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

2010 ANNUAL REPORT

PREPARED BY LINDA ALLISON
DESERT TORTOISE MONITORING COORDINATOR
U.S. FISH AND WILDLIFE SERVICE

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EXECUTIVE SUMMARY

The recovery program for the Mojave population of the desert tortoise requires range-wide, long-term monitoring to determine whether recovery goals are met. Specifically, will population trends within recovery units remain stable for a period of 25 years? In 1999, the Desert Tortoise Management Oversight Group endorsed the use of line distance sampling (Buckland et al., 2001) as the method for estimating range-wide desert tortoise density. From 2001 to 2005, and again from 2007 through 2009, desert tortoise populations in 5 of the 6 recovery units have been part of a coordinated, range-wide monitoring program using line distance sampling. (The Upper Virgin River Recovery Unit is monitored by Utah Division of Wildlife Resources.) The first 5 years of monitoring culminated in a summary report (USFWS, 2006) that included eleven recommendations, seven of which were tied to functioning of the monitoring program and are paraphrased here:

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

This report describes the full set of quality assurance steps and final results for the 2010 monitoring effort. The above issues continue to drive review and improvement of the program, so that reporting also addresses these aspects of the annual effort. The range-wide monitoring effort is directed each year at 13 strata that will be used to describe long-term trends. One of the critical habitat units (Chuckwalla) is handled as dual monitoring strata, with potentially unequal sampling effort in the areas managed by the Department of Defense (Chocolate Mountain Air Gunnery Range, CMAGR) and by the Bureau of Land Management (BLM). Data were collected on transects by field personnel working with three different groups, Kiva Biological (18 personnel), the Institute for Wildlife Studies (15 personnel), and Great Basin Institute (30 personnel). Four personnel from Joshua Tree National Park also collected telemetry data in the Park. After an intensive, 12-day specialized training session, crews completed 888 transects (9401km) between 22 March and 28 May. In the course of these surveys, they reported 540 live tortoises.

Training is provided each year so that field crews are familiar with the specifics of distance sampling. Training also ensures consistency between the many crews collecting data. Inexperienced crews as well as those with prior experience participated in preseason training and testing provided by the USFWS. Crews were passed after demonstrating appropriate detection curves, detection proportion on the transect line, and measurement accuracy from tortoise models to the transect line, as well as qualitative skills. Two of the teams passed after retesting with a different partner.

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

Separate detection curves were used to describe the decreasing ability of each team to see tortoises that were farther from the walked transect line. These detection curves reflect the terrain as well as the extent to which vegetation obscures the view in different parts of the range, and are used to account for tortoises that were present in the same area but not seen. In the southern part of the range, Kiva crews detected 67% of tortoises within 8m of the transect centerline, and 58% out to 12m from the line in the northern area that they sampled. GBI detected 41% out to 16m, and IWS detected 61% to 12m. The proportion of tortoises that were visible to be counted (G_0) varied in different parts of the range, which were surveyed at different times during the spring season. Visibility was as high as 98% in the Superior Cronese and Joshua Tree monitoring strata during the last and first 2 weeks of April, respectively. The lowest visibility was measured at 73% at the Gold Butte telemetry site, also monitored during the first 2 weeks of April. On average, crews walked 23km for each tortoise that was observed, but this number varied considerably from one monitoring stratum to the next. Although densities in the Northeastern Mojave Recovery Unit had been estimated at less than 2/km^2 in previous years, the density was estimated at 3.2/km^2 this year, similar to 2009. The Western and Eastern Mojave recovery units also had densities under 4/km^2, whereas the 2 recovery units in the Colorado Desert measured at 4.4/km^2 (Northern Colorado) and 5.9/km2 (Eastern Colorado). The single Desert Wildlife Management Area in the Eastern Colorado is sampled separately on lands administered by BLM and by Chocolate Mountain Air Gunnery Range; the BLM areas had a density of only 3.7/km^2, whereas the latter area had an unusually high density estimate of 13.8 tortoises/km^2. The Fenner and Ord-Rodman critical habitat units also had notably high density estimates at 7.5 tortoises/km^2. This pattern of high densities in these 3 monitored areas has been fairly consistent over the years.

To enable field crews to complete transects in previously unsampled areas, a set of guidelines was implemented in 2008 and 2009 for modifying transects in areas with rugged terrain or other obstacles (USFWS 2010a). These rules did enable crews to sample entire strata in a more representative way; however, in areas of California with lower funding, the resulting substrata never had enough transects or tortoise observations to separately evaluate tortoise densities in flat compared to rugged terrain. For this reason, in 2010, all transects in all recovery units except the Northeastern Mojave were to be completed to the extent possible along the original 12km path. Mountainous terrain in the path was circumvented without searching for tortoises, then the path was resumed when possible. This method keeps transects in representative areas and also allows the proportion of unwalkable terrain to be estimated. The proportion of kilometers actually walked under this new method matched the expected number of kilometers based on the earlier modified-transect protocols.

Finally, the success of the range-wide monitoring program also depends on developing reliable, adequate, and consistent funding. Results from earlier years of this project illustrated clearly that sufficient effort (transects) in each stratum is needed to encounter several tortoises, otherwise estimates are not possible. In 2010, funding enabled estimation of tortoise densities in all strata to at least a minimum extent, better than any year since 2005. Effective implementation of this program requires stable funding so that monitoring effort matches planning requirements rather than funding limitations.

RANGE-WIDE DESERT TORTOISE POPULATION MONITORING 2010

INTRODUCTION

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

Distance sampling methods use measurements taken from the center of the transect lines to tortoises to model detection as a function of distance from the walked path; tortoises farther from the travelled path have a lower probability of detection. In order to anchor the curve and estimate the true (not relative) proportion of tortoises detection within a given distance from the center of the transect, all tortoises must be detected on the transect center line (Anderson et al., 2001; Buckland et al., 2001). There are additional assumptions in distance analysis – that distance is measured to the point where the animal was first detected and that distance is measured accurately – but these are easily satisfied in line distance sampling of desert tortoises. The assumption that detection at the center line of the transect is perfect, however, can be violated during line distance sampling of tortoises, but the use of two observers minimizes these violations of the assumption and provides a correction factor in the form of an estimate of the number of tortoises on the line that were missed (USFWS, 2009).

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, 2009, and

2010a). This report includes results of training exercises for field crews, describes implementation of monitoring in 2010, and presents the analysis of desert tortoise density in 2010.

METHODS

Study areas and transect locations

Long-term monitoring strata will be used over the life of the project to describe population trends in areas managed to conserve tortoises (“tortoise conservation areas,” TCAs, Figure 1). The optimal number of transects in a monitoring stratum was determined by evaluating how these samples would contribute to the precision of the annual density estimate for a given recovery unit (Anderson and Burnham, 1996). Power to detect an increasing population size is a function of 1) the magnitude of the increasing trend, 2) the “background noise” against which the trend operates, and 3) the length of time the trend is followed (even a small annual population increase will result in a noticeably larger population size if the increase continues for many years).

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

The actual number of transects assigned in each stratum was a function of the optimal numbers described above, as well as on available funding. Once the number of transects in a stratum was determined, these were laid out systematically across strata, with a random origin for the lattice of transects. In strata with more assigned transects, nested lattices with smaller spacing (3km) were used to ensure sufficient transects. In strata with fewer transects, lattices 9km spacing were used. Systematic placement provides more even coverage of the entire stratum, something that may not occur when strictly random placement of transects is used. In both cases, transects are located at random with respect to the location of desert tortoises.

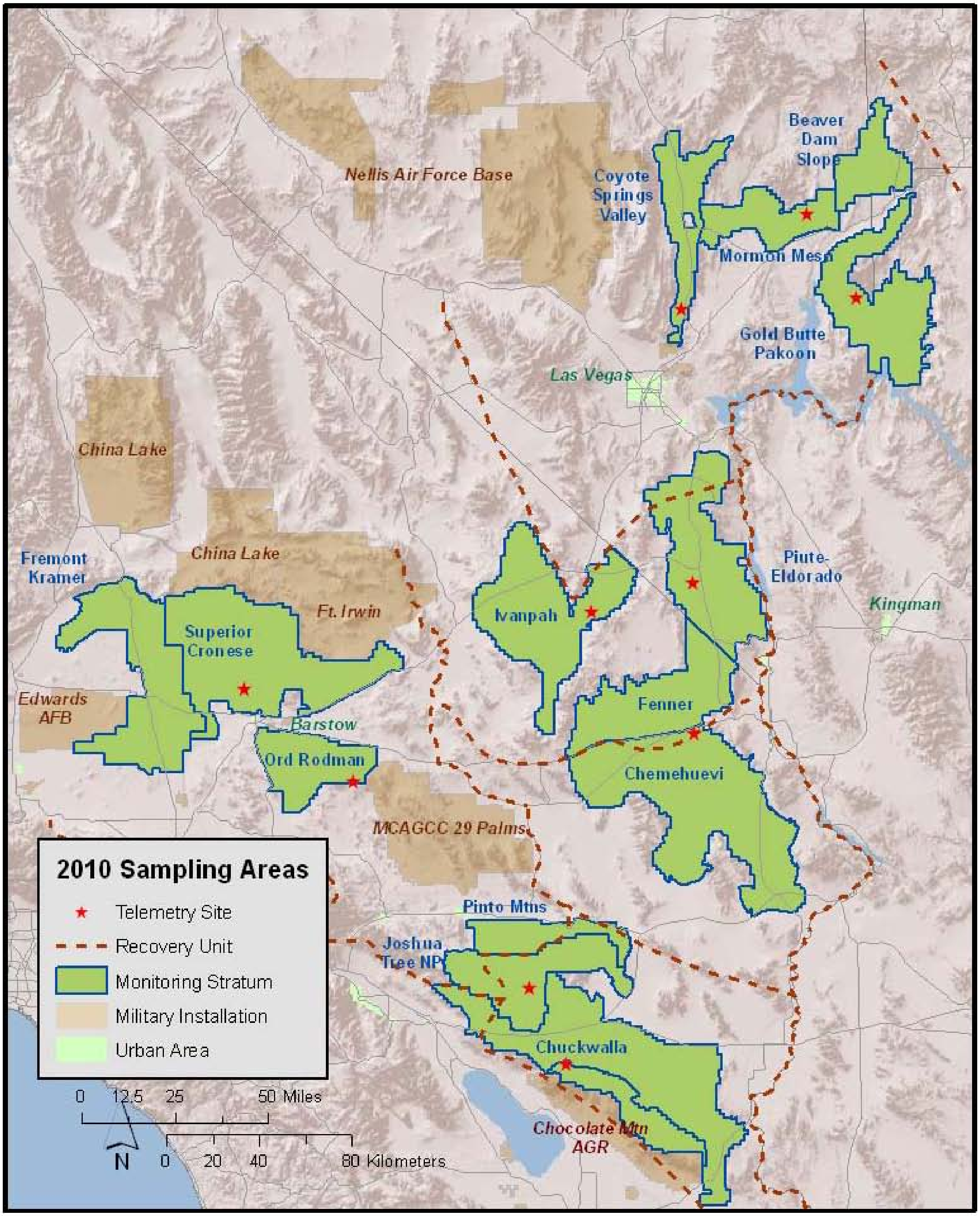


Figure 1. Sampled areas 2010.

Transect completion

One adaptation that tortoises have for living in the desert is to restrict surface activity to fairly narrow windows of time during the year. In general, tortoises predictably emerge from deep within shelters (burrows) from mid-March through mid-May and then again (less predictably) in the fall. These periods coincide with flowering of their preferred food plants (in spring) and with annual mating cycles (in fall). The annual range-wide monitoring effort is scheduled to match the spring activity period for tortoises.

During this season, not all tortoises are above ground or visible in burrows. To encounter as many tortoises as possible, monitoring is scheduled for early in the day and to be completed before the hottest time of day. Because tortoises are located visually, monitoring is restricted to daylight hours. Based on past experience, we expect tortoises to become most active after 7am at the beginning of April (it is usually too cool before this time), but to emerge earlier and earlier until their optimal activity period includes sunrise by the beginning of May. In May, we also expect daytime temperatures to limit tortoise above-ground activity as the morning progresses to afternoon.

Field crews complete transects during this optimal period each day. Start times are decided a week in advance, so crews arrive at transects at similar times on a given morning. However, completion times will be more variable, as a consequence of terrain, air temperature, number of tortoises encountered, etc. Although we have general expectations about when tortoises are most active each day, and indeed have expectations of the proportion that will be active, density estimates require real-time estimation of daily activity during the actual periods tortoises are counted. The role of telemetry crews is to provide these activity descriptions (=estimates of G_0).

Under normal conditions, each team walks one 12km square transect each day. Teams are comprised of 2 field personnel who alternate lead and follow positions at each corner of each transect, so they each spend an equal amount of time in the leader and follower positions. The leader starts by walking on the designated compass bearing while pulling a 25m length of durable line. The path that the leader walks becomes the centerline of the transect. The length of line also spaces the two independent observers and guides the path of the follower; when the line is placed on the ground after a tortoise or carcass is detected, the line facilitates measurement of the local transect bearing. The walked length of each transect is calculated as the straight-line distance between GPS point coordinates that are recorded at 500m intervals (waypoints) along the transect and/or whenever the transect bearing changes.

The follower will trail the leader at the end of the 25m line. Both leader and follower scan for tortoises independently without leaving the center line, and the role of the crew member finding each tortoise will be recorded in the data. Although the leader will see most of the tortoises, the role of the follower is to see all the remaining tortoises near the centerline, so the follower role is crucial to unbiased estimation of tortoise densities.

Distance sampling requires that distance from the transect line to tortoises is measured accurately. When a tortoise is observed, crews 1) use a compass to determine the local transect bearing based on the orientation of the 25m centerline, 2) use a compass to determine the bearing from the point of observation to the tortoise, and 3) use a measuring tape to determine the distance from the observer to the tortoise. These data are sufficient to calculate the perpendicular distance from the observed tortoise to the local transect line. If the tortoise is outside of a burrow, it can be handled enough to take mass and length information, to determine its sex, and to apply a small numbered tag to one scute. If a tortoise cannot be measured because it is in a burrow, because temperatures preclude handling, or for any other reason, crews attempt to establish by other means whether the animal is $\geq$ 180mm MCL, the criterion for including animals in density estimates.

Because transects are 3km on one side, it is not unusual for that path to cross through varied terrain or even be blocked by an obstacle such as an interstate highway. In the first years of this program, smaller transects in inconvenient locations were shifted or replaced, but this compromised the representative nature of the sample. Since 2007, the basic rules for modifying transects involve 1) reflecting or elongating transects to avoid obstacles associated with human infrastructure (large roads, private inholdings, etc.), or 2) shortening transects in rugged terrain. Substrate and access to transects can also make it difficult to complete transects during the optimal period of times, so 3) transects could be shortened to enable completion before 4pm each day.

