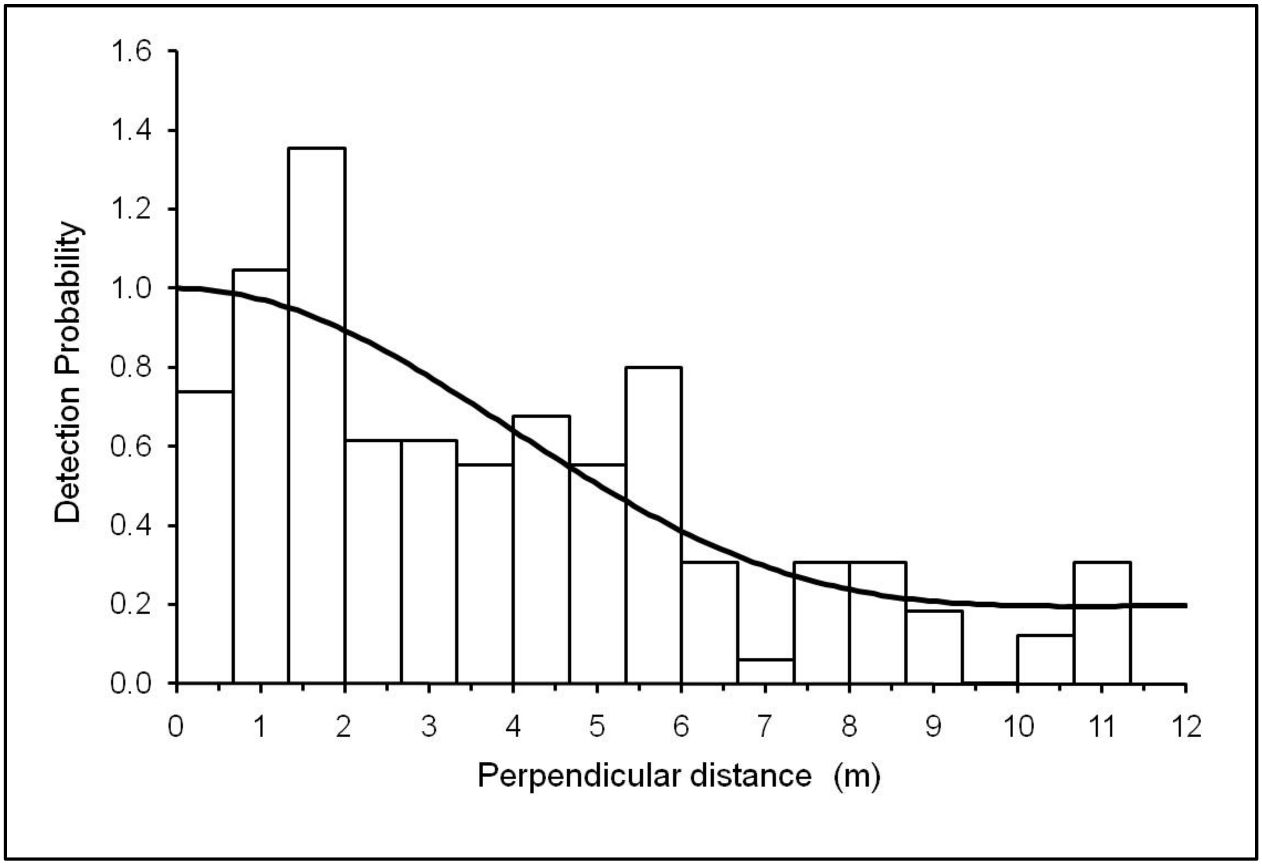

Figure 10. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by Kiva. Observations were truncated at 12m.

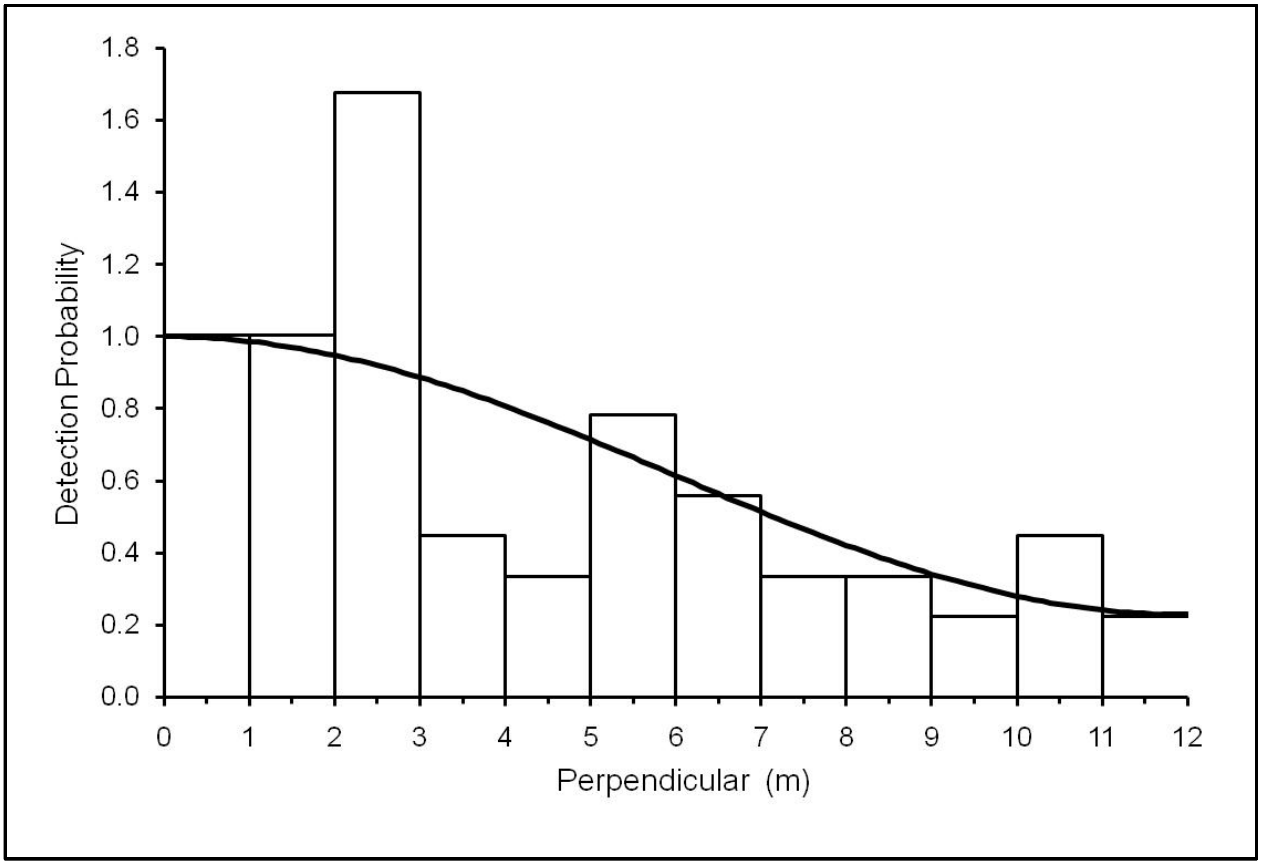

Figure 11. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by GBI. Observations were truncated at 12m.

Proportion of tortoises that are available for detection by line distance sampling, G_0

In general, telemetry sites and associated transects were completed sequentially, from south to north. This pattern corresponds to the expected timing of tortoise activity; activity should peak first in the south, later in the north. To match the scheduling of military operations on Chocolate Mountain Air Gunnery Range in Chuckwalla, the southern-most monitoring stratum, planning before the field season included a later start date for transects in the Chuckwalla stratum.

After the start of the field season, field crews changed their scheduling to 1) walk only the transects in the Pinto Mountains, Pinto Mountains 2, and Joshua Tree strata while tracking activity at the MCAGCC telemetry site, and 2) start walking transects in the Beaver Dam Slope stratum 20 days after initiating transects in other strata associated with the Coyote Springs telemetry site. These changes were addressed in the analysis by adding two more G_0 estimates to match the unique dates when Pinto Mountains, Pinto Mountains 2, Joshua Tree, and Beaver Dam Slope strata were walked. Dates, total days monitored, and G_0 estimates are given in Table 7.

Table 7. Availability of tortoises (G_0) during the period in 2007 when transects were walked in each group of neighboring strata.

G_0 sites	Strata	Dates	Days	G_0 (Std Error)
Piute, Chemehuevi, Ivanpah	Piute, Chemehuevi, Ivanpah, Fenner	1 – 9 April	9	0.79 (0.18)
MCAGCC	Joshua Tree, Pinto Mtns	6 – 11 April	6	0.97 (0.05)
Superior-Cronese, Ord-Rodman	Superior-Cronese, Ord-Rodman, Fremont-Kramer, Newberry Springs	13 – 26 April	14	0.80 (0.22)
Chuckwalla	Chuckwalla	28 April – 15 May	18	0.87 (0.06)
Coyote Springs	Coyote Springs, Mormon Mesa, Gold Butte	10 April – 30 May	51	0.79 (0.14)
Coyote Springs	Beaver Dam Slope	9 – 30 May	20	0.77 (0.17)

Proportion of available tortoises detected on the transect centerline, *g(0)*

Because they are cryptic, even tortoises that are visible (not covered by dense vegetation or out of sight in a burrow) may not be detected. 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, so that the probability of detection by single observer, $p = 0.708$, and the proportion detected using the dual observer method, $g(0) = 0.915$ (SE = 0.13). However, Fig. 12 shows that *g(0)* was converging on 1.0, indicating the assumption of perfect detection on the center line was met. No adjustment was made to the final density estimate. Because this assumption was not evaluated in USFWS (2006), Fig. 13 plots *g(0)* estimates for the three monitoring years since 2004, when the protocol was changed to use dual observers instead of the earlier 3-pass method to detect every tortoise on the transect. The curves support the premise that complete detection on the transect line was achieved for all years in which the dual-observer method was used. Note, however, that in 2005 and 2007, at 1m from the line the follower reported a higher proportion of detections than they did at either 0.5 or 1.5m from the line, resulting in a dip in the curve. The basis for this pattern is unclear.

