Range-wide Monitoring of the Mojave Population of the Desert Tortoise:

2007 Annual Report

U.S. Fish and wildlife Service
Desert Tortoise Recovery Office

November 2008

Recommended Citation: U.S. Fish and Wildlife Service. 2008. DRAFT Range-wide Monitoring of the Mojave Population of the Desert Tortoise: 2007 Annual Report. Report by the Desert Tortoise Recovery Office, U.S. Fish and Wildlife Service, Reno, Nevada.

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ACKNOWLEDGEMENTS

Suggestions and considerations for the design of this project were first set out in Anderson and Burnham (1996); this paper has continued to guide improvements to the project as new data update our understanding of desert tortoises. S. Buckland, L. Thomas, T. Marques, E. Rexsted, and D. Harris conducted a 2008 workshop for distance sampling in Marshall, California. Their general instruction and specific input during the analysis for this report were invaluable.

R. Scofield (U.S. Department of Interior) and C. Everly (U.S. Department of Defense) coordinated support by land managers (state and federal agencies, including military installations) in the Desert Managers Group for sampling in California.

The staff of the U.S. Bureau of Land Management, Riverside, California, provided spare styrotorts and molds for the training lines. R. Patil (University of Nevada, Reno) updated the Ruggedized Data Assistant (RDA) data-collection forms and procedures used in 2007. F. Getz (General Services Administration) assisted with contracting work in California. Funding or support-in-kind was provided by Edwards Air Force Base; Fort Irwin National Training Center; the Marine Corps Air Ground Combat Center; the Marine Corps Air Station, Yuma; Joshua Tree National Park; Clark County, Nevada, Multiple Species Habitat Conservation Plan; the California Desert Division of the Bureau of Land Management; and the Arizona Strip Office of the Bureau of Land Management.

Personnel from Kiva Biological Consulting (California) led by K. Wright and from the Great Basin Institute (Nevada, Arizona, and the Beaver Dam Slope of Utah) led by Dr. P. Kahn conducted the field surveys directly overseen by the USFWS. We acknowledge the hard work of all the field monitors who collected data:

L. Backus, E. Bonhett, G. Botello, J. Brouwer, M. Brouwer, A. Croisant, R. DePond, J. Dushane, T. Embrey, D. Focardi, M. Gallagher, T. Graham, N. Grenier, S. Harris, B. Hasskamp, M. Hasskamp, S. Jones, C. Keaton, K. Kermoian, P. Kermoian, C. Kuntzsch, M. MacIntosh, T. Manney, A. Padilla, L. Pavliscak, R. Saltmarsh, P. Seamount, J. Sonn, C. Spake, T. Thigpen, R. Vaghini, K. Weeks, J. Weidensee, R. Williamson, J. Wilson, S. Wong, K. Wright, J. Wright, J. Young, and S. Zimnavoda.

Drs. S. Corn, P. Medica, and K. Nussear (USGS); and E. Aldrich, and Drs. J. Heaton and R. Marlow (University of Nevada, Reno), were instrumental in field crew training. A. McLuckie coordinated field efforts on the Beaver Dam Slope and has written up a full report for the results summarized here from the Upper Virgin River Recovery Unit.

The following people provided much appreciated comments on the draft report:

RANGE-WIDE DESERT TORTOISE POPULATION MONITORING
2007

INTRODUCTION

The Mojave Desert populations of the desert tortoise (*Gopherus agassizii*) were listed as threatened under the Endangered Species Act in 1990. The initial recovery plan (USFWS, 1994) designated six recovery units and specified that decisions about continued listing could be applied to individual recovery units. 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 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; USFWS, 2006). In 1999 the Desert Tortoise Management Oversight Group (MOG) endorsed the use of line distance sampling (Buckland et al., 2001) as the method for estimating range-wide desert tortoise density.

Distance methods use the distance from the center of the transect lines to tortoises found in order to model a detection function. 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 other assumptions in distance analysis – 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 is often violated during line distance sampling of tortoises, but the use of two observers minimizes the associated error and allows use of a correction factor by estimating 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, and presents the analysis of abundance of desert tortoises in 2007.

METHODS

Study Areas and Transect Locations

Long-term monitoring strata are indicated in Figure 1. These will be used over the life of the project to describe population trends in areas managed to conserve tortoises. In addition, some strata are surveyed temporarily so that local density estimates can be made. Density estimates for these single-year strata (Figure 1) are not included in annual recovery-unit-level estimates that are assessed for long-term trends.

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 masked out 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 "slid" 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). A set of guidelines were developed after training to set conditions under which non-standard transects would be created by 1) deflecting transects inward, 2) creating rectangular transects along obstacles associated with human development (especially large roads), 3) shortened to enable transects to be completed before 4pm each day (Appendix A).

The optimal number of transects in a monitoring stratum is defined by our program as the number of transects that are expected to encounter enough tortoises to give sufficient precision to detect an increasing trend over a 25-year period. This precision was estimated by Anderson and Burnham (1996). The optimal number in a given stratum is a function of the number of tortoises that might be encountered there, as well as the area of the stratum – its proportional contribution to the recovery unit density estimate (Buckland et al. 2001). The number of transects planned in each stratum was a function of the optimal number as well as on available funding from associated land management agencies. 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. As in 2004 and 2005, the study design placed transects at random with respect to the location of desert tortoises. This was done using a systematic design of nested lattices, with each cell of the lattice holding a transect starting point. In strata with more transects, nested lattices with smaller spacing (3km spacing) 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 provide more even coverage of the entire stratum, something that may not occur if a strictly random placement of transects is used.

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 (**Error! Reference source not found.**). The goal of the final (joint) week is 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 approximately 100% of tortoises within 1m of the centerline, 2) shape of the team's detection function indicating appropriate search technique, and 3) leader detecting close to 80% of the tortoise models, which indicates the team together has a search pattern that will continue to detect approximately 100% of all tortoises on field transects.

This year, Nevada crews started in mid-March and were contracted biologists; most without experience. In the past, interns from the Student Conservation Association (SCAs) were used through the University of Nevada, Reno (UNR), and the crew leaders and members were provided with longer-term, broader training. In 2008, UNR did not hire SCAs, but 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 background in biology and the specialized skills needed for line distance sampling (March 12 to 22).