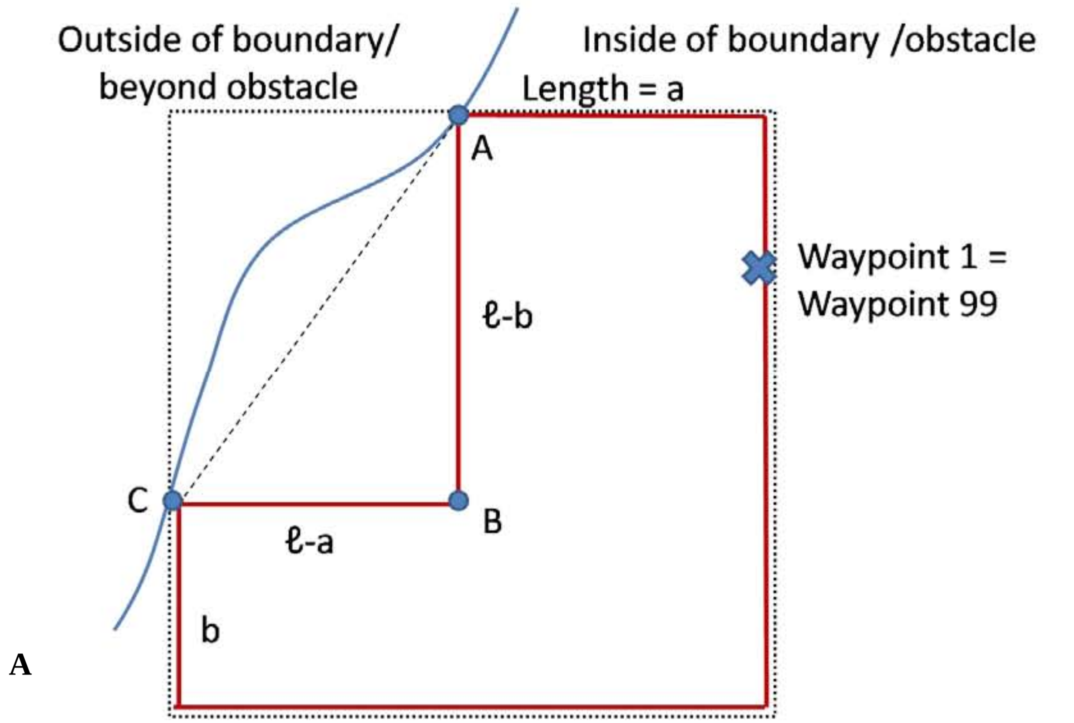
In 2008 and 2009, the rules for shortening transects were made more restrictive. Crews had the option to complete transects that were 12km long (in low-relief terrain) or 6km long (in higher-relief terrain that precluded completion of 12km in a working day). In the latter case, to avoid crews selecting particular terrain, the only way to shorten the transect was to walk it in the southwestern quadrant of the intended 12km square. If the southwestern quadrant was judged too rugged to be completed safely by transect walkers, the final option was to not complete the transect at all. As in previous years, unwalked transects were replaced from the list of alternates. More situations were anticipated by additional rules in 2010, as described below.

Modification of previous procedures

After the 2009 field season, it was clear that funding uncertainties in California meant that sufficient transects might not be completed in order to substratify analyses for 12km and 6km transects. However, substratification continued to hold promise for analyses in the Northeastern Mojave Recovery Unit. In 2010, the same option to shorten transects to 6km in rugged terrain were made available to GBI crews. However, IWS and Kiva crews shortened transects by following as much of the planned 12km route as was possible. If it was anticipated that fewer than 4km could be walked, the transect should be replaced instead with a transect from the alternate list. This second method of shortening transects would allow all transects in a stratum to be analyzed together. Instead of estimating the proportion of the area that is unwalkable based on the proportion of transects that were unwalkable, we would use the proportion of total planned kilometers (12 X number of planned transects) that were unwalkable.

In addition, transects that crossed stratum boundaries into public lands had previously been walked as planned (squares). Although this added sampling just outside the stratum, it seemed reasonable to assume the land management and tortoise fate would be similar on each side of the invisible boundary. Walking in a square is also less likely to introduce other problems compared to reflecting the transect. Starting in 2010, these transects, like those that encountered private lands or interstates in 2007-2009, were reflected. If the small segments of those transects outside the boundaries were not "replaced," there would be undersampling of the areas on stratum boundaries. An equivalent method to walking across the boundary is to reflect the outside portion of the transect into the stratum. In both cases, the same length of transect is walked at the same distance from the stratum boundary, but now it is walked inside the boundary instead of outside (Figure 2). The impetus for this change was the recent large scale development and construction on public lands, often just along the borders of critical habitat, especially for alternative energy facilities and transmission lines.

Specifics of how transect paths were to be modified for rugged terrain (shortened) or for administrative boundaries (reflected) can be found in the *2010 Desert Tortoise Monitoring Handbook* (USFWS 2010b).



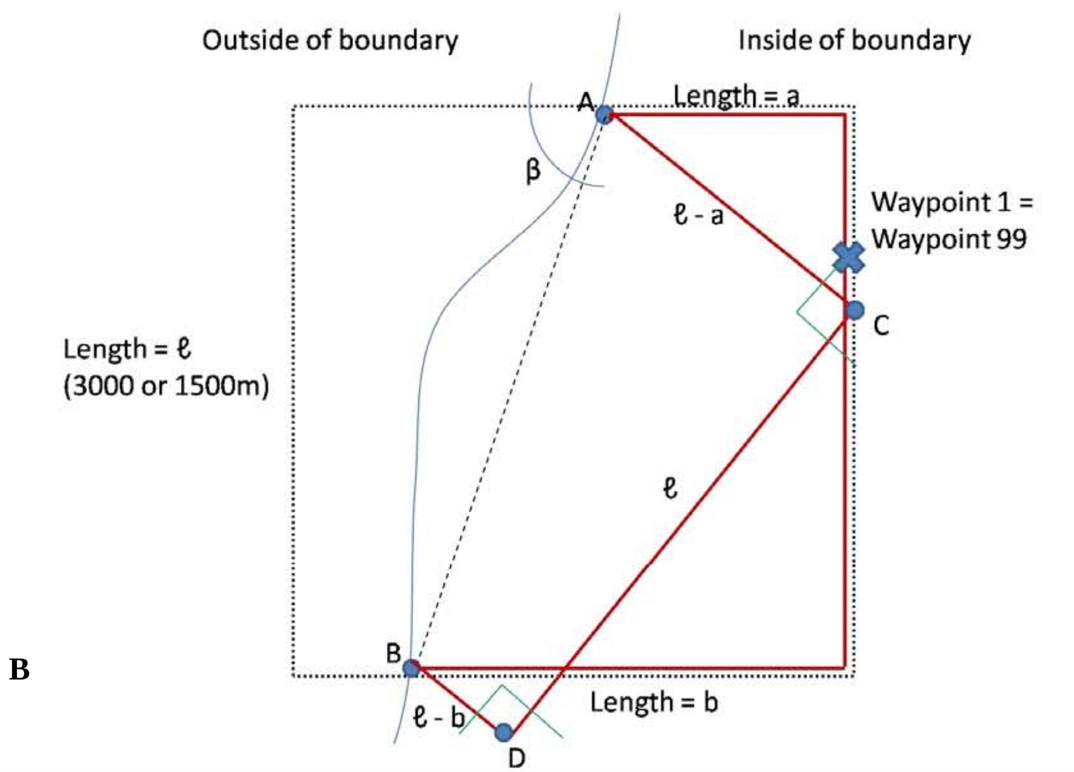


Figure 2. Planned (dotted lines) and reflected transect paths at administrative boundaries, now also applied to stratum edges. A) One-corner reflection. B) Two-corner reflection.

Field observer training

Training for careful data collection and consistency between crews is fundamental part of quality assurance for this project. The emphasis of this training is on providing sufficient time for instruction as well as practice on skill such as tortoise handling, walking practice transects and developing detection and distance-measuring techniques on a training course with tortoise models (Table 1). The handbook that serves as a training manual and documentation of training that is provided. The monitoring handbook developed in 2008 was comprehensive, and chapters posted to the DTRO website and printed for training have been updated each year as needed. This was the second year since the USFWS assumed responsibility for running the training program, although a training program has been in existence since the beginning of the project in 2001.

In 2010, three teams of field observers participated. Kiva Biological (Kiva) supplied crews for monitoring in the West Mojave and Eastern Colorado recovery units. The Institute for Wildlife Studies participated for the first time, monitoring in the Northern Colorado and Eastern Mojave recovery units. Great Basin Institute (GBI) supplied crews for monitoring in the Northeastern Mojave in Nevada, Arizona, and Utah. About half the personnel for Kiva were trained for the first time in 2008 and returned in 2009 and 2010. One of the 12 personnel for IWS had previous experience with this monitoring program, and 9 of the 28 personnel for GBI were returnees. Due to the large number of trainees, and to accommodate an earlier monitoring window on the Chocolate Mountain Air Gunnery Range, the three teams were trained in 2 overlapping periods, with some experienced Kiva personnel leaving the training group after rapid evaluation (Table 1). Nonetheless, there was extensive use of the same trainers between teams and experienced personnel from each group worked with the other groups.

A single evaluation was given to each paired team, based on performance on a field arena outfitted with a high density of polystyrene tortoise models placed in measured locations (Anderson et al., 2001). Crews were evaluated on 1) ability to detect all tortoises within 1m of the centerline, 2) shape of the team's detection function indicating appropriate search technique, 3) the leader detecting close to 80% of the tortoise models (related to above requirement for the pair to detect all tortoises on the centerline), and 4) ability to correctly report the distance of each model from the transect centerline.

Table 1. Training schedule for 2010.

	IWS Trainees		GBI Trainees		Kiva Trainees	
Day/Date	**Activity**	**Trainer**	**Activity**	**Trainer**	**Activity**	**Trainer**
WEEK 0			G0 only			
Thursday, 11-Mar	Beginning on-site G_0 instruction	Sparks	Beginning on-site G_0 instruction	Sparks		
Friday, 12-Mar	Familiarize G_0 with River Mtns	Sparks	Familiarize G_0 with River Mtns	Sparks		
WEEK 1			**WEEK 1**			
Monday, 15-Mar	Transect methods overview 6km transect	Allison/ Experienced crews			Transect methods overview 6km transect	Allison/ Experienced crews
Tuesday, 16-Mar	Introductions and DT Recovery/Monitoring Programmatic Overview	Allison			Introductions and DT Recovery/Monitoring Programmatic Overview	Allison
	Working on Public Lands	"			Working on Public Lands	"
	Tortoise Activity/G_0	"			Tortoise Activity/G_0	"
	Distance Sampling	"			Distance Sampling	"
	Transect methods lecture	"			Transect methods lecture	"
	Non-standard transects	"			Non-standard transects	"
	RDA/BT GPS, Pendragon Database Lecture and Exercises	Patil			RDA/BT GPS, Pendragon Database Lecture and Exercises	Patil
	Quality control procedures for field crews	Patil			Quality control procedures for field crews	Patil
	Compass/GPS Lecture	Allison	G0 on scheduled visit	Sparks	Compass/GPS Lecture	Allison
Wednesday, 17-Mar	Tortoise biology and handling instruction	Staff, Christopher	RDA/BT GPS, Pendragon Database Lecture and Exercises	Patil	Tortoise biology and handling instruction	Staff, Christopher
	Tortoise handling and data collection - small groups	"	Quality control procedures for field crews (transect and G0)	"	Tortoise handling and data collection - small groups	"
	Pen search image exercise	"	G0 in River Mtns -AM	Sparks	Pen search image exercise	"
	Training line lecture & crew	Allison/			Training line lecture & crew	Allison/

	IWS Trainees		GBI Trainees		Kiva Trainees	
Day/Date	**Activity**	**Trainer**	**Activity**	**Trainer**	**Activity**	**Trainer**
	quality control procedures Compass/GPS Exercise Data transfer and QA/QC (QAQC specialists only)	Brenneman Allison Patil	Data transfer and QA/QC (QA/QC specialists only)	Patil	quality control procedures Compass/GPS Exercise	Brenneman Allison
Thursday, 18-Mar	Training Lines (practice, 8km) Begin data download Beginning on-site G_0 instruction (IWS Kiva only)	Allison, Young Sparks			Training Lines (practice, 8km) Begin data download	Allison, Young
Friday, 19-Mar	Training Lines (practice, 8km) G_0 on-site training Initial QAQC (specialists only)	 Sparks Brenneman	Initial QAQC (specialists only)	Brenneman	Training Lines (practice, 8km) Begin data download from RDAs	
Saturday, 20-Mar					Full transects (12km)	
WEEK 2						
Monday, 22-Mar	Tortoise handling Training line debriefing,	Staff Allison	Transect methods overview 6km transect	Allison/ Experienced crews	Tortoise handling Training line debriefing,	Staff Allison
Tuesday, 23-Mar	Training Lines (evaluation, 8km)		Introductions and Recovery/Monitoring Program Overview Same as IWS on 16 Mar	Allison	Training Lines (evaluation, 8km)	
Wednesday, 24-Mar	Training Lines (evaluation, 8km)		Tortoise biology and handling instruction Same as IWS on 17 Mar	Staff, Christopher	Training Lines (evaluation, 8km)	
Thursday, 25-Mar	Full transects (12km) (1/2 crew) G_0 / activity observation (1/2 crew)	 Sparks	Training Lines (practice, 8km) Begin data download	Allison, Young		
Friday, 26-Mar	Full transects (12km) (half crew) G_0 / activity observation (half crew)	 Sparks	Training Lines (practice, 8km)			
WEEK 3						

	IWS Trainees		GBI Trainees		Kiva Trainees	
Day/Date	**Activity**	**Trainer**	**Activity**	**Trainer**	**Activity**	**Trainer**
Monday, 29-Mar	Tortoise handling Training line debriefing	Allison	Full transects (12km) (1/2 crew) G_0 / activity observation (1/2 crew)	Sparks		
Tuesday, 30-Mar	Full transects (non-standard) or repeat training lines as needed G_0 on-site practice	Sparks	Tortoise handling Training line debriefing	Staff Allison		
Wednesday 31-Mar	Repeat training lines as needed *Begin field data collection*		Training Lines (evaluation, 8km)			
Thursday, 1-Apr			Training Lines (evaluation, 8km)			
Friday, 2-Apr			Full transects (12km) (1/2 crew) G_0 / activity observation (1/2 crew)	Sparks		
WEEK 4						
Monday, 5-Apr	Deliver QA/QC'd data from practice transects electronically to ftp site		Tortoise handling Training line debriefing			
Tuesday, 6-Apr			Full transects (non-standard) or repeat training lines as needed G_0 on-site practice			
Wednesday 7-Apr			Repeat training lines as needed *Begin field data collection*			
WEEK 5						
Monday 12-Apr			Deliver QA/QC'd data			

Proportion of tortoises detected at varying distances from the transect centerline

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

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

Data management including quality assurance and quality control

Two sets of data tables are maintained through the field season, organizing data collected on transects and at the focal G_0 sites. Collection data forms, sheets, applications and databases are carefully designed to minimize data entry errors and facilitate data verification and validation. Data were collected in both electronic and hardcopy formats by the two survey organizations then combined and processed in a series of phases to create final database products. Data quality assurance and quality control (data QA/QC, also known as verification and validation) is performed during the data collection, data integration and data finalization phases. In addition, during the second phase of data processing, after combining data from separate groups, some attribute fields are added and all fields are formatted for final processing. The third phase, data finalization, involves consolidation, resolution of data inconsistencies, and geoprocessing. After data analysis and reporting are completed, electronic data are actively hosted and put in a format available for download from the internet through http://www.mojavedata.gov/lds. Figure 3describes the overall data flow.