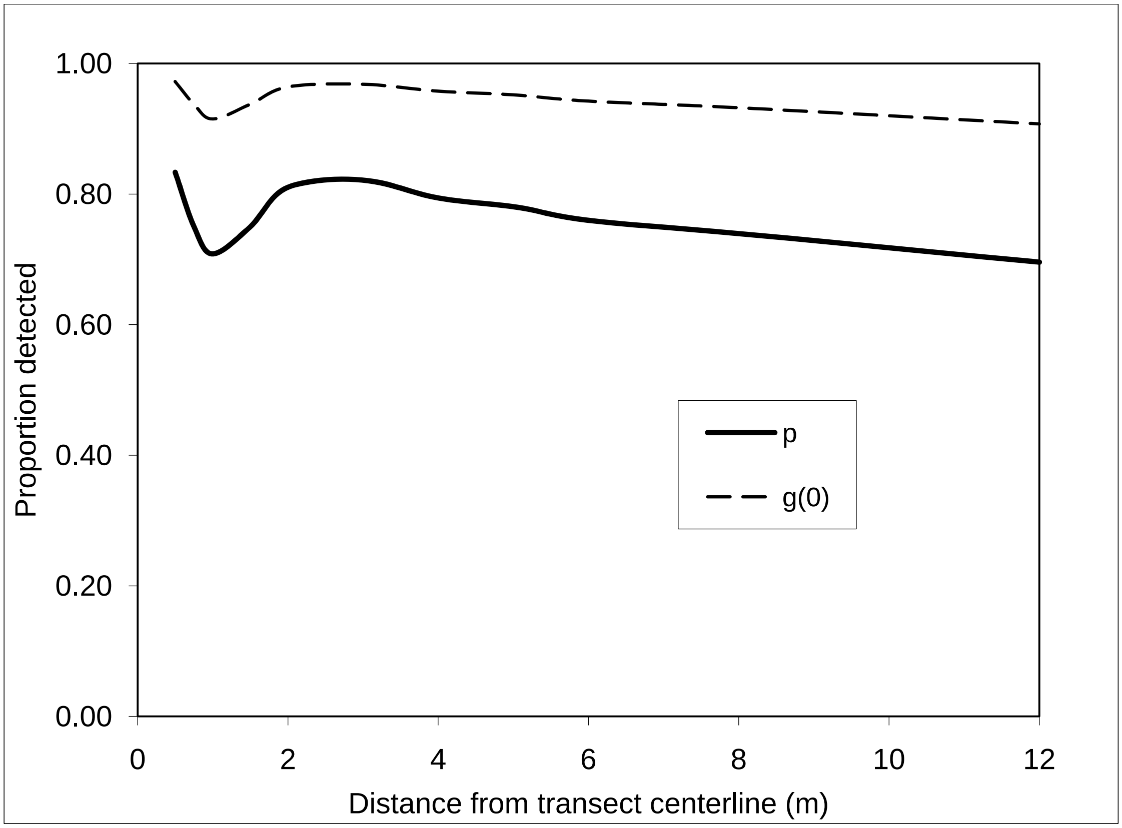

Figure 12. Behavior of detection on the line by the leader (*p*) and by the team (*g(0)*) based on all observations out to a given distance from the centerline in 2007. Note convergence of *g(0)* on 1.0 at the transect line (at distance=0).

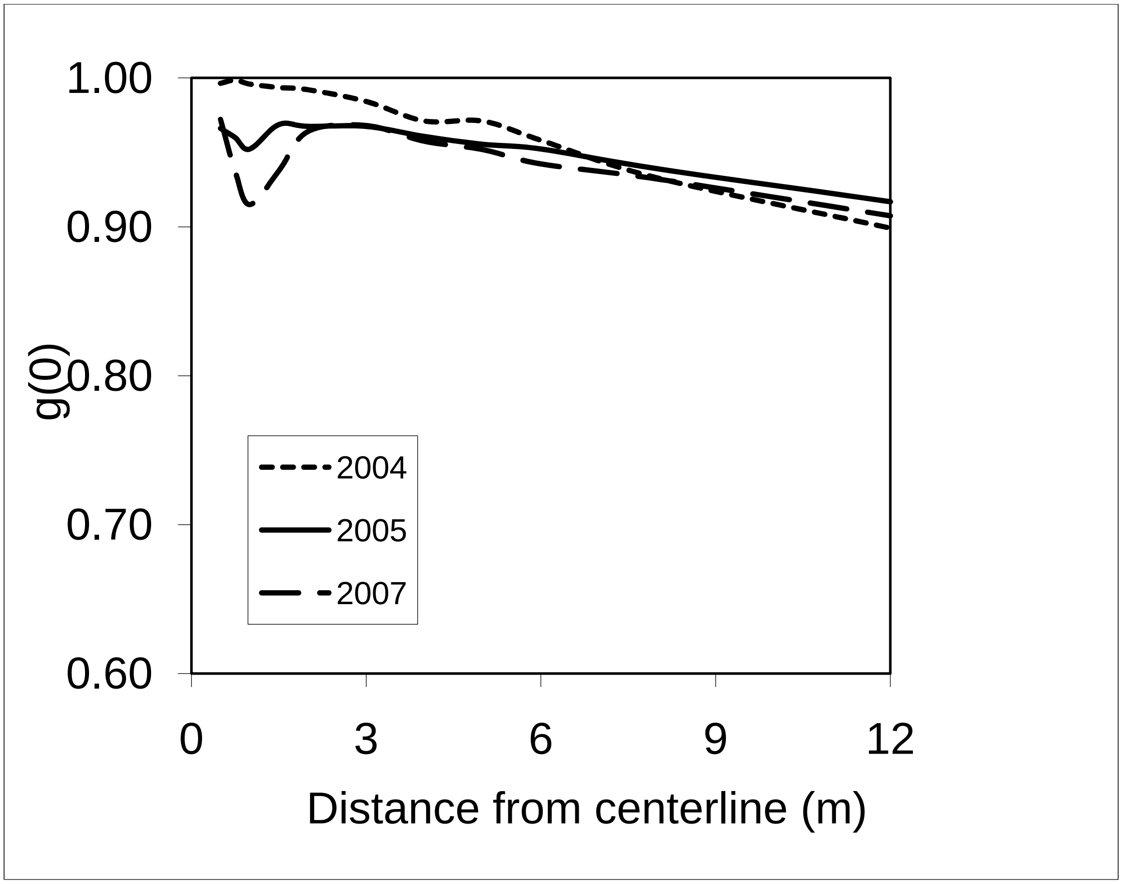

Figure 13. Estimates of *g(0)* based on smaller and smaller intervals of data around the transect centerline. The curves approach *g(0)* = 1 as the interval gets smaller. Curves are plotted for the 3 years when the dual-observer method was used.

Estimates of tortoise density

Density estimates were generated in DISTANCE separately for each monitoring stratum (Table 8). Stratum estimates were weighted by stratum area to arrive at average density in the monitored area of each recovery unit. Although encounter rates were estimated separately for each stratum, and have independent variances, the detection function and G_0 were estimated jointly (pooling data from multiple strata), so these variances are not independent (Figure 3 illustrated how estimates were pooled for 2007).

Recovery-unit-level density estimates are provided in Table 9. The final column indicates percent change from the updated density estimates for 2005 (Appendix D). In all recovery units, reported density is lower than in 2005. This might reflect true changes in population size, or might reflect the annual increases in the area of the sampling frame in each monitoring stratum; sampled areas have not been comparable from one year to the next. The only way to report comparable density or abundance statistics for years since 2001 will be to use model-based statistics, attempting to estimate density for unsampled areas (which are expected to have lower tortoise densities) based on sampled areas with similar characteristics (for instance,

Table 8. Recovery unit and stratum-level encounters and densities in 2007 for tortoises with MCL ≥ 180mm

Recovery Unit	Sampling Area		Area (km^2)	Number of Transects	Total Transect Length (km)	Sampling Dates		Field Observers	*n* (tortoises observed)	CV(*n*)	Density (/km)	CV(Density)
						Begin	End					
Northeastern Mojave			**4917**	**240**	**2316.1**	**10-Apr**	**30-May**		**46**		**1.7**	**25.0**
	Beaver Dam Slope	BD	828	53	478.0	9-May	30-May	GBI	6	46.8	1.2	53.2
	Coyote Springs	CS	1144	88	917.9	10-Apr	25-May	GBI	14	27.9	1.4	35.1
	Gold Butte-Pakoon	GB	1977	37	299.7	17-Apr	29-May	GBI	4	43.3	1.2	48.2
	Mormon Mesa	MM	968	62	620.5	10-Apr	25-May	GBI	22	22.8	3.3	31.2
Eastern Mojave			**6681**	**76**	**803.9**	**1-Apr**	**9-Apr**		**40**		**5.8**	**25.0**
	Fenner	FE	1862	15	178.2	1-Apr	6-Apr	Kiva	10	29.0	6.6	39.2
	Ivanpah	IV	2567	15	180.1	1-Apr	6-Apr	Kiva	10	23.9	6.5	35.6
	Piute-Eldorado	PI	2252	46	445.6	2-Apr	9-Apr	GBI	20	24.6	4.2	36.1
Eastern Colorado			**4263**	**100**	**1151.7**	**28-Apr**	**15-May**		**59**		**5.0**	**22.6**
	Chocolate Mtn AGR	AG	755	35	404.3	1-May	11-May	Kiva	27	21.2	7.1	25.3
	Chuckwalla	CK	3509	65	747.4	28-Apr	15-May	Kiva	32	25.4	4.5	29.0
Northern Colorado			**4038**	**15**	**180.0**	**1-Apr**	**6-Apr**		**7**		**4.6**	**43.4**
	Chemehuevi	CM	4038	15	180.0	1-Apr	6-Apr	Kiva	7	35.4	4.6	43.4
Western Mojave			**9298**	**97**	**1150.6**	**6-Apr**	**26-Apr**		**49**		**4.7**	**30.8**
	Fremont-Kramer	FK	2463	25	299.9	13-Apr	26-Apr	Kiva	7	38.7	2.7	49.3
	Joshua Tree NP	JT	1655	12	134.9	7-Apr	10-Apr	Kiva	4	58.8	2.8	60.2
	Newberry Springs*	NS	2682	15	172.2	16-Apr	22-Apr	Kiva	5	54.5	3.4	62.4
	Ord-Rodman	OR	1124	12	140.9	13-Apr	25-Apr	Kiva	10	35.3	8.2	46.7
	Pinto Mountains	PT	608	10	119.4	6-Apr	11-Apr	Kiva	3	50.7	2.4	52.4
	Pinto Mountains 2*	PT2	1113	14	161.4	6-Apr	11-Apr	Kiva	4	58.1	2.4	59.5
	Superior-Cronese	SC	3447	38	455.5	13-Apr	25-Apr	Kiva	25	25.1	6.3	39.6

* These strata are not part of long-term monitoring and were not included in recovery-unit summary rows.

elevation and/or vegetation type). This will be a more productive exercise once the draft Recovery Plan (USFWS, 2008) is finalized and recovery units with associated tortoise conservation areas have been confirmed.

The Northern Colorado Recovery Unit was under-sampled in 2007, reflected in the low precision (high CV) in Table 9. The low precision means that high between-year fluctuations in estimates are to be expected. Finally, the apparent population decrease in the Upper Virgin River Recovery Unit was described in McLuckie et al. (2008) as continuation of a pattern since 2003 of increased mortality from wildfires, disease, drought, and habitat degradation.

Table 9. Estimated density of desert tortoises in monitored areas of each recovery unit in the Mojave Desert in 2007.

Recovery Unit	Monitored area (km^2)	Transects	Tortoises detected	Density (/km^2)	SE(Density)	%CV (Density)	% change from 2005[b]
Eastern Colorado	4263	100	59	5.0	1.13	22.63	-37
Eastern Mojave	6681	76	40	5.8	1.44	24.98	-20
Northeastern Mojave	4089	240	46	1.7	0.42	25.03	-9
Northern Colorado	4038	15	7	4.6	1.98	43.36	-58
Western Mojave	9298	97	49	4.7	1.45	30.77	-23
Upper Virgin River[a]	114	157	92	14.9	2.04	13.70	-32

[a] Data for Upper Virgin River taken from McLuckie et al. 2008.

