

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

2008 AND 2009 REPORTING

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Personnel from Kiva Biological Consulting (California) led by L. Pavlischak (2008) and K. Herbinson (2009) and from the Great Basin Institute (Nevada, Arizona, and the Beaver Dam Slope of Utah) led by T. Christopher conducted the field surveys:

2008: M. Bassett, J. Brown, S. Casebolt, F. Chan, J. Clare, C. Corroy, R. Crawford, J. Creasser, I. Daly, A. Davila, A. d'Epresmenil, K. Dutcher, T. Embrey, J. Enneson, D. Essary, B. Farless, A. Fisher, J. Guarneri, A. Halbruner, B. Hanley, K. Hancock, E. Hunter, A. Johnson, S. Johnson, P. Kahn, G. Keyes, A. Knutson, P. Lien, K. Loope, E. Lyon, I. MacLeod, L. McPhun, W. Middleton, M. Minic, L. Mjos, K. Moeller, C. Noble, S. Noble, A. Padilla, J. Patterson, K. Petrasko, L. Rankin, B. Role, R. Saltmarsh, C. Scanlon, T. Scott, P. Segre, L. Smith, B. Sparks, J. St Peter, S. Sullivan, C. Tucker

2009: C. Anderson, L. Baltic, M. Bassett, J. Brinson, T. Bristle, J. Brouwer, M. Brouwer, J. Brown, B. Ciccotelli, J. Cipra, M. Cook, A. Cottone, I. Daly, W. Deacy, A. d'Epresmenil, A. Fisher, C. Furman, S. Green, A. Halbruner, B. Hanley, J. Harvester, P. Havlik, K. Herbinson, K. Holcomb, M. Hurst, A. Joslin, S. Karinen, C. Keaton, G. Keyes, A. Kissel, K. Lalumiere, W. Langworthy, W. Lee, P. Livingston, M. Maurer, C. McClurg, M. McLaughlin, L. McPhun, M. Micus, W. Middleton, L. Mjos, S. Paris, J. Patterson, K. Paulseth, B. Role, C. Scanlon, D. Scott, T. Scott, K. Shelp, B. Sieh, B. Sparks, S. Stanley, A. Sturgill, D. Turner, R. Vaghini, M. Vamstad, and P. Woodman

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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 numbers within recovery units remain stable or increase over 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 2008 and 2009 monitoring efforts. Since monitoring started again in 2007, the above recommendations guided improvements to the program (USFWS, 2009a). In 2008, the focus continued, with particular emphasis on a more comprehensive training program, consistent with the premise that training is the opportunity to develop and evaluate quality data collection and to build consistency between separate field teams. An expanded monitoring handbook was written as a reference for objective-driven training. The period of specialized training was extended, with teams intended to work only on general desert and field skills before the group training. Inexperienced crews as well as those with prior experience participated in preseason training and testing provided by the University of Nevada, Reno, and by the U.S. Geological Survey in 2008. In 2009, this training was provided directly by the USFWS. In depth examination of training results after the 2008 field season made it clear that better real-time evaluation was needed; before the 2009 training session, Topoworks and the USFWS had developed a system and database tools for this rapid assessment. In 2009, before leaving training for field data collection,

all crews passed quantitative evaluation of their ability to produce appropriate detection curves, detection proportion on the transect line, and measurement accuracy from tortoise models to the transect line.

The range-wide monitoring effort is directed each year at 13 strata that form the long-term monitor effort. One critical habitat unit (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). In addition, 2 short term strata were funded for monitoring only in 2008 and 2009, and two more short-term strata were funded by the USFWS on BLM lands north or south of Pahrump, in Nye County, Nevada. Data were collected on transects by 52 (2008) or 53 (2009) field personnel working with two different groups, Kiva Biological and Great Basin Institute. After an intensive, 12 day specialized training session, first-year crews were ready to work with returnees who had only a refresher course; they completed 680 transects (6941km) between 31 March and 30 May in 2008, and 765 transect surveys (7740km) between 1 April and 6 June in 2009. In the course of these surveys, they reported 196 live tortoises in 2008 and 273 in 2009.

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 2008, Kiva crews detected 39% of tortoises within 14m of the transect centerline, GBI detected 41% within 18m. In 2009, Kiva crews detected 36% of tortoises within 14m of the transect centerline, GBI detected 26% within 15m. Some of the difference between the two years was probably attributable to drier conditions in 2008 and less spring growth even in shrubs. This is one reason it is helpful to describe detection functions each year and for different parts of the range. Lack of moisture and of spring growth is probably also related to the decreased proportion of tortoises that were visible to be counted (G_0) in 2008 compared to 2009 and most other years. The

proportion also varies in different parts of the range, which were surveyed at different times during the spring season. Visibility in 2008 varied from a high of 83% in Coyote Springs during the second half of April and first half of May to 55% at the Chuckwalla telemetry site, monitored in the middle of May. In 2009, the highest proportion visible was 96% at Ord-Rodman in the middle of April, with a low visibility at 64% at Halfway Wash in the last week of April. Actually, only 58% of tortoises were available in Chuckwalla when this site was visited a second time, in the first week of June. Due to access issues on Chocolate Mountain Air Gunnery Range, this site was monitored outside the usual activity period, when such a low G_0 estimate would be expected.

On average, crews walked 39km for each tortoise that was observed in 2008, and 37km in 2009; both of these numbers reflect relatively low encounter rates compared to previous years. In addition, encounter rates varied considerably from one monitoring stratum to the next. As usual, in 2008 strata in the Northeastern Mojave Recovery Unit had the lowest densities (1.1, 1.2, and 1.9 per km², respectively, in the Beaver Dam Slope, Coyote Springs, and Mormon Mesa strata). Forty transects were completed in Gold Butte-Pakoon, but no tortoises were detected, so no density estimate was possible. Although this report provides density estimates in other strata, only 3 of these estimates are based on detecting at least 10 tortoises, so the estimates are less useful in and of themselves; however, they do contribute to developing the recovery-unit-level estimate. In 2009, with supplemental funding in Nevada, the effort was sufficient to find tortoises in all strata in the Northeastern Mojave; in fact, the density was estimated higher than in the past, at 3.4 tortoises/km². Consistent with patterns in the past, the Mormon Mesa stratum had densities about twice as high as the other 3 strata in the recovery unit. Other strata with densities over 7 tortoises/km² were Chemehuevi, Chocolate Mountain Air Gunnery Range, Ord-Rodman, and Fenner. Although this program was not developed or designed to accurately estimate stratum-level densities, it is useful that the same strata are associated with high and low densities each year. Due to funding limits, only 12 transects were walked in the BLM portion of Chuckwalla in 2009, and no tortoises were detected there; so there is no density estimate for the Eastern Mojave Recovery Unit that year.

To enable field crews to complete transects in some of these previously unsampled areas, rules implemented in 2007 required crews to walk the transect in place (no “sliding”) or determine that it was completely unwalkable. In 2008 and 2009, crews were given more rigid rules for how to modify transects depending on whether obstacles were 1) administrative or infrastructure (roads, private property, etc) or were 2) related to difficult terrain or substrate. These rules did enable crews to sample entire strata in a more representative way, and allowed us to estimate the proportion of area within each monitoring stratum that cannot be sampled by crews on foot. This allows us to apply the density to a particular acreage and arrive at an estimate of the number of tortoises in the sampled area of each stratum. Because these numbers incorporate uncertainty

about the exact acreage that cannot be sampled, the abundance estimates are slightly less precise than the density numbers they originate with.

During end-of-season debriefings, crew feedback both years showed that the focus on standardized, directed training was valuable to crews. In both years, crews expressed some uncertainty that they were correctly applying protocols for modifying transects. However, weekly written assessments from UNR (2008) and then from USFWS (2009) were able to identify and communicate early in the field season to specific crews about deviations from protocols, so the crews were performing generally better than they perceived. The additional quality control procedures in place resulted in data sets with fewer errors each year compared to any previous years of this program.

Finally, the success of the range-wide monitoring program also depends on developing reliable, adequate, and consistent funding. In 2008, sampling in Gold Butte (40 transects) did not detect any tortoises, and in 2009, with only 12 transects funded in the BLM portion of Chuckwalla, no tortoises were detected there either. 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 2008 AND 2009

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-mi² 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 for entire 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.

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 and 2009a). This

report includes results of training exercises for field crews, describes implementation of monitoring, and presents separate analysis of desert tortoise density based on data collected in 2008 and 2009.

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 depicts these strata as well as 2 more that were added for 2008 and 2009 only. The Ely Field Office of the Nevada Bureau of Land Management provided supplemental funding in order to develop density estimates in areas just north of Mormon Mesa and Beaver Dam Slope (long-term monitoring strata); these temporary strata are referred to in this report as Mormon Mesa 2 and Beaver Dam Slope 2. Density estimates for Beaver Dam Slope 2 and Mormon Mesa 2 strata are reported here but not included in annual recovery-unit-level estimates that are assessed for long-term trends. Supplemental funding in 2008 from Coyote Springs, Inc. allowed for additional transects in the Coyote Springs stratum. Finally, the USFWS provided additional funding in 2008 in order to sample on public lands in the Pahrump Valley in Nevada.

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

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. It is often converted to a percentage. Since recovery criteria target trends within recovery units (USFWS, 1994), precision in that density estimate was the focus. The target CV is achieved based on the number of tortoises that might be encountered there (some

strata currently have higher densities than others), as well as the area of the stratum – its proportional contribution to the recovery unit density estimate (Buckland et al., 2001).

The actual number of transects assigned in each stratum was a function of the optimal numbers described above, as well as on available funding. So that recovery unit estimates would be based on the same monitoring areas and therefore comparable between years, a minimum number of transects were placed in each long-term monitoring stratum, then that number was increased up to the optimal level, depending on funding. In 2009, all strata had at least 10 transects, but in 2008, Pinto Mountains and Chemehuevi strata were planned with fewer. This approach to allocating transects in each stratum differed from that in previous years, when transects numbers were assigned in proportion to sample area, and strata without dedicated funding were not sampled.

Once the number of transects in a stratum was determined, these were laid out systematically across strata, with a random origin for the lattice 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 with wider spacing (9- or 27-km spacing) were used. When the number of transects planned for a stratum were not sufficient to use all of the potential sites in the lattice, a subset of the potential sites were selected at random. Use of 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.

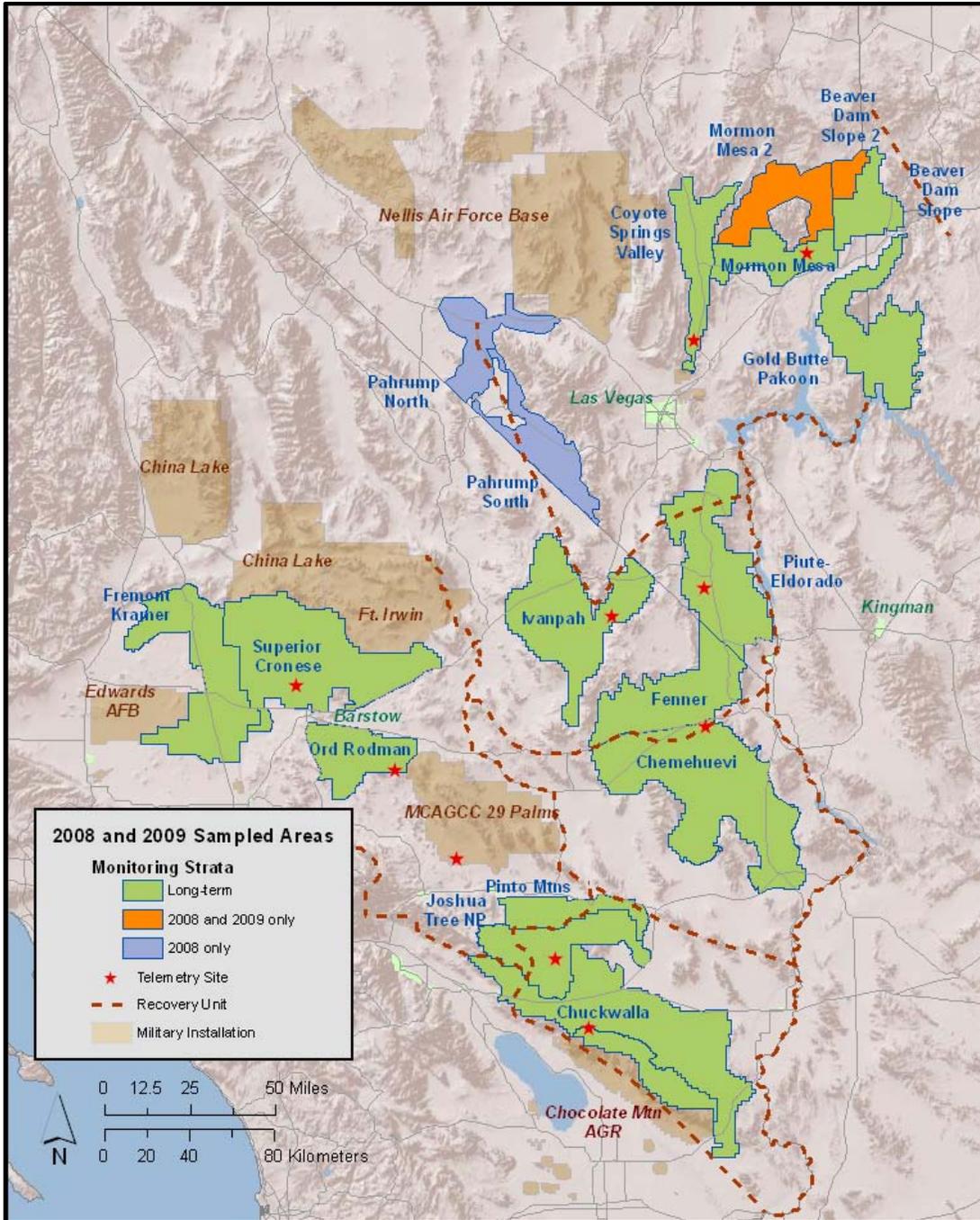


Figure 1. Sampled areas in 2008 and 2009.

For 2008 and 2009 only, the Mormon Mesa 2 and Beaver Dam Slope 2 strata were surveyed along with the long-term monitoring strata. In addition, public lands in the Pahrump Valley (Pahrump North and Pahrump South) were surveyed using distance sampling in 2008 only. The telemetry site on MCAGCC that had been monitored through 2008 was replaced by monitoring on Joshua Tree National Park in 2009. Unlike the former telemetry site, the latter one is located inside a current monitoring stratum. The additional telemetry site at Halfway Wash in Mormon Mesa was added in 2009.

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 should 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, and will be affected by 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 $\geq 180\text{mm}$ MCL, the criterion for including animals in density estimates.

Modification of previous procedures

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

In 2007, a new set of guidelines was provided to crews to give them options for completing transects without moving them away from the basic assigned location. These guidelines (USFWS, 2009) set conditions under which non-standard transects would be created by 1) reflecting transects inward, or 2) creating rectangular transects along obstacles associated with human infrastructure (large roads, private inholdings, etc.). In rugged terrain, 3) transects could be shortened to enable completion before 4pm each day.

Assessment of transect completion in 2007 (USFWS, 2009a) revealed that crews needed more rigid rules for completing non-standard transects; otherwise, different crews might implement very different protocols. In 2008 and 2009, 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 randomly ordered alternates. For more detail on field procedures including modification of transect paths, please refer to the *2009 Desert Tortoise Monitoring Handbook* (USFWS, 2009b).

Field observer training

Training improvement was a priority in 2008. A set of training modules was designated during the 2007 field season debriefing. For each module, USFWS worked with University of Nevada, Reno (UNR) researchers and their cooperators at USGS to develop training objectives and metrics, and UNR had the lead on developing written training materials. In addition to fundamental changes in the type of instruction provided, field contractor crews were given much more time to practice skills (Table 1 and Table 2), including tortoise handling, walking practice transects and developing detection and distance-measuring techniques on a training course with tortoise models. The monitoring handbook developed in 2008 was comprehensive, so that in 2009, individual chapters were revised as needed and all chapters were posted to the Desert Tortoise Recovery Office website (http://www.fws.gov/nevada/desert_tortoise/reports). Starting in 2009, the USFWS assumed responsibility for running the training program.

In 2008 and 2009, two teams of field observers participated. Kiva Biological (Kiva) supplied crews for monitoring in California. Great Basin Institute (GBI) supplied crews for monitoring in Nevada, Arizona, and Utah. Personnel for the former team were mostly trained for the first time in 2008 and most returned in 2009. The latter crew was comprised primarily of new personnel each year. Because there were half as many personnel to train, in 2008 the Kiva team began specialized training 5 days after the GBI team (Table 1). However, some of this time was spent working with the team leader for Kiva, who had many previous years of experience with distance sampling. In 2009, due to the experience level of returning Kiva personnel, the GBI crews were provided with 12 full days of preparatory training and practice, whereas the Kiva team was trained for only 5 days (Table 2).