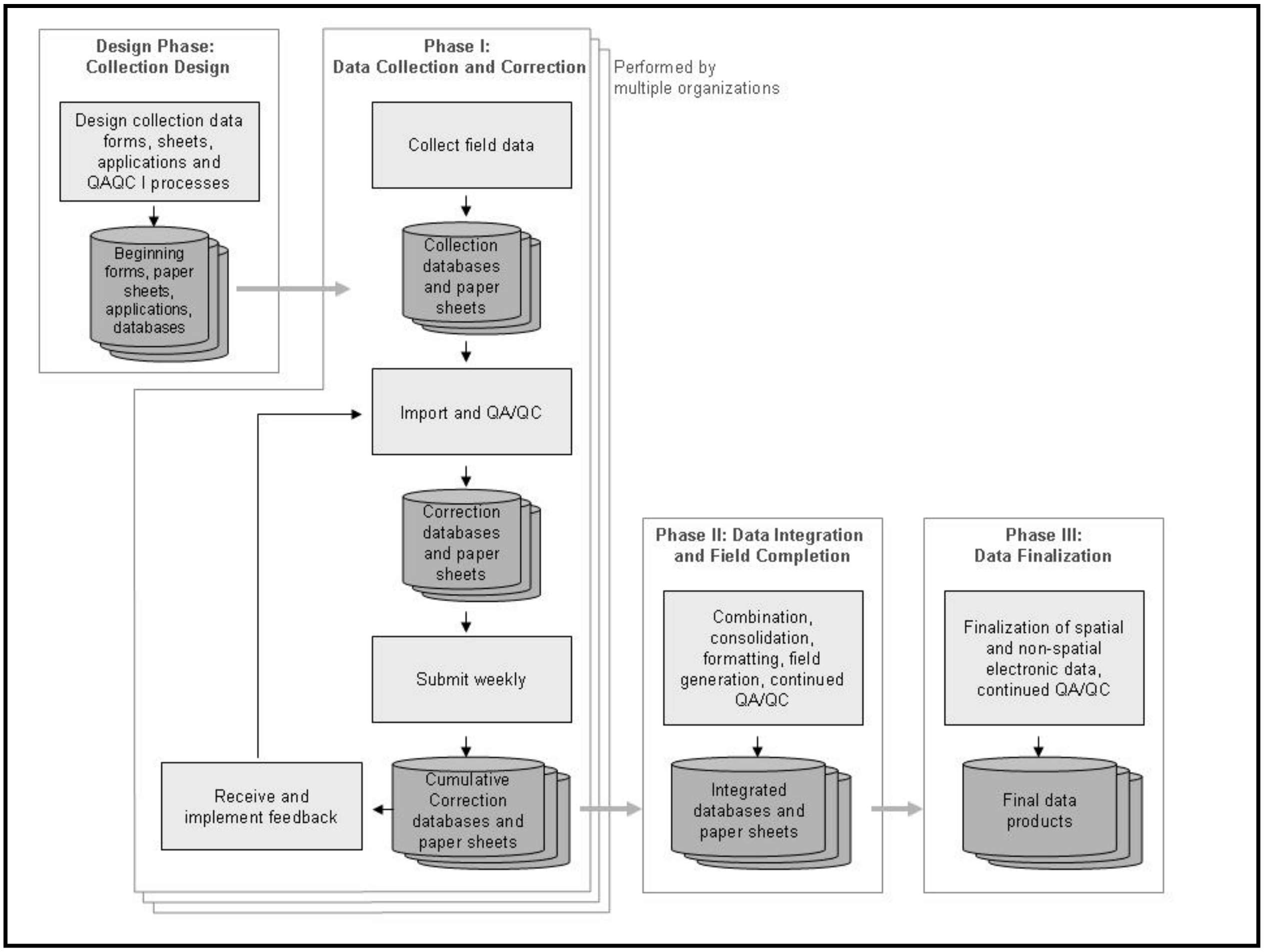


Figure 3. Data flow from collection through final products.

Tortoise encounter rate and development of detection functions

The number of tortoises seen in each stratum and their distances from the line are used to estimate the encounter rate (tortoises seen per kilometer walked), the detection rate (proportion of available tortoises that are detected out to a certain distance from the transect centerline), and their respective variances. Detection function estimation is “pooling robust” under most conditions (Buckland et al., 2001). This property holds as long as factors that cause variability in the curve shape are represented proportionately (Marques et al., 2007). Factors that can affect curve shape include vegetation that differentially obscures vision with distance, or different detection protocols used by individual crews (pairs). Field teams (IWS, GBI, Kiva) typically walk different number of transects. For this reason, after the field season I expected at least one curve for each field team, which also corresponds to different regions of the desert. The encounter rate is much less sensitive to small sample sizes, so it was estimated for each stratum separately.

I used Program DISTANCE, Version 6, Release 2 (Thomas et al., 2010) to fit appropriate detection functions, to estimate the encounter rate of tortoises in each stratum, and to calculate the associated variances. One record was created for each transect, with additional records for each additional tortoise on that transect. Analysis was applied to all live tortoises with midline carapace length (MCL) at least 180mm. Transects were packaged into monitoring strata ("regions" in Program DISTANCE).

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

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

Not all tortoises in a population can be detected on transects, even if they are on the center of the transect line. Typically, these are either undetectable in deep burrows or well hidden in dense vegetation. The existence of a portion of the population that is "invisible" to sampling will bias downward the density estimates derived from line distance sampling unless the proportion of the population available for sampling (G_0) can be estimated and used to correct the bias. Estimation of G_0 was conducted using focal tortoises in 10 sites located throughout the monitoring area (Fig. 1). At these telemetry sites, the focal animals are equipped with radio transmitters and observed daily while transects are sampled in the associated strata.

Each time a transmittered tortoise was observed, it was determined if the tortoise would have been visible to an observer conducting a line transect (*yes* or *no*). Through careful coordination, observers at telemetry sites monitored visibility during the same daily time period when field crews were walking transects. Observers completed a survey circuit of all focal animals as many times as possible during the allotted time, recording visibility each time. Bootstrapped estimates of G_0 started by selecting one visibility record at random for each tortoise each. The average visibility of all tortoise observations at a site on a given day was calculated and used to estimate the mean and variance of G_0 at that site. When there was more than one site in a given area, G_0 statistics were calculated for each G_0 group of sites as the grand mean of all G_0 sites in the group. One thousand bootstrap samples were generated in PASW Statistics (release 18.0.2; SPSS, Inc., 2 April 2010) to estimate G_0 and its standard error.

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

Transects were conducted by 2-person crews using the method adopted beginning in 2004 (USFWS, 2006). Transects were walked in a continuous fashion, with the lead crew member walking a straight line on a specified compass bearing, trailing about 25m of line, and the second crew member following at the end of the line. This technique involves little lateral movement off the transect center line, where attention is focused. Use of two observers allows "removal" type mark-recapture estimation of the proportion of tortoises detected on the line; this is a test of the assumption is that all tortoises on the transect centerline are recorded (*g(0)* = 1). The capture probability (*p*) for tortoises within increasing distances from the transect centerline was estimated as for a 2-pass removal estimator (White et al., 1982): p = (lead–follow)/lead, where lead = the number of tortoises first seen by the observer in the leading position and follow = the number of tortoises seen by the observer in the follower position. The corresponding proportion detected on the line by two observers was estimated by $1 - q^2$, where $q = 1 - p$. Figure 4 graphs the relationship between the single-observer detection rate (*p*) and the dual-observer detection rate (*g(x)*). The actual proportion detected can be estimated, but to avoid the necessity of compensating for imperfect detection, during training field crews (pairs) are expected to detect 96% of all models within 1m of the transect centerline. This corresponds to the leader being responsible for at least 80% of the team's detections near on the centerline in order to meet this standard (Fig. 4) and is the basis for one of the training metrics (see Table 3).

Few or no tortoises are located exactly on the line, and even examining a small interval (such as 1m on each side of the transect line) results in few observations to precisely estimate *g(0)*. Instead, my test of the assumption involves examination of the lead and follow proportions starting with counts of tortoises in larger intervals from the line, moving to smaller intervals centered on the transect centerline. As the intervals get smaller the sample sizes also get smaller, but the estimates are more relevant to the area right at the transect centerline. The expectation is that the estimates should converge on *g(0)* = 1.0.

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

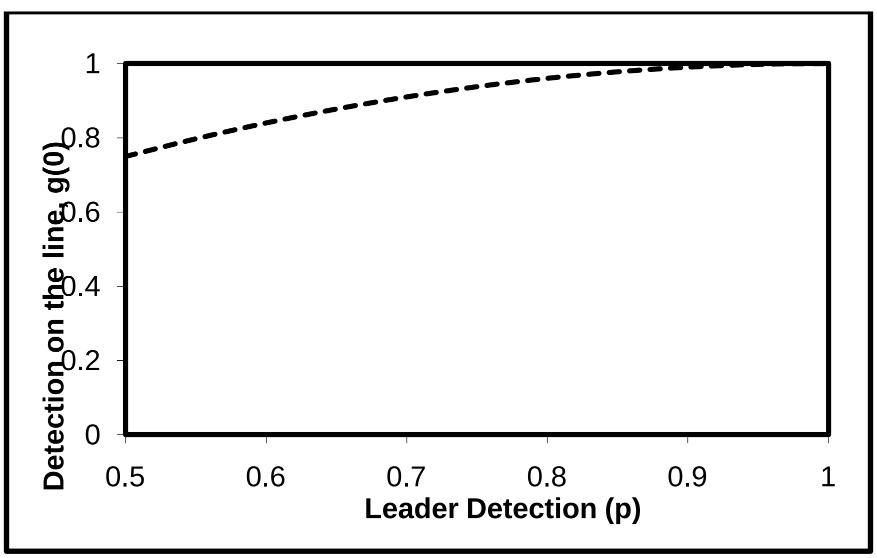


Figure 4. Relationship between single-observer detections (by the leader, *p*) and dual-observer (team) detections, *g(0)*.

Estimates of tortoise density

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

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

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

For desert tortoise densities, the encounter rate (n/L) is estimated independently for each stratum ("unpooled"), whereas proportion of available tortoises and proportion of available tortoises detected on the transect center line are estimated jointly for all strata ($g(0)$) or for all strata in the recovery unit (G_0). The detection function, which comes into the above equation as P_a, may be estimated jointly or separately, depending on the number and quality of observations. In 2010, separate detection curves were created for GBI and IWS, pooled across all strata surveyed by that team. Although a single detection curve was also considered for Kiva detections, the patterns were very different in the south (mostly Colorado Desert) compared to the north, so separate curves were developed for strata in the two areas (see *Results*). A schematic of the process leading to density estimates is given in Figure 5. Contributing estimates in the four left-hand columns are listed with the subsets of the data on which they are based. These estimates combined from left to right to generate stratum and recovery unit density estimates.

Whereas the number of tortoises in the set of strata representing a recovery unit can simply be added together, the variance must be arrived at by accounting for whether this involves pooled or unpooled estimates. As described above, three of the four estimates that contribute to calculating density in a stratum were based on data "pooled" from other strata as well, so when data from these strata are combined, the correlated nature of the variances has to be accounted for. Specifically, the method described in Buckland et al. (2001:89) was used to combine density variances correctly and arrive at the variance (and confidence intervals and CV) for the recovery unit. Pooled and unpooled variance estimates cannot currently be combined as needed in Program DISTANCE, so final construction of density mean and variance estimates from the above components was completed without specialized software.

<table>
<tr><th>Tortoise encounter rate</th><th>Proportion that are visible, G_0</th><th>Detection rate, P_a</th><th>Proportion seen on the line, g(0)</th><th>Density</th><th>Density</th></tr>
<tr><td>Stratum or substratified (*)</td><td>Neighboring G_0 sites</td><td>Data collection group</td><td>Overall</td><td>Stratum</td><td>Recovery unit</td></tr>
<tr><td>FK</td><td rowspan="3">Ord Rodman + Superior Cronese</td><td rowspan="3">Kiva north</td><td rowspan="15">Full set of tortoise observations</td><td>FK</td><td rowspan="5">Western Mojave</td></tr>
<tr><td>SC</td><td>SC</td></tr>
<tr><td>OR</td><td>OR</td></tr>
<tr><td>JT</td><td rowspan="4">Joshua Tree NP + Chuckwalla</td><td rowspan="4">Kiva south</td><td>JT</td></tr>
<tr><td>PT</td><td>PT</td></tr>
<tr><td>CK</td><td>CK</td><td rowspan="2">Eastern Colorado</td></tr>
<tr><td>AG</td><td>AG</td></tr>
<tr><td>CM</td><td rowspan="4">Piute + Chemehuevi + Ivanpah</td><td rowspan="4">IWS</td><td>CM</td><td>Northern Colorado</td></tr>
<tr><td>FE</td><td>FE</td><td rowspan="3">Eastern Mojave</td></tr>
<tr><td>IV</td><td>IV</td></tr>
<tr><td>PI</td><td>PI</td></tr>
<tr><td>GB*</td><td>Gold Butte + early Halfway Wash</td><td rowspan="4">GBI</td><td>GB</td><td rowspan="4">Northeastern Mojave</td></tr>
<tr><td>BD*</td><td rowspan="2">Halfway Wash (later)</td><td>BD</td></tr>
<tr><td>MM*</td><td>MM</td></tr>
<tr><td>CS*</td><td>Coyote Springs</td><td>CS</td></tr>
</table>

Figure 5. Process for developing density estimates in 2010. For each type of estimate, the full set of data was subdivided appropriately.

Estimating the area of each stratum sampled and the number of tortoises in that area

Before the 2008 field season, based on experience in 2007 and visual examination of DEM overlays, all assigned transects were classified as possible for completion as 12k, 6k, or as unwalkable (USFWS 2010a). These classifications before the field season are advisory only, because exact ground conditions, weather, and crew condition all affect the ability to complete a transect. If a non-standard (not 12km square) is walked, crews indicate the obstacles they encountered that forced the change in protocol. In addition to the above named factors, substrate that is very loose on a steep slope or that includes large boulders can make progress so slow or treacherous that crews modify the transect.