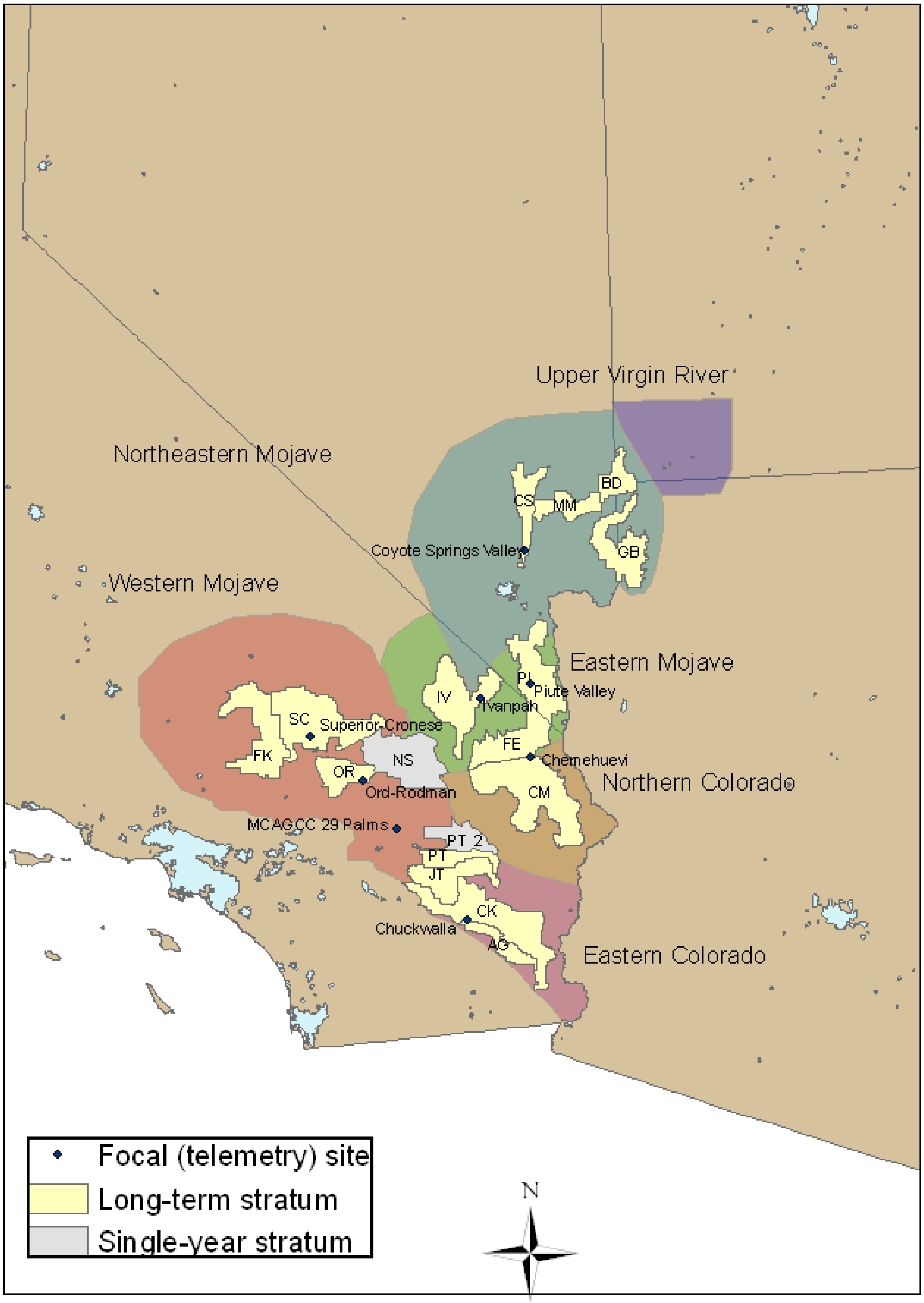

Figure 1. Range of tortoises in the Mojave population (USFWS 1994), color-blocked to show recovery units. Monitoring strata (long-term and single-year) fall within recovery units. Strata abbreviations in Table 1.

Table 1. Training schedule for 2007

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.

Week	Date	Activity	Location	Trainer
Wk1	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 Friday, 16 March	Practice transects (start with 400m, end with 12km)	LSTS	Marlow, Nussear, Medica
Wk2	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 Thursday, 22 March	Practice transects – teams of 5, with electronic and paper data collection	LSTS	Medica, Kahn
Wk3+	Monday, 26 March	Desert Tortoise Recovery and Monitoring Program	USGS	Allison (FWS)
		Introduction to Line Distance Sampling		Corn (USGS)
		Tortoise natural history		Woodman (Kiva Biological)
		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	

Estimation of the proportion of tortoises detected at varying distances from the transect centerline

Polystyrene models of desert tortoises ("styrotorts") 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 objects (styrotorts) on the transect center line, and 2) whether their survey techniques yield useful detection functions. For each purpose, many opportunities must be provided, so the course is populated at a very high density of styrotorts (410/km^2).

Crews are sent on transects and training lines as paired, independent observers. That is, the follower is 25m behind the leader and detects tortoises 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 styrotorts is known, data from training lines can also be used to assess 1) the dual-observer assumption that all styrotorts are equally detectable (detections attributed to the follower occur at the same rate as original detection rate by leader), 2) that detection within 1m of the transect centerline is approximately 100%, and 3) 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 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. Because funding sources differ by region for this monitoring program, all crews in the California crew (Kiva in 2007) have equal effort, and all crews in Nevada/Arizona/Utah (GBI in 2007) have equal effort, but the funding differences mean efforts will usually differ between crews on the two teams. For this reason, we estimated detection functions separately for GBI- and Kiva-monitored strata.

We 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 observation of a live tortoise with midline carapace length (MCL) greater than 180mm. A record was also created for each transect where no tortoises were seen. Transects were packaged into monitoring strata ("regions" in Program DISTANCE).

We 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, we use 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 by Buckland et al. (2001).

We also used AIC to compare models that estimated the detection function separately for each stratum or pooled across all strata. The encounter rate is much less sensitive to small sample sizes, so it was estimated for each stratum separately.

Proportion of tortoises that are available for detection by line distance sampling (G_0)
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 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 cohorts of focal tortoises in at least one of the sampling areas in each recovery unit (Figure 1). The focal animals are equipped with radio transmitters and observed daily while transects are sampled in the associated strata (Table 5).

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), and its position was recorded, either below ground (in burrow) or above ground (at mouth of burrow, under vegetation, or in the open). For each day, we calculated the proportion of observations where the tortoises were visible (available for sampling). We calculated G_0 statistics for each G_0 group as the grand mean of all G_0 sites in the group. Calculations started by averaging activity level for each tortoise each day and then for all tortoises at that site on a given day. These daily site values were used to estimate the mean and variance of G_0.

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 in terms of its contribution to the precision of density. 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 G_0.

During planning for the 2007 field season, an error was discovered in past calculations of G_0. In the past, the standard error for a given year was estimated as:

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

Where G_0 was computed as the weighted mean of all tortoise observations at all sites over the field season, and *n* was the total number of observations across all tortoises during the 2-month period.

Instead, we estimated G_0 as the marginal mean using the average proportion of visible observations per tortoise per day, and factoring effects of site and year. Further, the standard error was estimated as:

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

This had the effect of increasing the error estimate approximately ten-fold, decreasing the precision of the density estimate.

We examined the effect of this decrease in precision for the standard error of G_0 on the density estimate (Appendix B), and determined that G_0 estimation now contributed about 60% of the variance in density. Further analysis identified daily variance within sites as an important contributor to the total variance in G_0. This is not surprising, because over the 2-month field season, temperatures and flowering plant availability are expected to change considerably, affecting tortoise activity.

We used these assessments to change the sampling design 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 the past, the emphasis was instead on sampling randomly across the entire range, and a single G_0 estimate was used.

Proportion of available tortoises detected on the transect centerline by the dual observer method (g_0)
Transects were conducted by 2-person crews using the method adopted beginning in 2004 (USFWS, 2006). Transects are walked in a continuous fashion, with the lead crew member walking a straight line on a specified compass bearing, trailing about 25 m 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. Use of two observers allows estimation of the proportion of tortoises detected on the line; otherwise, the assumption is that all tortoises on the transect centerline are recorded ($g(0) = 1$). The capture probability (p) for tortoises within 1 m of the transect centerline was estimated as for a 2-pass removal estimator (White et al., 1982): $p = (\text{lead}–\text{follow})/\text{lead}$, 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: $\hat{g}(0) = 1 – q^2$, where $q = 1 – p$. The variance of p was estimated as the binomial variance: $var = q(1 + q)/np$ (White et al., 1982), where n = the estimated number of tortoises within 1 m of the transect centerline, and the variance of $\hat{g}(0)$ was estimated as twice the variance of p.

Estimates of Tortoise Density

Each year, the density of tortoises is estimated at the level of the recovery unit and for some monitoring strata of interest. The calculation of these densities starts with estimates of the number of tortoises in each stratum from Program DISTANCE, as well as their variance estimates.

$$\hat{D} = \frac{n}{2wL\hat{P}_a\hat{G}_0\hat{g}_0}$$

Where L is the total length of kilometers walked in each stratum, 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). $\hat{P}_a$ 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) was estimated in Program DISTANCE for each stratum. Estimation 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.

The number of tortoises in the set of strata representing a recovery unit can be arrived at by addition, but variances must be combined separately for pooled and unpooled estimates (Buckland et al., 2001:89). For desert tortoise densities, the encounter rate (n/L) is estimated independently for each stratum (“unpooled”), whereas proportion of available tortoises (G_0), and proportion of available tortoises detected on the transect center line (g_0) 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. When the latter three components are applied to the density in any one stratum, their estimation was based on data “pooled” from other strata as well, so the method described in Buckland et al. (2001) must be used to combine these variances correctly. Because the range-wide desert tortoise monitoring project has more than one level of analysis (strata and recovery units), pooled and unpooled variance estimates cannot currently be combined correctly 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), no estimate was made of the proportion of tortoises undetected on the line (g_0). This was assumed to be negligible based on training data (USFWS, 2006:25) and use of the dual observer technique since 2004. In these analyses, a single G_0 was used, reflecting the fact that transects were completed over the entire season in each stratum, so a single G_0 capturing all spatial and temporal variability was used. Program DISTANCE was able to account for this relatively simple structure of pooled and unpooled estimates, and was used to complete the entire 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 separately address topics in data management and field season preparation.

