RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE (*GOPHERUS AGASSIZII*):

2011 ANNUAL REPORT

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EXECUTIVE SUMMARY

The recovery program for desert tortoises in the Mojave and Colorado deserts (USFWS, 2011) requires range-wide, long-term monitoring to determine whether recovery goals are met. Specifically, will population trends within recovery units increase for a period of 25 years? In 1999, the Desert Tortoise Management Oversight Group endorsed the use of line distance sampling (Buckland et al., 2001) as the method for estimating range-wide desert tortoise density. From 2001 to 2005, and again from 2007 through 2011, desert tortoise populations in 4 of the 5 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 (McLuckie et al., 2012).) 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 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 2011 monitoring effort. The above issues continue to drive review and improvement of the program, so that reporting also addresses these aspects of the annual effort. The range-wide monitoring effort is directed each year at 16 strata that will be used to describe long-term trends. Data were collected on transects by field personnel working with three different groups, Kiva Biological (12 personnel), the Institute for Wildlife Studies (12 personnel), and Great Basin Institute (22 personnel). Four personnel from Joshua Tree National Park also collected telemetry data in the Park. After an intensive, 12-day specialized training session, crews completed 790 transects (8619 km) between 25 March and 27 May. In the course of these surveys, they reported 502 live tortoises.

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

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 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 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 will capture any differences between teams in application of the protocol, but are mostly expected to reflect the terrain as well as the extent to which vegetation obscures the view in different parts of the range, since the curves account for tortoises that were present in the same area but not seen. Kiva crews detected 53.2% of tortoises within 16 m of the transect centerline, GBI detected 42.9% out to 20 m, and IWS detected 31.9% to 20 m. The proportion of tortoises that were visible to be counted (G_0) varied in different parts of the range, which were surveyed at different times during the spring season. Visibility was as high as 94.9% in the Superior Cronese telemetry site during the last week of March and first 2 weeks of April. The lowest visibility was measured at 54.8% at the Halfway Wash telemetry site, monitored between 20 April and 12 May. On average, crews walked 21 km for each tortoise that was observed, but this number varied considerably from one monitoring stratum to the next. Although densities in the Northeastern Mojave Recovery Unit had been estimated at less than 2/km^2 in some previous years, the density was estimated at 3.4/km^2 this year, similar to the past 3 years. The Western and Eastern Mojave recovery units also had densities at or below 4/km^2, whereas the Colorado Desert recovery unit (missing information from the stratum that consistently has highest densities) had an estimated 4.6 tortoises/km^2. The Fenner critical habitat unit, which typically reports higher densities than surrounding strata had notably high density estimates at 6.8 tortoises/km^2,although Ord-Rodman did not maintain this pattern from past years and was estimated to have 3.2 tortoises/km^2.

To enable field crews to complete transects in previously unsampled areas within strata, a set of guidelines was implemented in 2008 and 2009 for modifying transects in areas with rugged terrain or other obstacles (USFWS 2010a). These rules did enable crews to sample entire strata in a more representative way; however, in areas of California with lower funding, the resulting substrata never had enough transects or tortoise observations to separately evaluate tortoise densities in flat compared to rugged terrain. For this reason, in 2011, all transects in all recovery units except the Northeastern Mojave were to be completed to the extent possible along the original 12 km path. Mountainous terrain in the path was circumnavigated without searching for tortoises, then the path was resumed when possible. This method samples walkable areas representatively and also allows the proportion of unwalkable terrain to be estimated. Our density estimates are applicable to the estimated 84.5% of terrain in critical habitat and other areas managed for tortoises that is also walkable.

RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE 2011

INTRODUCTION

The Mojave Desert population of the desert tortoise (*Gopherus agassizii*) was listed as threatened under the Endangered Species Act in 1990. This group of desert tortoises north and west of the Colorado River are now recognized as the species *G. agassizii*, separate from *G. morafkai* south and east of the Colorado River (Murphy et al., 2011). The revised recovery plan (USFWS, 2011) designates five recovery units and to which decisions about continued listing status should be applied. The recovery plan specifies that consideration of delisting should only proceed when populations in each recovery unit have increased 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 tortoise abundance categories based on calibration transects conducted in areas of better-known tortoise density, or by using capture-recapture population estimates on a limited number of (usually) 1-mi^2 study plots (Berry and Nicholson, 1984). Although data have continued to be collected on transects and study plots in recent years, these methods suffer statistical deficiencies and/or logistical constraints that render them unsuited for monitoring trends in abundance applicable to 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 centerline (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 centerline of the transect is perfect, however, can be violated during line distance sampling of tortoises, but the use of two observers minimizes the probability that tortoises are missed on the centerline and provides a correction factor in the form of an estimate of the number of tortoises on the line that were missed (USFWS, 2009).

Distance methods have been applied to estimate abundance of Sonoran Desert Tortoises (*G. morafkai*) since 2000 (Swann et al., 2002; Averill-Murray and Averill-Murray, 2005) and for *G. agassizii* in the Upper Virgin River Recovery Unit in Utah since a pilot study in 1997 (McLuckie et al., 2010). The USFWS used line distance sampling to estimate abundance of tortoises in the remaining five recovery units for *G. agassizii* in Utah, Arizona, Nevada, and California starting in 2001 (USFWS 2006, 2009, 2012a, 2012b). This report includes results of training exercises for field crews, describes implementation of monitoring in 2011, and presents the analysis of desert tortoise density in 2011.