[b] A decrease in reported tortoise densities was expected in 2007 as a simple result of placing transects throughout monitoring areas. In past years, including 2005, field crews completed surveys in areas of lower topography and in areas generally expected to have more tortoises. As indicated in the text, the shifting sampling frame will have to be addressed before interpreting any apparent "trends."

Appendix D provides density estimates for each recovery unit in the years 2001 through 2005. In addition to the original estimates (USFWS, 2006), the table reports densities using the updated analysis approaches initiated in 2007. It should be expected that the recalculated density estimates would be less precise once the incorrect calculation of G_0 was addressed. In addition, there is considerable variability (in the original and recalculated estimates) from year to year in the same recovery unit. For instance, in the Western Mojave the [revised] estimate is 4.4 tortoises/km^2 in 2004, up 30% to 6.1 in 2005, then down 25% to 4.7 tortoises/km^2 in 2007. This does not reflect realistic changes in population size in such a large area over one-year periods, but it is a consequence of the relatively imprecise annual estimates. When the annual estimates are imprecise, it should not be expected that there will be a close match from one year to the next. Over a period of many years, however, any underlying trend in the number of tortoises should be obvious through this "background noise."

Debriefing to identify strengths and weaknesses in preparation for future years

In previous years, planning did not include participation by field crews. This was also the case for 2007. However, it became apparent during the field season that this input would be necessary to address problems in training and data systems. My field visits with both of the groups providing field crews made it clear there were various ways that protocol and field season planning could be improved. As a result, two post-season debriefing meetings were held (one each for data management and field season preparation) to include representatives from all groups responsible for creating as well as using products. Field crew members were surveyed prior to the end of the field season to identify areas to target for improvement; although most crew members had finished their contracts and left before the debriefing meeting, survey results were provided to meeting participants, and some crew representatives were present. The meetings also included participants with data management (collection database development, QAQC I and II) and training responsibilities.

Study design

Because G_0 contributes the largest variance to density estimates, for 2008, it will be important to make more explicit connections between G_0 site data and information collected on transects. This involves more data collection to characterize visibility using transect protocols and visibility after tortoises are located using radiotelemetry. This additional data should clarify how detection in burrows and on the surface may differ based on the two ways to describe detectability (visual detection on transects compared to detection that also includes radio receivers).

Fewer alternate transects should be walked, with more emphasis on walking assigned transects. In 2007, alternate transects were used for some transects because the planned transects could not be accessed; this issue can often be overcome with funding for earlier planning. Other transects were walked, but the full 12km was not completed. Rules for alternative navigation of transects in rugged terrain were not written and distributed for 2007 until the field season had started, after requested by field crews. In future years, these guidelines will be part of start-up contract meetings and will be a subject of specialized training.

Training

Training for each year of the monitoring project, including 2007, has been developed around refining the search procedures of crews in California that were already proficient at finding desert tortoises using other techniques, and for training inexperienced student interns for monitoring the rest of the range. These inexperienced crews had been trained separately to acclimate to the desert and handle tortoises. The official training week itself served as the time when any protocol changes were introduced and when crews were tested for ability to detect fabricated tortoise models to give the correct detection curve.

As a result of the 2007 field season debriefing, a goal for 2008 was to use the training program to further standardize and consolidate the range-wide monitoring program. A specific objective was to develop a training program that frees the project from the constraints of using only experienced crews in California and relying on student crews in Nevada. This would also strengthen the monitoring program by severing its reliance on contracted crews with previous experience. The training program should be usable by inexperienced crew members from California as well, and experienced crew members from all contracted field teams should be involved in training on sampling techniques.

Standardization would also require a more comprehensive training program, with formal goals and objectives, and a monitoring handbook that could serve as reference for crews during the field season. At the debriefing meetings and subsequent communications, the following modules were identified. They were put into development by UNR for the 2008 field season (Table 10).

Table 10. Training modules to have objectives, standards, and metrics developed for 2008

Training module	Offered in 2007?*
Tortoise handling	Informally
Line distance sampling theory	Yes
Navigation – GPS and compass	Informally
Navigation on public lands	No
Implementation of line distance sampling techniques	Informally
RDA/Bluetooth GPS	Yes
Radio telemetry	Informally
Field contractor QAQC	Yes
Data collection	Informally

*"Informally" refers to training without written material, expressed objectives for training, and availability to all inexperienced crews.

"Yes" implies some written material, consequent opportunity for standardization across crews, and availability to inexperienced crews.

Field data collection

- Future field seasons should reflect more similar responsibilities between all field teams for providing their own logistical and material support. Some electronic equipment will be provided by the USFWS to all field crews, and equipment that does not require standardization will be the responsibility of the contracted teams. This will represent a change in the eastern part of the range in particular, where monitoring crews worked directly under UNR, which also had a strong leadership role in the range-wide effort.
- Database transfer procedures have been changed so that field crews can stay overnight in the field without data backup, and a laptop computer will travel in the field for collecting data from separate RDAs. This will increase logistical options for completing transects in remote areas.
- Transects that were not completed due to rugged terrain will have improved completion records once protocols for rugged terrain are in place.
- The same set of transects will form the core of sampling for 2008 as for 2007. Using information collected on transects in 2007, planning for transect access could start in the fall before the next spring field season, which will improve the transect completion record (see above *Study Design* improvements). It is clear that some transects have

accessibility issues, which can be planned for through coordination with local land managers. The USFWS has requested/invited increased land management agency representation at monitoring coordination meetings. One benefit will be updating maps and access information for future field seasons.

Data management

- A team was created at the debriefing meeting on 6 June 2007. This team began active coordination to provide materials for improved database design, for more extensive and targeted error-checking scripts, and to test the prototype collection database for 2008.
- Early development of the database was identified as an important part of training development. This development includes drafting a data dictionary that clarifies fields in the data forms and identifies those that require further instruction during training in order to reduce errors.
- To provide clarity and improve coordination between contractors involved in different stages of data handling, a data management plan will be in place in January before each field season. This is sufficient for all parties to be prepared for their responsibilities in the three stages of quality control.

Coordination, tasks and timelines

- Continue the open evaluation procedure by inviting field crews to debriefing meetings.
- Use agreements, planning meetings, and training to standardize monitoring range-wide.
- Restructure coordination meetings away from advisory functions to reporting and collaboration functions
- Move new functions to the oversight of the USFWS. In 2008 and subsequent years, USFWS will have a larger role in training, weekly field season oversight, and in data management.

When planning for the 2007 field season started in 2006, a proposed annual schedule had been developed based on the collective experience of UNR, MDEP, and Topoworks cooperators. This schedule was designed around data quality control needs. It served as the starting point for 2007 planning, although funding availability was one source of deviation from the schedule. After the debriefing meetings, at which the assembled groups developed timelines for completion of 2008 planning tasks, an updated schedule was developed.

Table 11 lists the tasks, the timeline proposed in 2006 for the 2007 field season, the timeline implemented in 2007, and the timeline recommended for 2008. Some times have shifted considerably, and unanticipated tasks have been added, primarily as a result of input from field monitors to this process.

Table 11. Planned and actual timelines for desert tortoise monitoring in 2007 and planned completion dates for the 2008 field season.

Activity	Product	2007 Planned Date*	2007 Actual Date*	2008 Planned Date*
Previous field season debriefings	Improvement activities and timelines	22-Oct	15-Jun	30-Jun
Coordination meeting	Updated timelines	15-Nov		20-Aug
Identify changes in data needs	Final database fields		1-Apr	1-Sep
Identify number of transects required	Number of transects required for each stratum	20-Oct	1-Nov	20-Oct
Develop collection database	Digital data form	15-Dec	25-Mar	1-Dec
Generate survey strata and transects	GIS shapefiles of monitoring strata and transect start points	15-Nov	15-Mar	15-Dec
Outline data processing steps	Final 2008 QA/QC Plan	28-Feb	25-Mar	1-Jan
Develop training program	Final Training Handbook	1-Apr	25-Mar	1-Jan
Develop and present budgets	Agency budget commitments	2-Jan	2-Jan	2-Jan
Develop collection QA/QC database	Digital database	15-Jan	25-Mar	15-Jan
Access coordination	Updated access information			15-Jan
Coordination meeting	Final coordination meeting	15-Feb	15-Dec	15-Jan
Develop and award contracts	Field crew contracts in place	30-Jan	1-Mar	30-Jan
Submit research permit requests	Federal and state permits	1-Nov	15-Feb	31-Jan
Develop maps for field crews	Paper maps for each stratum	15-Feb	15-Apr	1-Feb
Develop and coordinate	Training course preparations	15-Mar		1-Feb
Plan transect access	Transect completion strategy	28-Feb		28-Feb
Test contractor database	Final database & data forms	15-Feb	1-Apr	15-Mar
List of Authorized Individuals	Submit crew qualifications to permitting agencies	1-Feb	15-Mar	15-Mar
Conduct training	Trained field crew	30-Mar	30-Mar	30-Mar
Training reporting	Training report			30-Apr
Conduct field surveys	Contractor database	15-Jul	27-Jun	15-Jun
Field season reporting	Debriefing report			31-Jul
QA/QC 2	2nd level database	Continually	30-Aug	30-Aug
Quality control report	QAQC performance report			31-Oct
Results reporting	Range-wide density report		31-Dec	30-Nov
Annual reporting	Range-wide summary report		31-Dec	31-Dec

*Dates are sequential based on 2008 planned dates and start the year before field work is done.

DISCUSSION

Sampling representatively in all monitoring strata

In 2007, transects were placed systematically in monitoring strata; the placement scheme itself had a random origin so that transects were located at random with respect to tortoises. The goal of systematic placement is used to provide better coverage of sampled areas, and the set of potential transect locations will be used to sample from in future years as well. Because transects can be rewalked in the future, it is meaningful to collect information describing access and completion of each transect so that this information is available when planning to walk this transect location in future years.

Better planning opportunities should improve representative sampling in each monitoring stratum. Another change implemented to improve coverage was redevelopment of the set of rules for changing standard transect protocols when confronted with particular obstacles (Appendix A). Site visits with crews and visual (GIS) inspection of how these rules were applied on specific transects revealed that these guidelines were not always applied consistently. During end-of-season debriefings, crews reiterated that the rules were difficult to apply. A much-simplified, intensively instructed protocol for non-standard situations was developed for 2008.

These new rules are part of increasing efforts since 2004 to cover all areas within sampling strata. Even if tortoise numbers remain constant, it is expected that estimated tortoise densities will be lower if many of the areas added to the sampling frame contain lower densities of tortoises than the core areas sampled among all years. Estimates of density for 2007 are lower than previous estimates from 2005 (Table 9). This change coincides with efforts described above to sample from all of the areas managed for desert tortoises; the new areas of interest were excluded in the past as potentially low suitability to desert tortoises or logistical difficulties that may also correspond to lower tortoise densities.

How are density estimates to be compared between years? Unless there has been representative sampling, “design-based” density estimates are not possible, so they can only be compared if it is possible to generate “model-based” density estimates. This involves using model-based statistics to estimate density for unsampled areas based on sampled areas with similar characteristics. Transects might be characterized by whether they are in low- or high-relief areas, as a simple example. Even if high-relief areas were relatively under-sampled, a modeling approach could estimate the expected density in these areas based on the samples we do have. Based on the experience and transect descriptions generated by field crews in 2007, a design-based sampling approach was planned for 2008.