RESULTS

Field Observer Training
Crew trials were conducted on 27 and 28 March. 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 2 and 3 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 (Pa). Detection curves that fall more rapidly after the first few meters are believed to indicate the most 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).

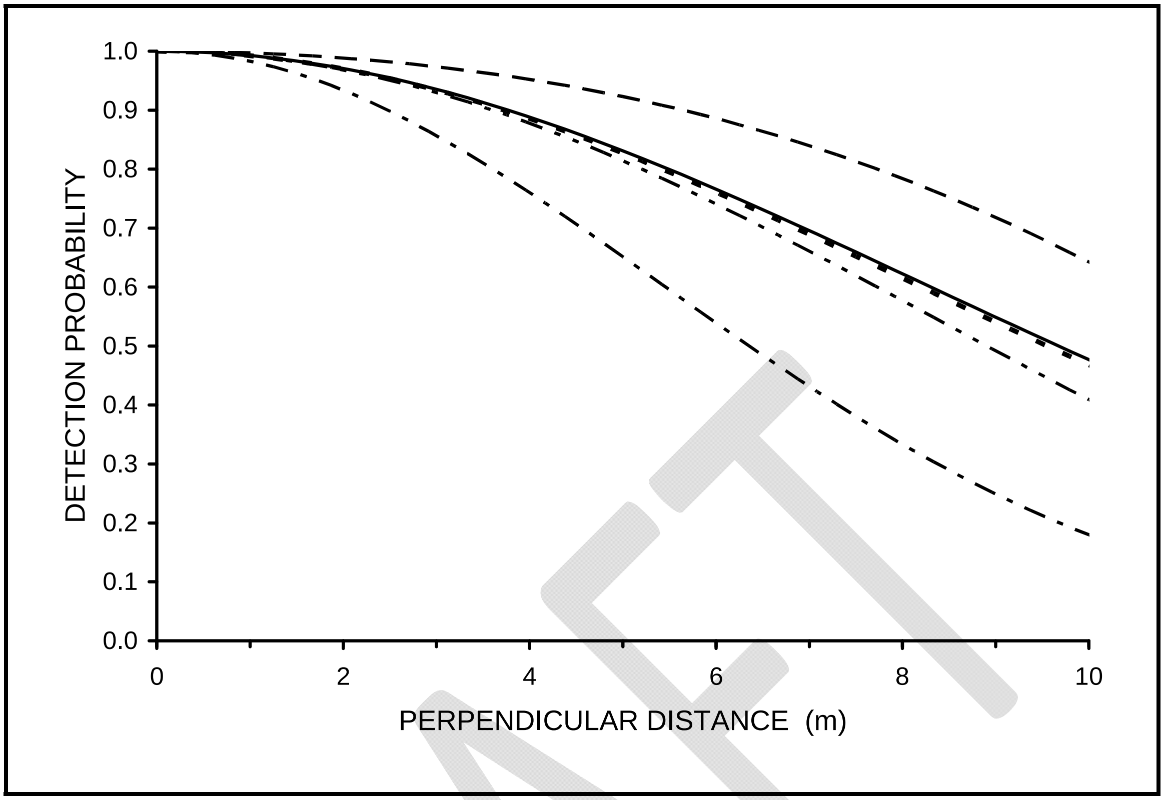

Figure 2. Detection curves for 2007 trainee teams returning after at least one year of monitoring experience. Curves are based on 16km trials.

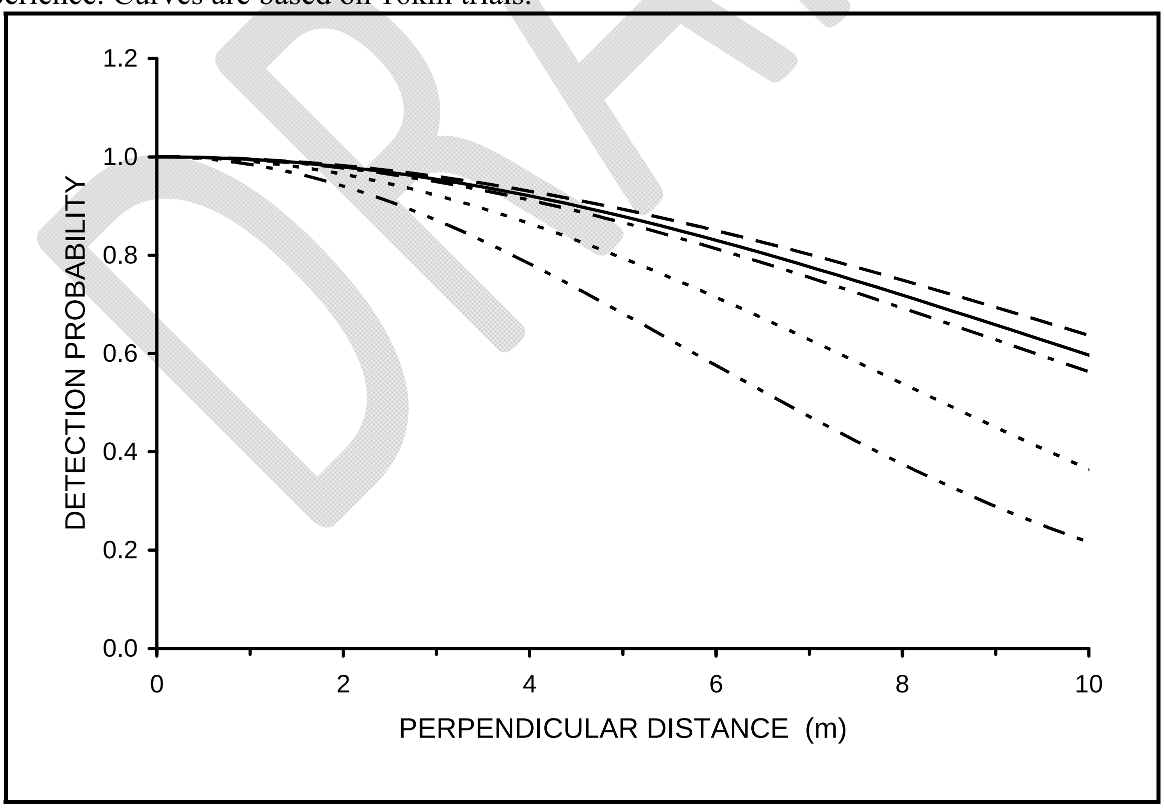

Figure 3. Detection curves for 2007 first-year trainees. Curves are based on 16km trials.

Estimation of the proportion of tortoises detected at varying distances from the transect centerline

Table 2 reports team statistics for each team after collecting data on 16km on the evaluation lines. Measurement accuracy reported in Table 2 gives the average absolute difference between the expected and measured perpendicular distances from the styrotort to the walked line. All measurements for all styrotorts 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 walking tape, 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 is added to measurements unless crews walk on exactly the measured line that was used to place the styrotort models. The "Detected by Leader" column reports the proportion of all styrotorts that were 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 styrotorts. With an 80% success rate for the leader, a 96% 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 3 reports the proportion of styrotorts 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 numbers for new pairings. Detection on the centerline was expected to be 100%, but with the returning crews 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.

Error! Reference source not found. reports the detection probability within 1m of the transect centerline using the dual-observer method, as well as the expected detection rate if tortoises detected by the leader and follower are seen with the same probability. The difference between single-observer and double-observer detection probabilities is consistent with the scenario under which 30% of styrotorts that are unreported by the leader were missed at random from the pool of equally detectable styrotorts; the remaining 55% that were missed have a lower probability of detection (and were not detected by the follower at the expected (single-observer) detection rate. This contrasts with the assumption that all tortoise models were equally detectable but some were missed at random; it affects our assumption that followers detect a high percentage of tortoises that were missed by the leaders. The average dual-observer proportion (g_0 pre-field season = 0.81) may apply to above-ground tortoises only, without describing success at detecting tortoises in burrows. Instead, we opted to use the g_0 calculated using leader detection proportions on walked transects (see *Estimates of Tortoise Abundance*, below) to modify the estimate of detectable tortoises (G_0).