Each year, some transects are repeated, providing new information on ground conditions, and new transects are attempted. At the end of each field season, transects that were completed differently from expected are evaluated. At that point, a decision is made whether to reclassify the transect. The classification is used to advise future transect completion, but also to estimate the proportion of each monitoring stratum that is actually represented by the walked transects.

Because each transect of any length is built off of the southwestern corner, how that transect is completed is one representation of transects built on all possible southwestern corners. In order to avoid selection bias by crews, there were only 3 classification options for entire transects, so that only 0, 6, or 12km were actually walked, but of course all of the distances between these options might actually have been walkable. Transects that were not walked represent all transects that could be walked for lengths of 0- to 6-km. It is parsimonious to therefore assume that on average, 3km could have been walked for each transect classified as “unwalkable.” Transects completed using the 6km option represent all of those that could have been completed for distances of 6- to 12km, averaging 9km, so that is the expected value for all of those transects. Transects completed as 12km represent the 100% completion option. The total area of the stratum that is unwalkable is estimated as:

If a given stratum covers 5000km^2, but only 90% was walkable and represented by our sampling design, then the density estimates applies to 4500km^2, and can be used to generate an estimate for the number of tortoises in those 4500km^2. Using these area estimates adds another source of imprecision, so abundance estimates are slightly less precise than the density estimates they derive from. The additional error of this estimate is calculated as the error for a binomial proportion.

In 2010, two new procedures for walking transects were implemented. First, although tortoise conservation areas are largely surrounded by public lands, these lands are used more and more for activities that are not compatible with tortoise maintenance. In previously years, to simplify transect completion, all transects with at least half their length inside a stratum were walked without modification when the transect path left the stratum boundary. Transects were, however, reflected to avoid signed private property or other infrastructure, including major roads. In 2010, in acknowledgment that public lands inside and outside tortoise conservation areas are becoming increasingly different, transects are now planned to reflect inward from these [usually] invisible boundaries. This new procedure has also caused the reclassification of some transects to walkable, where stratum boundaries exclude mountain ranges, for instance.

Next, because funding in California has resulted in so few transects in most strata, there are also very few 6k-modified transects. In some cases, there are so few that no tortoise detections occur on the few kilometers walked this way in a given stratum. In this case, substratification is not possible. In 2010, the field crews in California (Kiva and IWS, also on transects IWS walked in Nevada) always used the 12km square path, completing as much of that path as possible. The calculation of unwalkable area is now based on the proportion of unwalkable kilometers, not unwalkable transects.

Debriefing to describe strengths and weaknesses of project preparation and execution
At the end of each 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. Because the field teams had disbanded by then, field crew members were surveyed prior to the end of the field season to nonetheless gather their direct input was we identified areas to target for improvement. Although issues and/or tasks may be ascribed to individual entities, this meeting is most beneficial in identifying where centralized and/or coordinated response is required to improve the quality of the program.

RESULTS

Field observer training
The smaller Kiva and IWS groups trained alongside one another and mostly separate from GBI, although experienced crews worked between all three teams. Training started on 11 March and continued through 6 April in 2 staggered sessions (Table 1). Final tests of field detection abilities occurred toward the end of this period.

Proportion of tortoises detected at varying distances from the transect centerline
Table 2 reports the proportion of models that were available and were detected by each team at 1-, 2-, and 5-meters from the transect centerline. Teams were tested after a trial run on the detection lines (first-year/GBI crews) or after walking practice transects for returning crews that wanted to refresh the search pattern. Detection on the centerline was expected to be 100%, and most crews achieved this. First-year trainees detected a similar proportion of models at 1- and 2m compared to experienced crews, with first-year trainees detecting fewer models at 5m.

Table 3 reports further statistics for each team after collecting data on 16km on the evaluation lines. Measurement accuracy reported in Table 3 gives the average absolute difference between the expected and measured perpendicular distances from the model to the walked line. All measurements for all models during the 2-day trial are used for this estimate, and capture inaccuracies from 1) using a compass and measuring tape to record distances to the models, plus 2) inaccurately following the trajectory of the transect. The latter source of error does not occur on monitoring transects, because the walked transect is the true transect. On training lines, error in measurements is increased if crews do not walk on exactly the measured line that was used to place the models. The “Available Models Detected by Leader” column reports the proportion of all models 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. With an 80% success rate for the leader, a 96% detection rate is expected for the team.

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

	Proportion of existing models within a given distance and were detected by the team		
Team	1m	2m	5m
1	0.93	0.96	0.87
2	1.00	0.96	0.91
3	0.92	0.96	0.94
4	1.00	0.88	0.87
5	1.00	0.93	0.95
6	1.00	0.92	0.88
7	0.85	0.90	0.86
8	1.00	1.00	0.90
21	1.00	0.89	0.93
22	0.93	0.89	0.88
23	1.00	1.00	0.97
24	0.85	0.89	0.88
26	1.00	1.00	0.97
27	0.88	0.93	0.94
28	1.00	1.00	0.94
51	1.00	0.96	0.95
52	1.00	1.00	0.94
53	1.00	0.96	0.93
54	1.00	1.00	0.90
55	0.93	0.96	0.93
56	1.00	0.93	0.90
57	0.93	0.96	0.96
58	1.00	1.00	0.94
59	1.00	0.96	0.91
60	1.00	0.96	0.92
61	1.00	0.96	0.88
62	1.00	1.00	0.94
GBI	**0.99**	**0.97**	**0.93**
Kiva	**0.96**	**0.94**	**0.90**
IWS	**0.95**	**0.94**	**0.93**
Overall	**0.97**	**0.95**	**0.92**

Table 3. Diagnostics for individual teams after training

Team	Available models detected: Within 2m of centerline by leader	Available models detected: Within 2m of centerline by team	Measured v. exact model distance (m)	Estimated abundance	95% confidence interval: Lower limit	95% confidence interval: Upper limit
1	0.89	0.96	0.79	396	302.3	519.3
2	0.84	0.96	0.79	377	326.8	434.6
3	0.93	0.96	0.96	409	343.7	485.5
5	0.92	0.88	0.77	443	359.6	546.0
6	0.92	0.93	0.84	397	345.1	457.4
7	0.96	0.92	0.73	375	319.7	439.7
8	0.97	0.9	0.78	378	341.5	417.3
21	0.93	1	0.79	682	524.3	888.1
22	0.96	0.89	0.76	356	318.4	398.9
23	0.96	0.89	1.14	433	394.1	474.6
24	0.96	1	0.89	408	326.9	509.6
26	1.00	0.89	0.79	366	324.1	412.2
27	1.00	1	0.82	427	313.5	582.3
28	0.92	0.93	0.74	402	296.0	547.2
51	1.00	1	0.87	390	325.3	467.5
52	0.90	0.96	0.8	370	330.8	413.8
53	1.00	1	0.87	403	365.2	443.8
54	0.89	0.96	0.75	441	369.7	526.0
55	0.92	1	0.55	345	294.6	403.1
56	0.92	0.96	1.01	475	388.1	580.5
57	0.96	0.93	0.8	384	286.8	513.3
58	0.84	0.96	0.81	451	377.2	539.7
59	0.86	1	0.63	464	380.1	566.3
60	0.90	0.96	1.02	477	355.8	639.5
61	0.93	0.96	0.8	343	297.8	394.1
62	1.00	0.96	1.13	461	384.1	553.8
Target	**>0.80**	**>0.70**	**<1**	**410**		
GBI	**0.91**	**0.97**	**0.83**	**415.17**		
IWS	**0.97**	**0.94**	**0.86**	**397.45**		
Kiva	**0.92**	**0.94**	**0.81**	**432.09**		
Overall	**0.93**	**0.95**	**0.83**	**415.59**		

During training, personnel on 2 teams were switched after unsuccessful practice runs. The resulting 2 teams are included in Tables 2 and 3. Although some individual metrics were below-par (gray cells in the above tables), the teams were all judged to perform well overall and no further changes were made. During training, various models were fit to each crew's set of tortoise model observations. In no case did a negative exponential model best describe the data. Because this model does not involve fitting a "shoulder" to the data at g(0), these detection curves would have been unacceptable. The best-fitting of the 3 remaining basic types of models were then fit to the data to generate the density estimates in Table 3. In Figure 6 to Figure 8, each crew's data were fit to uniform or half-normal data (not hazard rate) for illustration purposes. By overlaying all of the detection curves for a single field team, we could also guide individual crews to better match the search patterns of their teammates. Crews were not "tested" on their ability to match teammates; this was seen as an opportunity to focus field personnel on an additional level of conformity. Distance sampling and development of a single detection curve from many observers is robust to the effects of pooling across observations from crews with variable search patterns, as long as all of the observers contribute proportionally to the overall pattern (Marques et al., 2007).

Within the GBI crews, teams 51 and 52 had the most anomalous curves (broadest shoulders) in Figure 6. These teams were coached on tightening their search pattern to better match other teams; however, neither team had other diagnostic issues. Although the IWS trainee curves as a group have broader shoulders than the GBI curves, the IWS curves are similar to one another, and no problems are evident. The Kiva detection curves are more disparate between themselves. Three of these teams (1, 3, and 8) left training a few days earlier than the others. They had passed all of the training metrics and left to match the earlier opening of CMAGR. Although the other teams received feedback and worked to match one another's detection curves in the final trials, the first three teams (the ones with the narrowest shoulders that most rapidly lose detections with increasing distance from the line) did not. It is possible that their early completion of training affected ability to match their peers.

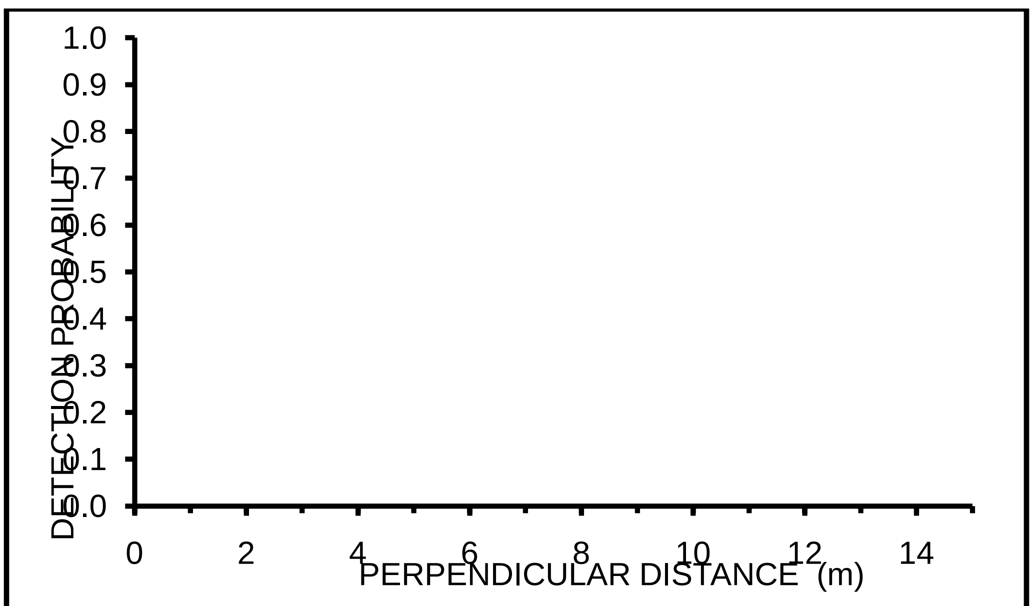


Figure 6. Detection curves for each of the 2010 GBI teams during training. Curves are based on 16km trials with approximately 100 detections. Anomalous patterns described in test are indicated with dotted lines.

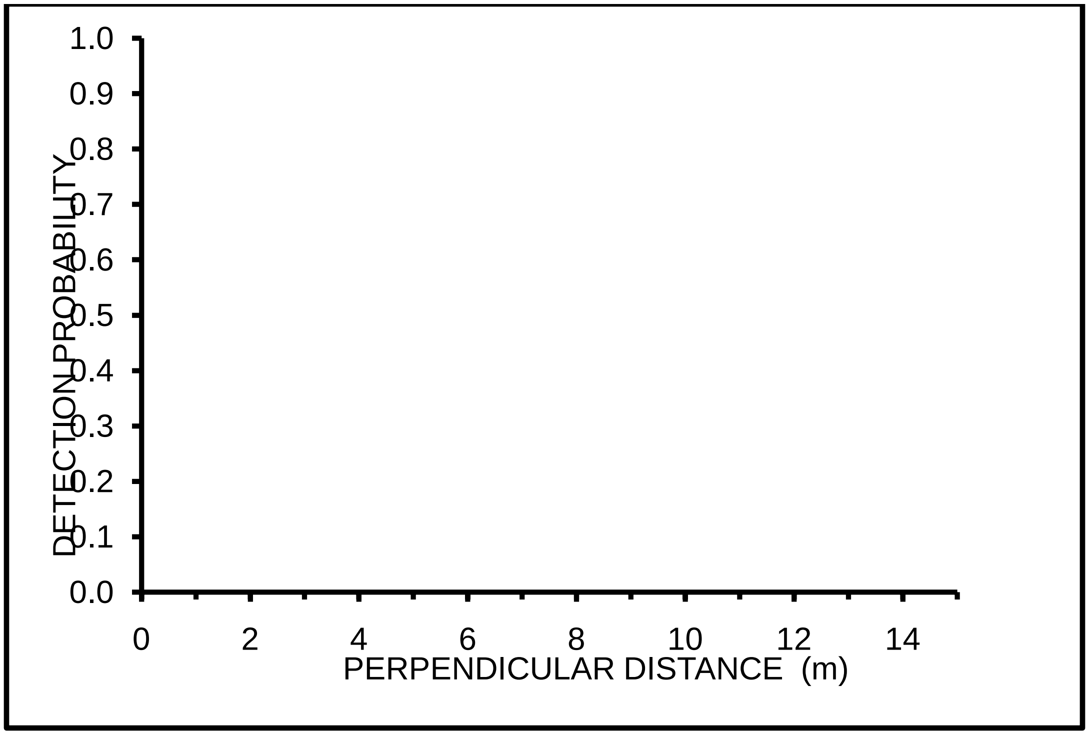


Figure 7. Detection curves for each of the 2010 IWS trainee teams. Curves are based on 16km trials with approximately 100 detections.