METHODS

Study areas and transect locations

Long-term monitoring strata (Figure 1) will be used over the life of the project to describe population trends in areas managed to conserve tortoises ("tortoise conservation areas," TCAs). Generally each critical habitat unit (CHU) is treated as one monitoring stratum, although the portion of Mormon Mesa CHU that is associated with Coyote Springs Valley is treated as a separate stratum. Chuckwalla CHU is also treated as dual monitoring strata, with potentially unequal sampling effort in the areas managed by the Department of Defense (Chocolate Mountain Aerial Gunnery Range, CMAGR) and by the Bureau of Land Management (BLM). In 2011, CMAGR was not sampled. New recovery units were established under the revised recovery plan (USFWS, 2011), so while revising our databases to match we also separated the Piute and Eldorado Valleys into 2 separate strata; they are in different recovery units. The Joshua Tree stratum does not encompass all suitable habitat for desert tortoises in Joshua Tree National Park (JTNP). The national park designation and current boundaries just post-date the designation of CHUs, so some of the Pinto Mountains and Chuckwalla CHUs (and monitoring strata) are in the current JTNP.

The optimal number of transects in a monitoring stratum was determined by evaluating how these samples would contribute to the precision of the annual density estimate for a given recovery unit (Anderson and Burnham, 1996). Power to detect an increasing population size is a function of 1) the magnitude of the increasing trend, 2) the "background noise" against which the trend operates, and 3) the length of time the trend is followed (even a small annual population increase will result in a noticeably larger population size if the increase continues for many years).

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

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

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 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.

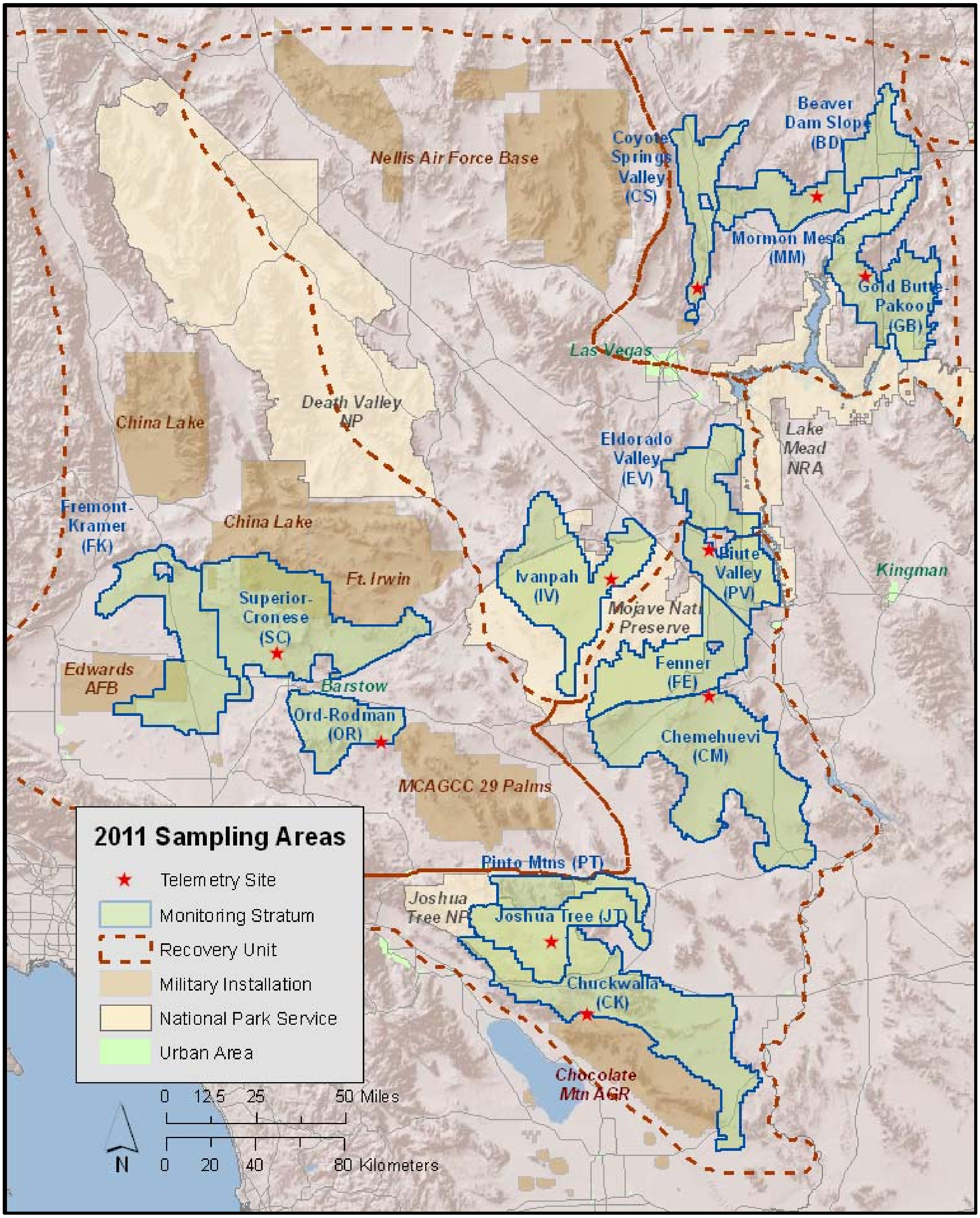

Figure 1. Sampled areas 2011.

Field crews complete transects during this optimal period each day. Start times are decided a week in advance, so crews arrive at transects at similar times on a given morning. However, completion times will be more variable, as a consequence of terrain, air temperature, number of tortoises encountered, etc. Under normal conditions, each team walked one 12 km square transect each day. Teams were comprised of 2 field personnel who switched lead and follow positions at each corner of each transect, so they each spent an equal amount of time in the leader and follower positions. The leader walked on the designated compass bearing while pulling a 25 m length of durable cord; the walked path is also the transect centerline and was indicated by the location of the cord. The length of cord also spaced the two independent observers, guiding the path of the follower; when the cord was placed on the ground after a tortoise or carcass was detected, it facilitated measurement of the local transect bearing. The walked length of each transect was calculated as the straight-line distance between GPS point coordinates that were recorded at 500 m intervals (waypoints) along the transect and/or whenever the transect bearing changed.