Table 2. Diagnostics for individual teams after training

Team	Detected by leader	Measured v. exact model distance (m)	Estimated abundance	Lower CL	Upper CL
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	**>0.75**	**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**		

Table 3. 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			

	Pre-Season Detection Probabilities			Post-Season Detection Probabilities		
Team	1m	2m	5m	1m	2m	5m
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**

Table 4. Proportion of tortoise models that were detected by the leader (single-observer) or leader-follower team (dual-observer) following training. **NUMBERS FOR 2004 AND 2005 ARE EXPECTED TO CHANGE IN THE FINAL VERSION OF THIS REPORT.**

				Observed proportion detected		Expected proportion detected	
Within *x* m of centerline	Time period	Year	# of Teams	Single observer (SD)	Dual observer (SD)	If 100% of tortoises missed by the leader were as visible as those that were detected	If 30% of tortoises missed by the leader were missed at random
1	Pre-field season	2004	11	0.66 (0.121)	0.73 (0.084)	0.88	0.72
		2005	13	0.69 (0.18)	0.75 (0.177)	0.90	0.75
		2007	20	0.72 (0.146)	0.81 (0.157)	0.88	0.72
1	Post-field season	2004	7	0.61 (0.322)	0.62 (0.326)	0.85	0.68
		2005	12	0.61 (0.206)	0.67 (0.194)	0.85	0.68
		2007	15	0.60 (0.214)	0.68 (0.220)	0.78	0.61
2	Pre-field season	2004	11	0.63 (0.048)	0.55 (0.123)	0.87	0.70
		2005	13	0.62 (0.177)	0.68 (0.192)	0.86	0.69
		2007	20	0.64 (0.126)	0.71 (0.117)	0.87	0.71
2	Post-field season	2004	7	0.55 (0.123)	0.63 (0.154)	0.80	0.63
		2005	12	0.52 (0.158)	0.6 (0.186)	0.77	0.60
		2007	16	0.52 (0.155)	0.65 (0.153)	0.77	0.60
5	Pre-field season	2004	11	0.56 (0.061)	0.68 (0.072)	0.80	0.63
		2005	13	0.59 (0.059)	0.69 (0.066)	0.83	0.67
		2007	20	0.59 (0.125)	0.69 (0.104)	0.83	0.66
5	Post-field season	2004	7	0.45 (0.123)	0.53 (0.141)	0.70	0.52
		2005	12	0.48 (0.122)	0.58 (0.126)	0.72	0.55
		2007	16	0.5 (0.128)	0.63 (0.105)	0.75	0.57

Teams were tested immediately after training, before and after the field season.

Further, Table 3 indicates the proportion of styrotorts detected each year within 5m of the transect centerline by the leader only (column 5). This number is relatively consistent (mean=0.58, SD=0.09) is one measure of the proportion of tortoises that are expected to be found using a centerline-scanning approach to detecting tortoises.

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. To avoid having too few observations to estimate curves, no attempt was made to create detection functions for individual strata. The resulting curves of expected detections are graphed against observed distances in plotted as histograms (Figure 4 and **Error! Reference source not found.**). The estimate of P_a for strata surveyed by GBI was 0.61 with $CV(P_a)$=0.086. The estimate of P_a for strata surveyed by Kiva was 0.49 with $CV(P_a)$=0.086.

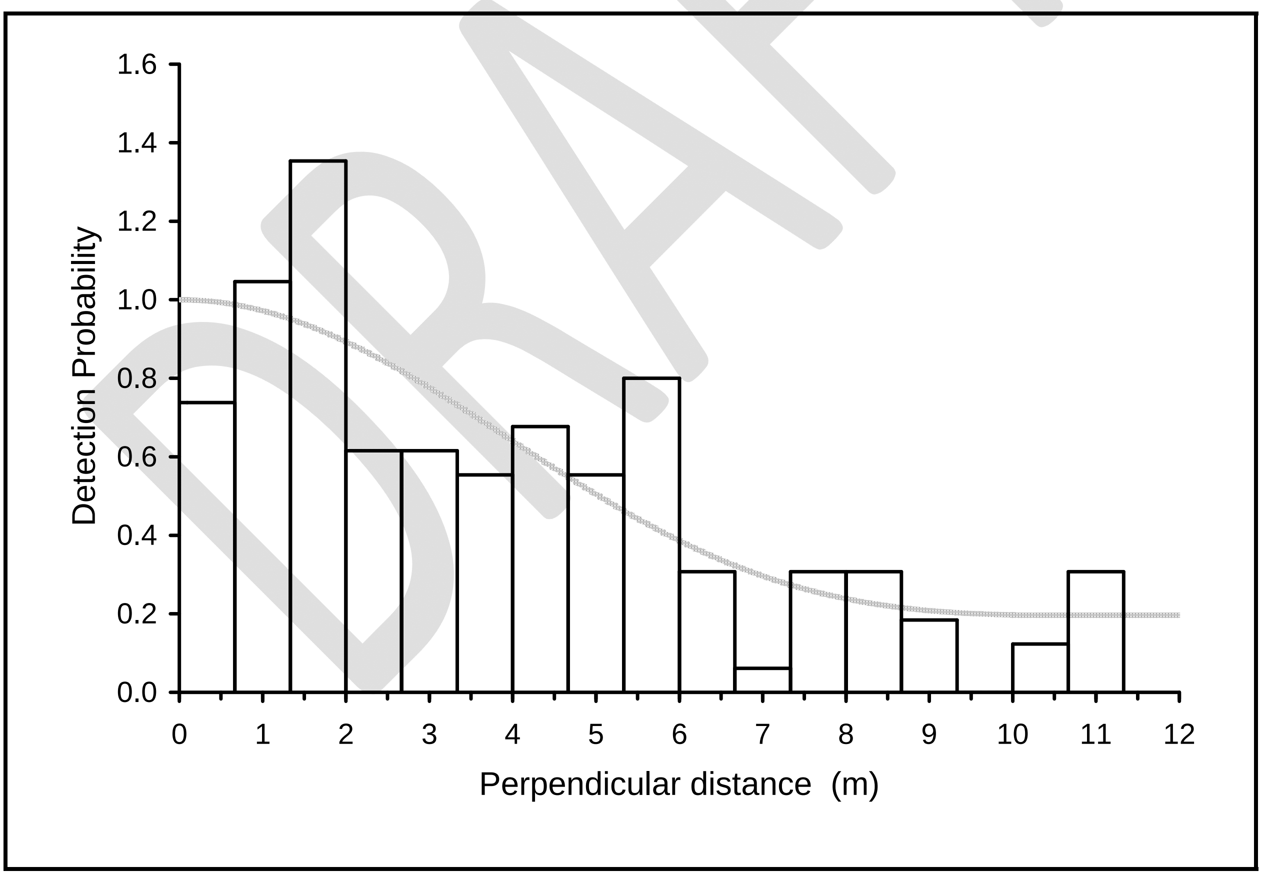

Figure 4. Detection function for live tortoises found by Kiva with MCL ≥ 180 mm. Observations were truncated at 12 m.