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.

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Table 1. Training schedule for 2008.

GBI trainees			Kiva Trainees	
Date	Activity	Trainer	Activity	Trainer
Week 1				
10-Mar	Desert Tortoise Recovery and Monitoring Program	Allison (FWS)		
	Working on Public Lands	Ronning (BIM)		
	Introduction to Line Distance Sampling & "G ₀ "	Corn (USGS)		
	Protocols for non-standard transects	Allison		
11-Mar	Tortoise biology and handling lecture/practice	Christopher (GBI)		
12-Mar	Transect methods lecture	Corn		
	Compass/GPS use for line distance sampling	Heaton (UNR)		
	Field: Compass/GPS Exercise	Heaton		
13-Mar	Training line lecture	Corn		
	Equipment and Database Lecture/Exercises	Heaton/Patil		
14-Mar	Training Lines (practice, 8km)	Corn/Allison		
	QAQC Specialist Training	Heaton		
Week 2				
17-Mar	Training Lines (practice, 8km)	Allison		
18-Mar	Training line debriefing	Allison /Corn		
	Tortoise Handling	Christopher		

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GBI trainees			Kiva Trainees	
Date	Activity	Trainer	Activity	Trainer
	Tortoise and burrow visibility training	Allison		
19-Mar	Practice transects (8km) G ₀ instruction on-site	Team leaders Essary (GBI)	Desert tortoise recovery and monitoring	Allison
			Introduction to Line Distance Sampling & “G ₀ ”	”
			Protocols for non-standard transects	”
			Equipment and database lecture and exercises	”
			Transect methods	PavliscaK (Kiva)
			Compass/GPS use for line distance sampling	”
			Training line lecture	”
	QA/QC specialist training	Heaton/Patil	QA/QC specialist training	Heaton/Patil
20-Mar	Practice transects (8km) + G ₀	Team leaders	Tortoise biology and handling lecture/practice	Woodman (Kiva), PavliscaK, Christopher
21-Mar	Training Lines (evaluation, 8km)		Practice transects (6km)	PavliscaK
			Field: Compass/GPS Exercise	
Week 3				
24-Mar	Training Lines (evaluation, 8km)		Training Lines (practice, 4km)	Allison
25-Mar	Practice transects (12km) + G ₀		G ₀	PavliscaK
26-Mar			Training lines (Evaluation, 8km)	Allison
27-Mar	Final electronic delivery of QA/QC'd training data		Training lines (Evaluation, 8km)	Allison
28-Mar			Practice transects (12km) incl. G ₀ and QA/QC	PavliscaK

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GBI trainees			Kiva Trainees	
Date	Activity	Trainer	Activity	Trainer
29-Mar			Practice transects (12km) incl. G ₀ and QA/QC	Pavliscaak
			Final electronic delivery of QA/QC'd training data	

Table 2. Training schedule for 2009.

GBI			Kiva	
Day/Date	Activity	Trainer	Activity	Trainer
WEEK 1				
Monday, 16-Mar	Transect methods lecture 6km transects	Allison/ Experienced crews		
Tuesday, 17-Mar	Introductions and DT Recovery/Monitoring Programmatic Overview Distance Sampling Tortoise Activity/G ₀ Working on Public Lands Transect methods lecture Non-standard transects RDA/BT GPS, Pendragon Database Lecture and Exercises Quality control procedures for field crews Compass/GPS Lecture	Allison “ “ BLM Districts Allison “ Patil Allison, Learmont, Patil Allison		
Wednesday, 18-Mar	Tortoise biology and handling instruction Tortoise handling and data collection - small groups Pen search image exercise (with RDA) Training line lecture & crew quality control procedures Compass/GPS Exercise Data transfer and QA/QC (for specialists)	DTCC Staff DTCC Staff “ Allison/ Brenneman Allison Patil, Learmont		

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GBI			Kiva	
Day/Date	Activity	Trainer	Activity	Trainer
Thursday, 19 March	Training Lines (practice, 8km) Begin data download from RDAs	Allison		
Friday, 20-Mar	Training Lines (practice, 8km) G ₀ Initial QAQC (QAQC specialists only)	Sparks Brenneman		
WEEK 2				
Monday, 23-Mar	Full transects (12km) (half crew) G ₀ / activity observation (half crew)	Sparks		
Tuesday, 24-Mar	Tortoise handling Pen search image exercise Training line debriefing	Staff “ Allison		
Wednesday, 25 Mar	Training Lines (evaluation, 8km)		Practice 8- or 12-km transects Data transfer and QA/QC	
Thursday, 26 Mar	Training Lines (evaluation, 8km)		Updates for 2009 (see material for GBI trainees, 17 March)	Allison
Friday, 27 March	Full transects (12km) (half crew) G ₀ / activity observation (half crew)	Sparks	Training Lines (evaluation, 8km)	Allison
WEEK 3				
Monday, 30-Mar	Tortoise handling Compass navigation exercise Training line debriefing	Staff Allison	Training Lines (evaluation, 8km)	
Tuesday, 31-Mar	Full transects (create non-standard) or repeat training lines as needed G ₀		Training lines debriefing Tortoise handling	Allison Staff
Wednesday 1-Apr	<i>Begin field data collection</i>		<i>Begin field data collection</i>	
Thursday, 2April	Deliver QA/QC'd data from practice transects		Deliver QA/QC'd data from practice transects	

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/km²).

In December 2008, it was discovered that the original training course had been tampered with. A new course was set out in a different location. The same procedures were used to determine placement of models in the new course; however, the detection patterns are expected to differ between 2008 and 2009 due to sparser vegetation and different substrate at the new site.

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 G₀ 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 2 describes the overall data flow.

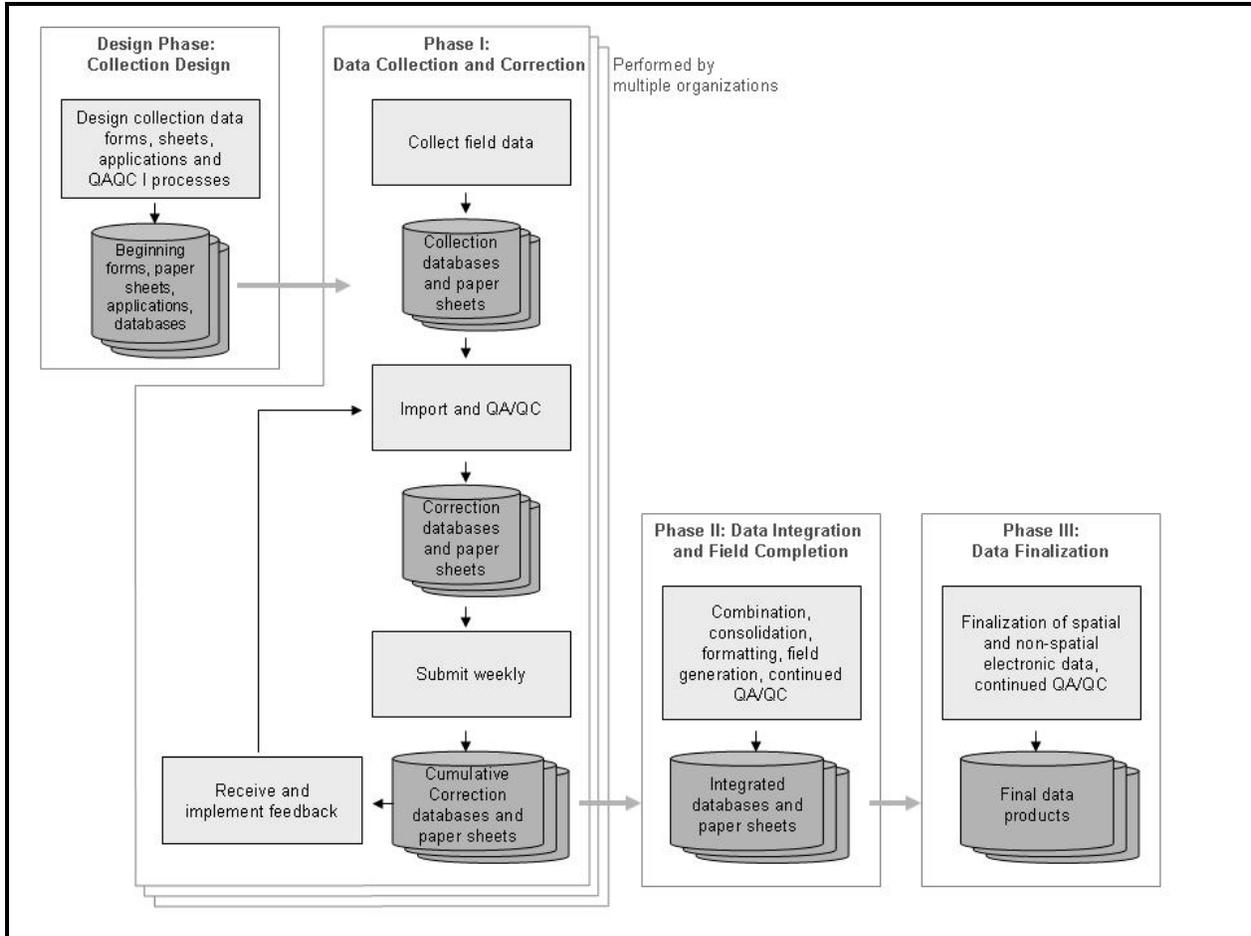


Figure 2. Data flow from collection through final products.

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 (GBI and Kiva) typically walk different number of transects from one another and between years. 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. Detections curves have also be fit separately for each team each year. 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 as long as their midline carapace length (MCL) was not measured as less than 180mm. Transects were packaged into monitoring strata (“regions” in Program DISTANCE).

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

Proportion of tortoises that are available for detection, G_0

Not all tortoises in a population can be detected on transects, even if they are close to 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 8 (2008) or 9 (2009) 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 transmitted 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 day that a tortoise was seen. The average visibility of all tortoise observations at a site on a given day was calculated and used to estimate the mean and variance of G_0 at that site. When there was more than one site in a given area, G_0 statistics were calculated for each G_0 group of sites as the grand mean of all G_0 sites in the group. One thousand bootstrap samples were generated in SPSS (release 16.0.2; SPSS, 2008) to estimate G_0 and its standard error.

Modification of previous procedures

Previous comparison of data collected on transects and at telemetry sites indicated that detection of tortoises in burrows from transect lines may not be proportionate to their actual occurrence in burrows. It has been hypothesized that the search image for burrows may not be similar to that for tortoises, although previous work has concluded that the types of search patterns are compatible (Krzysik, 2002). Starting in 2008, we collected additional information to test a separate

hypothesis as well, that visibility of tortoises even outside of burrows may be fundamentally different depending on whether the searcher is listening as well as searching visually, but able to locate the animal by walking in any promising direction (telemetry) versus only looking and walking in one direction (distance sampling).

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): $p = (\text{lead} - \text{follow}) / \text{lead}$, where lead = the number of tortoises first seen by the observer in the leading position and follow = the number of tortoises seen by the observer in the follower position. The corresponding proportion detected on the line by two observers was estimated by $1 - q^2$, where $q = 1 - p$. Figure 3 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. 3) and is the basis for one of the training metrics (see Table 4).

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 .

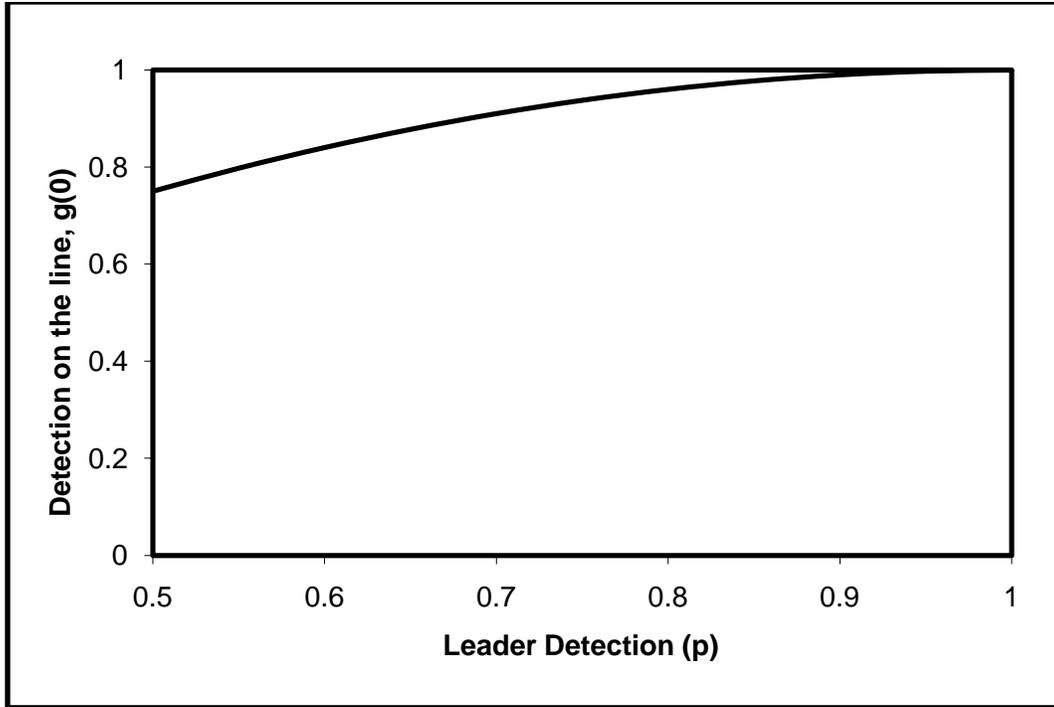


Figure 3. Relationship between single-observer detections (by the leader) and dual-observer (team) detections.

Estimates of tortoise density

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

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

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

For desert tortoise densities, the encounter rate (n/L) is estimated independently for each stratum (“unpooled”), whereas proportion of available tortoises and proportion of available tortoises detected on the transect center line are estimated jointly for all strata ($g(0)$) or for all strata in the recovery unit (G_0). The detection function, which comes into the above equation as P_a , may be

estimated jointly for all observations or separately for observations from each field team, depending on the number and quality of observations. In 2008 and 2009, separate detection curves were created for each field team (GBI and Kiva), pooled across all strata surveyed by that team. A schematic of the process leading to density estimates is given in Fig. Figure 4. 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. Estimates from Beaver Dam Slope 2, Mormon Mesa 2, and Pahrump North and South strata are not part of the long-term monitoring project and are not used to develop annual recovery-unit-level density estimates.

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

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Tortoise encounter rate	Proportion that are visible, G_0	Detection rate, P_a	Proportion seen on the line, $g(l)$	Density	Density	
<i>Stratum or substratified (*)</i>	<i>Neighboring G_0 sites</i>	<i>Data collection group</i>	<i>Overall</i>	<i>Stratum</i>	<i>Recovery unit</i>	
FK	Ord Rodman + Superior Cronese	Kiva	Full set of tortoise observations	FK	Western Mojave	
SC				SC		
OR				OR		
JT	JT					
PT	PT					
CK	CK					
AG	Chuckwalla			AG	Eastern Colorado	
CM	Piute + Ivanpah + Chemehuevi			CM	Northern Colorado	
FE				FE	Eastern Mojave	
IV				IV		
PI				PI		
BD	Coyote Springs through 13 May			GBI	BD	Northeastern Mojave
GB					GB	
CS					CS	
MM		MM				
MM2		MM2				
BD2		BD2				
PN	Coyote Springs after 13 May	PN				
PS		PS				

Tortoise encounter rate	Proportion that are visible, G_0	Detection rate, P_a	Proportion seen on the line, $g(l)$	Density	Density	
<i>Stratum or substratified (*)</i>	<i>Neighboring G_0 sites</i>	<i>Data collection group</i>	<i>Overall</i>	<i>Stratum</i>	<i>Recovery unit</i>	
AG	Chuckwalla (June)	Kiva	Full set of tortoise observations	AG	Eastern Colorado	
CK	Joshua Tree + Chuckwalla (pre-June)			CK		
JT				JT		
PT				PT		
FK	Superior Cronese + Ord Rodman			FK	Western Mojave	
OR				OR		
SC				SC		
CM	Chemehuevi + Ivanpah + Piute			CM	Northern Colorado	
FE				FE	Eastern Mojave	
IV				IV		
PI	PI					
CS*	Coyote Springs			GBI	CS	Northeastern Mojave
BD*	Halfway Wash				BD	
GB*					GB	
MM*		MM				
MM2*		MM2				
BD2*		BD2				

Figure 4. Process for developing density estimates in 2008 (top) and 2009 (bottom).