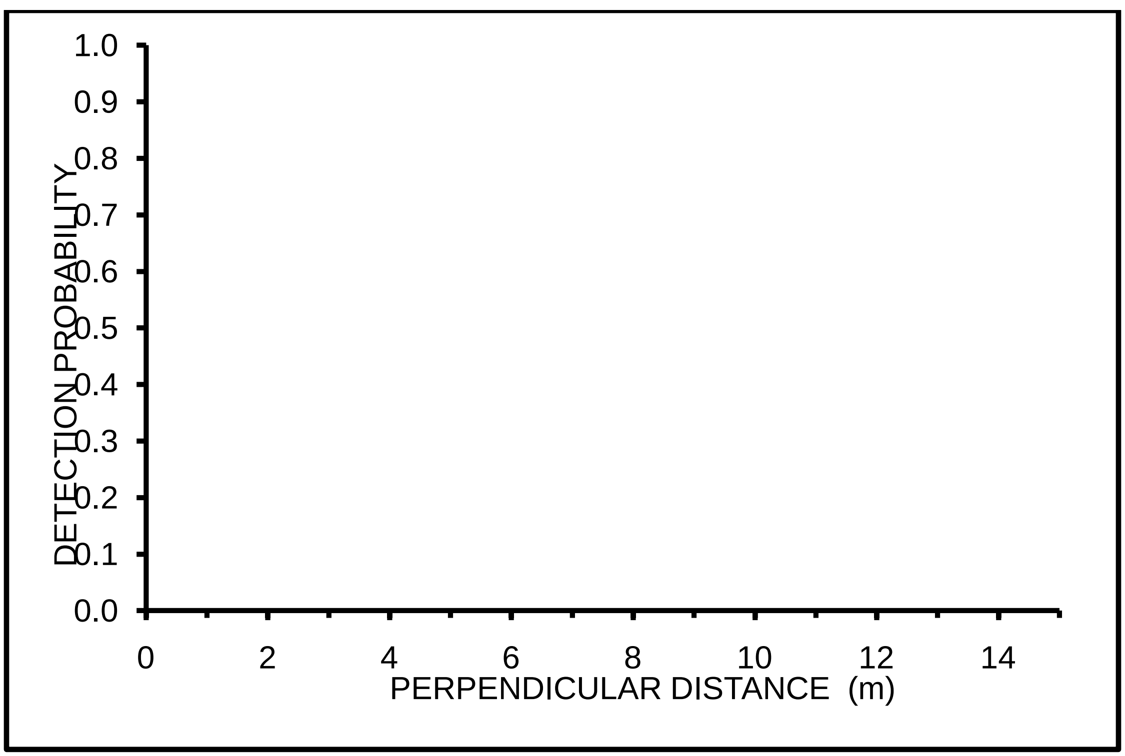


Figure 8. Detection curves for each of the 2010 Kiva trainee teams. Curves are based on 16km trials with approximately 100 detections. Anomalous patterns described in test are indicated with dotted lines.

Quality assurance and quality control
Field data have been been through phases I and II of the data processing steps, including QA/QC. At the time of this draft report, QA/QC has been completed; however, following the schedule for each field season, the summary from QA/QC products will be completed at the end of the calendar year.

Transect completion
Table 4 reports the number of assigned and completed transects in each stratum. Kiva was assigned 328 transects and walked this number, but were not always able to replace assigned unwalked transects with alternates in the same strata. As indicated in Table 4, too few transects were walked in Chuckwalla (BLM section), Joshua Tree National Park, and Pinto Mountain strata. All 7 of these transects were later completed in northern strata. Because these did not replace assigned transects in those strata, they are not part of the tally in Table 4. All assigned transects were completed or replaced by IWS. Another transect was inadvertently walked twice (counted once) and at the end of the field season one crew was able to complete an addition transect (not a replacement for any assigned), so they actually walked 135 transects. The Great Basin Institute completed more transects then the other 2 teams and also had more errors. Eight transects were inadvertently walked on two separate occasions (not indicated in Table 4), and 8 assigned transects were neither completed nor replaced by alternates in their strata. GBI did complete another 2 transects that were neither assigned nor replacements, so their walked tally is actually 425.

Great Basin Institute also addressed the issue of areas that have not been accessible. Base-camping into route-less areas allowed crews to be provisioned centrally with supplies, including water, while the crews hiked farther in to complete 24 transects in larger areas where crews would have had to complete more than 17km in one day (including access) or had to hike more than 6km over difficult terrain to access transects. Any field personnel provisioning these base camps for other crews are not themselves walking transects.

Table 4 indicates the number of assigned transects that could be completed as standard square 12km transects (column 4), as well as the number that were completed by reflecting around obstacles. These transects are all considered to represent flatter topography in the monitoring stratum. An additional number (column 5) were completed as 6km squares (GBI) or shortened as little as possible (IWS and Kiva), and represent more rugged terrain. Finally, some transects were considered unwalkable (column 6).

The last 2 columns of Table 4 represent situations that were not anticipated. Crews were to shorten or abandon transects if the terrain presented too much of an obstacle. Reflecting around terrain was not a planned option. However, on some, relatively rare, occasions (column 7), crews had partially walked a transect before determining that it could not be completed following the correct protocol. In these situations, they would not have sufficient time to move to an alternate transect on the same day, so they instead reflected around terrain to collect data for the lower topography portion of the current transect.

Column 8 reports transects that appear walkable based on remote imagery but were not completed. All of these were reevaluated and some were reclassified based on this [additional] year of field information (see *Evaluating transect classification*, below). Note that transects on military installations (Chocolate Mtn Air Gunnery Range, Ft. Irwin, and Edwards AFB) are regularly inaccessible due to military activities. This corresponds to the 7 transects listed here for Chocolate Mountain Air Gunnery Range (AG), 2 on Superior-Cronese, and 1 on Fremont-Kramer.

Figures 9 through 12 show locations of transects and observations of live tortoises.

Table 4. Number and type of transects in each stratum.

Stratum	Assigned transects	Assigned and alternate transects completed*	Assigned, completed 12k	Assigned, completed shortened	Assigned, judged unwalkable	Assigned, completed by reflecting to avoid terrain	Assigned, judged walkable, but not walked*
AG	33	33	22	3	8		7
BD	68	66	38	22	6		1
CK	64	61	34	21	6		3
CM	40	40	30	2	8	1	2
CS	100	99	58	21	20		9
FE	20	20	18	2	0		
FK	50	50	41	7	2		2
GB	130	128	59	46	23	4	7
IV	30	30	23	3	4		1
JT	27	25	11	11	3		1
MM	132	130	65	52	13		7
OR	25	25	14	7	4		1
PI	44	44	30	8	6	3	2
PT	20	18	8	6	4		
SC	109	109	91	12	6		3
Total	892	878	542	223	113	8	46
GBI	430	423	220	141	62	4	24
IWS	134	134	101	15	18	4	5
Kiva	328	321	221	67	33	0	17

*Assigned transects that were not walked were supposed to be replaced by alternates.

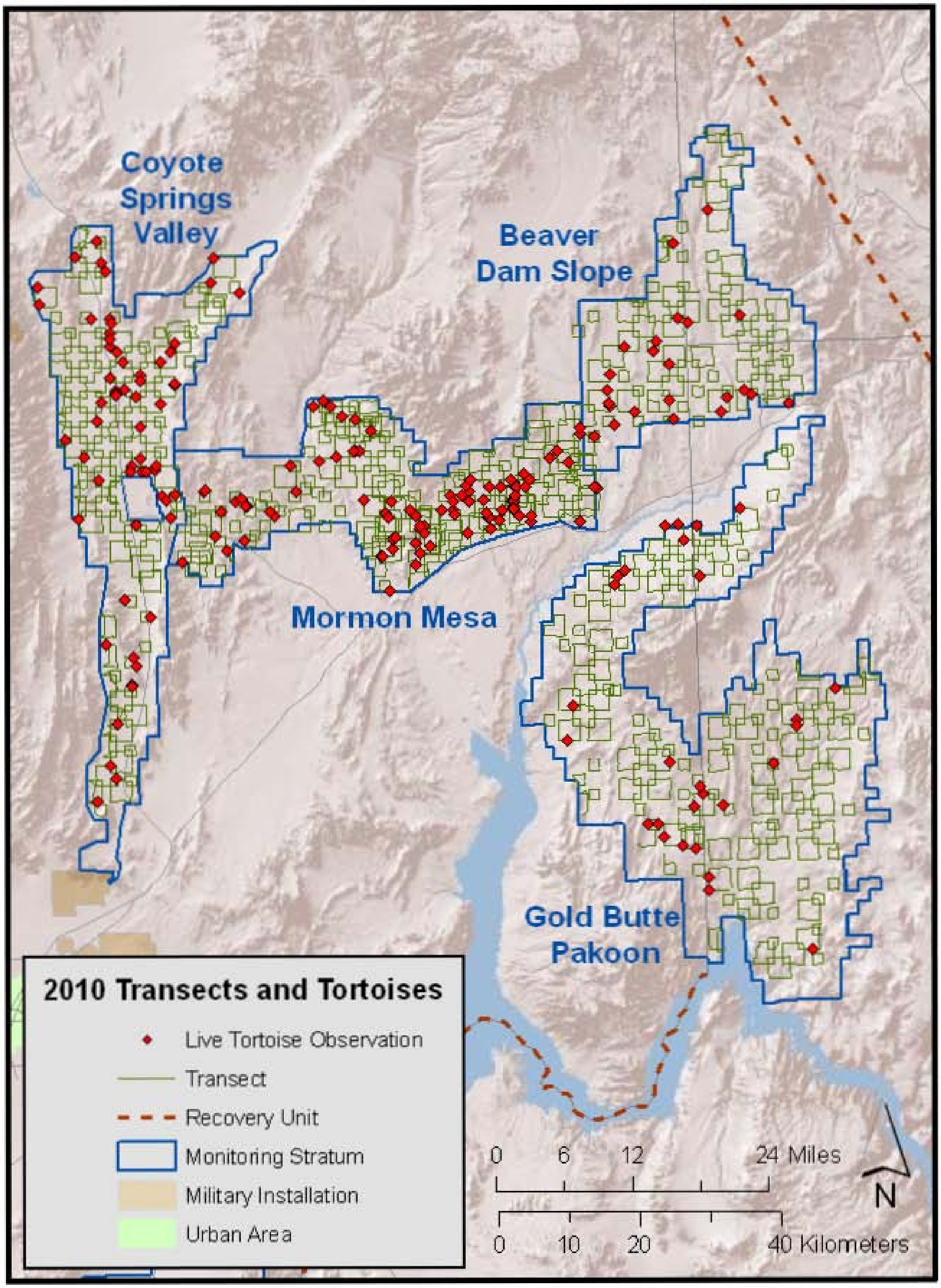


Figure 9. Distribution of distance sampling transects and live tortoise observations in the Coyote Springs Valley, Mormon Mesa, Beaver Dam Slope, and Gold Butte-Pakoon monitoring strata.

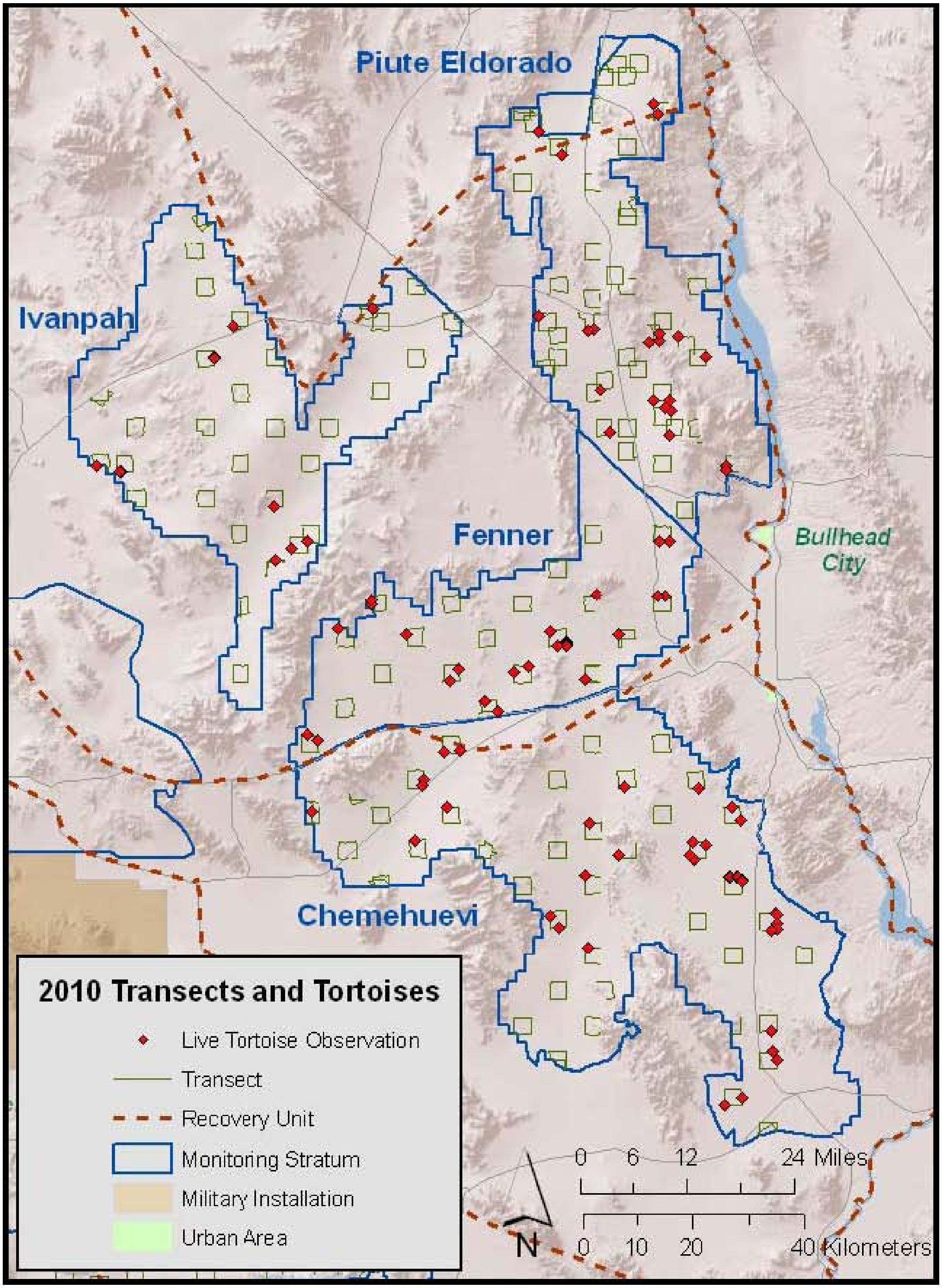


Figure 10. Distribution of distance sampling transects and live tortoise observations in the Piute-Eldorado Valleys, Ivanpah, Fenner, and Chemehuevi monitoring strata.