Estimation and use of G_0 to adjust density calculations

The previous report on the range-wide monitoring program (USFWS, 2006) drew attention and questions about reliance on a set of sites where radio-equipped tortoises are monitored to adjust abundance estimates for the proportion of tortoises that are not visually detectable. Criticism has focused on the software limitation that was used to explain why only one activity estimate could be applied to all transects across the range (USFWS, 2006). On the one hand, this has led to some questions about the value of maintaining so many focal sites (8 in 2007) when only one estimate is used, and on the other hand has led to criticism for allowing software to limit the ability to analyze data appropriately. Following assessment of the overall recovery effort (Tracy et al., 2004) and then the first five years of the range-wide desert tortoise monitoring program (USFWS, 2006), a consistent theme was the need to develop stand-alone analysis capability so that better and more customized density estimates could be developed.

Questions about the maintenance of multiple telemetry sites led researchers and agencies to ask whether a more cost-effective way could be found to adjust density estimates. Monitoring data from this program since 2001 indicates the enticing possibility that a simple model of tortoise "availability for detection" could be built, because G_0 estimates are usually very close to one another for different areas across the range (0.7-0.9 is typical). Recently, Inman (2008) began to address whether tortoise activity levels could be modeled using relatively inexpensive environmental measurements to bypass more expensive tortoise behavior monitoring. He collected relevant data to model individual tortoise behavior, and applied this to predicting population above-ground behavior over full 24-hour periods from mid-April to the end of June. This period includes the normal spring activity period (through mid- to late May), as well as a month (June) when above-ground activity is considered limited. Inman (2008) does not suggest that these modeling approaches will be successful for the range-wide monitoring program. Because he was describing individual-based variation in behavior, his models were mechanistic and more complex than the simpler phenomenological question, more pertinent to the issue of range-wide monitoring: How many are above ground at any one time? Inman (2008) does criticize the exclusive use of Program DISTANCE to complete distance analyses, and we are also in agreement on that point.

The design of the range-wide monitoring program limits G_0 to an acceptable range of variability. Restricting monitoring to 1 April to 30 May and constraining the time of day when sampling can occur (starting no earlier than 7am until 1 May, no later than sunrise thereafter), has the effect of incorporating qualitative models of tortoise activity to optimize the number of tortoises that are above-ground. However, this qualitative model is not sufficient to estimate the variance of tortoise activity or to forecast how the estimate itself will vary (2002 was an anomalous year, for instance), so for the immediate future, the monitoring program will continue to rely on focal tortoises in telemetry sites for local activity estimates. It remains to be seen whether modeling might be more successful for describing tortoise activity within the constraints of month (April-May) and time of day (sunrise to noon or mid-afternoon) when monitoring is conducted. Also, it is not always possible to monitor during the best period for a particular site. Due to annual military operations scheduled on Chocolate Mountain Air Gunnery Range, transects cannot be completed in early April, when the highest activity levels are expected to occur, close to or exceeding 0.80. All of these reasons indicate the value of maintaining regional sites to estimate tortoise detectability.

The second critique of the monitoring program's use of G_0 is that analysis should not be constrained by available software to use only one estimate for G_0. Starting in 2007, I used the most powerful features of Program DISTANCE to reasonably constrain and estimate detection functions, to estimate stratum-specific encounter rates, and to estimate variances for both. These estimates (for encounter rate and detection probability) were subsequently incorporated with one another and with regional G_0 estimates outside of DISTANCE in a final customized analysis that produced density estimates (and confidence intervals) for individual strata as well as recovery units. The regional G_0 estimates are also much more precise than a single, range-wide estimate would be, so maintenance of telemetry sites across the range provides more accurate and more precise density estimates.

Improving ability to detect trends in desert tortoise abundance

The primary goal of the monitoring program is to provide population estimates that are relevant to the recovery plan criteria (USFWS, 1994). The priority for the 2007 field season was therefore to improve ability to detect trends in desert tortoise abundance at the recovery unit level.

Impact of developing regional G_0 estimates

The changes described in the previous section, allowing use of more than one estimate of G_0, were an important step in developing precise density estimates. Analysis before the field season (Appendix B) indicated that: 1) a large source of variance to density estimates has been the estimation of G_0, and 2) much of the day-to-day variance in G_0 is due to monitoring over large spatial scales (where factors affecting tortoise activity may vary considerably) and over relatively large temporal scales (entire spring activity seasons) that describe activity over a period when the phenology of annual food plants changes considerably and when thermal regimes change markedly.

For 2007, the study design was changed to minimize the variance of G_0. Each telemetry site and neighboring transect strata were completed in sequence so that they could be completed as quickly as possible and so that only a limited spatial area was described. In some areas of the range in 2001 to 2005, a similar grouping approach had been used, completing local transects and monitoring telemetry sites in a short period of time. However, this approach was not used consistently, and the previous method of analyzing data could only accommodate one G_0 estimate per year. Table 12 reports G_0 estimates and coefficients of variation (a measure of precision) at sites that were monitored in 2005 and 2007. One site, Ivanpah, was monitored for the same number of days in both years. The CV both years and number of days were all among the lowest reported. At four of the remaining six sites, precision was higher (CV lower) when the site was monitored for a shorter time. This is not a strong pattern, but it is promising as one approach in the effort to increase the precision of the density estimates.

One of the sites that did not match the pattern was Ord-Rodman, where variability over 13 days in 2007 was high, and tortoise availability averaged only 64%. Because availability at this site was combined with that from Superior Cronese, where availability was uniformly high (94%), the spatial variability between the two sites was also high. This level of spatial variability was not as great in the Chemehuevi, Piute, and Ivanpah group of G_0 sites, although activity at Chemehuevi was consistently lower than that at Piute and Ivanpah during the same nine days of observation. Average G_0 (and CVs) for groups of sites is given in Table 7.

Table 12. Comparison of estimated G_0 and percent CV(G_0) at telemetry sites monitored in 2005 and 2007.

	2005			2007		
Telemetry Site	G_0	% CV(G_0)	Days	G_0	% CV(G_0)	Days
Chuckwalla	0.74	20.5	39	0.87	6.9	17
Chemehuevi	0.65	26.6	40	0.62	19.1	5
Ivanpah	0.87	11.7	5	0.94	9.7	5
Piute-Mid	0.91	13.0	59	0.81	22.0	7
MCAGCC	0.90	12.2	21	0.97	4.8	5
Ord-Rodman	0.92	9.0	32	0.64	33.4	13
Superior Cronese	0.92	10.3	37	0.96	5.2	13

Consequences of insufficient transects

Appendix D highlights recalculated density estimates at the level of the recovery unit. In some cases, such as the Northeastern Mojave in 2002, a density was reported in USFWS (2006) and is reprinted in Appendix D, but due to the very small sample size, a new estimate was not included in this report. Although in general less sampling effort is needed to develop a reasonable estimate of encounter rate (tortoises detected per kilometer walked) than to model a detection curve or estimate the proportion of visible tortoises, only 3 live tortoises were encountered on transects in the entire Northeastern Mojave sampling effort in 2002. This is of course too few to develop a useful encounter rate estimate for an entire recovery unit. In fact, no tortoises were encountered on transects in 3 of the 4 associated monitoring strata, so it would also be inappropriate to extrapolate an estimate for the entire recovery unit based on limited observations from a single stratum. Whereas much of this report has focused on ways to enhance efforts and develop more precise estimates to detect trends, this example illustrates that attention should also be focused on the lower limits of effort that can produce useful data. There should be sufficient transects in each monitoring stratum each year to detect several live tortoises in each stratum. This is one reason that over the years since 2001, the protocols have changed to allow more kilometers to be walked per day, increasing the number of tortoises encountered. However, the number of transects walked is limited by funding, which was only sufficient to complete 10 – 15 transects in 6 of the 9 long-term strata in the California portion of the range in 2007.

Reporting density estimates at other relevant spatial scales

Although the monitoring program is focused on density estimation for recovery units, it can also be compatible with reporting density estimates at smaller spatial scales that are relevant to recovery efforts and to land management agencies. The copyrighted software for distance analysis (Program DISTANCE, ver. 5.2), however, does not accommodate more than one level of stratification, so previous software-dependent analysis generated density estimates at only one level of analysis – the recovery unit. (This limitation is separate from the fact that only one estimate of G_0 can be used for each analysis.) By utilizing Program DISTANCE for the first analysis stages, then leaving the program for the final steps of the analysis, in 2007 I was able to provide separate density estimates for each monitoring stratum, as well as for one area smaller than a monitoring stratum (Chocolate Mountain Air Gunnery Range). Appendix C provides stratum level density estimates for all years of the monitoring program to date. This approach to analysis for the range-wide program, and revived attention to putting sufficient effort (transects) in each stratum, will allow for density estimates in each stratum each year.

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APPENDIX A. GUIDELINES FOR NON-STANDARD TRANSECTS

These guidelines were developed in the first week of April (after training) and provided to field crew leaders.

Below, some guidelines are laid out for planning transects. When possible, crews should have a plan for each transect before they arrive on site. However, that is not always possible, so the goals that should guide planning and on-site deviations from assigned transects are given first.

Goals of transect layout:

1. Transects sample areas defined by strata boundaries

   All terrains and habitats in the stratum are proportionally represented across the total kilometers walked in the stratum.

2. Transects are placed independent of tortoise locations

   Within strata, transects are placed without considering terrain, vegetation, or other potential predictors of tortoises.

3. Transects have been placed with optimal spacing between transects. This spacing would allow for additional transects to be added in years when there is sufficient funding.

   Moving transects away from their center point creates problems with transect spacing.

Guidelines (in order of priority) that arise from these goals:

1. Walk the assigned transect unless impossible in allotted time. (Goals 1, 2, 3)

2. Reflect transects.

   Any reflection should be mapped out before crews are on-site (Goal 2)

   Reflection should be designed to keep as many kilometers of the original transect in place as possible. (Goal 1; kilometers are important, not the start point or other corners *per se,* but see Goal 3 regarding moving all corners and the transect center point)

   > In the past, reflection has been at right angles to the line of travel. East-west and north-south obstacles (for instance, many major roadways in the Mojave Desert) cannot be reflected from by moving at right angles. If crews are confident they can walk in a straight trajectory without following an easting or northing reading, please reflect at non-right-angles instead of "sliding" transects away from obstacles. If non-right-angle reflection is not possible, choose the side of the obstacle where most of the transect occurs. Flatten the transect into a 12-km

> rectangle. For instance, if the transect is to be walked on the north side of a road that bisects it, the transect will be shorter in the north-south direction. Add this distance back in by extending the transect by the same number of waypoints to the west as you add to the east. (Goal 3)

3. Walk a shorter, square transect.
In some terrain, reflection may be constrained by ravines, excessive number of required reflections, etc. Instead, it is preferable to walk in a smaller square that requires less human judgment. The exact waypoints at which the square will be shortened can be determined while on the transect. If, after ~¼ of the allotted time, the crew decides they will not be able to complete the transect in the allotted time (for instance, they haven't completed one 3-km side), a right turn should be made to create the second leg of a smaller transect. The length of the first side sets the distance to walk the remaining 3 sides. In this way, the crews will also return to their start point. (Goals 1, 2)

> Note that this option is also available if transit time to a transect means that a 12km transect cannot be walked without endangering the crew. If a crew begins hiking to a transect at first light, time to transect and feasibility of the transect could not necessarily be determined before starting out. After arriving at the transect, the crew can determine the total time they should spend on the transect before hiking out again and can resize the transect accordingly.