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. 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.

In 2008 and 2009, some transects were repeated from the previous year(s), 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.

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 as 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

In 2008, crew trials were conducted for GBI trainees on 21 and 24 March (Table 1). Kiva's crews walked their trials on 26 and 27 March. Only one Kiva crew member was a returnee, so their results are evaluated here for consistency between the 2 teams. In 2009, crew trials were conducted for GBI trainees on 25 and 26 March (Table 2). Kiva's crews walked their trials on 27 and 28 March. In this case, most Kiva crews were comprised of returnees from 2008, so the comparison in this report is between first-year (GBI and some Kiva) or returning (most Kiva) crews.

Crews in 2009 performed better than in 2008. This may reflect the more open terrain for the training lines as well as a change in oversight. In 2009, a new database was used to provide trainees with comprehensive next-day feedback based on their practice trial. This type of feedback was more difficult to provide in earlier years and was not available in comprehensive form in 2008. Using the 2009 feedback system, USFWS worked with teams individually to modify their search patterns based on the practice trial that happened first. This correction was targeted to these reported performance measures and was specific to each team.

Proportion of tortoises detected at varying distances from the transect centerline

Table 3 and Table 4 report the proportion of models that were available and were detected by each team at 1-, 2-, and 5-meters from the transect centerline in 2008 and 2009, respectively. Detection on the centerline was expected to be 100%, and most crews achieved this in 2009, but achievement was extremely variable in 2008. Against this background, there was no meaningful difference between the performance of GBI crews compared to Kiva crews in 2008 (and most crews were participating for their first year.) In 2009, most of the Kiva crew was returning. First-year trainees (mostly GBI) detected a similar proportion of models at 1- and 2m compared to experienced crews, with first-year trainees detecting fewer models at 5m. As long as all tortoises (models) within a meter of the center are detected, the pattern of the drop off in detections is not of any consequence.

Table 3. Proportion of tortoise models detected by teams in 2008 within 1-, 2-, or 5-m of the transect center line.

Team	Proportion of existing models within a given distance and were detected by the team		
	1m	2m	5m
1	0.75	0.69	0.73
2	0.92	0.74	0.69
6	0.92	0.81	0.79
7	0.77	0.73	0.74
8	0.75	0.81	0.73
9	1.00	0.92	0.84
10	0.83	0.70	0.70
11	0.83	0.84	0.69
12	0.64	0.72	0.58
13	0.58	0.73	0.62
17	0.75	0.69	0.69
18	0.67	0.74	0.64
22	1.00	0.79	0.71
23	0.33	0.46	0.68
24	1.00	0.92	0.85
31	0.67	0.74	0.77
32	0.33	0.38	0.44
33	0.92	0.85	0.82
34	0.92	0.85	0.79
35	0.91	0.88	0.85
36	0.83	0.80	0.80
Kiva	0.76	0.75	0.75
GBI	0.78	0.75	0.71
Overall	0.78	0.75	0.72
<i>Gray-highlighted cells indicate sub-standard results</i>			

Table 4. Proportion of tortoise models detected by teams in 2009 within 1-, 2-, or 5-m of the transect center line.

Team	Proportion of existing models within a given distance and were detected by the team		
	1m	2m	5m
1	1.00	0.96	0.89
2	1.00	0.96	0.88
3	1.00	0.96	0.94
5	1.00	0.96	0.86
7	1.00	1.00	0.90
8	0.94	0.86	0.86
9	0.93	0.92	0.89
10	1.00	1.00	0.91
11	1.00	1.00	1.00
12	0.85	0.93	0.88
13	1.00	0.93	0.89
14	1.00	1.00	0.95
15	1.00	0.93	0.89
16	1.00	0.96	0.87
17	1.00	0.89	0.94
18	1.00	0.93	0.91
41	1.00	0.92	0.97
42	1.00	1.00	0.98
43	1.00	1.00	0.98
44	0.93	0.96	0.96
45	1.00	1.00	0.94
46	1.00	0.96	0.89
47	1.00	1.00	1.00
48	1.00	1.00	0.97
Returning crews	0.99	0.98	0.96
First-year crews	0.98	0.95	0.90
Overall	0.99	0.96	0.92
<i>Gray-highlighted cells indicate sub-standard results</i>			

Table 5 and Table 6 report further statistics for each team after collecting data on 16km on the evaluation lines. Measurement accuracy reported in these tables 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. The relatively low leader detections seen in 2008 are associated with the underestimates of tortoise (model) abundance on the right side of the table. These estimates assume that all models were detected on the centerline, although with the models, we know in this case that many were missed. The high proportion of leader detections in 2009 is likewise associated with better accuracy in estimating the overall density of models that year.

Table 5. Diagnostics for individual teams after training in 2008.

Team	Available models detected by leader		Measured v. exact model distance (m)	Estimated abundance	95% confidence interval	
	Within 1m of centerline	Within 2m of centerline			Lower limit	Upper limit
1	0.75	0.65	1.5	366	293.7	456.6
2	0.92	0.70	1.3	395	314.0	497.6
6	0.83	0.59	1.7	367	298.3	450.3
7	0.69	0.69	1.8	356	287.4	442.1
8	0.75	0.81	1.5	326	257.9	411.3
9	0.83	0.81	1.4	393	308.5	500.0
10	0.75	0.63	1.2	368	299.0	452.4
11	0.75	0.80	1.0	298	232.9	381.2
12	0.45	0.60	1.9	226	185.7	276.0
13	0.50	0.65	1.6	249	181.3	341.8
17	0.67	0.58	1.1	326	261.5	405.8
18	0.58	0.67	1.6	311	248.7	390.1
22	1.00	0.79	1.1	380	257.4	561.0
23	0.33	0.38	1.2	327	234.3	455.5
24	0.83	0.85	1.2	327	248.6	429.6
31	0.67	0.74	1.0	402	323.8	497.9
32	0.33	0.38	1.0	361	292.9	445.7
33	0.67	0.73	1.0	396	324.2	484.5
34	0.83	0.77	1.3	372	305.1	454.4
35	0.82	0.80	1.1	418	335.0	522.5
36	0.83	0.76	0.9	408	335.8	496.0
Target	>0.80	>0.70	<1	410		
GBI crews	0.72	0.69	1.49	334		
Kiva crews	0.69	0.70	1.05	393		
Overall	0.71	0.69	1.30	351		

Gray-highlighted cells indicate sub-standard results

Table 6. Diagnostics for individual teams after training in 2009.

Team	Available models detected by leader		Measured v. exact model distance (m)	Estimated abundance	95% confidence interval	
	Within 1m of centerline	Within 2m of centerline			Lower limit	Upper limit
1	0.93	0.92	0.69	439	361.8	533.9
2	1.00	0.89	0.76	407	294.0	563.4
3	0.93	0.93	0.62	463	383.1	558.9
5	1.00	0.93	0.69	384	304.6	482.9
7	1.00	0.96	0.67	387	286.4	523.1
8	0.88	0.79	0.78	407	338.5	488.4
9	0.73	0.77	0.78	395	292.8	532.9
10	1.00	1.00	0.92	437	330.0	578.3
11	0.93	0.97	0.91	514	460.0	573.3
12	0.85	0.89	0.62	455	380.2	543.8
13	0.92	0.85	1.21	391	270.6	564.0
14	1.00	1.00	1.05	500	441.7	566.3
15	0.92	0.82	0.79	467	411.3	530.5
16	0.93	0.93	0.94	432	353.8	527.0
17	0.92	0.82	0.93	430	365.5	506.5
18	0.93	0.89	0.79	376	294.3	480.7
41	1.00	0.92	0.94	506	400.9	639.4
42	0.86	0.93	0.87	472	419.7	531.5
43	1.00	1.00	0.63	435	331.0	572.9
44	0.93	0.96	0.80	480	399.5	575.8
45	0.85	0.89	0.78	502	422.9	595.8
46	1.00	0.96	0.87	416	274.1	631.3
47	0.83	0.93	1.05	464	404.4	532.1
48	1.00	1.00	0.98	498	421.8	588.5
Target	>0.80	>0.70	<1	410		
Returning crews	0.93	0.95	0.87	472		
First-year crews	0.93	0.91	0.81	430		
Overall	0.94	0.92	0.84	444		

Gray-highlighted cells indicate sub-standard results

Figure 5 through Figure 8 are detection curves for crews that remained together into the field season. Interpretation is provided for Figs. 7 and 8, which were used by the USFWS to diagnose and correct search patterns in 2009. Curves for first-year trainees in 2009 (Fig. 7) were generally well-shaped, although one of the curves (for Team 13) had 2 deflections and generally too many detections farther from the line. This team went through an additional test after consulting on ways to improve the curve.

Perhaps more surprisingly, the experienced teams had more difficulty maintaining the correct search pattern to develop an appropriate detection curve. In Fig. 8, the three upper-most curves correspond to teams 41, 43, and 48. As indicated in Table 6, these teams had perfect detection of models on the centerline, but team 48 had a very inaccurate final population estimate, and all three teams had unusually wide confidence intervals for this estimate. These issues arise when the deflection points of the detection curve are difficult to model (less precision), so all three teams had to change their search patterns before the field season started. Among the first year trainees (Fig. 7), Teams 7 and 9 also were tested with a wide detection shoulder. Team 7, like the experienced teams, detected all models on the centerline. Their overall estimate was therefore accurate, but also had a very wide confidence interval (imprecise). Team 9 did not have perfect detections on the centerline, so their task was to spend relatively more of their time searching near the line.

Within the set of teams with appropriate search patterns, there was considerable variability in the shapes of these curves, and strikingly different detection curves represent different detection probabilities (P_a). Detection curves that fall more rapidly after the first few meters generally indicate more appropriate search patterns, with more attention near the transect centerline. Distance sampling and development of a single detection curve from many observers is nonetheless robust to the effects of pooling these differences, as long as the observers contribute equally to the overall pattern (Marques et al., 2007) so that all teams walk the same number of transects.

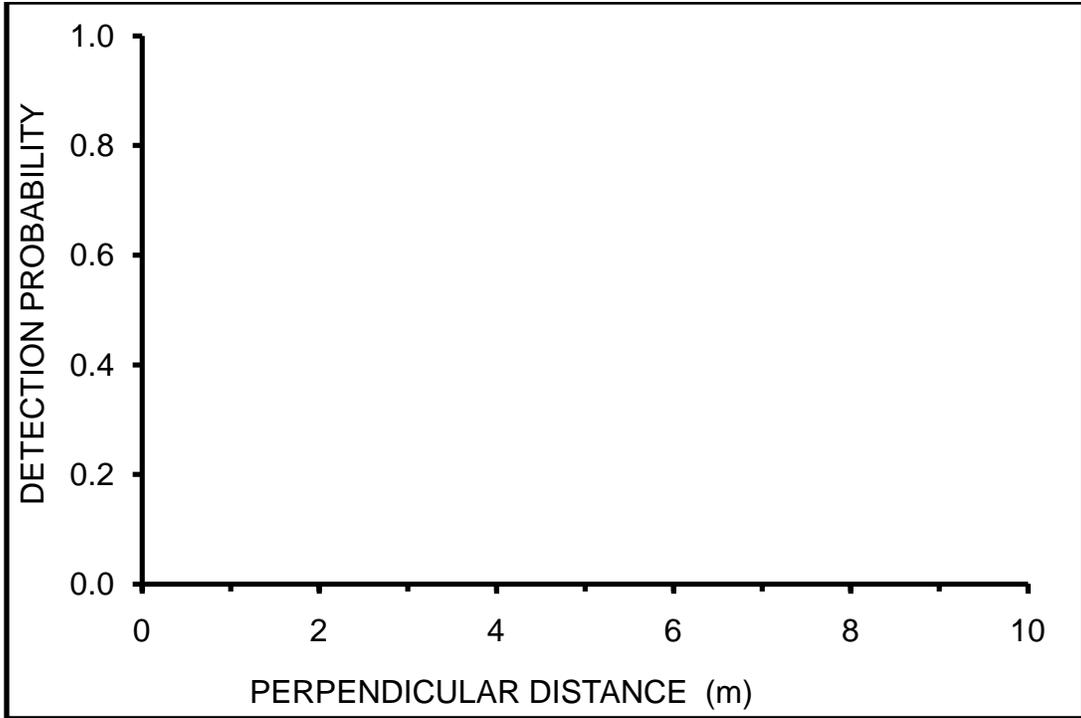


Figure 5. Training detection curves for Kiva crews in 2008.

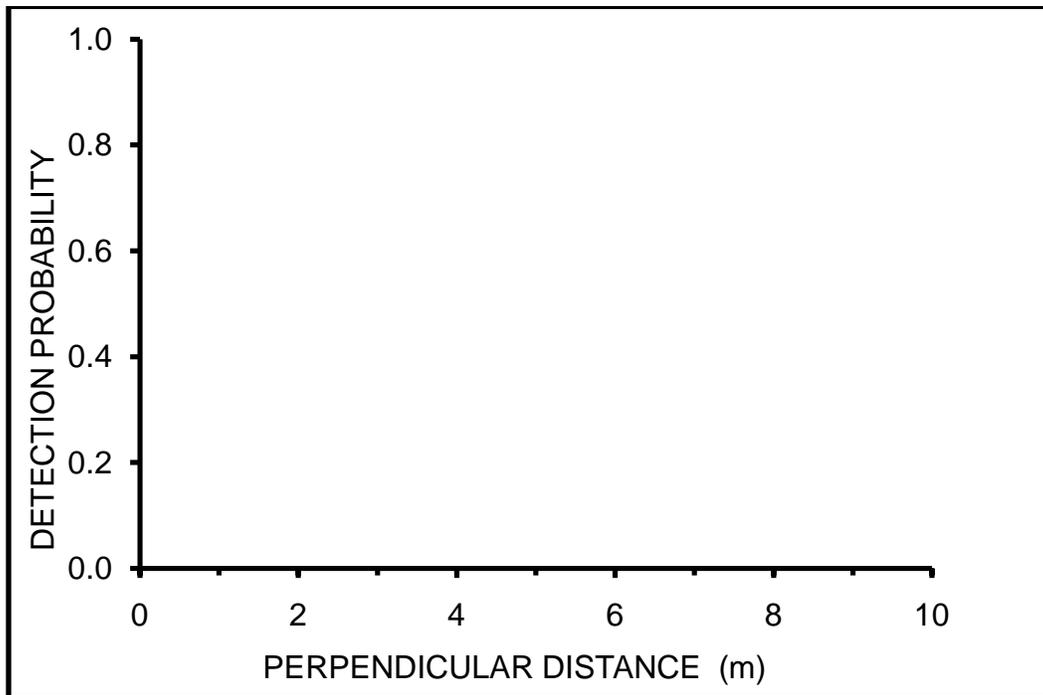


Figure 6. Training line detection curves for GBI in 2008.

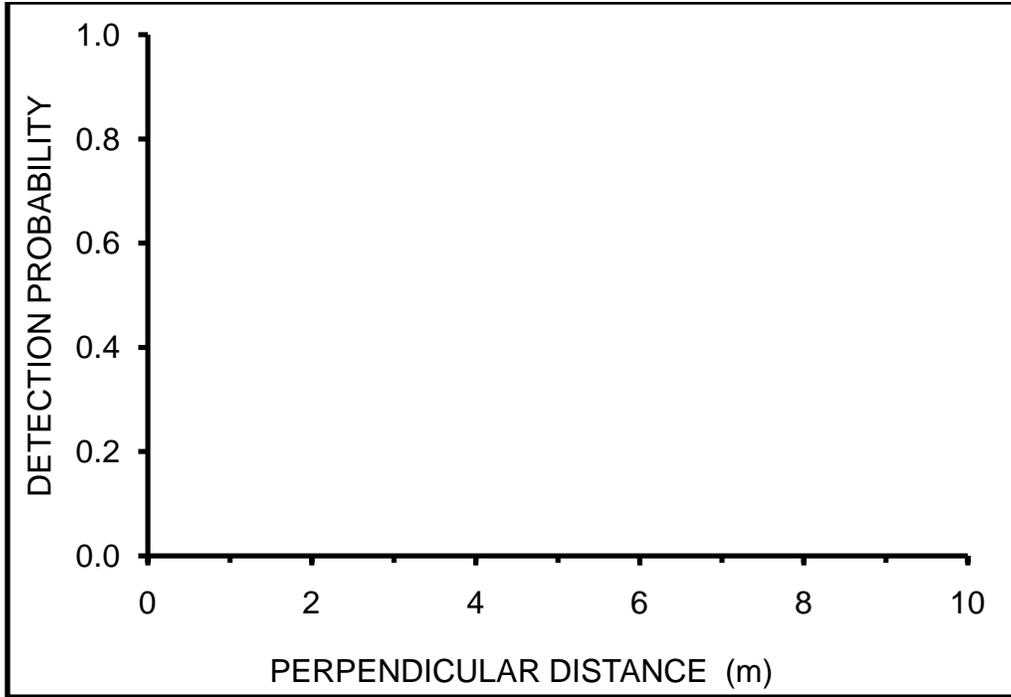


Figure 7. Detection curves for each of the 2009 first-year teams that were kept together into the field season. Curves are based on 16km trials with approximately 100 detections.