Both leader and follower scanned for tortoises independently without leaving the centerline, and the role of the crew member finding each tortoise was recorded in the data. Although the leader saw most of the tortoises, the role of the follower was to see any 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 centerline to tortoises is measured accurately. When a tortoise was observed, crews 1) used a compass to determine the local transect bearing based on the orientation of the 25 m centerline, 2) used a compass to determine the bearing from the point of observation to the tortoise, and 3) used 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 was outside of a burrow, was handled enough to measure midline carapace length (MCL), to determine its sex, and to apply a small numbered tag to one scute. If a tortoise could not be measured because it was in a burrow, because temperatures precluded handling, or for any other reason, crews attempted to establish by other means whether the animal was larger than 180 mm MCL, the criterion for including animals in density estimates.

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

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

In 2010 and 2011, the same option to shorten transects to 6km in rugged terrain were made available to GBI crews. However, IWS and Kiva crews shortened transects by following as much of the planned 12 km route as was possible. If it was anticipated that fewer than 4 km could be walked, the transect should be replaced instead with a transect from the alternate list. Instead of estimating the proportion of the area that is unwalkable based on the proportion of transects that were unwalkable, we would use the proportion of total planned kilometers (12 X number of planned transects) that were unwalkable.

In addition, transects that crossed stratum boundaries into public lands had previously been walked as planned (squares). Although this added sampling just outside the stratum, it seemed reasonable to assume the land management and tortoise fate would be similar on each side of the invisible boundary. Walking in a square is also less likely to introduce other problems compared to reflecting the transect. Nonetheless, starting in 2010, the protocol used to modify transects that intersected private lands or interstates since 2007 was applied to the portion of any transect that crossed out of monitoring strata, reflecting that portion into the stratum. Whether the segments of those transects outside the boundaries were walked outside the stratum or as a mirror image inside the stratum, the same length of transect is walked at the same distance from the stratum boundary, avoiding undersampling of areas on stratum boundaries (Figure 2). The impetus for this change was the recent large scale development and construction on public lands, often just along the borders of critical habitat, especially for renewable energy facilities and transmission lines.

Specifics of how transect paths were to be modified for rugged terrain (shortened) or for administrative boundaries (reflected) can be found in the *2011 Desert Tortoise Monitoring Handbook* (USFWS 2012c).

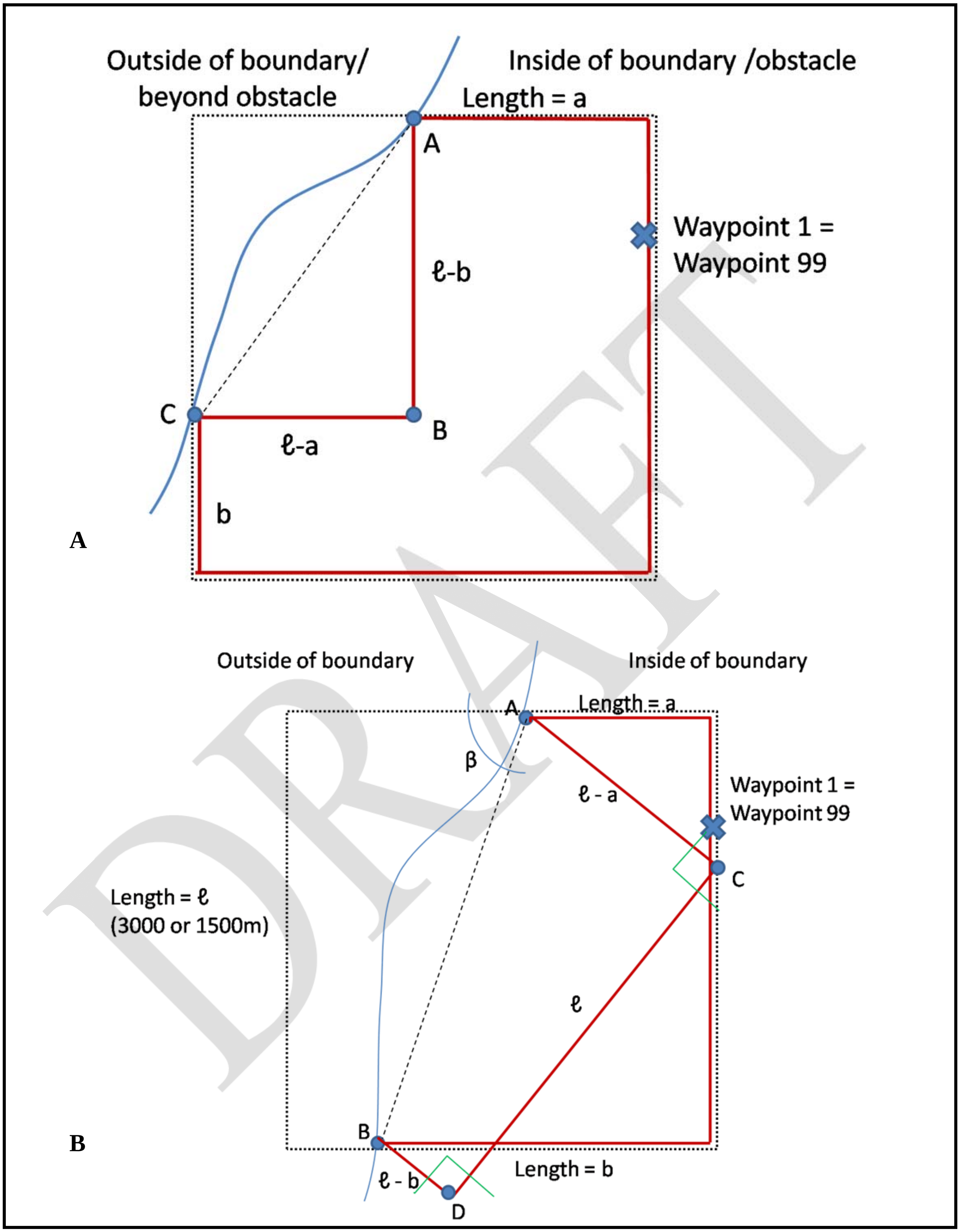

Figure 2. Planned (dotted lines) and reflected transect paths at administrative boundaries, now also applied to stratum edges. A) One-corner reflection. B) Two-corner reflection.