4. Interrupt the transect to navigate obstacles but allow most of the designated transect to be completed as planned. Some transects cross a ridge or have other relatively short, steep sections where LDS walking and searching techniques are probably not going to be implemented. When small obstacles occur on a transect, crews can use a short scramble (~20-30m) to get up or over something, look really hard before scrambling, turn around look really hard again. The lead scrambles up with the line, the follow stays at the bottom. After the line has been examined by both the lead and the follow, the follow scrambles up to meet the lead and the line is resumed as normal. The transect follows the regular assigned path.

However, if the obstacle requires more distance than this to navigate, and a really hard look will not cover the distance, the best option is to not collect data over this distance; the crews can "interrupt" the transect. Find a safe route around the obstacle and resume the transect at the point where it can once again be navigated. This will result in a shorter distance covered, but only a minimal deviation from the planned transect. (Goal 2)

> Data form procedures: If a transect is interrupted as described here, there are important changes required to document the fact that data are not collected for part of the planned transect. In order to clearly implement this in the database the transect will be officially

ended at this point of interruption (i.e. end waypoint 99, end time, summary of observations, etc. are all recorded). After the obstacle is navigated, crews will begin a totally new transect. The number for this transect is based on the original transect number. If the original transect was 42, for instance, the transect number for the section after the obstacle would be 42.1. If another interruption is required, a new transect would be created and designated as 42.2.

Treating the walkable segments as separate transects is an important bookkeeping device for data processing. A few things will be different though. Waypoints in added transect segments will be numbered sequentially from the last one recorded before the obstacle. For example, if the last waypoint recorded before the end waypoint (i.e. 99) of transect 42 was 7, the start waypoint for transect 42.1 will be 8. Continue transect 42.1 per normal transect procedures. When you have completed transect 42.1 record the end waypoint as 99 just as you normally do. Once you return to the vehicle you will need to record only the return time and waypoint (i.e. 100) for transect 42. No drop off or return times or waypoints will be recorded for transect 42.1.

Transect live and carcass finds must be summarized for each segment (i.e., separately for transects 42 and 42.1. Opportunistic observations are not recorded under transect 42.1, however. Record all opportunistic observations of tortoises or carcasses under the original transect. In this example, record all opportunistic observations observed on this day under transect 42.

In summary, other than consecutively ordering waypoint numbers, not recording transect drop off and return information, and using the original transect to record opportunistic observations, these subsequent transects will be treated as completely new, they will have their own transect number, their own transect form on the RDA, and their own paper data sheets. This also means that at least one extra set of forms should be carried by crews at all times.

APPENDIX B: ESTIMATING G_0 AND ITS ASSOCIATED VARIANCE

The following is a complete white paper that was prepared by Linda Allison and circulated to USGS and UNR technical advisors to the monitoring program in September 2006. The general conclusions were applied in 2007, although the final approach did not focus on estimating G_0 for entire recovery units as described here, but for the smallest local area possible given the distribution of telemetry sites.

A Fundamental Assumption of Line Distance Sampling (LDS)

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. The fact that this quantity must be estimated means that it contributes variability to detection and therefore to density estimates. This estimation comes at the cost of decreased precision of the estimated abundance. The consideration of how this variance in G_0 is portioned at different spatial and temporal scales will factor into decisions of how G_0 may be pooled and whether indirect estimation techniques may work as well as direct ones.

Focal Animals

Estimation of G_0 consists of the establishment of a cohort of focal tortoises in each monitoring stratum. Most DWMAs within each RU stratum had an associated “focal population” of 5-20 animals (targeting at least 10 sub-/adults), ideally with equal numbers of males and females (Table A). The focal animals are equipped with radio transmitters and observed daily while transects are sampled in the associated DWMA. Contractors developed data sheets to document activity for focal tortoises, with some slight variations, and included the following information: transmitter frequency, GPS coordinates, general weather conditions, sex of the animal, time of day, temperature 1 cm above the ground, behavior (above or below ground or under a shrub), whether the animal was visible or not, signs of disease, etc.

How much does variance in G_0 affect variance in the density estimate?

Use of focal animals to assess G_0 is quite expensive, and there has been discussion of discontinuing this program in favor of indirect estimation of G_0. Indirect estimation might be less precise, but if variability in G_0 contributes little to the variance of density estimates, precision of these estimates will not be compromised. Although the analysis works with variances, the related quantity that is usually reported is the standard error, the square root of the variance.

In order to evaluate whether accurate estimation of G_0 is important to density estimation, I started with the variance components break-down for the 2005 DISTANCE analysis (Table A, highlighted row). The example is for an analysis stratifying by recovery unit, where components are reported for Eastern Colorado. In 2005, the rangewide G_0 was 0.84 and G_0 SE was 0.018. I explored the effect of varying G_0 (first column) within the range of estimated values and the effect of varying the original estimated standard error by a factor of 5 or 10. This quick-and-dirty assessment was not comforting in that I suspected a 10-fold increase in the standard error of G_0 was within the range that might actually be expected, and at this level, the standard error of density was mostly a function of the variability in G_0. The last 2 columns of this table report range-wide density estimates for the same analyses, just to confirm the parallel with the original analysis. Note that variation in G_0 leads to changes in the estimate of density, as expected, but the variance in density is strictly a function of variance in G_0.

Table A. Component percentages of Var(D) as a function of G_0 and its standard error. The highlighted (7th) row of numbers indicates values used for 2005 analyses in USFWS (2006).

		Component of the variance in density (expressed as %)			Quantities of interest in USFWS (2006)	
G_0	Std Error(G_0)	Detection Probability (P_a)	Encounter rate (n/L)	G_0	Density	CV(Density)
0.64	0.018	11.1	86.3	2.6	7.5	0.09
0.64	0.09	6.8	53.1	40.1	7.5	0.16
0.64	0.18	3.1	24.1	72.8	7.5	0.29
0.74	0.018	11.1	86.9	2.0	6.5	0.08
0.74	0.09	7.6	59.1	33.3	6.5	0.15
0.74	0.18	3.8	29.5	66.7	6.5	0.26
0.84	0.018	11.5	87.0	1.5	5.8	0.08
0.84	0.09	8.4	63.7	27.9	5.8	0.14
0.84	0.18	4.6	34.7	60.7	5.8	0.23
0.94	0.018	11.2	87.6	1.2	5.1	0.08
0.94	0.09	8.7	67.7	23.7	5.1	0.13
0.94	0.18	5.1	39.6	55.4	5.1	0.21

Initial estimates of G_0

Each Program DISTANCE analysis accepts a single G_0 estimate. Under this sub-optimal situation, for the initial density estimates in 2001 through 2005, a single G_0 was estimated for each year, instead of separately for each DWMA or Recovery Unit. For each of the 57-119 telemetered animals each year with at least 10 observations, proportion visible was calculated as the proportion of observations where the tortoise was visible above ground or in a burrow. Overall annual G_0 was calculated as the mean over all tortoises of the individual proportion visible. The SEs were the SEs of these means.

Estimating G_0 to accurately reflect spatial and temporal variance

The above estimate of G_0 is not strictly accurate, since the goal is not to estimate the proportion of time that an individual is visible, but the proportion of the population that is visible. Generating this estimate across days within the same focal animal site, and then across sites within Recovery Units, allows estimation of G_0 as well as its variance at different spatial and temporal scales.

At any given site, all encounters with all telemetered tortoises were recorded (Table B). I used only the first observation of a tortoise on any date and limited the final date used to 1 June for 2001 and 2004, or 15 June for 2005, as described in the 2001-2005 report. The proportion visible on any date was the average of the 0/1 values (not visible/visible) at each site. At an extreme, if only one tortoise is detected at a site on a particular day, the resulting estimate of G_0 can only be 0 or 1. In order to maximize dates per site but also have a range of possible detection values, only those dates with at least 5 tortoise observations were used for each site (Table C). This removed 42 site-by-date combinations from consideration and left 590 for analysis (Table D).

Table B. Number of detections of a given tortoise on a single day. All detections of a tortoise were used in the original analysis. In the current analysis, only the first detection of each tortoise on a date was included.

Number of detections of a tortoise on a single day	Frequency of Tortoise X date combinations
1	2537
2	2341
3	588
4	166
5	46
6	22
7	9
8	0
9	1
Total	5710

Table C. Number of detected tortoises available for estimating G_0 for a given site X date combination. G_0 is initially estimated as the average of visible (“1”) and not-visible (“0”) tortoises, so the range of possible values is limited if there are few tortoises. Site X Date combinations were included in analysis if at least 5 tortoises were detected.

Number of tortoises detected	Frequency of Site X Date combinations
1	6
2	4
3	8
4	24
5	62
6	66
7	64
8	56
9	58
10	107
11	41
12	59
13	17
14	20
15	8
16	1
17	2
18	8
19	12
20	9
Total	632

Table D. Number of dates for which G_0 could be evaluated at each site each year

Recovery Unit	Focal Site	2001	2002	2003	2004	2005
Eastern Colorado	CK	20	11	8	12	12
Northern Colorado	CM	11		8	12	16
East Mojave	FE	0	9	0	0	0
	IV	0	10	0	8	3
	MP	22	0	0	0	0
	PB	7	11	12	8	12
	PM	12	10	15	9	33
	SV	5	0	0	0	0
	Total	25	51	35	37	60
Northeast Mojave	LS	13	14	9	6	0
	PB	4	0	0	0	10
	PM	0	0	1	0	0
	Total	17	14	10	6	10
Western Mojave	FK	26	16	8	0	0
	MC	31	5	7	4	5
	OR	10	18	11	6	6
	SC	19	27	14	10	14
	Total	86	66	40	20	25

Estimating G_0 across Recovery Units and years

There are three spatial scales of analysis (rangewide, Recovery Unit, focal site) and 2 temporal ones (years and days). I developed a model with Recovery Units as fixed effects but focal sites as random ones, nested within Recovery Units. Years were also treated as random effects, since the individual density estimates for each year are a sample of the year effects we are interested in. G_0 estimated once each day within sites was used to estimate within-site, between-date variation, also called "error variance."

Table E. Estimated marginal mean G_0 by Recovery Unit.

Recovery Unit	Mean	Standard Deviation	Standard Error
Eastern Colorado	0.773	0.078	0.021
Eastern Mojave	0.683	0.074	0.019
Northern Colorado	0.768	0.090	0.024
Northeastern Mojave	0.866	0.216	0.057
Western Mojave	0.863	0.047	0.012

Because there are different numbers of dates within focal sites, and the number of focal sites varies within Recovery Units and between years, ANOVA reports back estimated marginal means, which are more accurate but will not correspond exactly to simple averages. In Tables E and F, these estimated marginal means are reported with standard errors and standard deviations. Note that standard errors describe the distribution of *mean* G_0 given the factor of interest (overall, by Recovery Unit, by year, etc.), whereas the standard deviation describes the dispersion of particular G_0's. In Table G, simple means and standard deviations are reported.