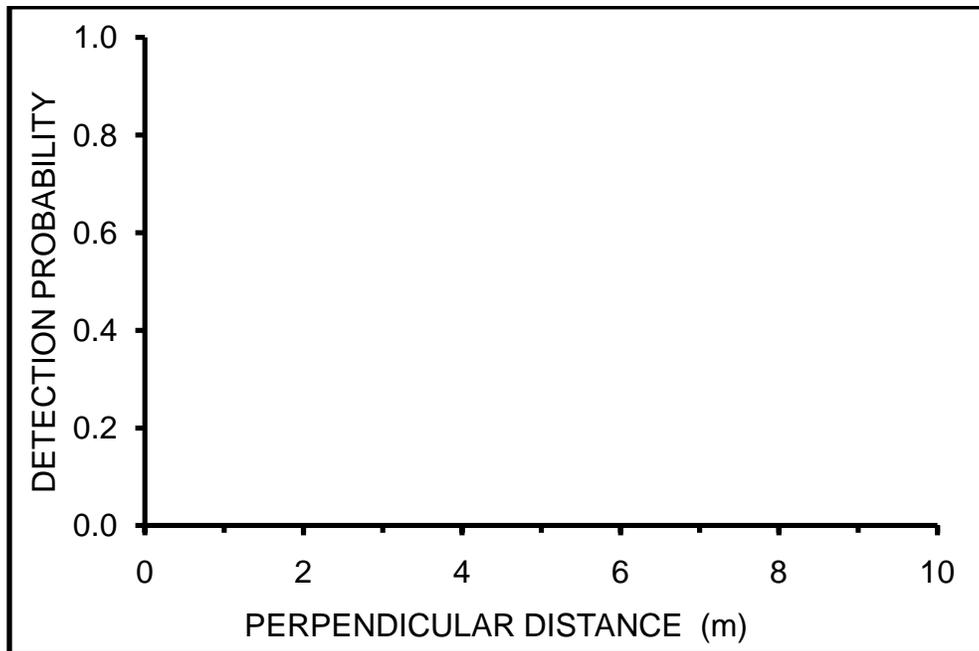


Figure 8. Detection curves for each of the 2009 trainee teams that returned after at least one year of monitoring experience. Curves are based on 16km trials with approximately 100 detections.

Quality assurance and quality control

There were 21,208 transect records and 4322 G₀ records associated with the monitoring effort in 2008. After data specialists with the field teams had finished verifying and validating the data, there were still 1212 cases where the data were inconsistent with constraints and expectations. (Note that many more issues are addressed each year by data specialists for field crews before the field data are submitted.) Of these, 978 were errors created by the field crews (sometimes faulty equipment, other times data entry error). Another 158 were checked and found to be correct but extreme values. Finally, 76 errors were “processing” errors. Processing steps are associated with correcting other errors (perhaps a word is misspelled) or with adding new fields, or any other manipulation that occurs after the data have been collected. When there are pages missed when paper datasheets are scanned, this is a processing error.

In 2009, the larger field effort is reflected in the increased number of records (22,884 transect records and 4413 from G₀ observations). Overall, 1593 inconsistencies were addressed after field teams had finished verifying and validating their data. Of these, 945 were errors generated by faulty data entry or faulty equipment. Possibly due to enhanced crew and specialist training, there were fewer data entry errors than in 2008. Possible due to aging electronic equipment, there were more equipment errors.

Of the inconsistencies identified in 2009, 350 were verified to be correct but extreme or unexpected entries. These are not errors and no correction was necessary. There were many more processing errors in 2009 than in 2008 (298), primarily due to incorrect data editing that later had to be repaired.

Transect completion

2008

In 2008, more formalized procedures were implemented and were taught during training so that field crews would apply standardized approach to sample in rugged areas but also adhere to safety guidelines. The proportion of transects that were altered due to terrain was used to estimate the proportion of the stratum in rugged terrain; a separate estimate was made using these transects, and was applied to that proportional area of the stratum. A certain proportion of transects were completely unwalkable by humans, and this proportion of the stratum area was also estimated. There were still alternative transects available, however, so that the same overall number of transects would be completed.

The number of transects completed, however, was still not very close to 100%. In California, this again resulted from lack of promised funding, but also from unexpected difficulties with the contracting mechanism that had been used since 2001. In this sense, the completion record in California is remarkably good, and reflects the flexibility demonstrated by Kiva this year. In Nevada, Arizona, and Utah, the numbers are a bit misleading. In the regular long-term monitoring strata (the ones they had experienced in 2007), GBI completed 98% of the planned

number of transects; quite good. However, as in 2007, the completion rate was much lower in strata the crews had no previous logistic experience with. In the new strata in Nye County, the primary difficulties were due to unmapped private property. In the new strata to the north of Mormon Mesa and Beaver Dam Slope, the issue continued to be lack of known access routes, combined with a large proportion of the sampling area being in rugged terrain. In Coyote Springs and Mormon Mesa, it was determined that access routes do not exist to some areas, and transects have never been completed (since 2001) in those areas. In 2008, base camping was used to establish a drop off location where water and other supplies could be reached on foot by a handful of crews. This procedure adds to the cost of a transect; however, so not all areas were accessed this way, as reflected in Table 7.

When GBI did need to replace transects, they did not always select from the transects in the same stratum, which resulted in only 2 transects out of 11 being completed in the new Beaver Dam Slope 2 stratum. Also, a single day of confusion over transects that had already been assigned contributed to this team walking 5 transects 2 times (counted once in Table 7). These 2 issues could be expected in future years without additional oversight.

Table 7. Transect completion in 2008 and classification as standard, shortened, or unwalkable lengths.

Stratum	Assigned	Completed (including replacements)	Percentage walked as 12k	Percentage walked as 6k	Percentage unwalkable	Assigned transects that were walkable but were not walked
AG	16	14	68.8	12.5	18.8	1
CK	6	10	50.0	0.0	50.0	0
BD	31	32	51.6	32.3	16.1	3
CS	167	159	45.5	27.3	27.3	4
GB	34	40	57.5	23.4	19.2	18
MM	73	74	32.4	41.2	26.5	2
BD2	11	2	53.4	28.8	17.8	2
MM2	53	51	52.8	28.3	18.9	10
PN	59	48	33.9	28.8	37.3	2
PS	74	75	70.3	12.2	17.6	0
PI	132	133	62.9	21.2	15.9	0
FE	10	9	100.0	0.0	0.0	2
IV	10	10	100.0	0.0	0.0	0
CM	10	7	90.0	0.0	10.0	0
FK	18	18	100.0	0.0	0.0	3
OR	10	9	70.0	20.0	10.0	0
SC	29	24	93.1	6.9	0.0	1
JT	7	10	57.1	28.6	14.3	3
PT	5	6	40.0	20.0	40.0	0
Total	755	731				
Total in long-term strata	558	555				

2009

Table 8 reports the number of assigned and completed transects in each stratum. The number completed in California was actually 1 more than the number planned (assigned). Although alternate transects are provided in case terrain precludes completion of some assigned transects, in 2009 large areas of Superior Cronese and Fremont-Kramer were inaccessible following the crash of a military plane from Edwards Air Force Base. This area corresponded to 2 assigned transects in the Fremont-Kramer monitoring stratum and 11 in Superior Cronese. Substitution of alternate transects for these assigned ones did not delay completion of transects in these strata. In pre-season planning, it was expected that the OR, FK, and SC strata would be completed by 27 April; they were actually finished by 28 April. Substitution of so many alternate transects did affect the team's ability to complete transects in the order they were assigned. The supplemental transects on Edwards Air Force Base and on Ft. Irwin could not be completed in the original time period that had been approved by the facilities.

Kiva was also unable to access Chocolate Mountain Air Gunnery Range during the requested time period, so these transects were not completed in the same time period as other transects in Chuckwalla, Joshua Tree, and Pinto Mountains strata. Those on CMAGR were instead completed in June, with additional monitoring of the telemetry site. Due to this time shift, the encounter rate on transects at CMAGR were corrected by a separate estimate of visibility (G_0).

Only 89% of transects assigned to GBI were completed. The primary issue preventing completion of 72 of the transects was early season loss of personnel. Four crew members left during the first 2 weeks of the field season for personal reasons or due to injury. Great Basin Institute had sufficient personnel to accommodate some attrition due to illness or other issues; however, since each crew was slated to walk 45 transects during the field season, loss of 2 crews for most of the available period could not be compensated for. After accounting for the ability of GBI to replace some of the missing transects, in May the USFWS reduced the number of expected transects by 71, adjusting the number of transects to complete in the remaining strata.

Great Basin Institute also used base-camping to sample 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 remote clusters of transects in areas that are more than 4km from a motorized route. In all, 24 remote transects were completed using base-camping in CS, 8 in MM, and 4 in GB. Any field personnel provisioning these base camps for other crews are not themselves walking transects.

Table 8 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, and represent more rugged terrain. Finally, some transects were considered unwalkable even when shortened to 6km

(column 6). The last 2 columns of Table 8 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. On investigation, all of these in the eastern part of the range were removed from the walk order during the field season to accommodate the reduced number of personnel (in BD, BD2, MM, MM2; see above). Those in California were not completed due to military restrictions such as those around the plane crash site or involving activities at particular installations (AG, FK, SC). Figures 6 through 9 show locations of transects and observations of live tortoises.

Table 8. Number and type of transects in each stratum in 2009.

Stratum	Assigned transects	Assigned and alternate transects completed*	Assigned, completed 12k	Assigned, completed 6k	Assigned, judged unwalkable	Assigned, completed by avoiding terrain	Assigned, judged walkable, but not walked*
AG	33	33	24	3	3		3
BD	69	66	26	19	10		8
BD2	20	19	7	6	6		1
CK	12	12	6	3			1
CM	10	10	8		2	2	0
CS	174	153	73	39	24	14	18
FE	10	10	8				0
FK	30	30	22		1		3
GB	77	76	25	18	9	1	1
IV	10	10	6				0
JT	25	25	11	6	4		2
MM	165	137	45	55	27		29
MM2	80	61	26	12	16		25
OR	20	20	6	7	2		2
PI	80	80	33	21	6		0
PT	17	17	5	3	4		3
SC	69	70	37	5	1	1	13
Total	901	829	368	197	115	18	109
Total in long-term strata	801	749					

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

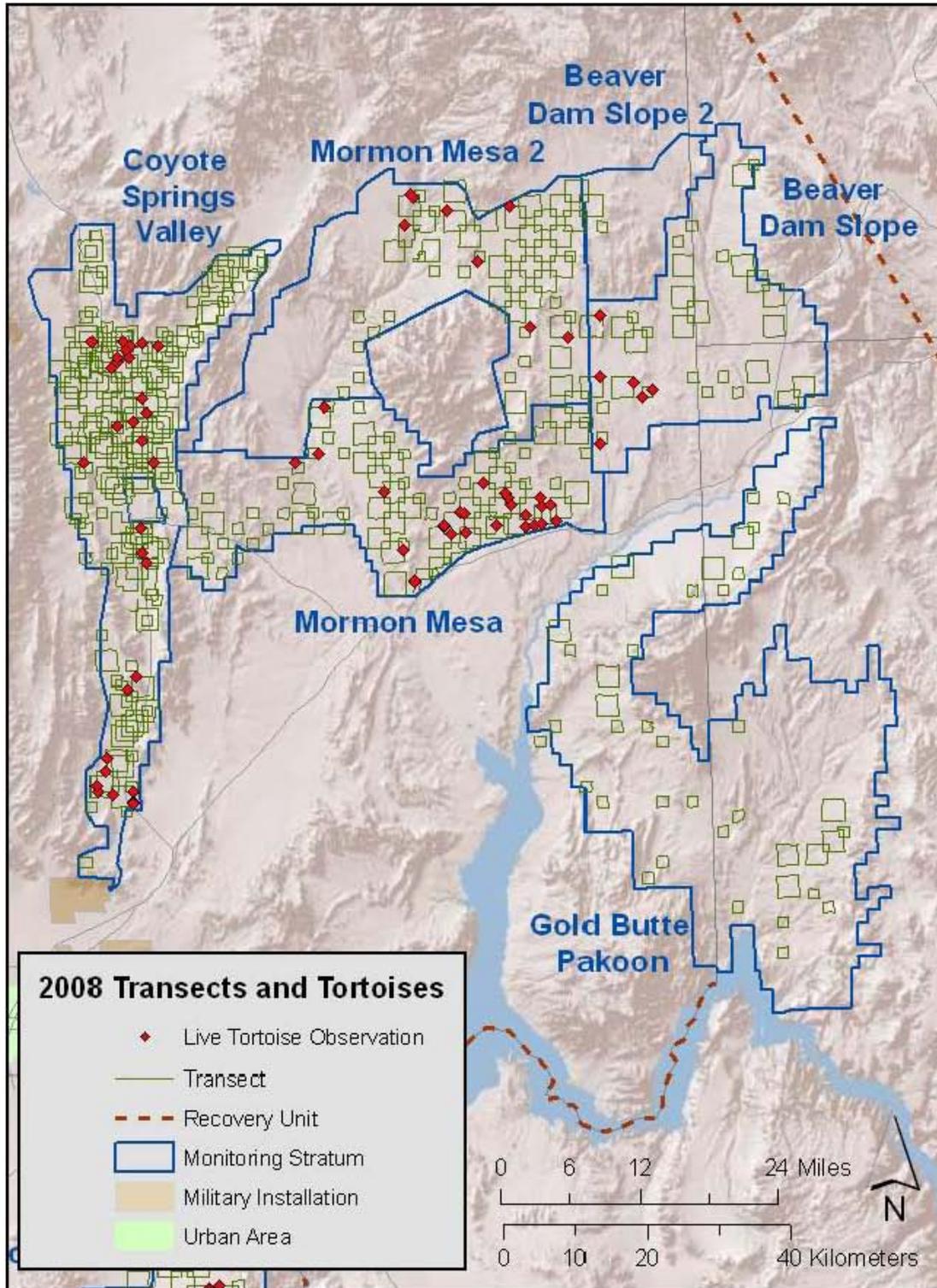


Figure 9. Distribution of distance sampling transects and live tortoise observations in the Coyote Springs Valley, Mormon Mesa, Mormon Mesa 2, Beaver Dam Slope, Beaver Dam Slope 2, and Gold Butte-Pakoon monitoring strata.