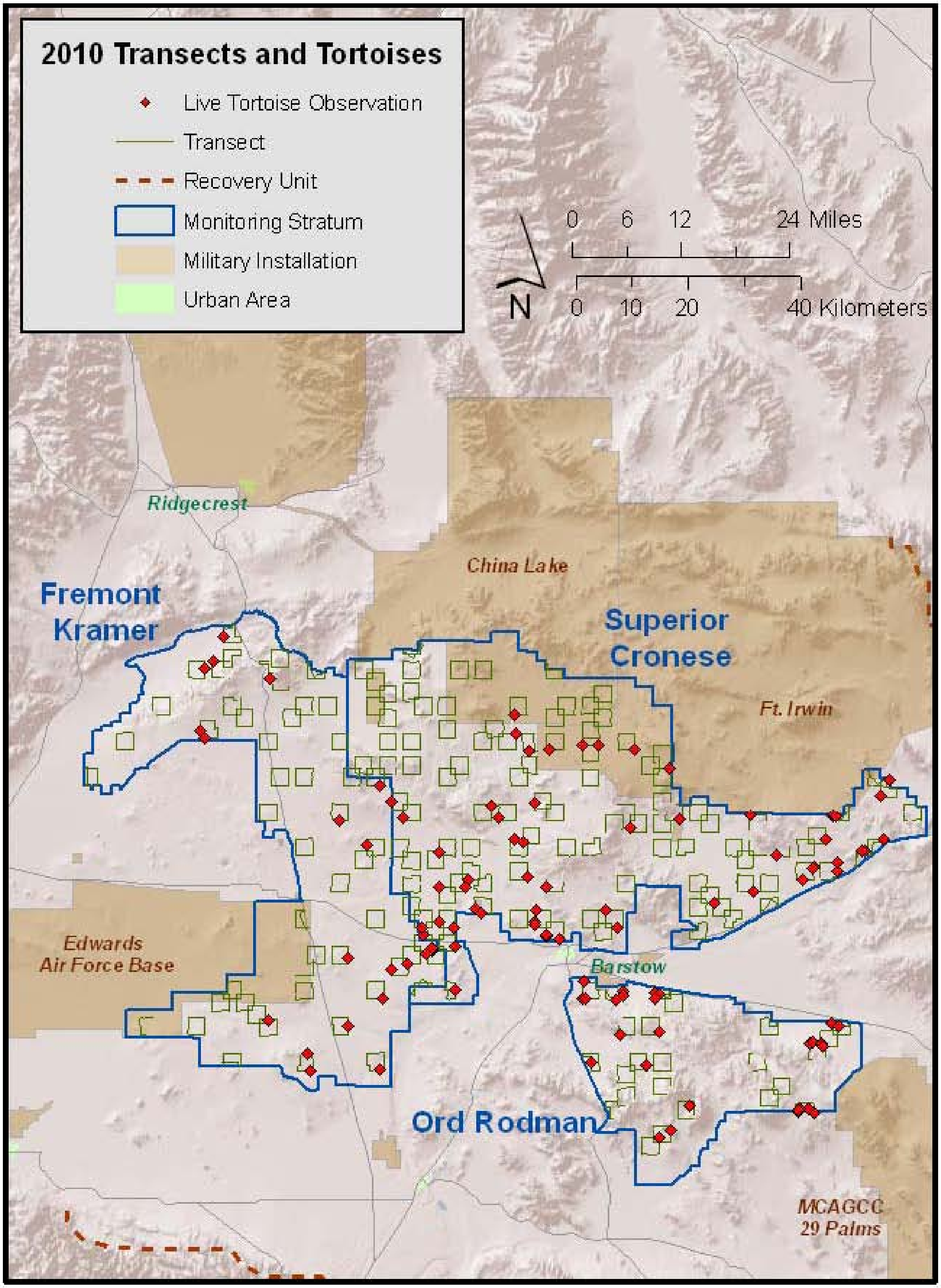


Figure 11. Distribution of distance sampling transects and live tortoise observations in the Fremont-Kramer, Superior-Cronese, and Ord-Rodman monitoring strata.

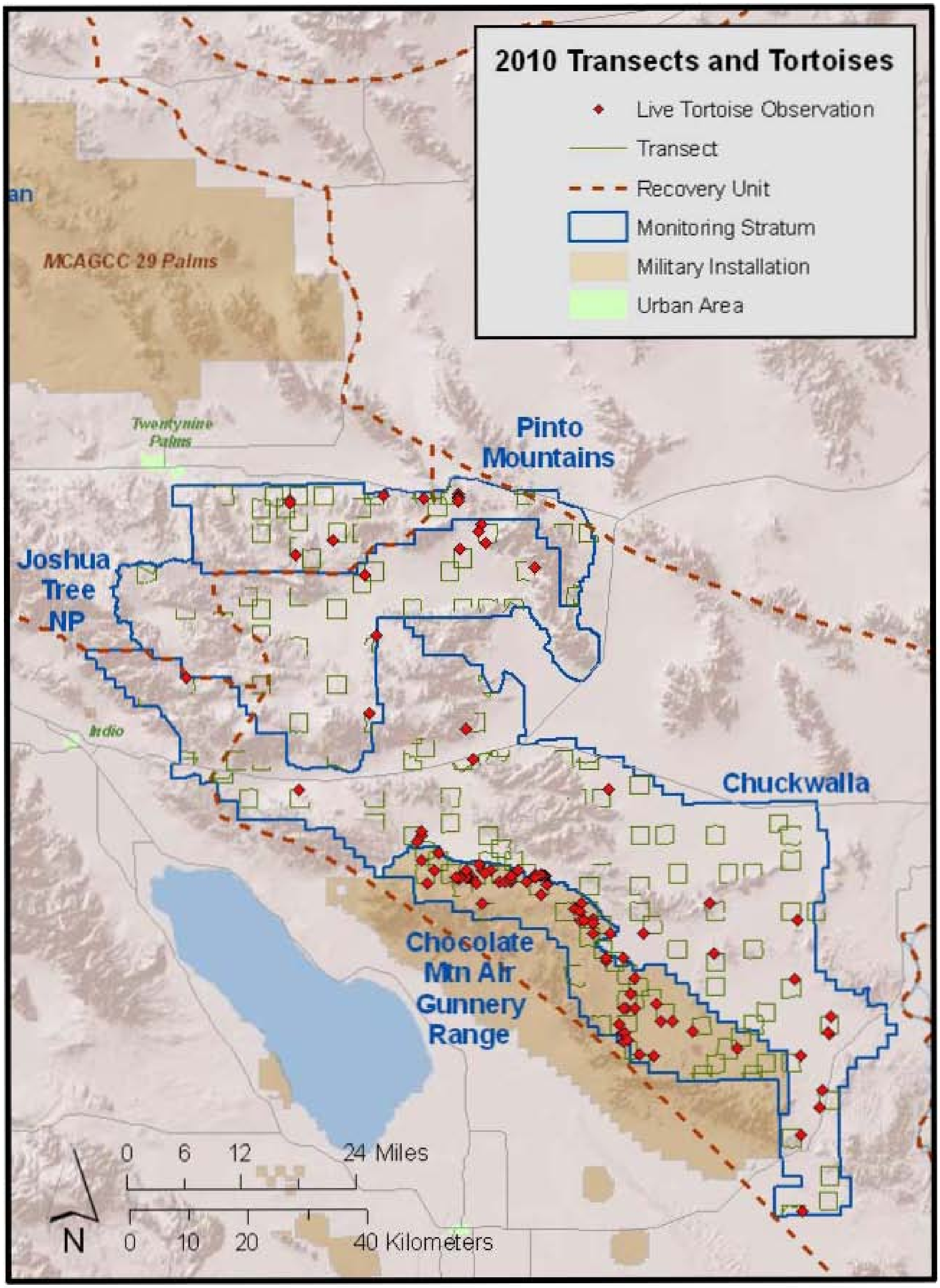


Figure 12. Distribution of distance sampling transects and live tortoise observations in the Pinto Mountains, Joshua Tree, Chuckwalla, and Chocolate Mountain AGR monitoring strata.

Tortoise encounter rates and detection functions

Figures 13 to 16 are histograms of the observed number of tortoises seen at increasing distance from the transect centerline. There is one histogram each for IWS and GBI, plus separate histograms for Kiva detections in the northern and southern areas that they surveyed. These observations were used to model detection curves, overlaid in the same figures. Based on detection function behavior, it is typical to discard a few observations in the tails of the histograms in order to build a more robust model. Each figure indicates the customized truncation distance that was applied. Truncation was conservative in order to maximize the number of observations per stratum. Any observations that are not used to estimate detection functions will also not be used to estimate the encounter rate (tortoises detected per kilometer walked). In distance sampling applications for many other species, encounter rate can be estimated with relatively high precision, but tortoise encounter rates are low enough that this becomes a factor in considering how to truncate observations to develop detection functions.

In 2010, all pairs worked together from the beginning to the end of the season. Each Kiva crew walked on average 41 transects and overall they detected 196 tortoises over 180mm MCL; GBI crews walked a median of 36 transects and detected 179 tortoises; and IWS crews had considerably lower effort, with a median of 23 transects and 80 tortoises over the field season. The effort for Kiva and GBI crews was similar, so a single detection curve could have been considered for these teams. However, GBI was still applying the single 6km option for shortening transects, and these teams were in very different parts of the range, so from the beginning I planned a minimum of 3 detection curves, each based on the count of tortoises noted above. For GBI, a hazard rate function fit best, but the best half-normal and uniform models were within ΔAIC=1.47 of the hazard rate model, with much better precision for the half-normal model but no meaningful difference in density estimate between the half-normal and hazard rate models. On the basis of precision, I used the half-normal model with second-order cosine adjustment to fit the detection function. The second-order adjustment is seen in the extra inflections in the tail of the curve (Fig. 13). This additional data fitting was called for unless observations were truncated at 8m, with a loss of 38 additional observations, so the second-order adjustment was kept instead. In the case of IWS, data were truncated at 12m and fit best to a uniform model with a cosine adjustment. Because there were so many detection for Kiva and because they walked transects a covering long north-south gradient, I also tested separate curves for northern and southern detections by Kiva, and this did result in a better fit to the data. In the north (Fremont-Kramer, Ord-Rodman, and Superior Cronese), the data were truncated at 12m and fitted best to a uniform model with cosine adjustment. In the south, data were truncated at 8m and fit to a half-normal model.

The area below these curves in Figs. 13 (GBI), 14 (IWS), 15 (Kiva south) and 16 (Kiva north) is the proportion of tortoises that were detected, P_a, estimated as far as the truncation distance (the farthest distance on the x-axis in each figure). Based on these curves, GBI detected 41.2% of the visible tortoises within 16m of the centerline (CV=0.085). The corresponding estimate of P_a for strata surveyed by IWS was 60.7% (CV=0.083) within 12m, for Kiva in the north was 58.3% (CV=0.070) within 12m, and for Kiva in the south it was 67.1% (CV=0.100) within 8m.

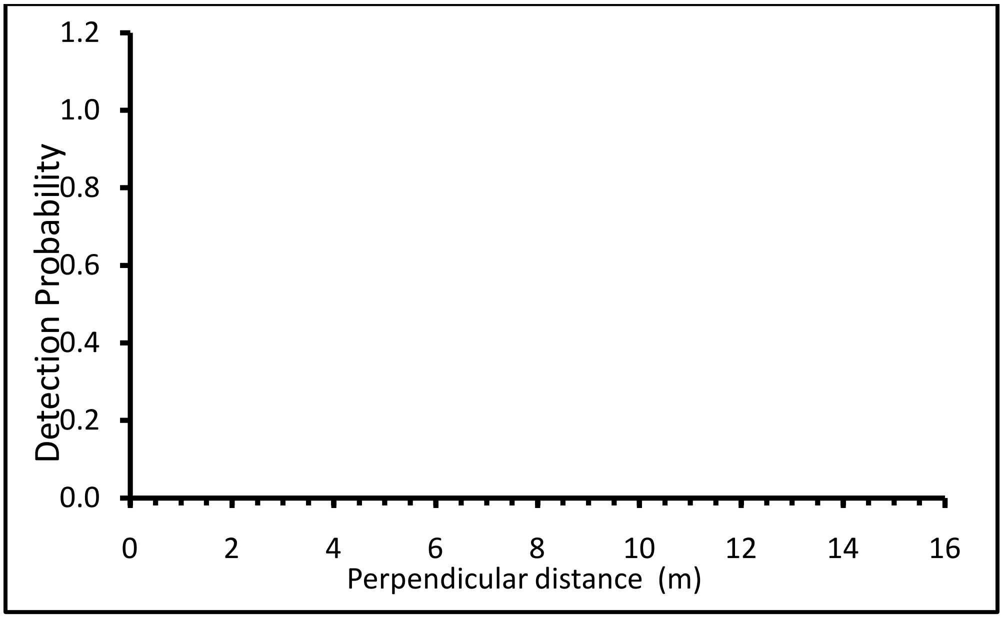


Figure 13. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by GBI. Observations were truncated at 16m.

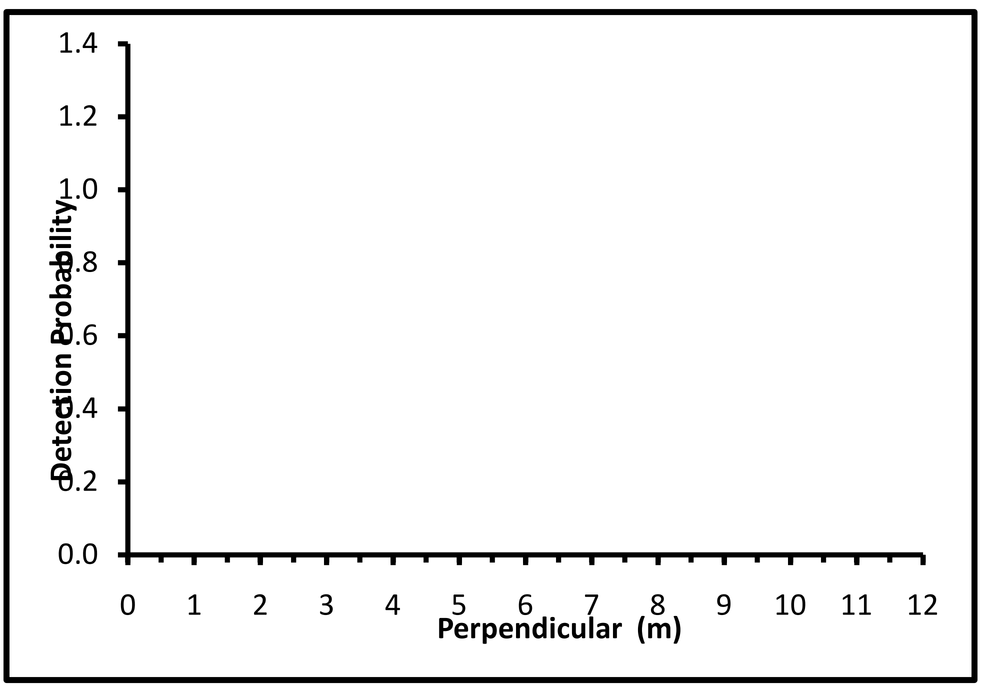


Figure 14. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by IWS. Observations were truncated at 12m.