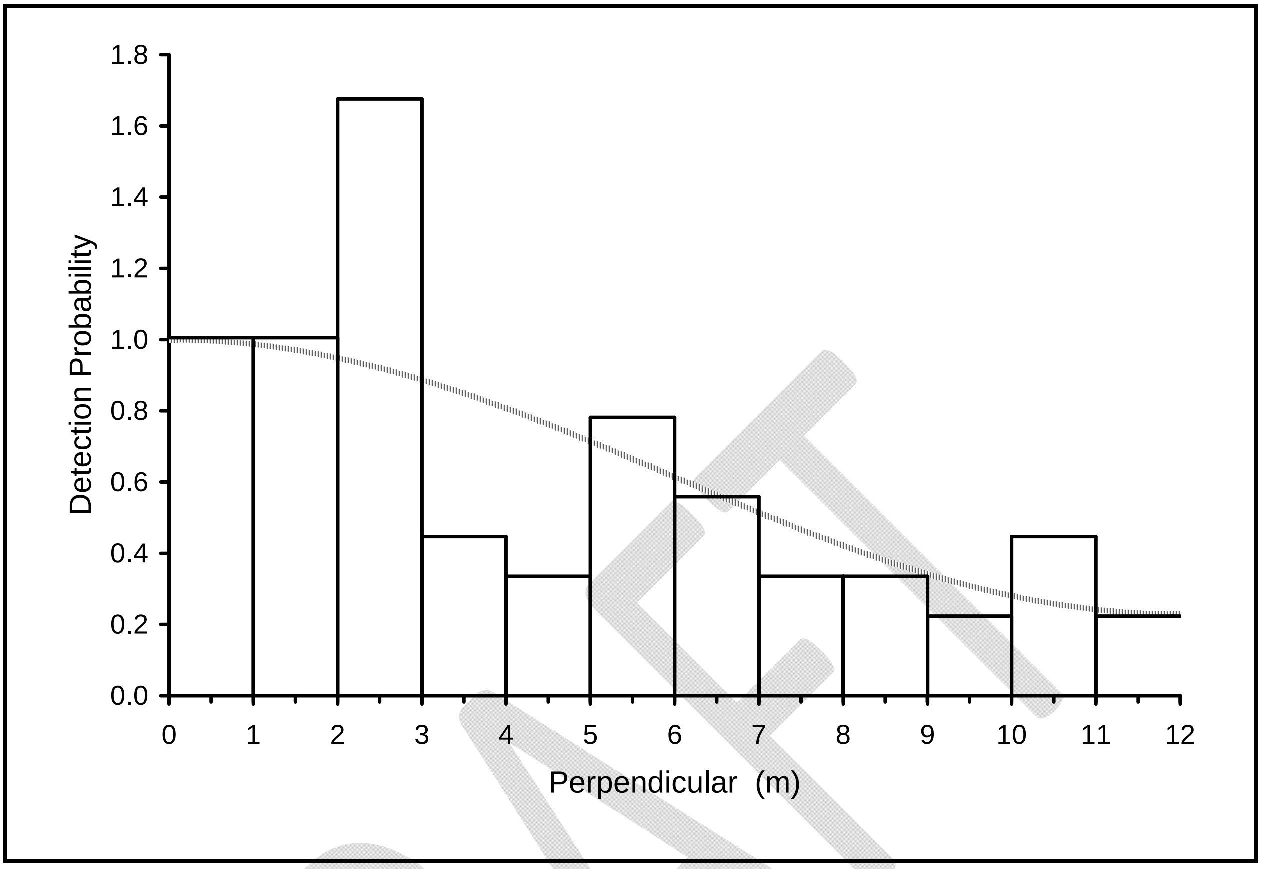

Figure 5. Detection function for live tortoises found by GBI with MCL ≥ 180 mm. Observations were truncated at 12 m.

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

Table 5. Jointly estimated statistics and standard errors used in conjunction with independently estimated encounter rates in each monitoring stratum in 2007. Standard errors in parentheses.

Recovery Unit	G_0 sites	Sampled area (km^2)	Detection rate (P_a)	Availability (G_0)	Detection on line (g_0)
Northeast Mojave	Coyote Springs	4917	0.61 (0.086)	0.70 (0.14)	0.915 (0.131)
Eastern Mojave	Piute, Chemehuevi, Ivanpah	6681	PI: 0.61 (0.086) FE, IV: 0.49 (0.086)	0.79 (0.14)	0.915 (0.131)
Eastern Colorado	Chuckwalla	4263	0.49 (0.086)	0.87 (0.07)	0.915 (0.131)
Northern Colorado	Piute, Chemehuevi, Ivanpah	4038	0.49 (0.086)	0.79 (0.14)	0.915 (0.131)
Western Mojave	Superior Cronese, Ord Rodman, MCAGCC	13092	0.49 (0.086)	0.85 (0.10)	0.915 (0.131)

Proportion of available tortoises detected on the transect centerline by the dual observer method (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, $\hat{p} = 0.708$, and the proportion detected using the dual observer method, $\hat{g}(0) = 0.915$ (SE = 0.13). This is equivalent to a "removal" type mark-recapture estimate.

Estimates of Tortoise Density

Density estimates were generated in DISTANCE separately for each monitoring stratum (Table 6). For average density in each recovery unit, these stratum estimates were weighted by area. Measures of precision were calculated separately. Although the encounter rate was estimated separately for each stratum, and independent variances can be added, the detection function and G_0 were estimated jointly, so these variances are not independent (Buckland et al., 2001:89). These jointly estimated values are in Table 5.

Table 6. Stratum-level descriptions and statistics

Recovery Unit	Sampling Area		Area (km^2)	Total Length of Transects (km)	Sampling Dates		Field Observers	n (tortoises observed)	CV(n)	Density	CV(Density)
					Begin	End					
Northeast Mojave			**4917**	**2316.1**	**10-Apr**	**30-May**					
	Beaver Dam Slope	BD	828	478.0	9-May	30-May	GBI	6	0.47	0.4	0.35
	Coyote Springs	CS	1144	917.9	10-Apr	25-May	GBI	14	0.28	0.2	0.23
	Gold Butte Pakoon	GB	1977	299.7	17-Apr	29-May	GBI	4	0.43	0.3	0.33
	Mormon Mesa	MM	968	620.5	10-Apr	25-May	GBI	22	0.23	0.2	0.20
Eastern Mojave			**6681**	**803.9**	**1-Apr**	**9-Apr**					
	Fenner	FE	1862	178.2	1-Apr	6-Apr	Kiva	10	0.24	7.1	0.21
	Ivanpah	IV	2567	180.1	1-Apr	6-Apr	Kiva	4	0.59	3.5	0.48
	Piute Eldorado	PI	2252	445.6	2-Apr	9-Apr	GBI	20	0.25	4.6	0.22
Eastern Colorado			**4263**	**1151.7**	**28-Apr**	**15-May**					
	Chocolate Mountain Air Gunnery Range	AG	755	404.3	1-May	11-May	Kiva	27	0.21	7.5	0.22
	Chuckwalla	CK	3509	747.4	28-Apr	15-May	Kiva	32	0.25	5.0	0.24
Northern Colorado			**4038**	**180.0**	**1-Apr**	**6-Apr**					
	Chemehuevi	CM	4038	180.0	1-Apr	6-Apr	Kiva	7	0.35	5.0	0.28
Western Mojave			**9298**	**1150.6**	**6-Apr**	**26-Apr**					
	Fremont Kramer	FK	2463	299.9	13-Apr	26-Apr	Kiva	7	0.39	2.8	0.33
	Joshua Tree NP	JT	1655	134.9	7-Apr	10-Apr	Kiva	4	0.59	3.5	0.48
	Newberry Springs*	NS	2682	172.2	16-Apr	22-Apr	Kiva	5	0.54	3.5	0.44
	Ord Rodman	OR	1124	140.9	13-Apr	25-Apr	Kiva	10	0.35	8.4	0.30
	Pinto Mountain	PT	608	119.4	6-Apr	11-Apr	Kiva	3	0.51	3.0	0.42
	Pinto Mountain 2*	PT2	1113	161.4	6-Apr	11-Apr	Kiva	4	0.58	2.9	0.47
	Superior Cronese	SC	3447	455.5	13-Apr	25-Apr	Kiva	25	0.25	6.5	0.24

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

Recovery-unit-level density estimates are provided in Table 7. The final column indicates percent change from the most recent density estimates in 2005 (USFWS 2006). In all but the Eastern Mojave, reported density is lower than in 2005. This might reflect true changes in population size, or might reflect the continuing changes in 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, elevation and/or vegetation type). This will be undertaken once the draft Recovery Plan (USFWS, 2008) is finalized and recovery units with associated tortoise conservation areas have been determined.

Table 7. Estimated abundance of Desert Tortoises in the Mojave Desert in 2007

Recovery Unit	Area (km^2)	Transects	n	Density ($/km^2$)	SE	CV %	% change from 2005
Eastern Colorado	4263	100	53	5.47	23.01742	6.38	-14
Northern Colorado	4038	15	6	4.98	40.50477	7.86	-37
Western Mojave	9298	97	47	5.00	22.43316	5.95	-16
Eastern Mojave	6681	76	35	5.34	24.7002	5.54	-4
Northeast Mojave	4917	240	43	1.87	26.4607	2.15	-13
Upper Virgin River*	114	157	92	14.9	2.04	13.7	-32

* Data for Upper Virgin River taken from McLuckie et al. 2008.

Debriefing to identify strengths and weaknesses in preparation for future years
In previous years, planning did not include field contractors. 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. Field visits by the DTRO Monitoring Coordinator made it clear that there were various ways that protocol and field season planning could be improved to address specific difficulties. The above observations led to 2 post-season debriefing meetings (one each for data management and field season preparation) to include contractors 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 from the data management (collection database development, QAQC I and II) and training cooperators.