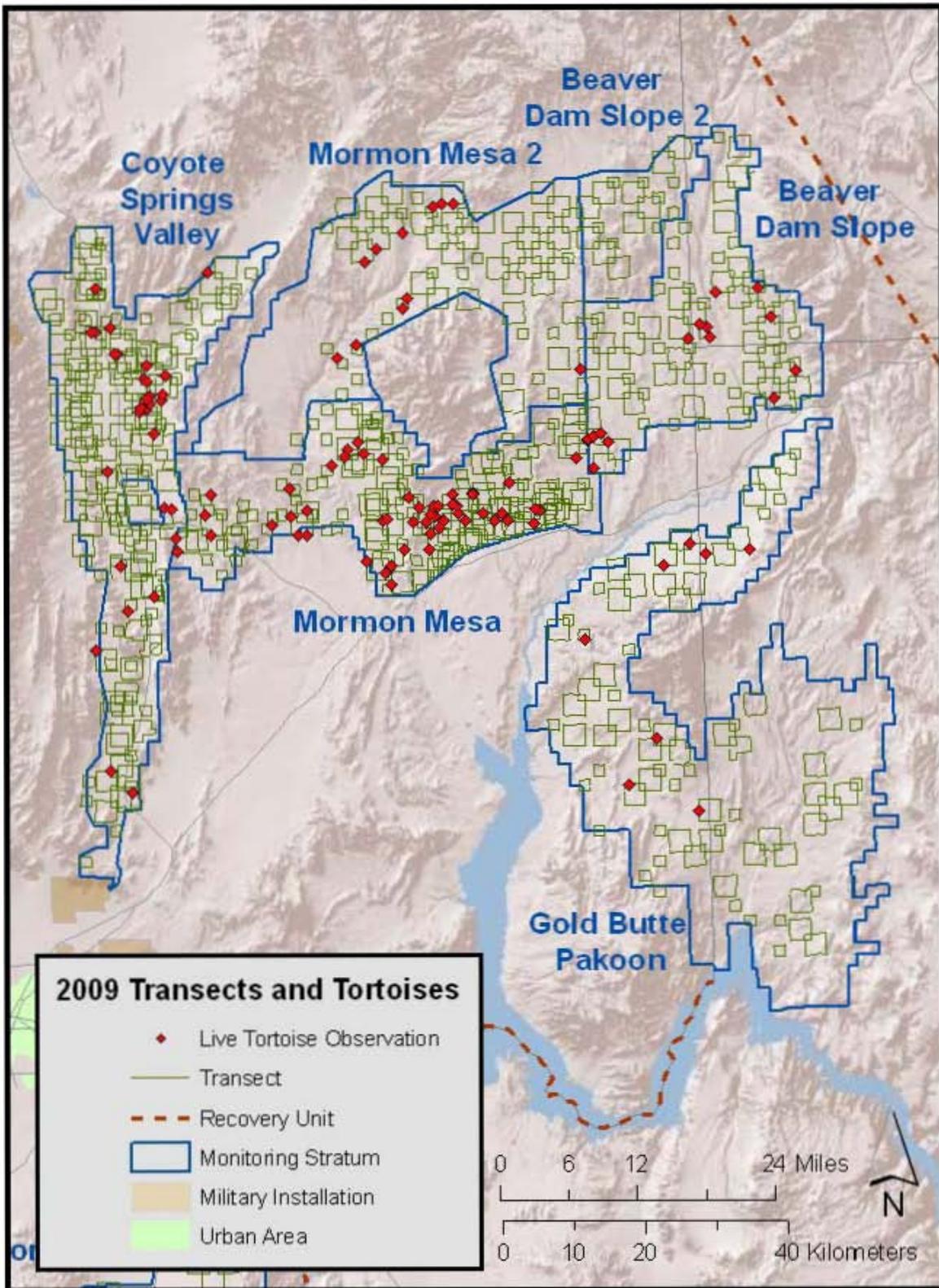


Figure 10. Distribution of distance sampling transects and live tortoise observations in the Coyote Springs Valley, Mormon Mesa, Mormon Mesa 2, Beaver Dam Slope, Beaver Dam Slope 2, and Gold Butte-Pakoon monitoring strata.

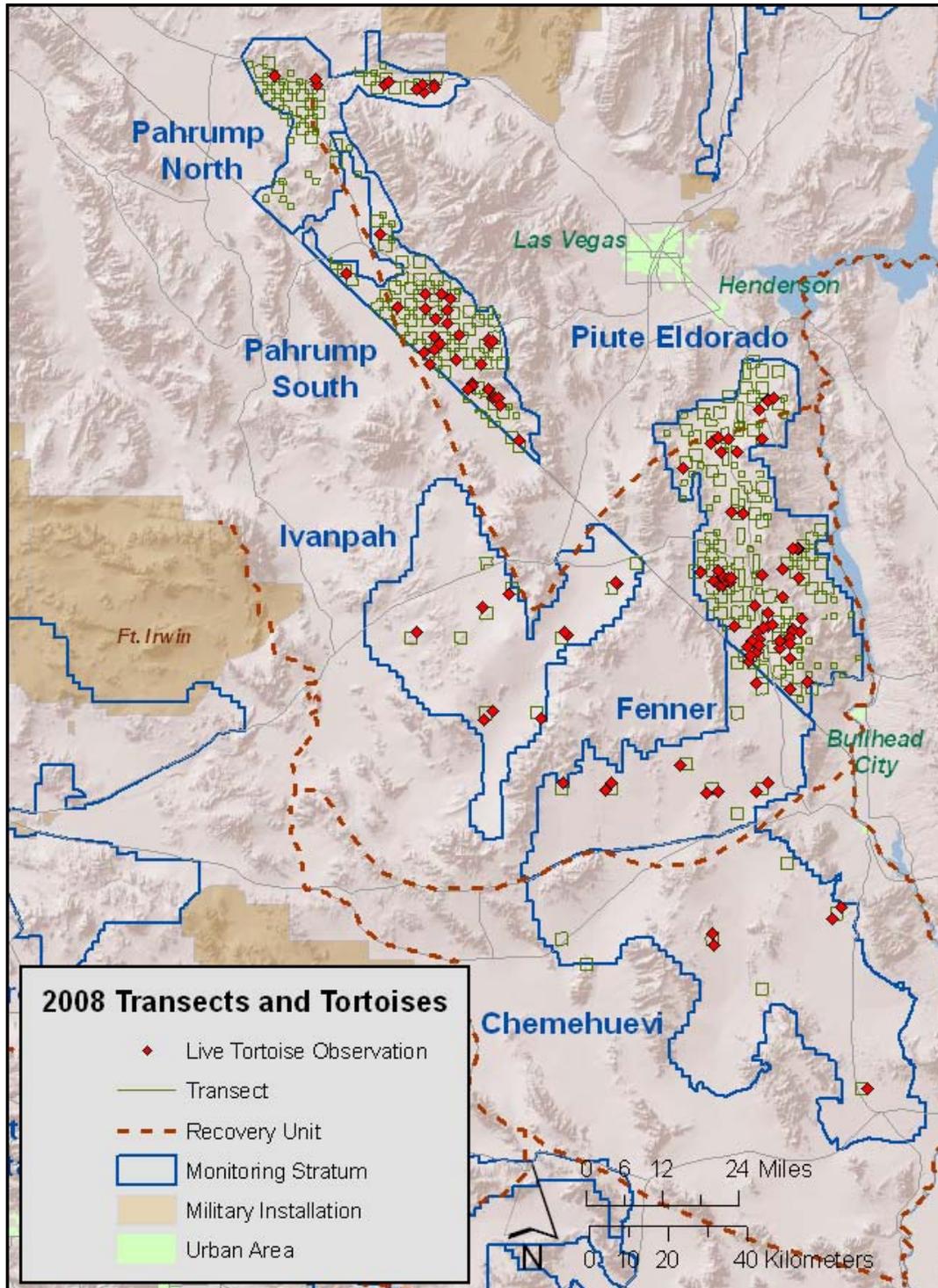


Figure 11. Distribution of distance sampling transects and live tortoise observations in 2008 in the the Piute-Eldorado, Ivanpah, Fenner, and Chemehuevi long-term monitoring strata. In 2008, transects were also surveyed in Pahrump North and Pahrump South.

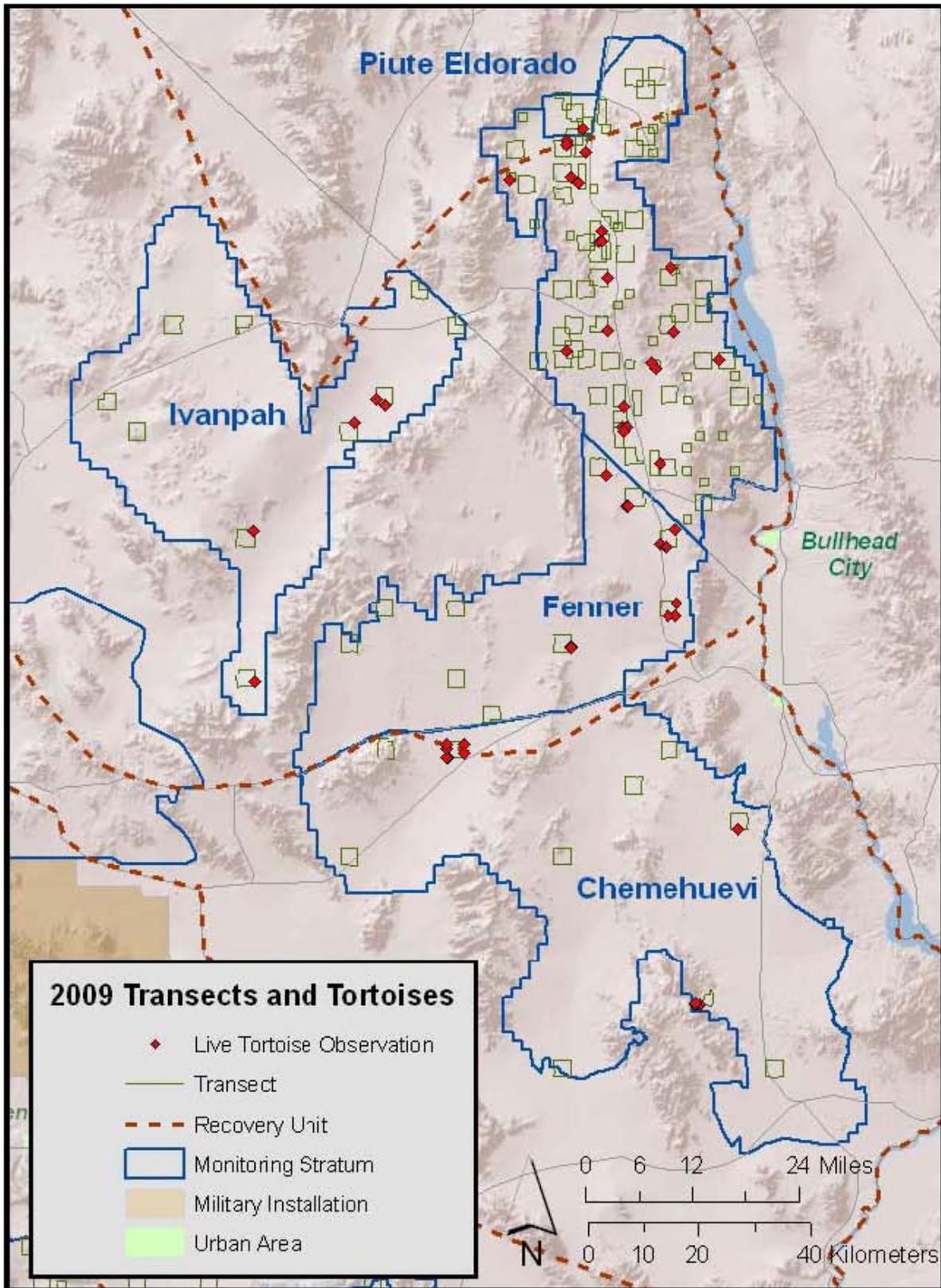


Figure 12. Distribution of distance sampling transects and live tortoise observations in the Piute-Eldorado Valleys, Ivanpah, Fenner, and Chemehuevi monitoring strata.

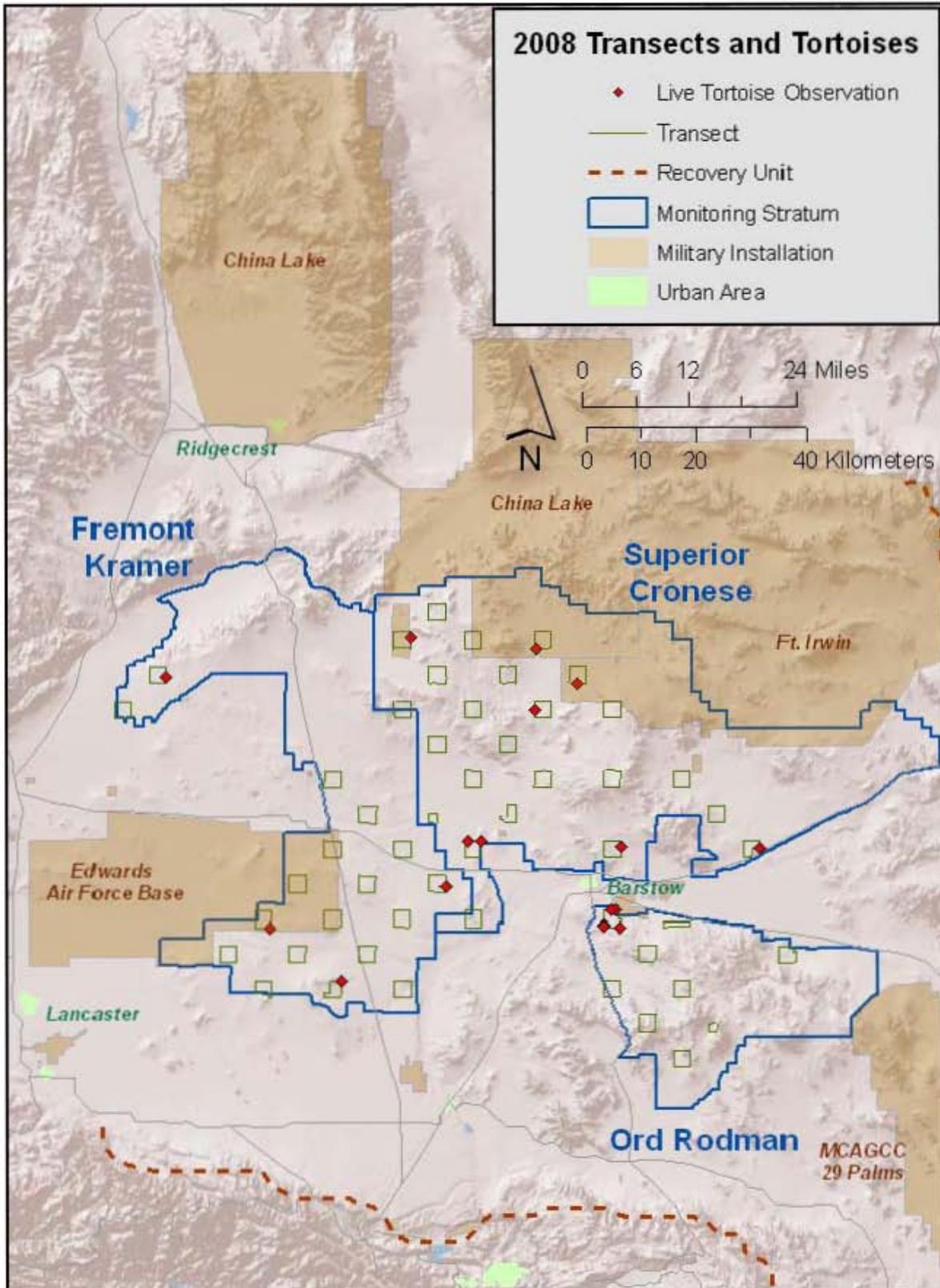


Figure 13. Distribution of distance sampling transects and live tortoise observations in 2008 in the Fremont-Kramer, Ord-Rodman, and Superior-Cronese monitoring strata.

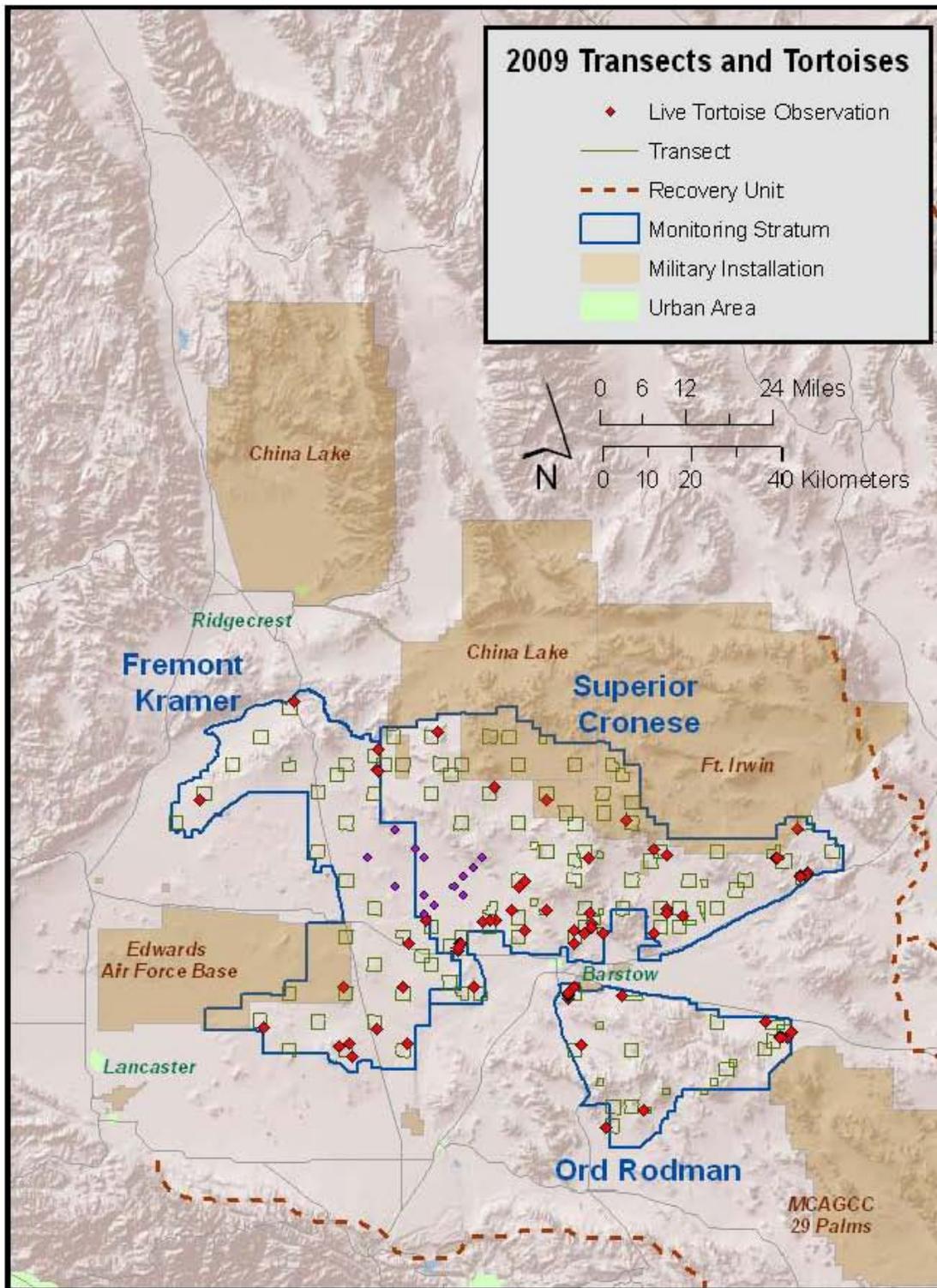


Figure 14. Distribution of distance sampling transects and live tortoise observations in 2009 in the Fremont-Kramer, Superior-Cronese, and Ord-Rodman monitoring strata. Purple diamonds mark the SW corner of transects that were planned in FK and SC, but were instead replaced after a plane crash led to road closures and removed access in this area.