Proportion of tortoises available for detection by line distance sampling, G0

Although we have general expectations about when tortoises are most active each day, and plan our sampling to match the best season and time of day, the fact remains that basing our density estimates only on the tortoises that are visible will result in density estimates that are consistently underestimated (biased low). Instead, we use telemetry to estimate the proportion of tortoises available for sampling, G_0 (“gee-sub-zero”), which is incorporated in the equation for estimating tortoise density and is used to correct this bias.

Telemetry allows us to locate radio-equipped tortoises that are visible as well as those that are otherwise undetectable in deep burrows or well hidden in dense vegetation. To quantify the proportion that were available for detection (“visible”) in 2010, telemetry technicians used a VHF radio receiver and directional antenna to locate 8-12 radio-equipped G_0 tortoises in each of 10 sites throughout the Mojave and Colorado deserts (Fig. 1).

Each time a transmittered tortoise was located, the observer determined whether the tortoise was visible (*yes* or *no*). Through careful coordination, observers at telemetry sites monitored visibility during the same daily time period when field crews were walking transects in the same region of the desert. Observers completed a survey circuit of all focal animals as many times as possible during the allotted time, recording visibility each time. Bootstrapped estimates of G_0 started by selecting one visibility record at random for each tortoise on each day it was located. 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, the G_0 estimate was calculated as the grand mean of all G_0 sites in the group. One thousand bootstrap samples were generated in PASW Statistics (release 18.0.2; SPSS, Inc., 2 April 2010) to estimate G_0 and its standard error.

Use of radio transmitters/receivers to locate tortoises is a technique that is very different from the method used to detect tortoises on line transects. Therefore, in addition to stating whether any part of the tortoise is visible when located, since 2008 behavioral observers and transect walkers have categorized all “visible” tortoises and burrows (when tortoises are found in burrows) as low, medium, or high visibility based on the ability to see part of the tortoise or its burrow from any angle of approach. For the telemetry observers it is a matter of locating a tortoise (visible or not) after they have determined its general location aurally, whereas transect walkers are not searching with certainty of locating a tortoise – they rely only on visual cues. We would therefore not be surprised if the distance sampling method results in detection of a higher proportion of “high” visibility and a lower proportion of “low” visibility tortoises/burrows than when tortoises are located using telemetry. If the odds be being detected differ not only by distance from the line but also a combination of method of detection used (visual or radio receiver) and visibility, we should be able to describe this difference and be able to modify our calculation of visibility following radio-receiver information to more accurately match the visibility to transect walkers.

Field observer training

Training for careful data collection and consistency between crews is fundamental part of quality assurance for this project. This training includes instruction as well as required practice time on skills such as tortoise handling, walking practice transects, and developing detection and distance-measuring techniques. The latter skills include practice on a training course with tortoise models (Table 1). The monitoring handbook developed in 2008 was comprehensive, and serves as a training manual and documentation of training that is provided. Chapters are updated each year as needed and printed for training. They are also posted to the Desert Tortoise Recovery Office website (http://www.fws.gov/nevada/desert_tortoise/reports).

In 2011, three teams of field observers participated. Kiva Biological (Kiva) supplied crews for monitoring in the West Mojave and the eastern portion of the Colorado Desert recovery units. The Institute for Wildlife Studies (IWS) monitored in the western portion of the Colorado Desert and in the Eastern Mojave recovery units. Great Basin Institute (GBI) supplied crews for monitoring in the Northeastern Mojave Recovery Unit. Eleven of 14 personnel for Kiva had previous experience with this monitoring program, as did 1 of the 15 personnel for IWS, and 7 of the 26 personnel for GBI were returnees. The three teams were trained in 2 overlapping periods, and to enhance consistency in application of field protocols across teams, where possible the same trainers were used in both training sessions and across teams. Also, for small-group training, experienced personnel from each team worked with the trainees from other teams.

Telemetry training

The primary goal of G_0 training is successful implementation of the G_0 protocol by telemetry crews. This includes correct use of telemetry equipment, understanding G_0 data collection fields, observation of as many radio-equipped tortoises as possible during the day, and covering a window of observation that overlaps the day's transect observation period for each sampling area. Although all telemetry crews had some prior telemetry experience, performance on this project differs from others that do not require confirmation of the exact location of the tortoise. Unless the exact location is determined, its visibility cannot be accurately recorded. Beyond instruction and testing on use of the equipment in desert terrain, several days of practice were compulsory to be able to troubleshoot locating the tortoise and confirming the location when it could not be seen, In addition, some instruction for telemetry and transect crews overlapped to help each group better understand the purpose their data serve and how separate data types are related to the final density estimate.

Distance sampling training

Transect walkers were given classroom instruction, field demonstrations, practice transects to complete, and ultimately each team was evaluated based on performance on a field arena outfitted with a high density of polystyrene tortoise models placed in measured locations (Anderson et al., 2001).