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 complex data collection to characterize visibility using transect protocols and visibility after tortoise are located using radiotelemetry.

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

Following training for the 2007 field season, the FWS requested copies of training products created under earlier agreements between Clark County and UNR. These products confirmed that the 2007 field training was not an anomaly. Training had been developed around refining the search procedures of crews in California that were already proficient at find desert tortoises using other protocols, and 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 could be characterized as the time when annual changes were introduced, and when crews were tested for ability to detect fabricated tortoise models to give the correct detection curve.

One goal for the 2008 field season 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 particular contracted crews. The training program should be usable by inexperienced crews 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 by the FWS Monitoring Coordinator with input from field crews and UNR. They were put into development by UNR for the 2008 field season (Table 8).

Table 8. 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 similar responsibilities between all field teams for providing their own logistical and material support. This will represents a change for the Nevada/Arizona/Utah field crews as UNR (which previously provide these benefits in the eastern part of the range) and FWS shift oversight responsibility. Some electronic equipment will be provided by the FWS to all field crews, and equipment that does not require standardization will be the responsibility of the contracted teams.
- 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. FWS has requested/invited increased BLM representations 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 coordinated actively to provide materials for database design, for error-checking script requirements, and to test the prototype database for 2008.
- Early development of the database included drafting a data dictionary that clarifies the simple field names in the data forms. Early development of the database was also identified as an important part of training development. The new dictionary also

identifies fields that require further instruction during training and/or have resulted in many errors in previous years.

- Improve coordination between contractors involved in data handling. Provide necessary clarity by putting a data management plan in place before field crews are contracted so that at all three stages of quality control, responsibilities are clear. Protocols need to be in place in January before each field season.

Coordination

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

Tasks and timelines

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 9 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 9. Planned and actual timelines for desert tortoise monitoring in 2007 and planned completion dates for the 2008 field season. Dates are sequential based on 2008 planned dates and start the year before field work is done.

Activity	Product	2007 Planned Date	2007 Actual Date	2008 Planned Date
First coordination meetings - field season debriefings	Improvement activities and timelines	22-Oct	15-Jun	30-Jun
Coordination meeting	Updated training/data mgmt/access 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

Activity	Product	2007 Planned Date	2007 Actual Date	2008 Planned Date
Generate survey strata and transects	GIS shapefiles of monitoring strata and transect start points	15-Nov	15-Mar	15-Dec
Outline field and 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 budgets, gain funding commitments	Agency budget commitments	2-Jan	2-Jan	2-Jan
Develop Contractor QA/QC database	Digital database	15-Jan	25-Mar	15-Jan
Access and permitting 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
Research Permits	Federal and state research permit requests submitted	1-Nov	15-Feb	31-Jan
Develop maps for field crews	Paper maps for each monitoring stratum	15-Feb	15-Apr	1-Feb
Develop and coordinate training session	Training course preparations	15-Mar		1-Feb
Plan transect access	Strategy for transect completion in each stratum	28-Feb		28-Feb
Test contractor database	Final contractor database & paper data forms	15-Feb	1-Apr	15-Mar
List of Authorized Individuals	Submit crew qualifications to USFWS and CDFG	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
Quality Assurance/Quality Control 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

DISCUSSION

Modification of previous procedures

To standardize rules for abandoning standard transect protocols given particular obstacles, a set of guidelines were developed at the beginning of the field season (Appendix A). Based on site visits with crews and visual (GIS) inspection of how these rules were applied on specific transects, these guidelines were not 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.

Two other significant changes were made to the sampling design for 2007. These changes in turn reflect a move away from artificial limitations of using a single software program to analyze distance sampling data.

The previous report on the range-wide monitoring program to date (USFWS 2006) has drawn attention and questions about reliance on a set of "focal" sites where radio-equipped tortoises are monitored to adjust abundance estimates to account for the proportion of tortoises that are not visually detectable during the field season. 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. On the one hand, this has led cooperating agencies to question the value of maintaining so many focal sites (8 in 2007), and on the other hand has led to criticism for allowing software to limit our ability to analyze data appropriately.

The first type of questioning led researchers and agencies to ask whether a more cost effective way could be found to adjust density estimates. Our own data 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 attempt 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, of 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 in agreement on that point.

The design of the range-wide monitoring program does use a model to limit G_0 to an acceptable range of variability. By restricting monitoring to 1 April to 30 May and by constraining the time of day when sampling can occur (starting no earlier than 7am until 1 May, no later than sunrise thereafter), we incorporate qualitative models of tortoise activity to optimize the number of tortoises that are above-ground. 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, we will continue to rely on focal 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 we conduct monitoring. Also, we can not always monitor during the best period for a particular site. Due to annual military operations scheduled on Chocolate Mountain Air Gunnery Range, we know that transects cannot be completed in early April, which we project would have the highest activity levels, close to or exceeding 0.80. All of these reason indicate the value of maintaining regional sites to monitoring tortoise activity.

The second critique of the monitoring program's use of G_0 is that we should not be constrained by available software to use only one estimate for G_0. Many statistical procedures were implemented before computers (let alone specialized software) were available, and distance estimation is also possible without specialized software. Starting in 2007, we set up a sampling design that requires estimation of multiple G_0, and we were able to use these for analysis by moving outside of Program DISTANCE. That software is very useful for developing several components of a distance analysis, but it is not necessary. In 2007, we used it to reasonably constrain and estimate our fairly straightforward detection function, to estimate stratum-specific encounter rates, and to estimate variances for both.

Progress in 2007 and Plans for the Future

The 2007 field season was shaped by a shift in oversight to the FWS. The FWS is tasked with coordinating the range-wide monitoring program to provide population estimates that are relevant to the recovery plan criteria (USFWS, 1994), but cooperating agencies will also have more local questions concerning the abundance of desert tortoises. Priorities for the 2007 field season included 1) putting a focus on improving ability to detect trends in desert tortoise abundance at the recovery unit level, and 2) reporting density estimates at spatial scales that are relevant to recovery efforts and to cooperating agencies.

Improving ability to detect trends in desert tortoise abundance

A large source of variance to abundance 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 thermal characteristics changed markedly.

For 2007, the study design was changed to minimize the variance of G_0. Each G_0 site and neighboring transect strata were completed in sequence so that they could be completed as quickly as possible and only a limited spatial area was described. Table 10 compares the estimates of G_0 between the 2005 with the estimates and their standard error (the measure of imprecision) from 2007. In one recovery unit, the standard error of the estimate apparently increased, but in all others, the standard error is lower, which has the effect of increasing the precision of the density estimates. The method for calculating the variance of G_0 was also corrected – Appendix C updates Table 8 from USFWS (2006) to reflect higher variances for G_0.

Table 10. Comparison of estimated G_0 and standard error by recovery unit in 2005 and 2007.

	2005			2007		
Recovery Unit	Mean	Standard Error (#focal sites)	Days	Mean	Standard Error (#focal sites)	Days
Eastern Colorado	0.66	0.16 (1)	52	0.87	0.07 (1)	5
Eastern Mojave	0.85	0.08 (3)	52	0.79	0.14 (3)	12
Northern Colorado	0.68	0.20 (1)	52	0.79	0.14 (3)	3
Northeastern Mojave	0.92	0.21 (1)	52	0.70	0.14 (1)	37
Western Mojave	0.91	0.11 (3)	52	0.85	0.10 (3)	12

Reporting density estimates at other relevant spatial scales

When describing the modified approach to incorporating G_0 estimates in final calculation of density and/or abundance, it was noted that the new approach requires the analyst to use copyrighted software only for some parts of the analysis instead of using it for all purposes. The copyrighted software for distance sampling (Program DISTANCE, ver. 5.0) does not accommodate separate estimates of G_0 for different sampling strata, so this part of the analysis must be completed "by hand." Program DISTANCE also does not accommodate more than one level of stratification, so previous software-dependent analysis only generated density estimates at one level of analysis – the recovery unit. This spatial scale is not the only one of interest to land managers and other cooperators, however. By moving the final steps of the analysis out of Program DISTANCE, in 2007 we are able to provide density estimates for Chocolate Mountain Air Gunnery Range, for instance, as well as separately for each monitoring stratum. Appendix C provides stratum level density estimates as well as corrections to the variance for G_0 (see above). Density estimates at the level of the recovery unit will differ from those in USFWS (2006) because they were generated by weighting these stratum-specific densities according the area they represent in the recovery unit. These smaller scale density estimates can be correctly used to generate recovery unit-level density estimates.