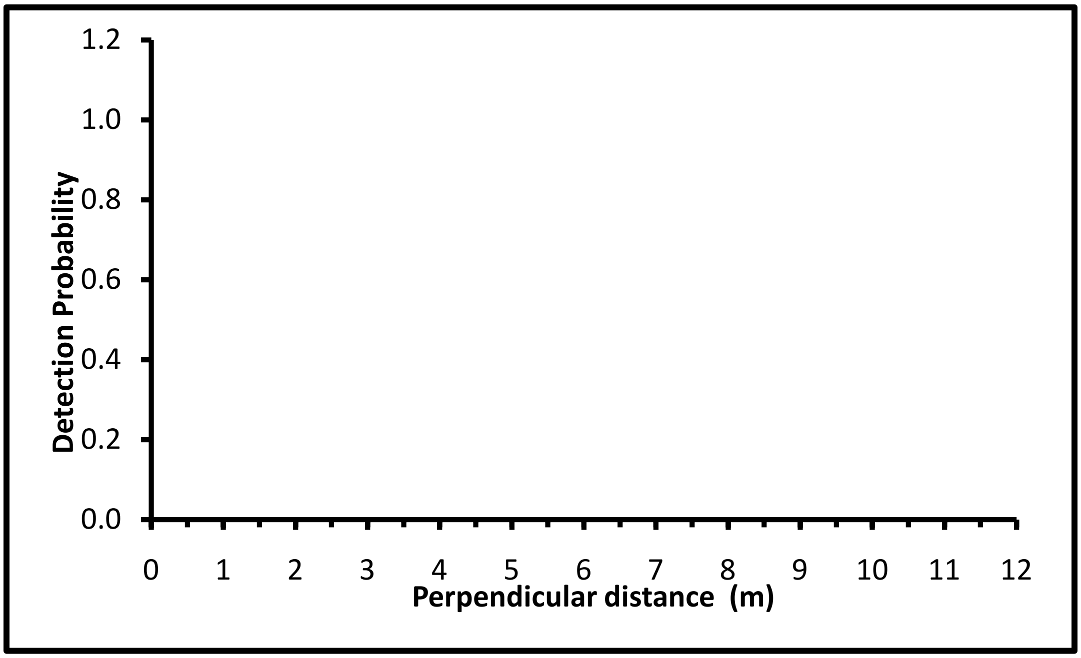


Figure 15. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by Kiva in Fremont-Kramer, Superior-Cronese, and Ord-Rodman. Observations were truncated at 12m.

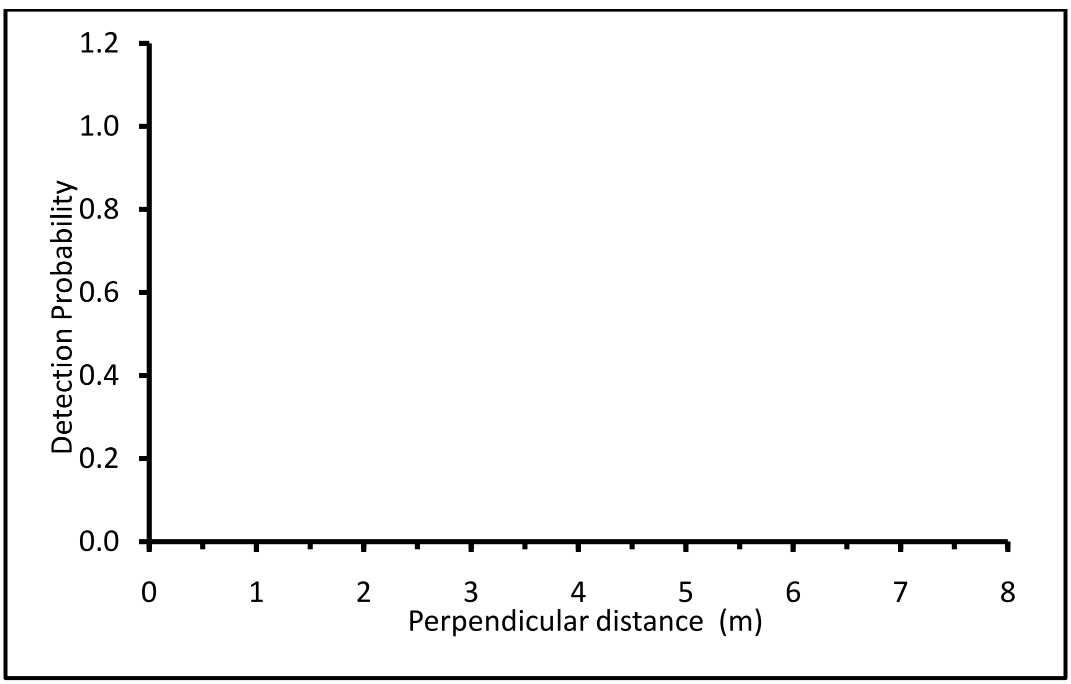


Figure 16. Observed detections (histogram) and fitted detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by Kiva in Joshua Tree National Park, Pinto Mountains, Chuckwalla (BLM) and Chuckwalla (Chocolate Mtn Air Gunnery Range). Observations were truncated at 8m.

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

In general, telemetry sites and associated transects were completed sequentially, from south to north. This pattern corresponds to the expected timing of tortoise activity; activity should peak first in the south, later in the north. Tortoise availability was estimated separately transects in each of these areas. Dates, total days monitored, and G_0 estimates are given in Table 5.

Table 5. Availability of tortoises (G_0) during the period in 2010 when transects were walked in each group of neighboring strata.

G_0 sites	Strata	Dates	Days	G_0 (Std Error)
Gold-Butte/ Halfway Wash (through 22 April)	Gold Butte	7 Apr – 22 Apr	16	0.75 (0.184)
Halfway Wash (after 22 April)	Beaver Dam Slope, Mormon Mesa	23 Apr – 15 May	23	0.80 (0.115)
Coyote Springs Valley	Coyote Springs Valley	16 May – 28 May	13	0.86 (0.130)
Piute/ Ivanpah/ Chemehuevi	Piute-Eldorado, Chemehuevi, Fenner, Ivanpah	31 Mar – 29 Apr	30	0.82 (0.179)
Joshua Tree/ Chuckwalla	Chuckwalla (DoD), Chuckwalla (BLM), Joshua Tree NP, Pinto Mtns	23 Mar – 10 Apr	19	0.89 (0.124)
Ord-Rodman/ Superior Cronese	Fremont-Kramer, Ord-Rodman, Superior Cronese	13 Apr – 6 May	24	0.96 (0.067)

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

Because they are cryptic, even tortoises that are visible (not covered by dense vegetation or out of sight in a burrow) may not be detected. For 50 detections of tortoises within 1m of the transect centerline, 44 were found by the observer in the lead position and 6 by the follower, so that the probability of detection by single observer, $p = 0.864$, and the proportion detected using the dual observer method, $g(0) = 0.981$ (SE = 0.06). Figure 17 shows that *g(0)* was converging on 1.0, indicating the assumption of perfect detection on the center line was met. No adjustment was made to the final density estimate. In USFWS (2009) and USFWS (2010a), this assumption was evaluated for years since 2004. The 6 years involved are those for which dual observers were part of the protocol instead of the earlier 3-pass method to detect every tortoise on the transect. The curves since 2004 have all supported the premise that complete detection on the transect line was achieved for years in which the dual-observer method was used.

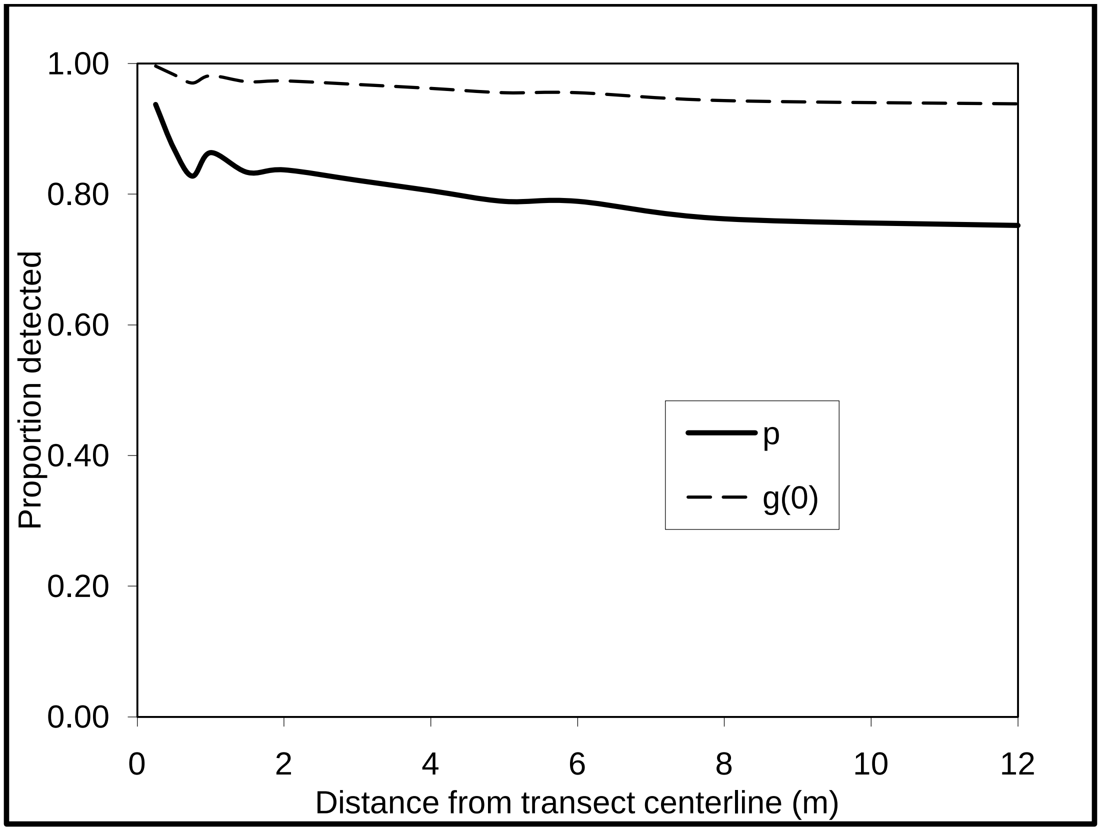


Figure 17. Behavior of detection on the line by the leader (*p*) and by the team (*g(0)*) based on all observations out to a given distance from the centerline in 2010. Note convergence of *g(0)* on 1.0 at the transect line (at distance=0).

Estimates of tortoise density

Density estimates were generated separately for each monitoring stratum (Table 6), then weighted by stratum area to arrive at average density in the monitored area of each recovery unit (Table 7). Although encounter rates were estimated separately for each stratum, and have independent variances, the detection function and G_0 were estimated jointly (pooling data from multiple strata), so these variances are not independent (Fig. 5 illustrates how estimates were pooled for 2010).

When the annual estimates are imprecise, it should not be expected that there will be a close match from one year to the next. Over a period of many years, however, any underlying trend in the number of tortoises should be obvious through this "background noise." The CVs in 2010 represent an overall improvement in precision from previous years, a function of improved funding in this one year.

Table 6. Recovery unit and stratum-level encounters and densities in 2010 for tortoises with MCL ≥ 180mm.

Recovery Unit	Stratum		Area (km2)	Number of Transects	Total transect length (km)	Sampling Dates		Field Observers	*n* (tortoises observed)	CV(*n*)	Density (/km)	CV(Density)
						Begin	End					
Northeastern Mojave			**4889**	**425**	**4265**	**7-Apr**	**28-May**	**GBI**	**164**		**3.2**	**15.9**
	Beaver Dam Slope	BD	828	66	662	23-Apr	15-May	GBI	23	22. 8	3.3	28.2
	Coyote Springs Valley	CS	1117	99	1046	16-May	28-May	GBI	43	16.7	3.6	24.0
	Gold Butte-Pakoon	GB	1977	128	1258	7-Apr	22-Apr	GBI	22	25.0	1.8	36.0
	Mormon Mesa	MM	968	132	1298	24-Apr	16-May	GBI	76	12.3	5.5	20.7
Eastern Mojave			**6763**	**95**	**1096**	**31-Mar**	**29-Apr**	**IWS**	**45**		**3.6**	**30.2**
	Fenner	FE	1862	20	246	31-Mar	27-Apr	IWS	22	29.2	7.5	37.3
	Ivanpah	IV	2567	31	365	1-Apr	29-Apr	IWS	5	41.6	1.1	47.7
	Piute-Eldorado	PI	2334	44	485	31-Mar	29-Apr	IWS	18	24.6	3.1	33.8
Northern Colorado			**4038**	**40**	**458**	**31-Mar**	**30-Apr**	**IWS**	**24**	**26.9**	**4.4**	**35.6**
	Chemehuevi	CM	4038	40	458	31-Mar	30-Apr	IWS	24	26.9	4.4	35.6
Western Mojave			**9351**	**234**	**2591**	**23-Mar**	**6-May**	**Kiva**	**105**		**3.1**	**14.7**
	Fremont-Kramer	FK	2462	50	574	15-Apr	6-May	Kiva	19	22.4	2.5	24.5
	Joshua Tree National Park	JT	1567	25	227	25-Mar	13-Apr	Kiva	6	53.9	2.8	56.5
	Ord-Rodman	OR	1124	25	270	17-Apr	4-May	Kiva	27	22.8	7.5	24.8
	Pinto Mountains	PT	751	21	213	25-Mar	10-Apr	Kiva	7	51.4	3.4	54.2
	Superior Cronese	SC	3447	113	1307	13-Apr	6-May	Kiva	46	15.9	2.6	18.7
Eastern Colorado			**4263**	**94**	**991**	**23-Mar**	**10-Apr**	**Kiva**	**72**		**5.9**	**18.7**
	Chocolate Mountain Air Gunnery Range	AG	755	33	378	25-Mar	5-Apr	Kiva	50	19.2	13.8	25.7
	Chuckwalla	CK	3509	61	613	23-Mar	10-Apr	Kiva	22	25.2	3.7	30.5

Table 7. Estimated density of desert tortoises in monitored areas of each recovery unit in the Mojave and Colorado deserts in 2010.

Recovery Unit	Sampled area (km^2)	Transects	Tortoises detected	Density ($/km^2$)	SE(Density)	%CV (Density)
Eastern Colorado	3472	94	72	5.8	1.09	18.8
Eastern Mojave	6030	95	45	3.6	1.10	30.3
Northeastern Mojave	3850	425	164	3.2	0.52	15.9
Northern Colorado	3572	40	24	4.4	1.56	35.6
Western Mojave	8152	234	105	3.2	0.47	14.8

Area of each stratum sampled and the number of tortoises in that area

Evaluating transect classification

In 2010, 196 of the 888 walked transects were not completed as predicted. The following table summarizes conclusions after examining these transects.