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

Crews were sent on transects and training lines as paired, independent observers. That is, the follower was 25 m behind the leader, with the opportunity to detect models not found by the leader. If the leader detects 80% of all tortoises that are found, the assumption is that the follower detects 80% of the tortoises that are missed by the leader. If this assumption is true, in this example, the pair together will detect 0.80 + (0.80 X (1 – 0.80)) = 0.96 of all tortoises on the centerline. Because the location of all models was known, data from training lines were also used to 1) assess the dual-observer assumption that all models were 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 were used to evaluate and correct crew performance before the field season, but were not used in any way to estimate densities of live tortoises once field surveys began.

Table 1. Training schedule for 2011.

	IWS and Kiva Trainees		Experienced Kiva Trainees		GBI Trainees	
Day/ Date	**Activity**	**Trainer**	**Activity**	**Trainer**	**Activity**	**Trainer**
WEEK 1					**WEEK 1**	
Monday, 14-Mar	Transect methods overview 6km transect (paper forms)	Allison/ Experienced GBI crews				
Tuesday, 15-Mar	Introductions and DT Recovery/Monitoring Programmatic Overview Working on Public Lands Tortoise Activity/G_0 Distance Sampling Transect methods Non-standard transects Juno, Pendragon Database Lecture and Exercises (PM) Quality control procedures for field crews Compass and GPS for Distance Sampling	Allison BLM LE " " " " Patil Patil Allison			Juno, Pendragon Database Lecture and Exercises (AM) Quality control procedures for field crews	Patil Patil
Wed, 16-Mar	Tortoise biology and handling Tortoise handling practice Training line preview and crew QAQC Compass/GPS Exercise	Christopher, Woodman GBI Staff Allison Crew				
Thursday, 17-Mar	Training Lines (practice, 8km) Data transfer and QA/QC	Allison Patil/ Brenneman			Tortoise handling Training line debriefing Data transfer and QA/QC	Veterinarian Allison Patil/ Brenneman
Friday, 18-Mar	Full transects (12km) Initial QAQC (specialists only)	Mullen/ Grouios	Intro to new Junos Training lines (practice)	Allison		
Saturday, 19 Mar			Training lines (evaluation)			
Sunday, 20 March			Training lines (evaluation)			
WEEK 2						
Monday, 21-Mar	Tortoise handling Pen search and tort handling Training line debriefing	Staff " Allison	Powerpoint (abbrev)		Transect methods overview 6km transect (paper forms)	Allison/ Experienced crews
Tuesday, 22-Mar	Training Lines (eval, 8km)	Crew	Full transects (reflection)		"Powerpoint Day" Same as IWS on 15 Mar	Allison

Day/ Date	IWS and Kiva Trainees		Experienced Kiva Trainees		GBI Trainees	
	Activity	**Trainer**	**Activity**	**Trainer**	**Activity**	**Trainer**
Wednesday, 23-Mar	Training Lines (evaluation, 8km)	Crew	Tortoise handling practice Training line debriefing		Tortoise biology and handling instruction Same as IWS on 16 Mar	GBI staff, Woodman Allison
Thursday, 24-Mar	Full transects (rugged)		Repeat training lines as needed		Training Lines (practice, 8km) Begin data download	Allison
Friday, 25-Mar	G0 / activity observation	Sparks	*Begin field data collection*		Full transects (12km)	DTRO/Mullen
WEEK 3						
Monday, 28-Mar	Tortoise handling Training line debriefing	Veterinarian Allison			Full transects (rugged) (half crew) G_0 / activity observation (half crew)	Sparks
Tuesday, 29-Mar	Full transects (adminobstacle) or repeat training lines				Tortoise handling Training line debriefing	Veterinarian Allison
Wednesday 30-Mar	Repeat training lines as needed *Begin field data collection*				Training Lines (evaluation, 8km)	
Thursday, 31-Mar					Training Lines (evaluation, 8km)	
Friday, 1-Apr					Full transects (rugged) (half crew) G_0 / activity observation (half crew)	Sparks
WEEK 4						
Monday, 4-Apr	Deliver QA/QC'd training data				Tortoise handling Training line debriefing	Allison
Tuesday, 5-Apr					Full transects (admin obstacle) or repeat training lines as needed	
Wednesday 6-Apr					Repeat training lines as needed *Begin field data collection*	
WEEK 5						
Monday 11-Apr					Deliver QA/QC'd training data	

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 G_0 sites. Collection data forms, sheets, applications, and databases are designed to minimize data entry errors and facilitate data verification and validation. Data were collected in both electronic and paper 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. During the second, data integration phase, 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 generation of final spatial and non-spatial data products used for analysis. After data analysis and reporting are completed, electronic data are actively hosted for download from the internet through http://www.mojavedata.gov/deserttortoise_gov/recovery/data.php. Figure 3 describes the overall data flow.