Future plans for the range-wide monitoring program

We report the planning and preparation actions that were developed in June 2007 under "Debriefing to describe strengths and weaknesses of project preparation and execution." These are measures taken on the path of quality assurance, to ensure data collected will address the goals of the project. The focus of these goals for 2007 was to improve the precision of the density estimate, and to refine estimates so that density estimates could be provided at the recovery unit and smaller scales. Data collection in 2007 was also targeted at describing the amount and type of landscape where 12km transects are not feasible and sampling is compromised. For future years, the immediate goals will be to improve consistency between field procedures across the range and the formalize consistency in the sampling frame between years.

Density estimates

Our estimates of density for 2007 are lower than previous estimates from 2005 (Table 7). 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. Since 2004, there have been increasing efforts to cover all areas within sampling strata. We would expect estimated overall tortoise densities to decrease if many of the areas added to the sampling frame contain lower densities of tortoises than the core areas sampled among all years.

How are these population estimates to be compared between years? Sampling designs from year to year do not allow “design-based” population estimates, so they can only be compared if it is possible to generate “model-based” population estimates. As mentioned earlier, we can use use model-based statistics to estimate density for unsampled areas based on sampled areas with similar characteristics. This approach requires strata to be further subdivided into substrata. Substrata might include low-relief areas and high-relief areas, as a simple example. Even if high-relief areas were relatively undersampled, 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, we planned a design-based sampling approach for 2008. Before the next 5-year summary report, a priority will be to assess the feasibility of modeling density to represent entire strata, and then to complete these analyses for 2001-2007, if possible. From this, we will be able to report abundance estimates for individual strata and recovery units, comparable between years.

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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 area 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 judgement. 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 is 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

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 row 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	5.9	0.09
0.64	0.09	6.8	53.1	40.1	5.9	0.16
0.64	0.18	3.1	24.1	72.8	5.9	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 give site, all encounters with all telemetered tortoises were recorded (Table B). We 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). We 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 one each day within sites was used to estimate within-site, between date variation, also called "error variance."

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 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

Table F. Estimated marginal mean G_0 by year.			
Year	Mean	Standard Deviation	Standard Error

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 that we used above to test effects and estimate marginal means, we also ran a variance components analysis. Although Recovery Unit is theoretically a fixed effect (because we report values 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, we 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). We 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 and the fact that DISTANCE analyses can use only a global estimate of G_0, density estimates may be more accurate (if less precise) if analysis is restricted to a single year and a single recovery unit or even a single DWMA.

APPENDIX C: UPDATES TO TABLE 8 OF THE 2001-2005 SUMMARY REPORT

The current report is based on spatially constructed estimates of G_0, different estimation of the standard error for G_0, and 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. **Error! Reference source not found.** reports stratum-level density estimates and density estimates for each recovery unit as a result of the above changes. 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, thus making annual estimates represent different types of terrain. For this reason, density estimates are still not comparable between years, but in upcoming evaluations, we anticipate using model-based estimation to adjust the contributions of encounter rates to prior density estimates.

Updates to portions of Table 8 from USFWS (2006)

Year	Recovery Unit	Sampling Area		Area (km^2)	G_0	SE(G_0)	Total Length (km)	n	Density	%CV (Density)	95% CI Lower	95% CI Upper
2001	**Northeast Mojave**			**4549**	**0.896**	**0.219**	**254.8**	**7**	**1.1**	**62.19**	**0.32**	**3.55**
		Beaver Dam Slope	BD	773			7.1	0	0.0			
		Coyote Springs	CS	529			78.8	4	3.4	73.72	0.87	12.99
		Gold Butte Pakoon	GB	1603			94.2	2	1.4	76.47	0.35	5.62
		Mormon Mesa	MM	870			72.5	1	0.9	130.66	0.12	6.82
		Lake Mead NRA North	MN	774			2.3	0	0.0			
	Eastern Mojave			**7122**	**0.747**	**0.502**	**371.5**	**17**	**5.4**	**54.69**	**1.84**	**15.71**
		Fenner	FE	1383			18.7	3	13.5	80.92	2.83	63.95
		Ivanpah	IV	1991			184.9	7	3.2	52.84	1.19	8.48
		Mojave Natl Preserve	MP	1606			24.3	1	3.4	104.53	0.55	21.47
		Lake Mead NRA South	MS	615			19.3	1	4.3	114.52	0.50	37.71
		Piute Eldorado	PI	1527			124.3	5	3.4	62.53	1.07	10.60
	Eastern Colorado			**2861**	**0.930**	**0.065**	**328.0**	**54**	**9.5**	**27.51**	**5.56**	**16.23**
		Chuckwalla	CK	2861			328.0	54	9.5	27.51	5.56	16.23
	Northern Colorado			**2989**	**0.867**	**0.096**	**321.6**	**39**	**7.0**	**22.82**	**4.46**	**10.86**
		Chemehuevi	CM	2989			321.6	39	7.0	22.82	4.46	10.86
	Western Mojave			**8860**	**0.905**	**0.098**	**1384.0**	**160**	**5.1**	**14.24**	**3.86**	**6.75**
		Edwards AFB	EA	1215			1.6	0	0.0			

Year	Recovery Unit	Sampling Area		Area (km^2)	G_0	$SE(G_0)$	Total Length (km)	n	Density	%CV (Density)	95% CI Lower	95% CI Upper
		Fremont Kramer	FK	1403			337.6	35	5.6	20.05	3.81	8.34
		Joshua Tree NP	JT	1035			123.2	13	5.7	27.29	3.37	9.79
		MCAGCC	MC	2030			140.8	18	7.0	27.04	4.10	11.79
		Ord Rodman	OR	601			315.2	53	9.1	17.52	6.49	12.89
		Pinto Mountain	PT	440			128.0	15	6.4	31.71	3.44	11.80
		Superior Cronese	SC	2136			337.6	26	4.2	22.91	2.68	6.54
2002	**Northeast Mojave**			**773**	**0.605**	**0.661**	**293.3**	**3**	**6.2**	**97.67**	**0.33**	**116.19**
		Beaver Dam Slope	BD	201			106.5	0	0.0			
		Coyote Springs	CS	152			45.5	2	22.5	104.02	1.63	309.43
		Gold Butte Pakoon	GB	162			47.5	0	0.0			
		Mormon Mesa	MM	258			93.7	1	5.5	128	0.55	54.14
	Eastern Mojave			**3234**	**0.724**	**0.277**	**1120.4**	**56**	**4.4**	**26.99**	**2.61**	**7.43**
		Fenner	FE	1259			293.2	14	4.1	40.55	1.87	8.83
		Ivanpah	IV	1240			446.1	31	5.9	29.68	3.33	10.50
		Piute Eldorado	PI	735			381.1	11	2.5	39.2	1.16	5.20
	Eastern Colorado			**1531**	**0.775**	**0.271**	**416.7**	**42**	**6.4**	**31.43**	**3.48**	**11.72**
		Chuckwalla	CK	1531			416.7	42	6.4	31.43	3.48	11.72
	Northern Colorado			**0**								
		Chemehuevi	CM									
	Western Mojave			**2647**	**0.639**	**0.490**	**2176.8**	**188**	**7.1**	**35.81**	**3.54**	**14.24**
		Fremont Kramer	FK	458			523.7	31	5.4	39.09	2.58	11.45
		Joshua Tree NP	JT	332			196.1	9	4.2	58.62	1.41	12.56
		MCAGCC	MC	1052			160.3	15	8.6	45.48	3.58	20.63
		Ord Rodman	OR	68			423.5	70	15.2	34.22	7.85	29.31
		Pinto Mountain	PT	192			192.0	12	5.7	43.91	2.47	13.34
		Superior Cronese	SC	545			681.2	51	6.9	35.41	3.49	13.54
2003	**Northeast Mojave**			**572**	**0.660**	**0.310**	**442.4**	**29**	**5.7**	**29.27**	**3.22**	**10.05**
		Beaver Dam Slope	BD									
		Coyote Springs	CS	152			141.5	14	8.6	31.68	4.61	15.91
		Gold Butte Pakoon	GB	162			138.6	3	1.9	60.04	0.61	5.76
		Mormon Mesa	MM	258			162.2	12	6.4	36.29	3.16	12.96
	Eastern Mojave			**735**	**0.769**	**0.445**	**171.4**	**9**	**3.5**	**53.82**	**1.27**	**9.62**