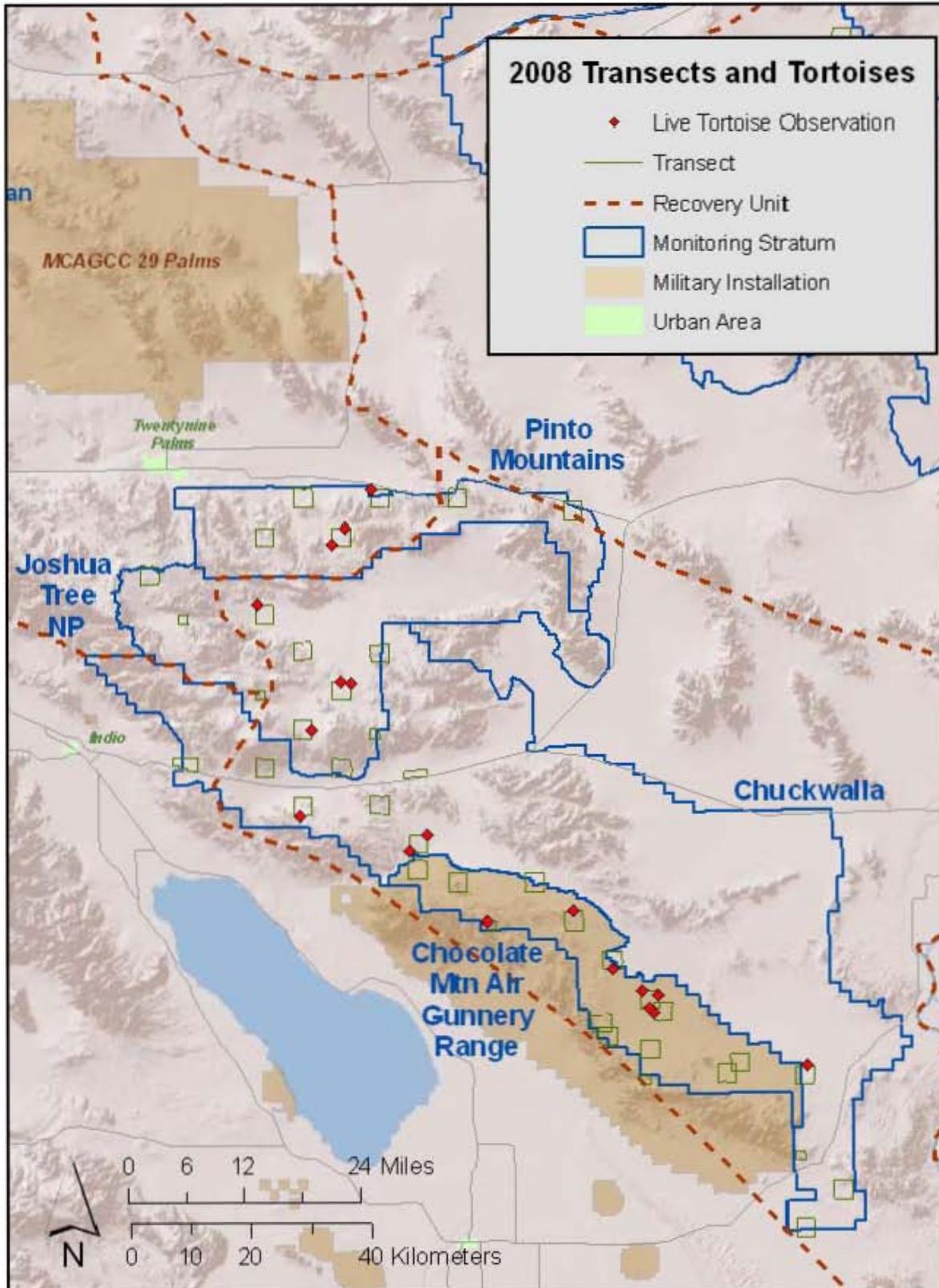


Figure 15. Distribution of distance sampling transects and live tortoise observations in 2008 in the Pinto Mountains, Joshua Tree, Chuckwalla, and Chocolate Mountain AGR monitoring strata.

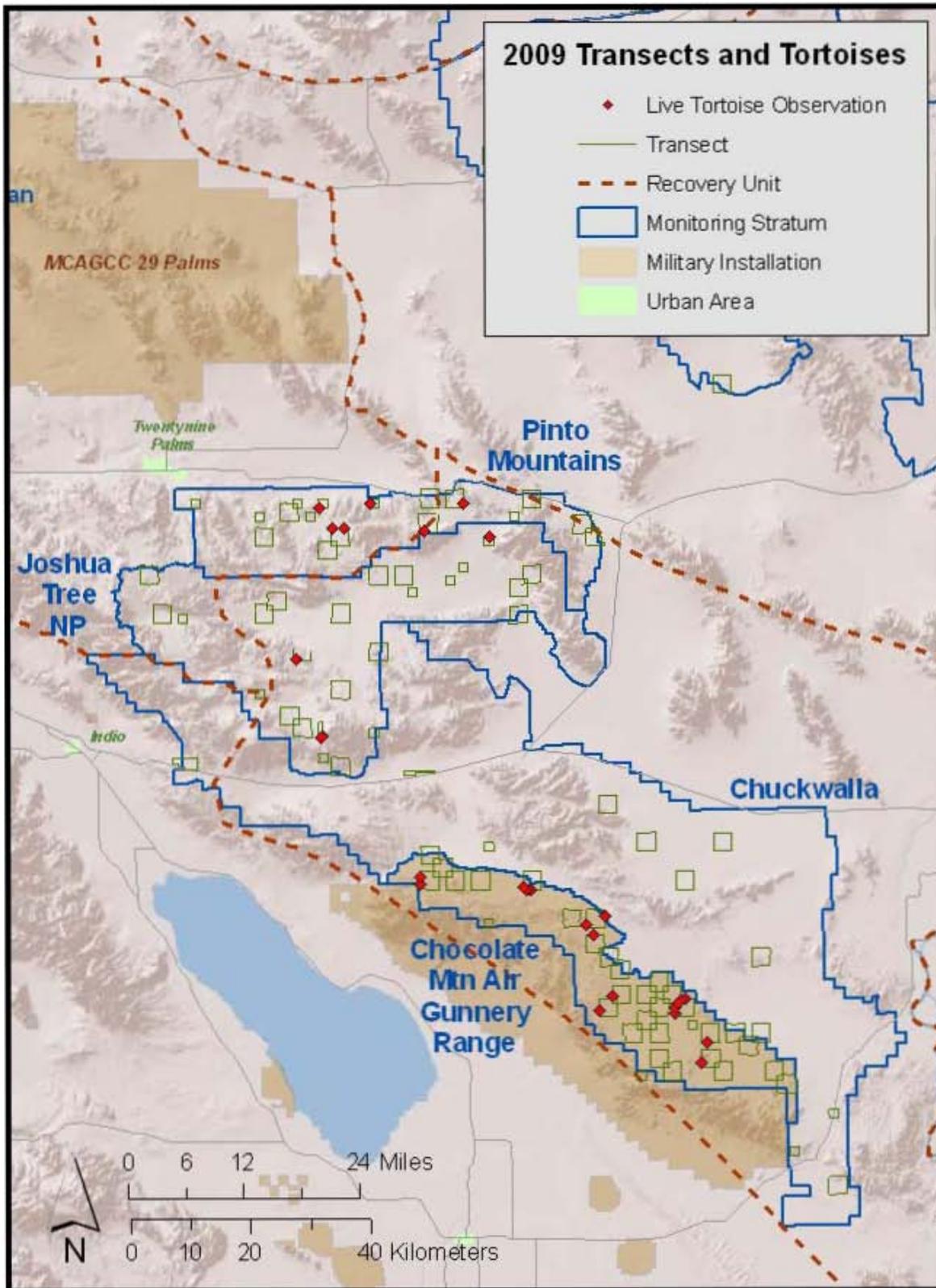


Figure 16. Distribution of distance sampling transects and live tortoise observations in 2009 in the Pinto Mountains, Joshua Tree, Chuckwalla, and Chocolate Mountain AGR monitoring strata.

Tortoise encounter rates and detection functions

Figures 16 to 19 are histograms of the observed number of tortoises seen at increasing distance from the transect centerline, with one curve for each field team each year. 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.

Detection curves were estimated separately for each of the monitoring field teams (GBI and Kiva) each year. In 2008, crews for Kiva and GBI walked very different numbers of transects and were in different halves of the range, with characteristic vegetation. I therefore considered building a single detection curve to optimize use of the relatively few live tortoise observations, but also tested separate models for Kiva and GBI in order to benefit from pooling robustness. In fact, the curves for the two teams were considerably different, so separate detection functions were built. For Kiva, a hazard rate function was selected. The best of the potential uniform and half-normal adjusted models fit to the same data had delta AIC less than 0.3, so on this basis alone, a more conservative model than the hazard rate could be selected. However, examination of the curve indicated that the hazard rate function best fit $g(x)$ values near $x=0$. In fact, the density estimates for the hazard rate function were higher than for the other two models, so fitting the “shoulder” was deemed important to avoid bias. For GBI in 2008, a hazard rate function also fit best. In this case, the best half-normal and uniform models were within $\Delta AIC = 1.51$ of the hazard rate model, with no meaningful difference in density estimate between the uniform and hazard rate models. Because bias was therefore not an issue, on the basis of precision, I selected the uniform model with a cosine adjustment to fit the detection function.

The area below these curves in Figs. 16 (Kiva) and 17 (GBI) 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 18m of the centerline (CV=0.100). The corresponding estimate of P_a for strata surveyed by Kiva was 39.0% (CV=0.337) within 14m.

In 2009, for Kiva (Fig. 18), a half-normal function with second-order cosine adjustment had the lowest AIC value (the spread between the best 3 models was 1.58, which does not raise any concerns). The precision of the best hazard, uniform, and half-normal models was similar, and

there was no other reason to use a model with a larger AIC. On the basis of the half-normal model, Kiva crews detected 35.8% (CV=0.097) of tortoises within 14m of the transect centerline. For GBI, a hazard rate function was selected (Fig. 19). The best-fitting half-normal and uniform models had Δ AIC s of 2.96 And 4.64, respectively, so neither of them was considered. The detection rate for GBI crews within 15m of the transect centerline was 25.9% (CV=0.214).

Individual crews for Kiva walked approximately $\frac{3}{4}$ as many transects as crews for GBI, which is a similar level of effort. A single detection function was considered for both groups combined, but the shoulder and final detection rate were different enough that separate models were preferred.

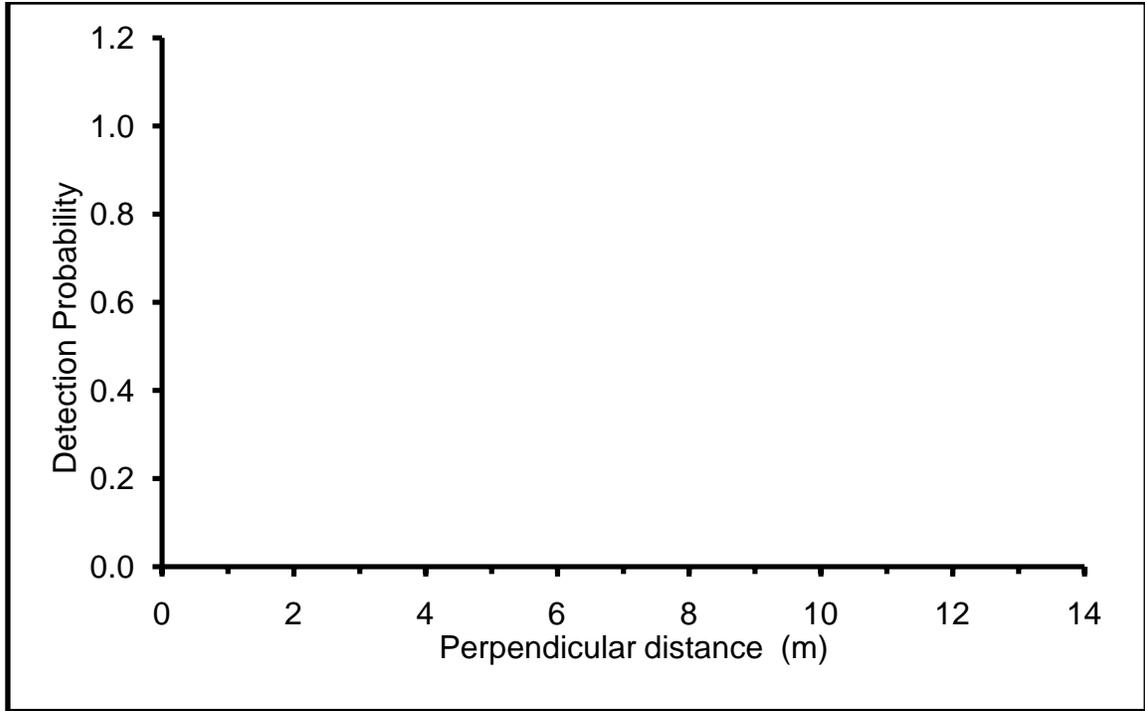


Figure 17. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with $MCL \geq 180\text{mm}$ found by Kiva in 2008 ($n=50$).