Table F. Estimated marginal mean G_0 by year.

Year	Mean	Standard Deviation	Standard Error
2001	0.854	0.075	0.018
2002	0.641	0.085	0.020
2003	0.811	0.086	0.021
2004	0.795	0.100	0.023
2005	0.795	0.096	0.021

Table G. Mean G_0 by year within recovery unit.

Recovery Unit	Year	Mean	Std Deviation	N (days with more than 5 tortoises)
Eastern Colorado	2001	0.930	0.056	20
	2002	0.775	0.163	11
	2003	0.893	0.101	8
	2004	0.596	0.162	12
	2005	0.655	0.155	12
Eastern Mojave	2001	0.747	0.280	32
	2002	0.724	0.145	29
	2003	0.769	0.263	26
	2004	0.825	0.124	20
	2005	0.875	0.156	40
Northern Colorado	2001	0.867	0.072	11
	2002			
	2003	0.858	0.084	8
	2004	0.854	0.104	12
	2005	0.684	0.199	16
Northeastern Mojave	2001	0.896	0.176	17
	2002	0.605	0.242	14
	2003	0.660	0.135	10
	2004	0.867	0.163	6
	2005	0.919	0.211	10
Western Mojave	2001	0.905	0.080	51
	2002	0.639	0.200	45
	2003	0.951	0.059	37
	2004	0.948	0.086	18
	2005	0.907	0.095	20

Estimating Var(G_0) and variance components

Using the same ANOVA model used above to test effects and estimate marginal means, I also ran a variance components analysis. Although Recovery Unit is theoretically a fixed effect (because values are reported for all Recovery Units of interest, not a random sample of them), operationally, we cannot use these separate estimates due to limitation of DISTANCE unless we use a different analysis for each Recovery Unit. In order to explore the relative value of separate analyses for years versus Recovery Units, the analysis treated Recovery Unit as a random variable.

Using this model, I estimated var(G_0) as well as the variance components attributable to variance between years, between Recovery Units, to variance attributable to the interaction between year and Recovery Unit, to sites within Recovery Units, and to different days within sites (the error variance). I used ANOVA and Restricted Maximum Likelihood (REML) methods to estimate variance components. They did not result in exactly comparable estimates (Table H).

The total variance estimated using the ANOVA estimation technique was much lower than that using REML. Also, the ANOVA estimation allows negative (non-sensical) variance estimates. These estimates correspond to very small (approaching zero) variances and are also zero when the *Recovery Unit X year* interaction is removed (not shown). In this case, the *Recovery Unit X year* combinations should be interpreted instead. Although there are general year-to-year patterns in variance, there are no strong patterns seen for Recovery Units. Instead, some Recovery Units vary more year-to-year than others.

The REML estimate is generally more robust, and allows development of confidence intervals for the variances. The ANOVA estimate is often informative because it produces variance estimates based on expected sums of squares, so parallels to the analysis for effect size estimation is possible.

Table H. Variance estimates using alternative estimation techniques.

Component	Estimate using ANOVA	Estimate using REML
Var(Year)	0.003	0.002
Var(Recovery Unit)	-0.006	0.001
Var(Recovery Unit X year)	0.008	0.010
Var(Site nested in Recovery Unit)	0.012	0.039
Var(Error) = Var(Day)	0.023	0.023
Total	0.046	0.075
Standard Deviation	0.214	0.274

Table I. Variance estimates using restricted maximum likelihood estimation techniques. Separate analyses each year.

Component	2001	2002	2003	2004	2005
Var(Recovery Unit)	.002	.000	.011	.015	.015
Var(Site nested in Recovery Unit)	.046	.012	.000	.002	.000
Var(Error) = Var(Day)	.015	.030	.026	.015	.025
Total	0.063	0.042	0.037	0.032	0.040
Standard Deviation	0.251	0.205	0.192	0.179	0.200

The ANOVA indicates that there is an important year X Recovery Unit interaction, so that annual visibility estimates did not go up and down in the same way for each Recovery Unit. This analysis did not assess whether visiting the Recovery Units in the same temporal sequence each year might remove this interaction effect. In other words, any attempts to "randomize" visits to transects in different Recovery Units might be making trend detection more difficult.

Due to this interaction effect, a separate analysis investigated within-year variance component patterns (Table I). In 2001 and 2002, the between focal-area variance was much more important than the between-Recovery Unit pattern. In subsequent years, the opposite was true.

Conclusions

Due to potential difficulties with precision of density estimates, the relatively large standard errors associated with G_0 may play an important estimate in developing useful density estimates. The actual variability seen in G_0 should lead to consideration of whether 1) transects within a Recovery Unit should be visited during a narrower window of time, potentially by concentrating efforts in one recovery unit at a time, 2) Due to the inherent variability in G_0, density estimates may be more accurate (if less precise) if analyses are customized for each year and each recovery unit or even each DWMA.

APPENDIX C: UPDATES TO TABLES 7 AND 8 OF THE 2001-2005 SUMMARY REPORT (USFWS 2006)

The current report is based on separate detection curves for teams with different levels of effort, spatially constructed estimates of G_0, different estimation of the standard error for G_0, and it estimates encounter rate first for each monitoring stratum before generating a recovery-unit-wide density estimate. These are the differences implemented for analysis since USFWS (2006) was written. This appendix reports stratum- and recovery-unit-level density estimates as a result of the same type of analysis applied to data from 2001 through 2005. Program DISTANCE was used to develop detection curves and develop encounter rate statistics reported below. When data are collected, crews report all tortoises detected, no matter how far from the line (training conditions them to focus close to the line, however). The first step in modeling the detection function is to "truncate" the data by determining the farthest distance for which observations will be modeled. Differences between truncation distance in USFWS (2006) and in the current analyses result in slight differences in the number of tortoises used in the analysis (*n*). Before 2007, monitoring sometimes extended late into June. Evaluating detection functions, USFWS (2006) concluded that this had a noticeable decrease in the proportion of tortoises detected, so date was included as a covariate in models. In contrast, during this reanalysis, models were more robust when they did not include data from these later periods. This is reflected in somewhat fewer observations and kilometers analyzed in 2003, in particular.

A remaining issue is the non-standard sampling frame each year, which resulted in over-sampling areas that were expected to have higher encounter rates. When densities in these areas were applied to the entire area of the monitoring strata, the resulting annual estimates were not appropriate. The reanalysis provided here does not address the fact that different landscapes were monitored each year, so density estimates are still not comparable between years. In upcoming evaluations, I anticipate using model-based estimation to correctly report the previous years of density estimates for the entire areas of interest and comparison year-to-year.

The analysis tables below are structured so that each year is represented by two tables. The first one documents the components of encounter rate, proportion visible, and detection rate. The second table in each pair provides the resulting density estimates at the stratum and recovery unit levels. In this latter table, the represented area for each stratum/recovery unit is reported. In years when the same stratum is representing a smaller area, this should be interpreted to mean that the density applies to a smaller, more homogeneous portion of the DWMA/critical habitat unit. In order to provide all of this information in only two tables for each year, G_0 sites and monitoring strata are abbreviated as in Table 13. Summary tables are in Tables 14-23.

Table 13. Abbreviations for transect strata and telemetry sites.

Abbreviation	Site name	Transect stratum	Telemetry site
AG	Chocolate Mountain Air Gunnery Range	X	
CM	Chemehuevi	X	X
CK	Chuckwalla	X	X
CS	Coyote Springs Valley	X	X
FE	Fenner	X	X
FK	Fremont-Kramer	X	X
GB	Gold Butte-Pakoon	X	
IV	Ivanpah	X	X
JT	Joshua Tree National Park	X	
MN	Lake Mead NRA North	X	
MS	Lake Mead NRA South	X	
LSTS	Large Scale Translocation Site		X
MC	Marine Corps Air Ground Combat Center (MCAGCC)	X	X
MP	Mojave National Preserve		X
MM	Mormon Mesa	X	
NS	Newberry Springs	X	
OR	Ord-Rodman	X	X
PT	Pinto Mountains	X	
PT2	Pinto Mountains (non-critical habitat)	X	
PB	Piute (Border)		X
PM	Piute Mid		X
PI	Piute-Eldorado	X	
SV	Shadow Valley		X
SC	Superior Cronese	X	X

Table 14. 2001 estimates of encounter rates, proportion of tortoises that were visible, and detection rates.

Encounter rate (*n/L*)							Proportion of tortoises visible to be counted (G_0)					Detection rate (P_a)				
Stratum	*Start date*	*End date*	*Transects (k)*	*Kilometers walked (L)*	*Tortoises (n)*	*CV(n/L)*	*Telemetry sites*	*Start date*	*End date*	G_0	$CV(G_0)$	*Data collection group(s)*	*Truncation distance (m)*	*Effective strip half-width (m)*	P_a	$CV(P_a)$
CM	1-Apr	11-Apr	189	302	36	17.9	CM	1-Apr	11-Apr	0.84	11.3	Kiva + Mojave Natl Preserve	18	9.9	0.55	8.2
CK	23-Apr	16-May	204	326	60	15.0	CK	23-Apr	16-May	0.92	6.7					
FE	21-May	13-Jun	20	31	6	48.9	MP	21-May	13-Jun	0.61	38.4					
IV	24-Apr	29-May	117	185	7	36.8	SV + MP	23-Apr	29-May	0.68	49.7					
PI	23-Apr	16-May	71	124	5	51.2	PM + PB	11-Apr	18-Jun	0.88	19.4	UDWR + Chambers + UNR	18	10.9	0.61	8.0
BD	4-Jun	19-Jun	47	57	5	43.0	LSTS	4-Jun	19-Jun	0.72	36.7					
CS	17-Apr	25-Jun	51	99	4	49.4	LSTS	17-Apr	25-Jun	0.86	20.5					
GB	10-May	22-Jun	65	137	3	56.0										
MM	23-Apr	16-May	47	87	3	57.0										
FK	4-Apr	11-May	211	338	36	17.1	FK + SC + OR	3-Apr	24-May	0.89	14.1					
SC	3-Apr	24-May	211	338	28	19.7										
OR	15-Apr	24-May	197	315	56	14.3						Kiva + Mojave Natl Preserve	18	9.9	0.55	8.2
JT	13-Apr	17-May	77	123	13	25.5	MC	12-Apr	25-May	0.92	9.7					
PT	12-Apr	12-May	80	128	15	30.1										
MC	19-Apr	25-May	90	144	21	24.5										

In USFWS (2006), the single G_0 (with incorrectly calculated %CV) for 2001 was 0.868 (1.5). The single P_a to 15m (with %CV) was 0.585 (3.9)

Four monitoring strata that are not part of DWMAs were monitored in 2001. Lake Mead South and Mojave National Preserve each reported only 1 live observation that was not smaller than 180mm. The single tortoise found at Lake Mead North was smaller than the threshold size. Stratum-level density estimates were therefore not estimated. No tortoises were seen on transects at Edwards Air Force Base (non-critical habitat that was surveyed very late in the season in mid-June. Transects at MCAGCC are also outside of long-term monitoring strata and critical habitat. However, sufficient tortoises over 180mm MCL were encountered (n=15) to estimate density for this stand-alone stratum. This density was not used in the Western Mojave Recovery Unit estimate, however.