Year	Recovery Unit	Sampling Area		Area (km^2)	G_0	SE(G_0)	Total Length (km)	n	Density	%CV (Density)	95% CI Lower	95% CI Upper
		Piute Eldorado	PI	735			171.4	9	3.5	53.82	1.27	9.62
	Eastern Colorado			**1531**	**0.893**	**0.127**	**431.7**	**32**	**4.5**	**23.63**	**2.84**	**7.15**
		Chuckwalla	CK	1531			431.7	32	4.5	23.63	2.84	7.15
	Northern Colorado			**2484**	**0.858**	**0.114**	**445.2**	**54**	**5.9**	**19.99**	**3.98**	**8.72**
		Chemehuevi	CM	2484			445.2	54	5.9	19.99	3.98	8.72
	Western Mojave			**1595**	**0.951**	**0.065**	**2027.2**	**210**	**3.7**	**12.47**	**2.88**	**4.69**
		Fremont Kramer	FK	458			518.9	38	3.2	19.84	2.20	4.78
		Joshua Tree NP	JT	332			199.5	12	2.7	29.24	1.50	4.73
		Ord Rodman	OR	68			505.9	87	7.6	15	5.67	10.23
		Pinto Mountain	PT	192			195.8	18	4.1	26.05	2.44	6.81
		Superior Cronese	SC	545			607.1	55	4.0	18.36	2.80	5.75
2004	**Northeast Mojave**			**4345**	**0.867**	**0.217**	**947.3**	**18**	**1.8**	**34.04**	**0.91**	**3.38**
		Beaver Dam Slope	BD	827								
		Coyote Springs	CS	638			275.8	7	2.9	45.3	1.19	6.90
		Gold Butte Pakoon	GB	1923			360.5	2	0.6	74.84	0.16	2.42
		Mormon Mesa	MM	957			311.0	9	3.3	40.33	1.49	7.17
	Eastern Mojave			**6017**	**0.825**	**0.182**	**1511.2**	**114**	**5.0**	**22.91**	**3.22**	**7.87**
		Fenner	FE	1833			410.5	50	7.9	28.24	4.52	13.69
		Ivanpah	IV	2112			514.7	35	4.4	30.62	2.41	7.99
		Piute Eldorado	PI	2072			586.0	29	3.2	26.34	1.91	5.34
	Eastern Colorado			**4137**	**0.596**	**0.456**	**1414.0**	**102**	**8.5**	**30.54**	**4.70**	**15.27**
		Chuckwalla	CK	4137			1414.0	102	8.5	30.54	4.70	15.27
	Northern Colorado			**3789**	**0.854**	**0.143**	**835.9**	**79**	**7.1**	**21.41**	**4.65**	**10.74**
		Chemehuevi	CM	3789			835.9	79	7.1	21.41	4.65	10.74
	Western Mojave			**7911**	**0.948**	**0.096**	**1867.9**	**133**	**4.6**	**16.71**	**3.28**	**6.32**
		Fremont Kramer	FK	2070			462.8	46	6.6	22.78	4.23	10.44
		Joshua Tree NP	JT	1313			277.9	8	1.9	31.39	1.02	3.62
		Ord Rodman	OR	836			381.2	31	5.4	27.58	3.15	9.40
		Pinto Mountain	PT	605			55.6	2	2.4	96.05	0.26	22.50
		Superior Cronese	SC	3087			690.4	46	4.5	23.88	2.79	7.12
2005	**Northeast Mojave**			**6089**	**0.919**	**0.250**	**1754.4**	**40**	**1.8**	**32.83**	**0.97**	**3.49**
		Beaver Dam Slope	BD	828			468.9	5	0.9	56.38	0.32	2.65

Year	Recovery Unit	Sampling Area		Area (km^2)	G_0	SE(G_0)	Total Length (km)	n	Density	%CV (Density)	95% CI	
											Lower	Upper
		Coyote Springs	CS	762			245.9	9	3.2	45.24	1.31	7.67
		Gold Butte Pakoon	GB	1977			432.2	1	0.2	103.79	0.04	1.12
		Mormon Mesa	MM	970			468.3	21	3.9	36.46	1.91	7.86
		Lake Mead NRA North	MN	1552			139.1	4	2.5	51.37	0.89	6.97
	Eastern Mojave			**7195**	**0.875**	**0.276**	**1839.5**	**108**	**7.0**	**34.7**	**3.61**	**13.76**
		Fenner	FE	1857			288.2	40	14.3	34.76	7.33	28.06
		Ivanpah	IV	2565			168.2	8	4.9	62.24	1.46	16.51
		Lake Mead South	MS	824			227.7	5	2.3	47.77	0.90	5.70
		Piute Eldorado	PI	1949			1155.4	55	4.9	33.8	2.57	9.42
	Eastern Colorado			**4199**	**0.655**	**0.361**	**1094.3**	**74**	**6.5**	**30.06**	**3.64**	**11.64**
		Chuckwalla	CK	4199			1094.3	74	6.5	30.06	3.64	11.64
	Northern Colorado			**4038**	**0.684**	**0.425**	**1128.8**	**94**	**10.8**	**34.05**	**5.60**	**20.68**
		Chemehuevi	CM	4038			1128.8	94	10.8	34.05	5.60	20.68
	Western Mojave			**9358**	**0.907**	**0.115**	**2746.6**	**173**	**5.5**	**19.51**	**3.73**	**7.98**
		Fremont Kramer	FK	2405			672.5	41	5.2	25.71	3.12	8.51
		Joshua Tree NP	JT	1774			600.8	18	2.5	29.03	1.44	4.46
		Ord Rodman	OR	1124			309.9	27	7.4	25.44	4.46	12.17
		Pinto Mountain	PT	608			154.7	17	9.3	37.99	4.27	20.24
		Superior Cronese	SC	3447			1008.7	70	5.9	23.38	3.72	9.25
2007	**Northeast Mojave**			**4917**	**0.70**	**0.14**	**2316.1**	**46**	**1.9**	**26.46**	**1.12**	**3.11**
		Beaver Dam Slope	BD	828			478	6	0.4	0.35	0.52	0.89
		Coyote Springs	CS	1144			917.9	14	0.2	0.23	0.88	0.42
		Gold Butte Pakoon	GB	1977			299.7	4	0.3	0.33	0.58	0.79
		Mormon Mesa	MM	968			620.5	22	0.2	0.20	2.23	0.33
	Eastern Mojave			**6681**	**0.79**	**0.14**	**803.9**	**34**	**5.3**	**24.70**	**3.32**	**8.61**
		Fenner	FE	1862			178.2	10	7.1	0.21	3.78	0.46
		Ivanpah	IV	2567			180.1	4	3.5	0.48	4.12	0.36
		Piute Eldorado	PI	2252			445.6	20	4.6	0.22	2.69	0.37
	Eastern Colorado			**4263**	**0.87**	**0.07**	**1151.7**	**59**	**5.5**	**23.02**	**3.50**	**8.54**
		Choc Mtn AGR	AG	755			404.3	27	7.5	0.22	4.80	0.35
		Chuckwalla	CK	3509			747.4	32	5.0	0.24	2.88	0.42

Year	Recovery Unit	Sampling Area		Area (km^2)	G_0	$SE(G_0)$	Total Length (km)	n	Density	%CV (Density)	95% CI Lower	95% CI Upper
	Northern Colorado			**4038**	**0.79**	**0.14**	**180**	**7**	**5.0**	**40.50**	**2.32**	**10.69**
		Chemehuevi	CM	4038			180	7	5.0	0.28	2.32	0.61
	Western Mojave			**9298**	**0.85**	**0.10**	**1150.6**	**49**	**5.0**	**22.43**	**3.24**	**7.72**
		Fremont Kramer	FK	2463			299.9	7	2.8	0.33	1.25	0.73
		Joshua Tree NP	JT	1655			134.9	4	3.5	0.48	1.05	1.59
		Ord Rodman	OR	1124			140.9	5	3.5	0.44	1.14	1.34
		Pinto Mountain	PT	608			119.4	10	8.4	0.30	3.89	0.66
		Pinto Mountain 2	PT2	1113			161.4	3	3.0	0.42	1.00	1.24
		Superior Cronese	SC	3447			455.5	4	2.9	0.47	0.91	1.53