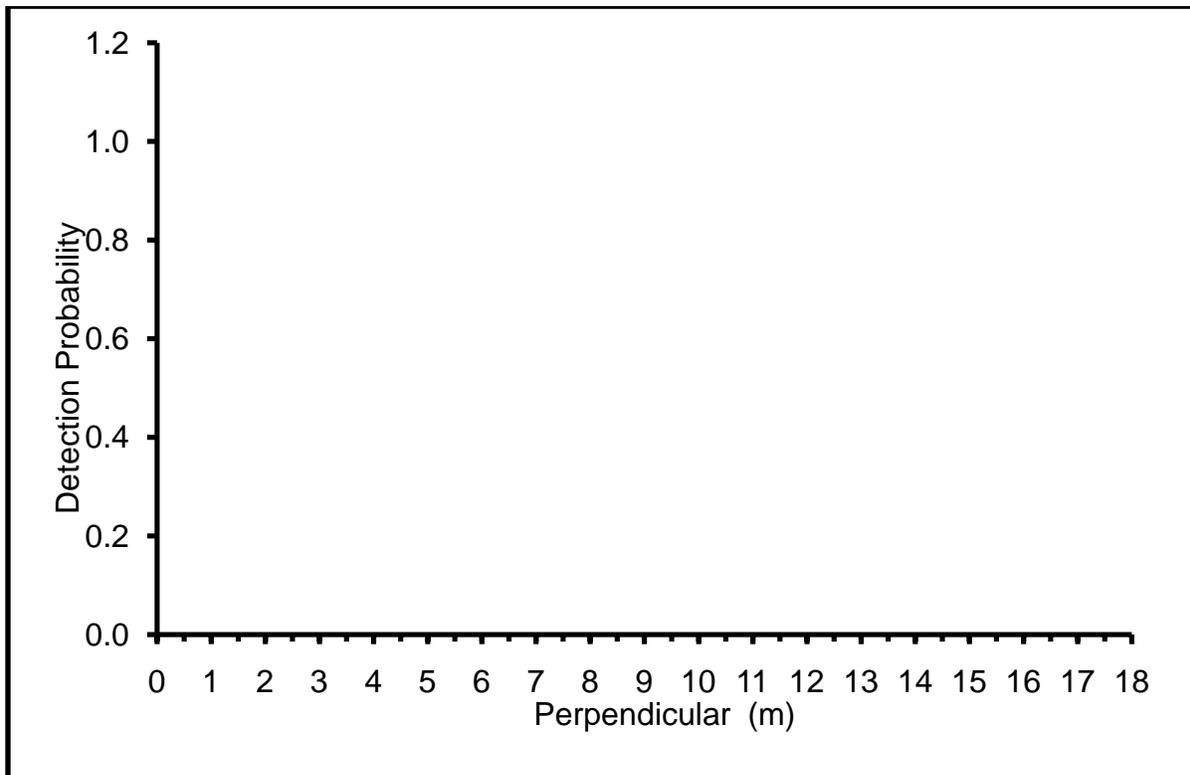


Figure 18. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with $MCL \geq 180\text{mm}$ found by GBI in 2008 ($n=134$).

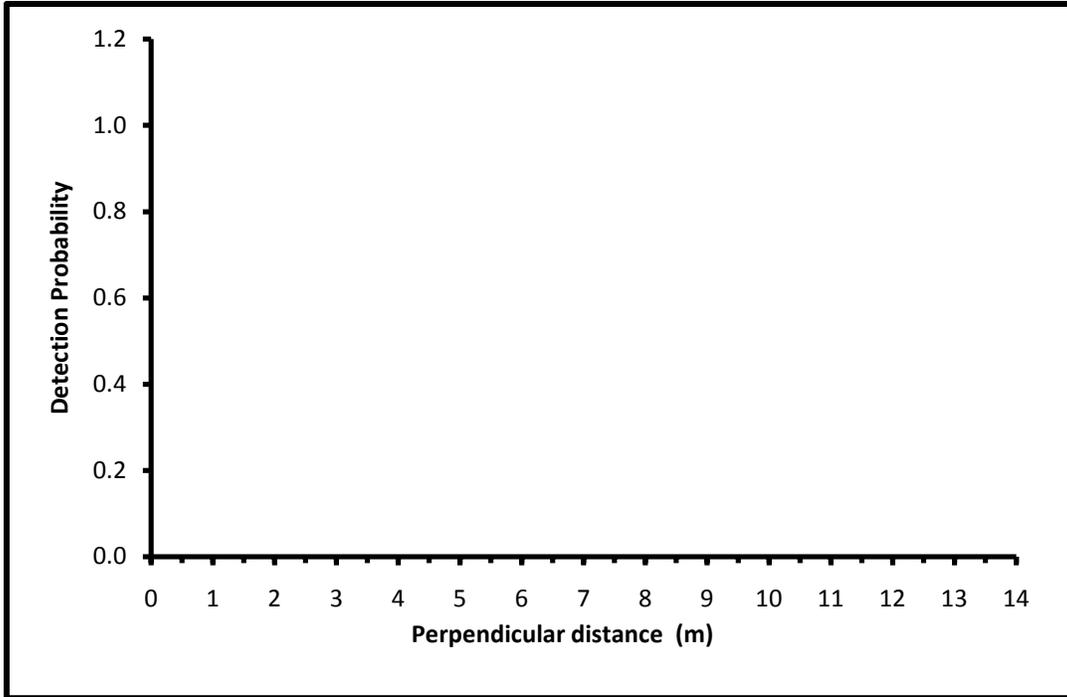


Figure 19. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL \geq 180mm found by Kiva in 2009 (n=107).

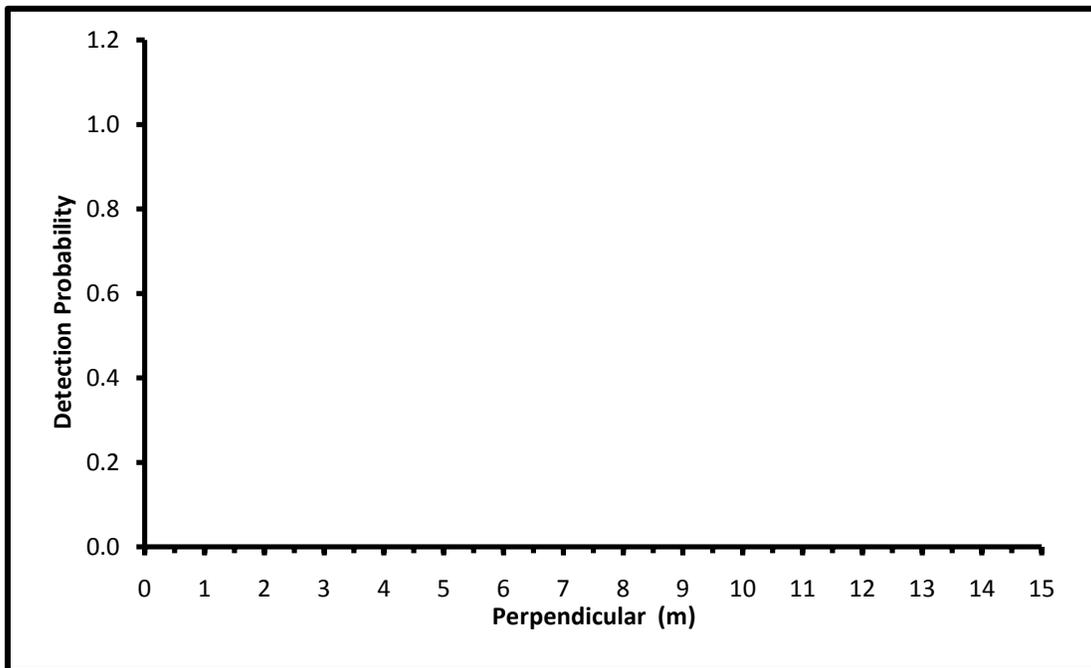


Figure 20. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL \geq 180mm found by GBI in 2009 (n=111).

Proportion of tortoises that are available for detection, G_0

2008

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.

Table 9. Availability of tortoises (G_0) during the period in 2008 when transects were walked in each group of neighboring strata.

G_0 sites	Strata	Dates	Days	G_0 (Std Error)
Chemehuevi, Ivanpah, Piute	Piute, Chemehuevi, Ivanpah, Fenner	31 Mar – 11 April	12	0.75 (0.13)
MCAGCC, Chuckwalla	Joshua Tree, Pinto Mtns, Chuckwalla	8 – 12 April	5	0.64 (0.15)
Superior-Cronese, Ord-Rodman	Superior-Cronese, Ord-Rodman, Fremont-Kramer	13 – 24 May	12	0.75 (0.16)
Coyote Springs	Beaver Dam Slope, Beaver Dam Slope 2, Coyote Springs, Mormon Mesa2, Mormon Mesa, Gold Butte	12 April – 16 May	35	0.83 (0.15)
Coyote Springs late	Pahrump North, Pahrump South	17 – 30 May	14	0.67 (0.24)

2009

In general, telemetry sites and associated transects were completed sequentially, from south to north. To match the scheduling of military operations on Chocolate Mountain Air Gunnery Range in Chuckwalla, the southern-most monitoring stratum, transects in this portion of the Eastern Colorado Recovery Unit were completed a month later than those in the portion of the Chuckwalla critical habitat unit that is managed by the BLM. Tortoise availability was also estimated separately for the 2 different time periods. Dates, total days monitored, and G_0 estimates are given in Table 10.

Table 10. Availability of tortoises (G_0) during the period in 2009 when transects were walked in each group of neighboring strata.

G_0 sites	Strata	Dates	Days	G_0 (Std Error)
Chemehuevi, Ivanpah	Piute, Chemehuevi, Ivanpah, Fenner	1 – 5 April	5	0.82 (0.13)
Joshua Tree, Chuckwalla	Joshua Tree, Pinto Mtns, Chuckwalla	27 April – 6 May	10	0.73 (0.18)
Superior-Cronese, Ord-	Superior-Cronese, Ord-Rodman,	6 – 25 April	20	0.93 (0.10)

Rodman	Fremont-Kramer			
Chuckwalla	Chocolate Mountain Air Gunnery Range	2 – 6 June	5	0.58 (0.11)
Halfway Wash	Beaver Dam Slope, Beaver Dam Slope 2, Mormon Mesa2, Mormon Mesa, Gold Butte	23 April – 30 May	38	0.64 (0.17)
Coyote Springs	Coyote Springs	8 – 23 April	16	0.88 (0.12)

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. In 2008, for 23 detections of tortoises within 1m of the transect centerline, 22 were found by the observer in the lead position and 1 by the follower. Although this is technically the ratio of interest, with only one detection by the follower, it is an unreliable estimate, which is why the proportion detected by the leader (and the resulting $g(0)$ estimate) were examined graphically, based on smaller and smaller intervals from the transect line. Using a wider interval, say 5m from the transect line, the overall number of detection is greater (95, with 16 by the follower), so the ratio is easier to estimate but also less relevant to figuring out the detection probability right at the line. In 2009, for 43 detections of tortoises within 1m of the transect centerline, 38 were found by the observer in the lead position and 5 by the follower, so that the probability of detection by single observer, $p = 0.868$, and the proportion detected using the dual observer method, $g(0) = 0.989$ (SE = 0.06). However, Fig. 12 shows that $g(0)$ was converging on 1.0 in both 2008 and 2009, indicating the assumption of perfect detection on the center line was met. No adjustment was made to the final density estimate. In USFWS (2009a), this assumption was evaluated for 2004, 2005, and 2007, when 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.

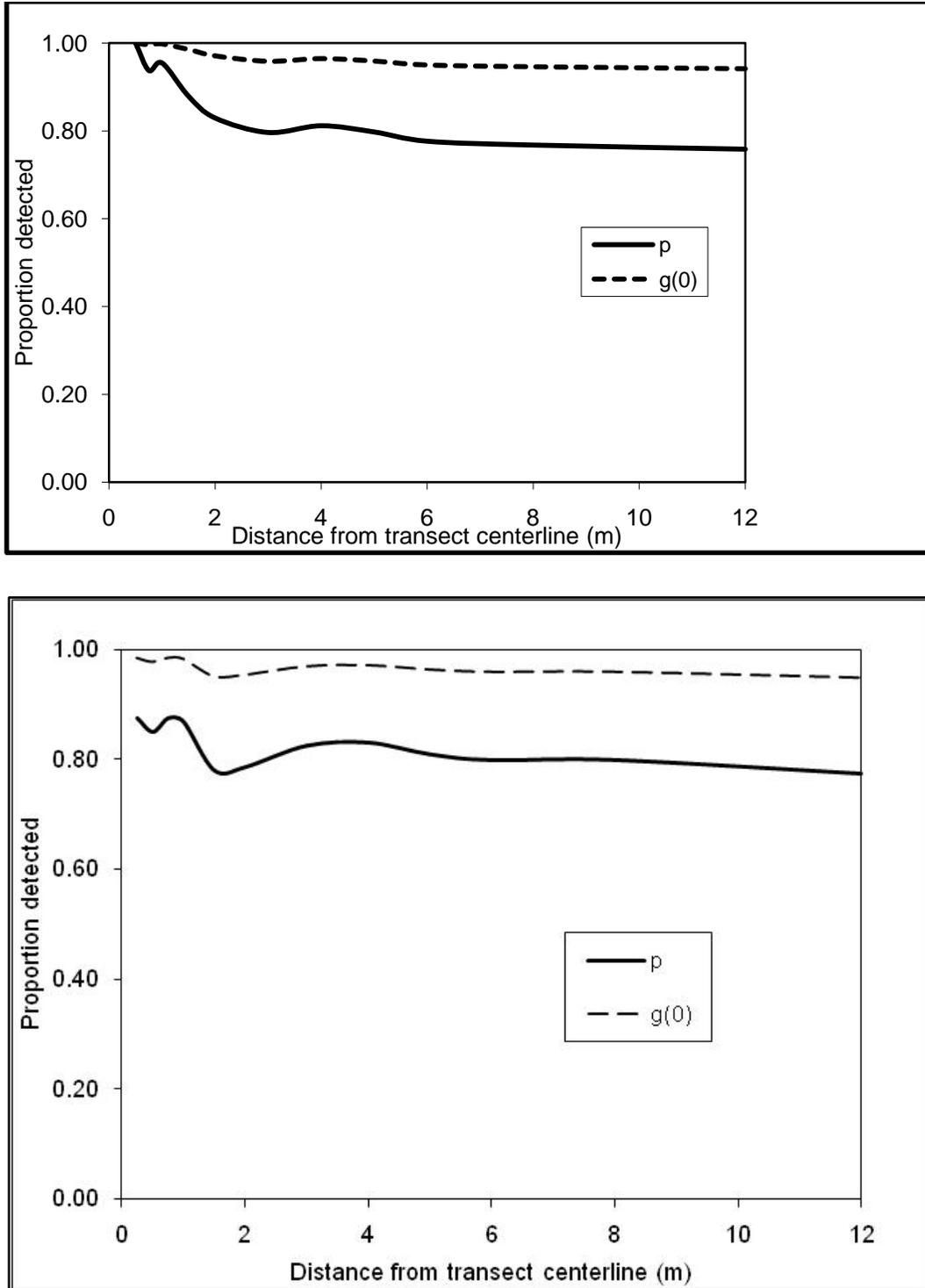


Figure 21. Behavior of detection on the line by the leader (p) and by the team ($g(0)$) based on all observations out to a given distance from the centerline in 2008 (above) and 2009 (below). In both years, the leader generally made 75-80% of all detections, increasing within 1.5m of the line. Note convergence 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 11 and Table 12). Stratum estimates were weighted by stratum area to arrive at average density in the monitored area of each recovery unit. Although encounter rates were estimated separately for each stratum, and have independent variances, the detection function and G_0 were estimated jointly (pooling data from multiple strata), so these variances are not independent (Figure 4 illustrated how estimates were pooled each year).

Recovery-unit-level density estimates are provided in Table 13 and 14. The Northern and Eastern Colorado recovery units were under-sampled in both years, reflected in the low precision (high CV) reported for the Northern Colorado. The low precision means that high between-year fluctuations in estimates are to be expected. Although only 12 transects were placed on BLM lands in the Eastern Colorado in 2009, it was expected that this would be sufficient to detect at least 2 tortoises. This was not the case, so the under-sampling in this recovery unit is reflected in the complete inability to estimate density.

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Table 11. Recovery unit and stratum-level encounters and densities in 2008 for tortoises with MCL \geq 180mm.