Table 8. Transects completed other than as planned and any resulting reclassification

Previous substratum	Situation	New substratum	Number of transects
12k	On-the-ground observation differs from imagery	6k	21
12k	Shortened in 2010, but previous experience or correct modification would allow completion	12k	52
6k	On-the-ground observation differs from imagery	12k	31
Unwalkable	On-the-ground observation differs from imagery	12k	16
Unwalkable	New rules to reflect into stratum moved transect out of too-rugged terrain	12k	12
Unwalkable	On-the-ground observation differs from imagery	6k	19
6k	Lengthened in 2010, but other crews might be unable to walk as a 12k	6k	18
Unwalkable	Crew completed the transect using incorrect protocols or attempted new rules but couldn't walk at least 6km	Unwalkable	11
Unwalkable	New shortening rules allowed at least 6km completed, but earlier rules would have classified these as unwalkable	Shortened	16

Twenty-eight transects that would have been unwalkable under the previous protocols were attempted and completed this year using new rules to reflect into stratum boundaries (rangewide) and to shorten transects by walking only the safely walkable portions of the 12km route (Kiva and IWS field teams only). In the first case, 12 transects were completed because they were correctly reflected into strata under new rules. These otherwise unwalkable transects were completed because stratum boundaries were often drawn to exclude more rugged topography. Sixteen previously unwalkable transects were walked for at least 6km using new rules to shorten transects without completing the SW quadrant. These would still be "unwalkable" under the original classification system.

After the field season, 168 anomalous transects were reviewed. Of these, 87 were reclassified based on crew experience. In some cases, this reflects discrepancy between interpretation of terrain from imagery; in many others, classification is ambiguous because over the course of a 12km transect, terrain is so variable to that it was not a simple matter to evaluate the ability of a typical crew to complete it. The remaining 81 anomalous transects were not reclassified, either because the classification still seems ambiguous, or because the crew's modification was based on access, illness, or something else unrelated to terrain.

Proportion of each stratum walked

The proportion of each stratum walked in 2010 could be calculated based on the proportion of transects shortened and/or replaced (GBI) or based on the proportion of kilometers walked, based on the expectation that 12km should be walked for each transect assigned (Kiva and IWS). In 2008 and 2009, only the previous method was used, and all transects assigned in 2010 had already been classified as 12k, 6k, or unwalkable. To test the comparability of estimating the unsampled part of each stratum, we calculated the number of kilometers expected to be walked based on the 12/6/unwalkable classification of each assigned transect, then compared this to the proportion of kilometers estimate (Table 9).

Table 9. Proportion of each stratum that can be sampled.

		Proportion assigned transects expected to be walked as…			Km walked		
Stratum	Assigned transects*	12k	6k	Replaced	Expected	Observed	Chi-sq
AG	33	84.8	12.1	3	375	288.6	19.8
BD	66	60.6	30.3	9.1	600	590.5	0.1
CK	61	63.9	18	18	600	565.2	2.0
CM	40	77.5	7.5	15	417	377.2	3.8
CS	99	60.6	27.3	12.1	882	824.3	3.8
FE	20	100	0	0	240	233.5	0.2
FK	50	94	6	0	591	549.6	2.9
GB	128	48.4	35.2	16.4	1014	990.2	0.5
IV	30	86.7	0	13.3	324	305.1	1.1
JT	25	56	24	20	237	197.6	6.6
MM	130	53.1	39.2	7.7	1134	1091.5	1.6
OR	25	68	20	12	258	232.9	2.4
PI	44	70.5	18.2	11.4	459	417.5	3.8
PT	18	50	11.1	38.9	147	140.6	0.3
SC	109	89	6.4	4.6	1242	1202.9	1.2
Total	**878**				**8520**	**8007**	**50.1**
GBI	**423**				**3630**	**3496**	**6.1**
IWS	**134**				**1440**	**1333**	**8.9**
Kiva	**321**				**3449**	**3177**	**35.2**

Chi-squared values in the final column indicate a poor fit between predictions and completion at CMAGR, which is typical, given constraints on access to different parts of the range each year (crews frequently cannot get access to otherwise walkable transects, so these transects are replaced). With the exception of the gunnery range, the strata individually and for each group combined indicate that the kilometers completed was predicted accurately regardless of method used to estimate unwalkable terrain.

This means we can use the observed kilometers walked to estimate the area over which our density estimates apply. However, for strata walked by GBI, we can use the total experience since 2008 (many more total transects assigned) to estimate the proportion of walkable transects. In fact, the similar results using the 2 methods in 2010 show that even though Kiva and IWS developed estimates for the number of walkable kilometers in their strata, we can use the larger data set for walkable transects (1399 transects evaluated in these strata since 2008; of the 880 evaluated in 2010 many were revisits) to better estimate the walkable area in those strata. Table 10 gives the area of each stratum, the proportion covered by our density estimates, and converts the density in each stratum into an estimate of tortoise abundance.

Table 10. Estimated tortoise abundance in sampled areas of each stratum

Stratum	Area (km^2)	Proportion sampled	SE(Prop. Sampled)	Sampled area	N (number of tortoises)	95% Confidence Interval	
						Lower Limit	Upper Limit
AG	755	0.94	0.028	712	9820	5965.1	16164.4
BD	828	0.86	0.036	708	2323	1342.8	4018.4
CK	3509	0.77	0.040	2710	10140	5609.4	18330.5
CM	4038	0.88	0.046	3543	15483	7814.4	30677.9
CS	1117	0.84	0.032	943	3412	2132.9	5459.3
FE	1862	0.95	0.037	1761	13162	6461.2	26814.1
FK	2462	0.99	0.016	2428	6006	3736.2	9654.4
GB	1977	0.76	0.030	1500	2640	1327.1	5249.8
IV	2567	0.89	0.041	2297	2622	1075.5	6390.5
JT	1567	0.76	0.055	1195	3298	1166.0	9326.1
MM	968	0.84	0.036	811	4486	2977.6	6758.7
OR	1124	0.77	0.059	865	6453	3911.4	10646.4
PI	2334	0.85	0.026	1989	6152	3219.5	11753.8
PT	751	0.72	0.068	538	1842	672.2	5047.5
SC	3332	0.95	0.019	3158	8301	5761.7	11960.5

Debriefing to identify strengths and weaknesses in preparation for future years

This meeting was held on 8 June, about 1 week after all field work was completed. The following issues were identified to be addressed by coordinated effort rather than by efforts of single parties.

Need for more central responsibility for planning data
It was decided that starting in 2011, MDEP will host server-based [GIS] information for use by mapmakers. Through 2010, MDEP has provided Mojave-wide data layers to individual field teams, and assigned transects were identified by the UTM coordinates of their southwestern corners. Because there was little central oversight over how these data were acquired and used, different field teams had variable map quality and occasionally shifted transects when processing the corner coordinates into full square transects. This processing, including any planned shortening and/or reflections should be repeatable each time the same transect is assigned, so centralized responsibility for this would be a better option.

Training improvements to make more effective use of same time period
In 2010, there were more trainees from more teams in the same areas for training at the same time. Use of the Desert Tortoise Conservation Center would be improved by setting up more stations (with more instructors) for smaller groups of trainees. Also, although objectives have been articulated for instructed material, this is not the case for the many days available for "practice." On those days, additional oversight and specific objectives that can be evaluated would improve effectiveness and provide additional feedback to crews.

Current hardware has become less trustworthy and cannot implement recent, improved software
Since 2007, responsibility for providing the same data collection systems to all field teams has been centralized with the USFWS. Those units (data collection systems including connected GPS) are now outdated and will be replaced under advisement from MDEP and UNR.

Not all QA/QC errors remedied by the end of field season
Two types of errors occurred during the field season and were not corrected effectively. This resulted in 7 of the 888 transects inadvertently being walked twice and in different types of first-level QA/QC reporting errors from the 2 different data specialists. Although they were trained together by UNR, their approaches seemed to diverge as they addressed data errors. In 2011, the "end-user" (Topoworks) will spend more time training specialists. This work will also emphasize steps to take to avoid duplicating effort on any transects.

DISCUSSION

Sampling representatively in all monitoring strata

Since 2007, transects have been placed systematically in monitoring strata; the placement scheme itself had a random origin so that transects were located at random with respect to tortoises. The goal of systematic placement is used to provide better coverage of sampled areas, yet the random aspect of this design also allows inference about the entire sampled area. Because the same set of potential transect locations will be used to sample from in future years, it is meaningful to collect information describing access and completion of each transect so that this information is available when planning to walk this transect location in future years.

The current sampling design allows us to 1) estimate the actual area to which our density estimates apply; some areas are too rugged for humans to access, and therefore 2) also apply the density estimate to this sampled area to arrive at an abundance estimate in each monitoring stratum.

Training developments

Training has received focused attention each year. This training improves the performance of individual crews, but also helps to standardize the application of protocols among different field teams. In 2010, experienced crew personnel worked with new trainees in their own and in different teams to add a new level of cohesiveness between field teams. This attention to standardized procedures is maintained during the field season, with frequent, customized, written crew evaluations, and we attribute continued high performance in 2010 directly to this focus on standardized training and implementation of protocols. No correction for failure to detect visible tortoises on the centerline have been made to density estimates since 2004 (prior to that, a 3-pass method was used to ensure all tortoises were detected). Training data in 2010 indicate that crews were detecting all tortoise models on the testing centerline, and by the end of training, first-year crews were performing as well as experienced crews.

Improving ability to detect trends in desert tortoise abundance

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

Consequences of sufficient transects

There were new and enhanced funding sources in 2010, so that all strata had more than the minimum number of transects. Associated with the relatively high estimates of tortoise visibility (G_0), more tortoises were seen in some recovery units, even accounting for the enhanced level of effort. Whereas funding opportunities are under agency control, the particularly mild spring season also contributed to improved density estimates in most of the range. The notable exception was the Eastern Mojave/Northern Colorado, where the number of funded transects was still below optimal and the spring weather was cooler than optimal for tortoises to be out and visible most of the time. In the remaining 3 monitored recovery units, the coefficient of variation for density estimates was between 15 and 20% of the density estimate – reflecting and extremely successful field season. The Eastern Mojave/Northern Colorado recovery units had density estimates with lower precision (30.2 and 35.6%, respectively), a reminder that decreased funding and unseasonable conditions can act separately to thwart our coordinated efforts for range-wide density estimates.

LITERATURE CITED

Anderson, D.R., and K.P. Burnham. 1996. A monitoring program for the desert tortoise. Report to the Desert Tortoise Management Oversight Group.

Anderson, D.R., K.P. Burnham, B.C. Lubow, L. Thomas, P.S. Corn, P.A. Medica, and R.W. Marlow. 2001. Field trials of line transect methods applied to estimation of desert tortoise abundance. Journal of Wildlife Management 65:583-597.

Averill-Murray, R.C., and A. Averill-Murray. 2005. Regional-scale estimation of density and habitat use of the desert tortoise (Gopherus agassizii) in Arizona. Journal of Herpetology 39:65–72.

Berry, K.H., and L.L. Nicholson. 1984. The distribution and density of desert tortoise populations in California in the 1970's. Chapter 2 *in* K.H. Berry (ed.), The status of the desert tortoise (*Gopherus agassizii*) in the United States. Desert Tortoise Council Report to the U.S. Fish and Wildlife Service. Order No. 11310-0083-81.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford Univ. Press, Oxford. 432 pp.

Corn, P. S. 1994. Recent trends of desert tortoise populations in the Mojave Desert. Fish and Wildlife Research 13:85-93.

Luckenbach, R.A. 1982. Ecology and management of the desert tortoise *(Gopherus agassizii)* in California. *In* R.B. Bury (ed.). North American Tortoises: Conservation and Ecology. U.S. Fish and Wildlife Service, Wildlife Research Report 12, Washington, D.C.

Marques, T.A., L. Thomas, S.G. Fancy, and S. T. Buckland. 2007. Improving estimates of bird density using multiple-covariate distance sampling. The Auk 124(4) 1229-1243.

McLuckie, A.M., M.M. Reitz, and R.A. Fridell. 2008. Regional desert tortoise monitoring in the Red cliffs Desert Reserve, 2007. Salt Lake City: Utah Division of Wildlife Resources, Publication Number 08-19. 57pp.

SPSS, Inc. 2010. PASW Statistics, Rel. 18.0.2. Chicago: SPSS Inc.

Swann, D.E., R.C. Averill-Murray, and C.R. Schwalbe. 2002. Distance sampling for Sonoran desert tortoises. Journal of Wildlife Management 66:969–975.

Thomas, L, S.T. Buckland, E.A. Rexstad, J.L. Laake, S. Strindberg, S.L. Hedley, J.R.B. Bishop, T.A. Marques, and K.P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47:5-14.

Tracy, C.R., R.C. Averill-Murray, W.I. Boarman, D. Delehanty, J.S. Heaton, E.D. McCoy, D.J. Morafka, K.E. Nussear, B.E. Hagerty, and P.A. Medica. 2004. Desert Tortoise Recovery Plan Assessment. Report to the U.S. Fish and Wildlife Service, Reno, Nevada.

[USFWS] U.S. Fish and Wildlife Service. 1994. Desert Tortoise (Mojave Population) Recovery Plan. U.S. Fish and Wildlife Service, Portland, Oregon.

[USFWS] U.S. Fish and Wildlife Service. 2006. Range-wide Monitoring of the Mojave Population of the Desert Tortoise: 2001-2005 Summary Report. Report by the Desert Tortoise Recovery Office, U.S. Fish and Wildlife Service, Reno, Nevada.

[USFWS] U.S. Fish and Wildlife Service. 2008. Draft revised recovery plan for the Mojave population of the desert tortoise (*Gopherus agassizii*). U.S. Fish and Wildlife Service, California and Nevada Region, Sacramento, California. 209 pp.

[USFWS] U.S. Fish and Wildlife Service. 2009. 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.

[USFWS] U.S. Fish and Wildlife Service. 2010a. Range-wide Monitoring of the Mojave Population of the Desert Tortoise: 2008 and 2009 Reporting. Report by the Desert Tortoise Recovery Office, U.S. Fish and Wildlife Service, Reno, Nevada.

[USFWS] U.S. Fish and Wildlife Service. 2010b. Desert Tortoise Monitoring Handbook. Desert Tortoise Recovery Office, U.S. Fish and Wildlife Service, Reno, Nevada. Version: 2 March 2010. http://www.fws.gov/nevada/desert_tortoise/reports.

White, G.C., D.R. Anderson, K.P. Burnham, and D.L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. LA-87-87-NERP. Los Alamos National Laboratory, Los Alamos, NM. 235pp.