Table 15. 2001 density estimates for monitoring strata and recovery units

Stratum density (*D*, tortoises/km^2)						Recovery unit density (*D*, tortoises/km^2)					
Stratum	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*	*Recovery unit*	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*
CM	2989	7.2	22.6	4.64	11.15	Northern Colorado	2989	7.2	22.6	4.64	11.15
CK	2861	10.1	18.3	7.04	14.36	Eastern Colorado	2861	10.1	18.3	7.04	14.36
FE	1383	15.7	62.7	5.08	48.61	Eastern Mojave	4901	6.2	46.6	2.62	14.87
IV	1991	2.8	62.3	0.92	8.69						
PI	1527	2.1	55.4	0.76	5.78						
BD	773	5.6	57.1	1.98	15.91	Northeastern Mojave	3775	2.4	34.8	1.22	4.60
CS	529	2.2	54.1	0.80	5.80						
GB	1603	1.2	60.2	0.39	3.47						
MM	870	1.8	61.1	0.61	5.55						
FK	1403	5.5	23.6	3.47	8.64	Western Mojave	5615	5.6	13.8	4.32	7.39
SC	2136	4.3	25.5	2.60	6.97						
OR	601	10.1	21.7	6.62	15.33						
JT	1035	5.8	28.4	3.37	10.07						
PT	440	6.5	32.7	3.46	12.09						
MC	2030	8.1	27.6	4.74	13.69						

Table 16. 2002 estimates of encounter rates, proportion of tortoises that were visible, and detection rates.

Encounter rate (*n/L*)							Proportion of tortoises visible to be counted (G_0)					Detection rate (P_a)				
Stratum	*Start date*	*End date*	*Transects (k)*	*Kilometers walked (L)*	*Tortoises (n)*	*CV(n/L)*	*Telemetry sites*	*Start date*	*End date*	G_0	CV(G_0)	*Data collection group(s)*	*Truncation distance (m)*	*Effective strip half-width (m)*	P_a	CV(P_a)
CK	2-May	19-May	104	417	42	19.3	CK	3-May	19-May	0.76	20.5	Kiva	16	8.6	0.54	5.9
FE	15-Apr	3-May	73	293	14	34.7	FE + IV	15-Apr	3-May	0.75	19.8					
IV	24-Apr	1-May	112	446	31	21.1										
PI	16-Apr	21-May	98	377	11	33.8	PM + PB	16-Apr	21-May	0.70	31.2	UDWR + Chambers + UNR	16	8.9	0.56	8.1
BD	16-Apr	17-May	27	107	0	0	LSTS*	23-Apr	26-Apr	0.71	26.7					
CS	22-Apr	23-Apr	12	46	2	66.8										
GB	24-Apr	25-Apr	12	48	0	0										
MM	18-Apr	6-May	24	94	0	0										
FK	13-Apr	1-May	129	512	33	24.0	FK	13-Apr	30-Apr	0.78	17.2					
SC	1-Apr	19-May	171	677	51	16.0	SC	1-Apr	19-May	0.52	41.6					
OR	2-Apr	10-May	106	424	71	13.1	OR	2-Apr	10-May	0.75	17.6	Kiva	16	8.6	0.54	5.9
JT	18-Apr	26-Apr	39	156	8	54.3	MC	18-Apr	24-Apr	0.91	6.6					
PT	8-Apr	11-Apr	48	192	12	30.4										
MC	18-Apr	24-Apr	40	160	15	32.7										

In USFWS (2006), the single G_0 (with incorrectly calculated %CV) for 2002 was 0.708 (4.3). The single P_a to 15m (with %CV) was 0.565 (4.1)

*The LSTS telemetry site was monitored for a longer period, but since only CS transect data were analyzed (see below), the analyzed telemetry dates were trimmed to match those when transects were walked in CS.

Transects at MCAGCC are outside of long-term monitoring strata and critical habitat. However, sufficient tortoises over 180mm MCL were encountered (n=18) to estimate density for this stand-alone stratum. This density was not be part of the Western Mojave Recovery Unit estimate, however.

No monitoring occurred in the Northern Colorado Recovery Unit. Although transects were walked in the Northeastern Mojave, only 2 tortoises were seen over 180mm. Both of these were in the Coyote Springs Valley stratum; no separate estimate is available for the other 3 strata in this recovery unit. No recovery unit estimate was calculated for the Northeastern Mojave in 2002.

The numbers of observed tortoises do not tell all. As an example, transects in Beaver Dam Slope were walked throughout the stratum, whereas transects walked in Coyote Springs Valley and Mormon Mesa were completed in localized areas less than one-fourth of the area in those monitoring strata. In Gold Butte, the transects were packaged into an area less than one-tenth as large as the stratum. This is an example of how density estimates should not be viewed as representative of the larger stratum for this year.

Table 17. 2002 density estimates for monitoring strata and recovery units.

Stratum density (*D*, tortoises/km^2)						Recovery unit density (*D*, tortoises/km^2)					
Stratum	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*	*Recovery unit*	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*
CK	1531	7.7	28.8	4.44	13.41	Eastern Colorado	1531	7.7	28.8	4.44	13.41
FE	1259	3.7	40.4	1.73	7.96	Eastern Mojave	3234	4.1	22.1	2.64	6.22
IV	1240	5.4	29.5	3.07	9.53						
PI	735	2.3	46.7	0.98	5.60						
CS	152	3.5	72.4	0.98	12.46	Northeastern Mojave					
FK	458	4.7	30.6	2.59	8.37	Western Mojave	1595	5.8	24.2	3.66	9.31
SC	545	8.1	45.2	3.49	18.96						
OR	68	13.1	22.7	8.43	20.31						
JT	332	3.3	55.0	1.20	8.97						
PT	192	4.0	31.7	2.18	7.32						
MC	1052	6.0	33.9	3.14	11.41						

Table 18. 2003 estimates of encounter rates, proportion of tortoises that were visible, and detection rates.

Encounter rate (*n/L*)							Proportion of tortoises visible to be counted (G_0)					Detection rate (P_a)				
Stratum	*Start date*	*End date*	*Transects (k)*	*Kilometers walked (L)*	*Tortoises (n)*	*CV(n/L)*	*Telemetry sites*	*Start date*	*End date*	G_0	*CV*(G_0)	*Data collection group(s)*	*Truncation distance (m)*	*Effective strip half-width (m)*	P_a	*CV*(P_a)
FK	7-Apr	31-May	130	519	43	17.9	FK	14-Apr	31-May	0.96	6.19	Kiva - West Mojave	22	12.5	0.57	4.0
OR	8-Apr	21-Apr	166	663	63	15.4	OR	8-Apr	21-Apr	0.97	3.66					
SC	22-Apr	1-Jun	127	506	96	11.8	SC	22-Apr	1-Jun	0.93	7.36					
JT	30-Apr	4-May	50	200	13	26.5	MC	26-Apr	3-May	0.96	7.43					
PT	26-Apr	30-Apr	49	196	18	24.7										
CK	3-May	14-May	106	424	35	19.4	CK	3-May	14-May	0.92	10.57	Kiva - Colorado	20	11.1	0.56	5.4
CM	3-May	21-May	112	445	53	18.1	CM	4-May	19-May	0.86	8.08					
CS	14-Apr	11-Jun	40	157	14	21.6	LSTS + PM + PB	24-Apr	17-Jun	0.71	39.32	UNR	20	11.4	0.57	7.6
GB	30-Apr	17-Jun	70	238	7	41.0										
MM	24-Apr	28-Jun	77	296	18	26.0										
PI	23-Apr	29-May	48	171	11	36.82	PM + PB	21-Apr	29-May	0.89	23.40					

In USFWS (2006), the single G_0 (with incorrectly calculated %CV) for 2003 was 0.874 (2.1). The single P_a to 15m (with %CV) was 0.707 (3.0).

Not all of the conventional strata were surveyed in the Northeastern Recovery unit, so the density cannot be meaningfully compared to other years. Only one of four strata in the Eastern Mojave was surveyed, so no estimate is possible at the level of the recovery unit.

Table 19. 2003 density estimates for monitoring strata and recovery units.

Stratum density (*D*, tortoises/km^2)						Recovery unit density (*D*, tortoises/km^2)					
Stratum	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*	*Recovery unit*	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*
FK	458	3.4	19.4	2.36	5.01	Western Mojave	1595	3.8	10.6	3.05	4.61
OR	545	4.1	17.5	2.92	5.77						
SC	68	7.8	13.0	6.05	10.04						
JT	332	2.7	27.8	1.59	4.65						
PT	192	3.8	26.1	2.32	6.35						
CK	1531	4.0	22.7	2.61	6.28	Eastern Colorado	1531	4.0	22.7	2.61	6.28
CM	2484	6.3	20.6	4.20	9.33	Northern Colorado	2484	6.3	20.6	4.20	9.33
CS	152	5.5	45.5	2.37	12.98	Northeastern Mojave	572	3.7	43.1	1.65	8.30
GB	162	1.8	57.3	0.65	5.22						
MM	258	3.8	47.7	1.56	9.20						
PI	735	3.2	44.3	1.38	7.27	Eastern Mojave*					

*Only one of four strata in the Eastern Mojave was surveyed, so no estimate is possible at the level of the recovery unit.

Table 20. 2004 estimates for encounter rates, proportion of tortoises that were visible, and detection rates.

Encounter rate (*n/L*)							Proportion of tortoises visible to be counted (G_0)					Detection rate (P_a)				
Stratum	*Start date*	*End date*	*Transects (k)*	*Kilometers walked (L)*	*Tortoises (n)*	*CV(n/L)*	*Telemetry sites*	*Start date*	*End date*	G_0	CV(G_0)	*Data collection group(s)*	*Truncation distance (m)*	*Effective strip half-width (m)*	P_a	CV(P_a)
FK	6-Apr	24-Apr	41	463	47	19.8	SC + OR	2-Apr	26-Apr	0.96	7.1	Kiva	14	8.46	0.60	3.3
SC	2-Apr	25-Apr	62	690	52	21.1										
OR	4-Apr	26-Apr	35	381	33	24.3										
JT	12-Apr	3-May	23	278	8	29.2	MC	12-Apr	3-May	0.98	2.9					
PT	2-May	2-May	5	56	2	98.1										
CK	8-Apr	10-May	132	1414	108	11.9	CK	8-Apr	10-May	0.70	26.1					
CM	13-Apr	1-May	76	836	84	14.7	IV + PM + PB	13-Apr	4-Jun	0.86	17.1					
FE	16-Apr	28-Apr	37	410	52	20.6										
IV	17-Apr	12-May	43	515	35	24.2										
PI	14-Apr	4-Jun	70	686	32	21.6						UNR	20	9.92	0.50	10.5
BD	15-Jun	16-Jun	10	100	0	0										
CS	23-Apr	4-Jun	37	365	8	36.3										
GB	21-Apr	19-May	37	361	4	48.1										
MM	23-Apr	16-May	31	311	12	30.9										

In USFWS (2006), the single G_0 (with incorrectly calculated %CV) for 2004 was 0.864 (2.1). The single P_a to 12m (with %CV) was 0.647 (2.8).