Recovery Unit	Stratum	Area (km ²)	Number of Transects	Total transect length (km)	Sampling Dates		Field Observers	<i>n</i> (tortoises observed)	CV(<i>n</i>)	Density (/km)	CV(Density)	
					Begin	End						
Northeastern Mojave		4917	305	2886	11-Apr	18-May	GBI	44		0.9	28.3	
	Beaver Dam Slope	BD	828	32	295	12-Apr	14-May	GBI	4	48.0	1.1	52.3
	Beaver Dam Slope 2*	BD2	260	2	18	3-May	3-May	GBI	0	0.00	0.0	0.0
	Coyote Springs Valley	CS	1144	159	1592	11-Apr	18-May	GBI	24	22.0	1.2	30.2
	Gold Butte-Pakoon	GB	1977	40	308	13-Apr	16-May	GBI	0	0.0	0.0	0.0
	Mormon Mesa	MM	968	74	691	12-Apr	15-May	GBI	16	31.8	1.9	38.0
	Mormon Mesa 2*	MM2	1154	51	499	13-Apr	16-May	GBI	6	38.8	1.0	44.1
Northeastern Mojave (Pahrump)		2178	123	1321	17-May	30-May	GBI	36		2.6	42.7	
	Pahrump North*	PN	1062	48	474	17-May	30-May	GBI	9	43.8	1.9	57.6
	Pahrump South*	PS	1117	75	847	19-May	29-May	GBI	27	21.2	3.2	43.1
Eastern Mojave		6763	153	1590	31-Mar	11-Apr	Kiva	63		6.4	37.5	
	Fenner	FE	1862	9	108	2-Apr	5-Apr	Kiva	8	29.3	9.0	47.6
	Ivanpah	IV	2567	10	120	1-Apr	4-Apr	Kiva	7	37.2	7.1	52.8
	Piute-Eldorado	PI	2334	134	1362	31-Mar	11-Apr	GBI	48	20.4	3.2	28.0
Northern Colorado		4038	7	84	3-Apr	4-Apr	Kiva	4	52.0	5.8	64.3	
	Chemehuevi	CM	4038	7	84	3-Apr	4-Apr	Kiva	4	52.0	5.8	35.6
Western Mojave		9351	67	772	7-May	24-May	Kiva	21		3.4	46.9	
	Fremont-Kramer	FK	2462	18	216	14-May	23-May	Kiva	3	54.2	1.7	67.5
	Joshua Tree National Park	JT	1567	10	102	7-May	9-May	Kiva	4	52.3	5.6	66.2
	Ord-Rodman	OR	1124	9	102	13-May	24-May	Kiva	5	99.4	6.0	107.2
	Pinto Mountains	PT	751	6	72	7-May	10-May	Kiva	2	100.0	3.9	107.9
	Superior Cronese	SC	3447	24	281	13-May	21-May	Kiva	7	38.3	3.1	55.5
Eastern Colorado		4263	25	270	8-May	13-May	Kiva	10		5.1	59.3	
	Chocolate Mountain AGR	AG	755	15	158	11-May	13-May	Kiva	6	40.8	5.4	57.5
	Chuckwalla	CK	3509	10	112	8-May	10-May	Kiva	4	54.2	5.1	67.7

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

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Table 12. Recovery unit and stratum-level encounters and densities in 2009 for tortoises with MCL \geq 180mm

Recovery Unit	Sampling Area	Area (km ²)	Number of Transects	Total Transect Length (km)	Sampling Dates		Field Observers	<i>n</i> (tortoises observed)	CV(<i>n</i>)	Density (/km)	CV(Density)	
					Begin	End						
Northeastern Mojave		4889	449	4328.4	8-Apr	30-May		85		3.4	34.0	
	Beaver Dam Slope	BD	828	66	631.5	29-Apr	29-May	GBI	10	35.8	3.2	49.2
	Beaver Dam Slope 2*	BD2	260	19	174.3	28-Apr	28-May	GBI	0			
	Coyote Springs Valley	CS	1117	151	1503.8	8-Apr	25-Apr	GBI	20	26.2	2.0	36.4
	Gold Butte-Pakoon	GB	1977	76	733.3	27-Apr	30-May	GBI	8	37.6	2.2	50.5
	Mormon Mesa	MM	968	137	1285.5	22-Apr	29-May	GBI	47	16.9	7.3	37.7
	Mormon Mesa 2*	MM2	1157	61	589.0	23-Apr	30-May	GBI	7	36.2	2.4	49.4
Eastern Mojave		6763	100	1047.0	1-Apr	8-Apr		31		5.1	29.1	
	Fenner	FE	1862	10	120.6	1-Apr	4-Apr	Kiva	7	47.9	8.1	48.6
	Ivanpah	IV	2567	10	120.4	1-Apr	5-Apr	Kiva	4	40.9	4.0	44.9
	Piute-Eldorado	PI	2334	80	806.0	1-Apr	8-Apr	GBI	19	22.6	3.7	34.9
Northern Colorado		4038	10	118.5	1-Apr	4-Apr		9		9.2	63.3	
	Chemehuevi	CM	4038	10	118.5	1-Apr	4-Apr	Kiva	9	60.5	9.2	63.3
Western Mojave		9351	161	1741.7	6-Apr	6-May		70		4.3	19.3	
	Fremont-Kramer	FK	2462	30	360.7	6-Apr	28-Apr	Kiva	11	30.6	3.3	33.7
	Joshua Tree National Park	JT	1567	25	244.4	26-Apr	6-May	Kiva	4	61.9	2.3	67.0
	Ord-Rodman	OR	1124	20	197.1	5-Apr	26-Apr	Kiva	13	33.8	7.1	36.7
	Pinto Mountains	PT	751	17	162.3	26-Apr	5-May	Kiva	6	41.7	5.0	49.0
	Superior Cronese	SC	3447	69	781.2	5-Apr	26-Apr	Kiva	36	19.1	4.9	23.8
Eastern Colorado		4263	45	504.2	25-Apr	6-Jun		16				
	Chocolate Mountain Air											
	Gunnery Range	AG	755	33	378.3	2-Jun	6-Jun	Kiva	16	29.6	7.3	36.4
	Chuckwalla	CK	3509	12	125.9	25-Apr	6-May	Kiva	0			

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

Table 13. Estimated density of desert tortoises in monitored areas of Pahrump Valley and in tortoise conservation areas of each recovery unit in the Mojave Desert in 2008.

Recovery Unit	Monitored area (km ²)	Transects	Tortoises detected	Density (/km ²)	SE(Density)	%CV (Density)
Eastern Colorado	4263	25	10	5.1	3.05	59.3
Eastern Mojave	6763	153	63	6.4	2.39	37.5
Northeastern Mojave ^a	4917	305	44	-	-	-
Northern Colorado	4038	7	4	5.8	3.73	64.3
Western Mojave	9351	67	21	3.4	1.58	46.9
Pahrump Valley	2178	123	36	2.6	1.13	42.7

^a No tortoises were detected on the 40 transects that were walked in the Gold Butte stratum. This prevents estimation of the number of tortoises in the larger Northeastern Recovery Unit as well.

Table 14. Estimated density of desert tortoises in monitored areas of each recovery unit in the Mojave Desert in 2009.

Recovery Unit	Monitored area (km ²)	Transects	Tortoises detected	Density (/km ²)	SE(Density)	%CV (Density)
Eastern Colorado ^a	4263	45	16	-	-	-
Eastern Mojave	6763	100	31	5.1	1.48	29.1
Northeastern Mojave	4889	449	85	3.4	1.14	34.0
Northern Colorado	4038	10	9	9.2	5.84	63.3
Western Mojave	9351	161	70	4.3	0.83	19.3

^a No tortoises were detected on the 12 transects that were on BLM lands (not on Chocolate Mtn AGR). Since the two areas were surveyed a month apart, with different G_0 estimates, there is no way to estimate the number of tortoises across the entire Recovery Unit, only on CMAGR.

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.”

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

Proportion of each stratum walked

Since 2008, transects have been selected from the same set of potential transects, and these have been classified as transects that should be walked for a full 12km, shortened to 6km, or should not be attempted at all. Since 2009, a further year of transects has been completed. Each year, new transects are tested, and previously walked transects are reevaluated by field crews. The proportion of each stratum represented by distance sampling is calculated based on the proportion of transects shortened and/or replaced (Table 15). Table 16 (2008) and Table 17 (2009) report the area of each stratum, the proportion covered by our density estimates, and the associated estimate of tortoise abundance.

Table 15. Proportion of each stratum that can be sampled based on all transects classified from 2008 through 2010.

Stratum	Transects classified	Percentage of transects expected to be walked as...			Proportion of stratum that can be sampled
		12k	6k	Replaced	
AG	66	86.4	9.1	4.5	0.943
BD	95	61.1	29.5	9.5	0.855
BD2	27	48.1	29.6	22.2	0.759
CK	112	60.7	13.4	25.9	0.772
CM	51	78.4	7.8	13.7	0.877
CS	127	59.8	29.1	11.0	0.844
FE	37	89.2	5.4	5.4	0.946
FK	53	94.3	5.7	0.0	0.986
GB	203	45.8	33.0	21.2	0.759
IV	57	78.9	10.5	10.5	0.895
JT	60	51.7	25.0	23.3	0.763
MM	105	52.4	39.0	8.6	0.838
MM2	112	53.6	28.6	17.9	0.795
OR	51	54.9	21.6	23.5	0.770
PI	194	67.5	19.1	13.4	0.852
PN	77	42.9	28.6	28.6	0.714
PS	88	75.0	10.2	14.8	0.864
PT	44	45.5	25.0	29.5	0.716
SC	144	87.5	8.3	4.2	0.948
Total	1703				

Table 16. Estimated tortoise abundance in sampled areas of each stratum in 2008

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	3841	1345.3	10966.1
BD	828	0.86	0.036	708	778	295.8	2046.6
BD2	260	0.76	0.082	197			
CK	3509	0.77	0.040	2710	13762	4118.3	45985.0
CM	4038	0.88	0.046	3543	20578	6491.0	65238.4
CS	1144	0.84	0.032	966	1180	658.1	2116.8
FE	1862	0.95	0.037	1761	15879	6527.2	38628.4
FK	2462	0.99	0.016	2428	4141	1245.7	13763.6
GB	1977	0.76	0.030	1500			
IV	2567	0.89	0.041	2297	16301	6143.9	43247.9
JT	1567	0.76	0.055	1195	6662	2031.4	21847.8
MM	968	0.84	0.036	811	1521	737.9	3135.2
MM2	1154	0.79	0.038	917	894	389.8	2050.0
OR	1124	0.77	0.059	865	5202	933.8	28985.7
PI	2334	0.85	0.026	1989	6283	3653.8	10803.6
PN	1062	0.71	0.051	758	1450	504.2	4170.1
PS	1117	0.86	0.037	964	3100	1376.2	6980.7
PT	751	0.72	0.068	538	2122	377.3	11931.8
SC	3447	0.95	0.019	3267	10012	3623.2	27664.9

Table 17. Estimated tortoise abundance in sampled areas of each stratum in 2009

Stratum	Area (km ²)	Proportion sampled	SE(Prop. Sampled)	Sampled area	N (number of tortoises)	95% Confidence Interval	
						Lower Limit	Upper Limit
AG	755	0.943	0.028	712	5217	2605.8	10445.8
BD	828	0.855	0.036	708	2251	901.9	5620.3
	260	0.759	0.082	197			
CK	3509	0.772	0.040	2710			
CM	4038	0.877	0.046	3543	32674	10444.0	102221.3
CS	1117	0.844	0.032	943	1847	921.0	3702.4
FE	1862	0.946	0.037	1761	14189	5741.2	35069.4
FK	2462	0.986	0.016	2428	7919	4160.7	15070.5
GB	1977	0.759	0.030	1500	3284	1286.8	8378.7
IV	2567	0.895	0.041	2297	9272	3990.2	21546.7
JT	1567	0.763	0.055	1195	2709	816.1	8990.6
MM	968	0.838	0.036	811	5954	2903.1	12209.8
	1154	0.795	0.038	917	2188	871.9	5490.7
OR	1124	0.770	0.059	865	6105	3000.0	12423.0
PI	2334	0.852	0.026	1989	7356	3775.3	14334.1
PT	751	0.716	0.068	538	2709	1075.0	6826.5
SC	3447	0.948	0.019	3267	16108	10156.7	25546.3

Debriefing to identify project priorities for future years

Post-season 2008, to implement for 2009

- The new handbook
 - The 2008 version was a major revision. It was developed to highlight specialized skills that were the target of instruction, but also could serve as a handbook. Future versions will be posted as chapters on the Desert Tortoise Recovery Office website, updating chapters as needed.
- Training improvements
 - Training in 2008 was more extensive than in the past. Crew comments focused on a need to use more of this time for practice, especially to practice modifying transects against a variety of obstacles. Participants also recommended relatively less classroom instruction and faster feedback on field training performance.
- Imperfect transect completion record should be improved upon
 - The new QA/QC procedures include weekly data reviews. Although this allows reviewers to identify transects that were completed, it does not allow insight into why other transects were not completed or whether some transects were skipped but will be completed. A separate database was proposed to allow tracking the planning process.
- New USFWS functions

Performance in 2009 will be affected by the transition to oversight by USFWS of the training and QA/QC teams. In both cases, the group recommended an earlier start to planning for 2009.

Post-season 2009, to implement for 2010

- More consolidated QA/QC I
If field crews are better able to verify their own data, there is reduced value in having a fellow crew member as a QA/QC specialist for this level. Instead, the functions of data collection and processing might benefit from being separated. In 2010, we will use one specialist to interact with 2 field teams.
- Use of weekly assessments to communicate from FWS to the crews directly not only to field team leaders and QA/QC I specialists
- Modification of transects to pull them inside administrative boundaries.
Modification of the standard transect shape can introduce mistakes; however, as land uses on public lands outside tortoise conservation areas becomes less compatible with recovery tortoises, we cannot continue to simplify transect paths and allow them to leave monitoring strata. In 2010, the procedures for reflecting away from visible objects like fences and interstate highways will also be applied to administrative boundaries.
- Training improvements to target
In general, training has improved to the point that all crews are fully prepared when they start the field season. With increased expectations on their performance, crews are asking for better understanding of how collected data are used in distance analysis, including the use of telemetry data. They also feel less confident about protocols in rugged terrain than under standard situations, so they want more opportunities for practice and feedback.

DISCUSSION

Sampling representatively in all monitoring strata

In 2007, transects were placed systematically in monitoring strata; the placement scheme itself had a random origin so that transects were located at random with respect to tortoises. The goal of systematic placement is used to provide better coverage of sampled areas, and the set of potential transect locations will be used to sample from in future years as well. Because transects can be rewalked in the future, it is meaningful to collect information describing access and completion of each transect so that this information is available when planning to walk this transect location in future years. In 2008, 4 new strata were surveyed by GBI on a temporary basis; the crew noted that access was much more difficult to plan for than in the long-term strata where they had already been planning entry routes to individual transects in 2007.

Better planning opportunities should improve representative sampling in each monitoring stratum. Another change implemented to improve coverage was redevelopment of the set of rules for changing standard transect protocols when confronted with particular obstacles. These new rules are part of increasing efforts since 2004 to cover all areas within sampling strata. Since

2007, field teams have left transects in their planned locations, reporting any modifications to the transect shape or length. Following the 2008 field season, this reporting was expanded to include describing the reasons for not walking a transect. Because the existing databases only allowed data entry for transects that were walked, an additional database was developed in 2009 to collecting data on the unwalked transects. The current sampling design allowed us for the first time 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

Differences in training results between 2008 and 2009 coincide with a variety of important changes in the training program. In 2008, training was led by UNR and USGS, but this function moved to the USFWS in 2009. There was, however, continuity during this transition since USFWS was working with trainers in 2007 and 2008. Possibly of greater importance, a new data analysis system was put in place in 2009 so that crew summaries could be developed overnight for feedback the next day. Before this, crews might receive delayed input, or might only hear about some performance measures, or might not receive customized guidance on how each crew should try to change their performance. Also in 2009, the training arena had to be moved. The new course, set up similar to the old one, is in a less vegetated area, so training results should not be identical in specifics anyway. Note, however, that under all situations, crews should see all models or live tortoises on the transect line. Only the shape of the detection function should change if the crews are well-trained. Training data in 2009 indicate that crews were detecting all tortoise models on the testing centerline, and first-year crews were performing at least as well as experienced crews. Training in 2009 also included considerable increase in instruction for QA/QC specialists, to which we attribute a dramatic improvement in field season databases.

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 these and every other field season is therefore to improve ability to detect trends in desert tortoise abundance at the recovery unit level.

Impact of developing regional G_0 estimates

By completing density analysis outside the DISTANCE software program, we are able to use more than one annual estimate of G_0 . This was implemented to achieve a more precise and accurate (less biased) density estimate for each area monitored. We do continue to see regional differences in G_0 estimates, which means that without localized estimates of G_0 we might introduce bias in our density estimates. On the other hand, Tables 9 and 10 indicate that reducing the number of days monitored in any region has not been as predictably associated with greater precision.

Consequences of insufficient transects

One stratum where only 12 transects were completed (Chuckwalla-BLM) also had no detected tortoises in 2009. Consequently, no density estimate was possible for that area, but also for the combined Chuckwalla DWMA, which is also the Eastern Colorado Recovery Unit. Whereas much of this program has focused on ways to enhance efforts and develop more precise estimates to detect trends, this example illustrates that attention should also be focused on the lower limits of effort that can produce useful data. There should be sufficient transects in each monitoring stratum each year to detect several live tortoises in each stratum. This is one reason that over the years since 2001, the protocols have changed to allow more kilometers to be walked per day, increasing the number of tortoises encountered. However, the number of transects walked is limited by funding, which was not sufficient to complete more than 10 transects in 7 of the 10 long-term strata in the California portion of the range in 2008 and 3 of them in 2009. In areas with low tortoise densities, even relatively more transects may not be sufficient for any tortoise detections. This happened in Gold Butte in 2008, where 40 transects were walked, which was nonetheless less than half of what had been planned for. Since then, additional funding has been applied in that stratum and sufficient tortoises were detected in 2009.

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