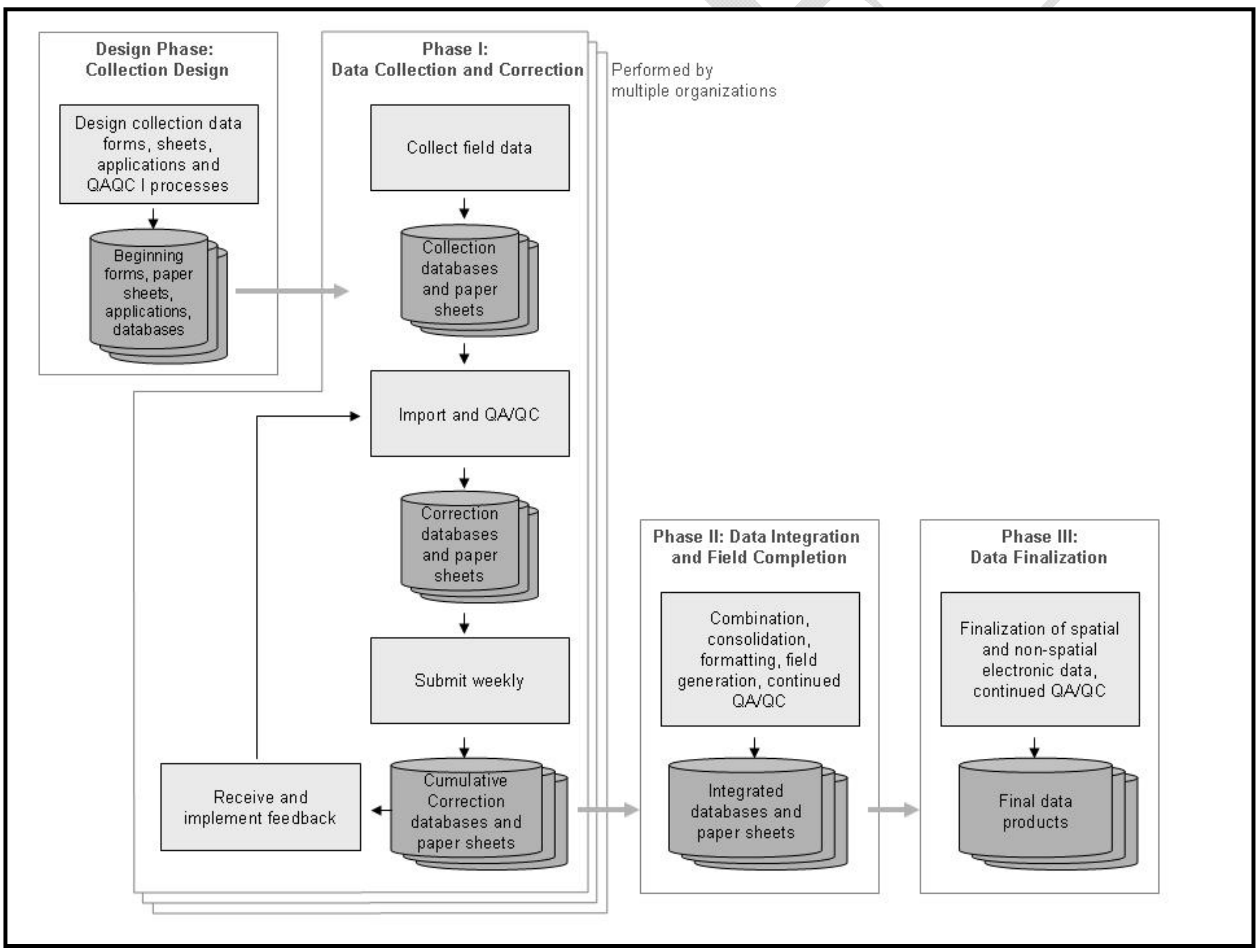

Figure 3. Data flow from collection through final products.

Tortoise encounter rate and development of detection functions

The number of tortoises seen in each stratum and their distances from the line are used to estimate the encounter rate (tortoises seen per kilometer walked), the detection rate (proportion of available tortoises that are detected out to a certain distance from the transect centerline), and their respective variances. Detection function estimation is "pooling robust" under most conditions (Buckland et al., 2001). This property holds as long as factors that cause variability in the curve shape are represented proportionately (Marques et al., 2007). Factors that can affect curve shape include vegetation that differentially obscures vision with distance, and different detection protocols used by individual crews (pairs). Field teams (IWS, GBI, Kiva) typically walk different number of transects. For this reason, after the field season I expected to develop at least one curve for each field team, which also corresponds to different regions of the desert. The encounter rate is 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 larger than 180 mm MCL. 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 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 25 m of line, and the second crew member following at the end of the line. This technique involves little lateral movement off the transect centerline, where attention is focused. Use of two observers allows estimation of the proportion of tortoises detected on the line; this provides a test of the assumption is that all tortoises on the transect centerline are recorded ($g(0) = 1$). The capture probability (p) for tortoises within increasing distances from the transect centerline was estimated as for a 2-pass removal estimator (White et al., 1982): p = (lead–follow)/lead, where lead = the number of tortoises first seen by the observer in the leading position and follow = the number of tortoises seen by the observer in the follower position. The corresponding proportion detected on the line by two observers was estimated by $g = 1 - q^2$, where $q = 1 - p$. Figure 4 graphs the relationship between the single-observer detection rate (p) and the corresponding dual-observer detection rate (*g(0); "gee at zero"*). 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 1 m of the transect centerline. This corresponds to the leader being responsible for at least 80% of the team's detections near on the centerline in order to meet this standard (Fig. 4) and is the basis for one of the training metrics (see Table 3).