All surveyed strata for 2004 are long-term monitoring strata. Most had sufficient detections to estimate stratum-level densities. Although 10 transects were walked in Beaver Dam Slope, these were completed in mid-June, and no tortoises were detected. No stratum level estimate is possible, so these later transects did not affect the decision to limit analysis to transects on and before 4 June. The Northeastern Mojave Recovery Unit density estimate does not reflect information in Beaver Dam Slope.

Table 21. 2004 density estimates for monitoring strata and recovery units.

Stratum density (*D*, tortoises/km^2)						Recovery unit density (*D*, tortoises/km^2)					
Stratum	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*	*Recovery unit*	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*
FK	2070	6.1	20.2	3.77	9.93	Western Mojave	7911	4.4	13.0	3.40	5.64
SC	3087	4.5	21.5	3.02	6.82						
OR	836	5.2	24.7	2.84	9.57						
JT	1313	1.7	29.6	1.29	2.33						
PT	605	2.2	98.2	0.17	27.52						
CK	4137	6.4	28.9	3.70	11.22	Eastern Colorado	4137	6.4	28.9	3.70	11.22
CM	3789	6.9	22.8	4.46	10.78	Northern Colorado	3789	6.9	22.8	4.46	10.78
FE	1833	8.7	27.0	2.79	27.33	Eastern Mojave	6017	5.3	20.0	3.56	7.74
IV	2112	4.7	29.9	2.14	10.29						
PI	2072	2.7	29.5	1.73	4.35						
CS	638	1.3	41.5	0.84	1.98	Northeastern* Mojave	3518	1.2	30.1	0.68	2.15
GB	1923	0.7	52.1	0.46	0.92						
MM	957	2.3	36.9	1.26	4.10						
*Estimate of density does not include information for Beaver Dam Slope.											

Table 22. 2005 estimation of encounter rates, proportion of tortoises that were visible, and detection rates.

Encounter rate (*n/L*)							Proportion of tortoises visible to be counted (G_0)					Detection rate (P_a)				
Stratum	*Start date*	*End date*	*Transects (k)*	*Kilometers walked (L)*	*Tortoises (n)*	*CV(n/L)*	*Telemetry sites*	*Start date*	*End date*	G_0	$CV(G_0)$	*Data collection group(s)*	*Truncation distance (m)*	*Effective strip half-width (m)*	P_a	$CV(P_a)$
CK	22-Apr	31-May	91	1094	77	16.0	CK	22-Apr	31-May	0.74	20.5	Kiva	14	6.0	0.43	6.1
CM	28-Apr	7-Jun	94	1129	95	12.1	CM	28-Apr	7-Jun	0.65	26.6					
FK	14-Apr	20-May	56	673	41	19.2	OR + SC	16-Apr	24-May	0.92	9.8					
SC	16-Apr	23-May	84	1009	72	15.8										
OR	21-Apr	24-Apr	26	310	27	18.9										
JT	24-Apr	14-May	50	601	18	23.5	MC	23-Apr	14-May	0.90	12.2					
PT	23-Apr	14-May	13	155	17	33.4										
FE	2-May	6-May	24	288	42	15.9	IV	2-May	7-May	0.87	11.7					
IV	4-May	7-Jun	14	168	8	54.2										
PI	12-Apr	10-Jun	95	1062	59	14.0	PM + PB	12-Apr	10-Jun	0.90	15.8	UNR	18	7.2	0.40	10.0
MS	5-May	9-Jun	23	228	5	38.8										
BD	13-Apr	9-Jun	40	421	5	50.8										
CS	12-Apr	8-Jun	22	237	10	34.0										
GB	12-Apr	7-Jun	43	432	1	100.1										
MM	21-Apr	3-Jun	36	398	25	23.2										
MN	5-May	9-Jun	12	117	4	42.4										

In USFWS (2006), the single G_0 (with incorrectly calculated %CV) for 2005 was 0.840 (2.1). The single P_a to 12m (with %CV) was 0.525 (3.1).

All monitored strata reported enough observations to estimate stratum-specific densities. Two monitoring strata that are not part of DWMAs were monitored this year. Lake Mead North and Lake Mead South densities were not included in estimates of Northeastern Mojave and Eastern Mojave recovery unit densities, respectively.

Table 23. 2005 density estimates for monitoring strata and recovery units.

Stratum density (*D*, tortoises/km^2)						Recovery unit density (*D*, tortoises/km^2)					
Stratum	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*	*Recovery unit*	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*
CK	4199	7.9	26.7	4.73	13.24	Eastern Colorado	4199	7.9	26.7	4.73	13.24
CM	4038	10.8	29.9	6.07	19.10	Northern Colorado	4038	10.8	29.9	6.07	19.10
FK	2405	5.7	25.6	3.48	9.34	Western Mojave	9358	6.1	17.2	4.36	8.52
SC	3447	6.7	23.1	4.26	10.44						
OR	1124	8.1	25.3	5.00	13.28						
JT	1774	2.8	28.9	1.61	4.88						
PT	608	10.3	37.4	5.05	20.89						
FE	1857	14.0	20.6	9.36	20.82	Eastern Mojave	6371	7.2	20.1	4.90	10.67
IV	2565	4.6	55.7	1.64	12.63						
PI	1949	4.3	23.3	2.76	6.80						
MS	824	1.7	43.1	0.76	3.84						
BD	828	0.9	54.1	0.34	2.50	Northeastern Mojave	4537	1.8	25.8	1.12	3.04
CS	762	3.3	38.8	1.58	6.86						
GB	1977	0.2	101.8	0.03	0.94						
MM	970	4.9	29.8	2.76	8.67						
MN	1552	2.7	46.3	1.13	6.33						

APPENDIX D: ORIGINAL AND RECALCULATED RECOVERY UNIT DENSITY ESTIMATES, 2001 TO 2005

As described in this report, the standard error used in USFWS (2006) for G_0 was miscalculated. The resulting coefficient of variation (CV = standard error/estimate) was too small, and resulted in smaller confidence intervals than were appropriate. Also, in order to simplify use of the software DISTANCE, only one G_0 estimate was created for each year.

Although the correct calculation of the standard error for G_0 has the effect of decreasing apparent precision, other parts of the reanalysis added precision to the density estimates. By providing more customized estimates of G_0 for smaller areas, by developing separate detection curves for each monitoring group, and by estimating encounter rates for each stratum instead of each of the larger recovery units, the new analysis provides the optimum precision available for each year's study design. In general, Table 24 reports only slightly reduced precision between the original analysis and the current one.

Another pattern that can be seen in the table is the annually improving precision of density estimates within each recovery unit. This is a reflection of the increasing effort (kilometers walked) that planners implemented to improve estimates of encounter rate. The improved precision reflects an approximately 3-1/2-fold increase in the number of kilometers walked since the first year of this program (see tables in Appendix C).

The areas sampled in each recovery unit changed from year to year, and this is also reported in Table 24. When areas sampled in a given recovery unit are smaller, this also translates into a more restricted type of habitat, and may best reflect densities of tortoises in optimal habitat in that recovery unit. Since 2004, the sampling frame has been expanded to sample all of a given DWMA; however, sampling in rugged terrain has not been consistent.

Table 24. Comparison of original density estimates (USFWS 2006) with corrected estimates in this report.

	USFWS (2006)				**95% Confidence Interval**		**Revised in this report**		**95% Confidence Interval**	
Recovery Unit	**Year**	**Sampled area (km^2)**	**Density ($/km^2$)**	**%CV(Density)**	**Lower Limit**	**Upper Limit**	**Density (km^2)**	**%CV(Density)**	**Lower Limit**	**Upper Limit**
Northeastern Mojave	2001	3775	2.3	34.0	1.20	4.45	2.4	34.8	1.22	4.60
	2002	152	0.8	56.6	0.29	2.40	*			
	2003	572	3.0	15.4	2.22	4.08	3.7	43.1	1.65	8.30
	2004	3518	1.4	24.2	0.88	2.27	1.2	30.1	0.68	2.15
	2005	4537	2.2	18.6	1.50	3.10	1.8	25.8	1.12	3.04
	2007	4917					1.7	25.0	1.04	2.73
Eastern Mojave	2001	4901	3.0	26.2	1.81	4.98	6.2	46.6	2.62	14.87
	2002	3234	4.1	17.0	2.94	5.72	4.1	22.1	2.64	6.22
	2003	735	2.8	31.7	1.49	5.12	*			
	2004	6017	5.6	13.4	4.28	7.26	5.3	20.0	3.56	7.74
	2005	6371	5.5	11.8	4.39	6.99	7.2	20.1	4.90	10.67
	2007	6681					5.8	25.0	3.56	9.34
Eastern Colorado	2001	2861	10.8	15.9	7.91	14.73	10.1	18.3	7.04	14.36
	2002	1531	8.3	20.2	5.58	12.30	7.7	28.8	4.44	13.41
	2003	1531	4.0	19.3	2.74	5.85	4.0	22.7	2.61	6.28
	2004	4137	5.4	12.7	4.18	6.91	6.4	28.9	3.70	11.22
	2005	4199	6.4	16.6	4.60	8.86	7.9	26.7	4.73	13.24
	2007	4263					5.0	22.6	3.21	7.72
Northern Colorado	2001	2989	8.0	17.5	5.65	11.19	7.2	22.6	4.64	11.15
	2002						*			
	2003	2484	6.6	17.1	4.67	9.17	6.3	20.6	4.20	9.33
	2004	3789	7.0	15.6	5.17	9.59	6.9	22.8	4.46	10.78
	2005	4038	7.9	12.8	6.11	10.12	10.8	29.9	6.07	19.10
	2007	4038					4.6	43.4	2.03	10.31

Table 24. (continued)

	USFWS (2006)				95% Confidence Interval		Revised in this report		95% Confidence Interval	
Recovery Unit	**Year**	**Sampled area (km^2)**	**Density ($/km^2$)**	**%CV(Density)**	**Lower Limit**	**Upper Limit**	**Density (km^2)**	**%CV(Density)**	**Lower Limit**	**Upper Limit**
Western Mojave	2001	5615	7.6	9.4	6.31	9.11	5.6	13.8	4.32	7.39
	2002	1595	7.1	10.6	5.77	8.73	5.8	24.2	3.66	9.31
	2003	1595	5.7	8.8	4.75	6.72	3.8	10.6	3.05	4.61
	2004	7911	5.3	12.5	4.15	6.78	4.4	13.0	3.40	5.64
	2005	9358	6.0	10.3	4.86	7.28	6.1	17.2	4.36	8.52
	2007	9298					4.7	30.8	2.62	8.51

*In the Northeastern Mojave, there are 4 long-term monitoring strata. Only CS could be analyzed in 2002, while in 2003 and 2004, BD could not be analyzed. No recovery unit estimate is provided for 2002, and the 2003 and 2004 estimates are based on 3 of 4 strata. In the Eastern Mojave, only one of the three strata (Piute-Eldorado) was surveyed in 2003, so no estimate is provided for the recovery unit. The single stratum in the Northern Colorado Recovery Unit was not surveyed in 2002.