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

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

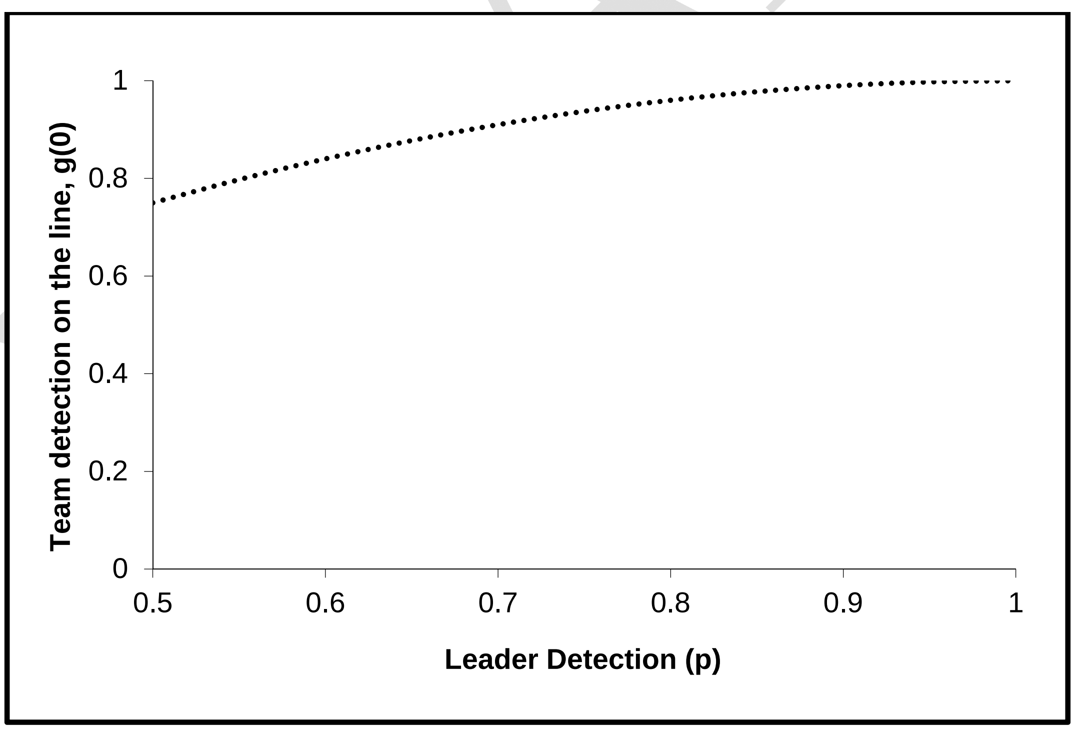

Figure 4. Relationship between single-observer detections (by the leader, p) and dual-observer (team) detections, *g(0)*.

Estimates of tortoise density

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

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

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

For desert tortoise densities, the encounter rate (n/L) is estimated independently for each stratum ("unpooled"), whereas proportion of available tortoises and proportion of available tortoises detected on the transect centerline are estimated jointly for all strata ($g(0)$) or for all strata in the recovery unit (G_0). The detection function, which comes into the above equation as P_a, may be estimated jointly or separately for each team, depending on the number and quality of observations. In 2011, separate detection curves were created for each team (GBI, Kiva, and IWS, pooled across all strata surveyed by that team. A schematic of the process leading to density estimates is given in Figure 5. Contributing estimates in the four left-hand columns are listed with the subsets of the data on which they are based. These estimates combined from left to right to generate stratum and recovery unit density estimates.

Whereas the number of tortoises in the set of strata representing a recovery unit can simply be added together, the variance must be arrived at by accounting for whether this involves pooled or unpooled estimates. As described above, three of the four estimates that contribute to calculating density in a stratum were based on data "pooled" from other strata as well, so when encounter rate and detection probability data from these strata are combined, the correlated nature of the detection probability variances has to be accounted for, for instance. 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.

Tortoise encounter rate	**Proportion that are visible, G_0**	**Detection rate, P_a**	**Proportion seen on the line, $g(0)$**	**Density**	**Density**
Stratum or substratified	*Neighboring G_0 sites*	*Data collection group*	*Overall*	*Stratum*	*Recovery unit*
FK	Ord Rodman + Superior Cronese	Kiva	Full set of tortoise observations	FK	Western Mojave
SC				SC	
OR				OR	
JT	Joshua Tree NP + Chuckwalla			JT	Colorado Deserts
PT				PT	
CK				CK	
PV	Piute + Chemehuevi + Ivanpah	IWS		PV	
CM				CM	
FE				FE	
IV	Piute + Chemehuevi + Ivanpah			IV	Eastern Mojave
EV				EV	
GB	Gold Butte	GBI		GB	Northeastern Mojave
BD	Halfway Wash			BD	
MM				MM	
CS	Coyote Springs			CS	

Figure 5. Process for developing density estimates in 2011. For each type of estimate, the full set of data was subdivided appropriately, as indicated by columns.

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

Before the 2008 field season, based on experience in 2007 and visual examination of DEM overlays, all assigned transects were classified as possible for completion as 12k, 6k, or as unwalkable (USFWS 2012a). 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 transect (not 12 km square) is walked, crews indicate the obstacles they encountered that forced the change in protocol. In addition to the above named factors, substrate that is very loose on a steep slope or that includes large boulders can make progress so slow or treacherous that crews modify the transect.

Each year, some transects are repeated, providing new information on ground conditions, and new transects are attempted. At the end of each field season, transects that were completed differently from expected are evaluated. At that point, a decision is made whether to reclassify the transect. The classification is used to advise future transect completion, but also to estimate the proportion of each monitoring stratum that is actually represented by the walked transects. Proportions used in this report reflect experience with this set of transects through December 2011.

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 12-km 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, 3 km could have been walked for each transect classified as "unwalkable." Transects completed using the 6 km option represent all of those that could have been completed for distances of 6- to 12-km, averaging 9 km, so that is the expected value for all of those transects. Transects completed as 12 km represent the 100% completion option. The total area of the stratum that is unwalkable is estimated as:

$$Proportion\ unwalkable = \frac{0.25(\#\ 6k\ transects) + 0.75(\#\ unwalkable\ transects)}{\#\ transects\ classified\ since\ 2008}.$$

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

In 2010 and now in 2011, crews completed all transects except those walked by GBI in Nevada using the 12 km square path, completing as much of that path as possible. The calculation of unwalkable area in these strata now based on the proportion of unwalkable kilometers, not unwalkable transects.

Debriefing to describe strengths and weaknesses of project preparation and execution

At the end of each field season, a debriefing meeting was held to review tasks and responsibilities, strengths and weaknesses of the program, and to plan for the next field season. Because the field teams had disbanded by then, field crew members were surveyed prior to the end of the field season to nonetheless gather their direct input as we identified training and logistical issues to target for improvement before the next field season. Although issues and/or tasks may be ascribed to individual entities, this meeting is most beneficial in identifying where centralized and/or coordinated response is required to improve the quality of the program.

RESULTS

Field observer training

The smaller Kiva and IWS groups trained alongside one another and mostly separate from GBI, although experienced crews worked between all three teams. Training started on 14 March and continued through 5 April (Table 1). Final tests of field detection abilities occurred toward the end of this period.

Proportion of tortoises detected at distances from the transect centerline

Table 2 reports the proportion of models that were available and were detected by each team at 1-, 2-, and 5-m from the transect centerline. Teams were tested after a trial run on the detection lines (GBI and IWS crews) or after returning crews walked practice transects to refresh the search pattern (Kiva). Detection on the centerline should be 100%, and most crews achieved this. All trainees, regardless of experience level, detected a similar proportion of models at each distance.

Table 3 reports further statistics for each team after collecting data on 16 km on the evaluation lines. Measurement accuracy reported in Table 3 gives the average absolute difference between the expected and measured perpendicular distances from the model to the walked line. All measurements for all models during the 2-day trial are used for this estimate, and capture inaccuracies from 1) using a compass and measuring tape to record distances to the models, plus 2) inaccurately following the trajectory of the transect. The latter source of error does not occur on monitoring transects, because the walked transect is the true transect. On training lines, measurement error increases if crew paths diverge from 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% detection rate for the leader, a 96% detection rate is expected for the team.

Although some individual metrics were below-par (gray cells in Tables 2 and 3), all teams performed well overall and no further changes were made. During training, detection curves were fit to each crew’s set of tortoise model observations. In no case did a negative exponential model best describe the data. Because this model does not involve fitting a “shoulder” to the data near the centerline, detection curves reflecting such a model would have led to additional practice. The best-fitting of the 3 remaining basic types of models were then fit to the data to generate density estimates in Table 3. In Figure 6 to Figure 8, all of the crew detection curves for each field team are overlaid. Crews were not evaluated on their ability to match teammates; such overlays were used to focus field personnel on an additional level of conformity they could work toward. Distance sampling and development of a single detection curve from many observers is robust to the effects of pooling across observations from crews with variable search patterns, when observers contribute proportionally to the overall pattern (Marques et al., 2007).

Table 2. Proportion of tortoise models detected by teams within 1-, 2-, or 5-m of the transect centerline. Values that scored below the target of 0.90 at 1- and 2-m are highlighted.

Team Number	1m	2m	5m
1	1.00	1.00	0.99
2	0.94	0.93	0.94
3	1.00	0.96	0.91
4	1.00	0.93	0.87
5	1.00	0.93	0.85
6	1.00	1.00	0.90
21	1.00	1.00	0.97
22	1.00	1.00	0.94
23	1.00	0.93	0.93
24	1.00	0.93	0.86
25	1.00	0.93	0.94
26	1.00	1.00	0.94
41	0.93	0.93	0.83
42	1.00	0.93	0.96
43	1.00	0.96	0.90
44	0.93	0.89	0.93
45	1.00	0.97	0.90
46	1.00	0.96	0.94
47	0.93	0.92	0.90
48	0.94	0.93	0.85
49	1.00	0.96	0.91
50	1.00	1.00	0.89
51	0.89	0.92	0.94
GBI	**0.97**	**0.94**	**0.90**
Kiva	**0.99**	**0.96**	**0.91**
IWS	**1.00**	**0.97**	**0.93**
Overall	**0.98**	**0.95**	**0.91**

Within the GBI crews, teams 44, 46, and 49 had the most anomalous curves (broadest shoulders) in Figure 6. These teams were coached on tightening their search pattern to better match other teams; however, the usual concern when crews are successful searching farther from the line is that they will focus less close to the line. Only Team 44 seemed to show lower detection near the line. The extra detections by some crews out past 10m (curves with bumps seen in the figures for GBI and IWS), are of most concern when this indicates that one of the searchers is not detecting tortoises at the line. These teams, 25, 41, and 42, otherwise were judged to have fairly healthy diagnostics. The testing arena differs from the normal field setting in ways that make it easier to evaluate trainees (higher encounter rate, for example), but also make it more difficult to use as an absolute standard for search patterns.

Table 3. Diagnostics for individual teams after training

Team	Available models detected: Within 2m of centerline by leader	Available models detected: Within 2m of centerline by team	Measured v. exact model distance (m)	Estimated abundance	95% confidence interval: Lower limit	95% confidence interval: Upper limit
1	0.93	1.00	0.73	498	364	681
2	0.93	0.93	0.93	416	355	488
3	0.96	0.96	0.85	523	442	618
4	0.90	0.93	0.61	426	360	504
5	0.93	0.93	0.83	467	383	571
6	0.96	1.00	0.71	507	408	630
21	0.92	1.00	0.78	382	281	520
22	0.93	1.00	0.63	498	408	607
23	0.93	0.93	0.78	431	373	499
24	0.86	0.93	0.69	426	318	570
25	0.87	0.93	0.71	409	303	551
26	0.85	1.00	0.94	449	355	569
41	0.83	0.93	0.84	367	291	464
42	0.85	0.93	0.73	439	359	535
43	0.85	0.96	0.71	418	340	514
44	0.82	0.89	0.73	350	316	389
45	0.97	0.97	0.90	473	404	554
46	0.85	0.96	0.74	364	319	415
47	0.92	0.92	0.54	411	308	549
48	0.85	0.93	0.83	421	375	471
49	0.96	0.96	0.83	381	333	436
50	0.86	1.00	0.79	409	266	627
51	0.75	0.92	1.05	462	362	589
Target	**>0.80**	**>0.90**	**<1**	**410**		
GBI	**0.86**	**0.94**	**0.79**	**409**		
Kiva	**0.94**	**0.96**	**0.78**	**473**		
IWS	**0.89**	**0.97**	**0.76**	**433**		
Overall	**0.89**	**0.95**	**0.78**	**432**		

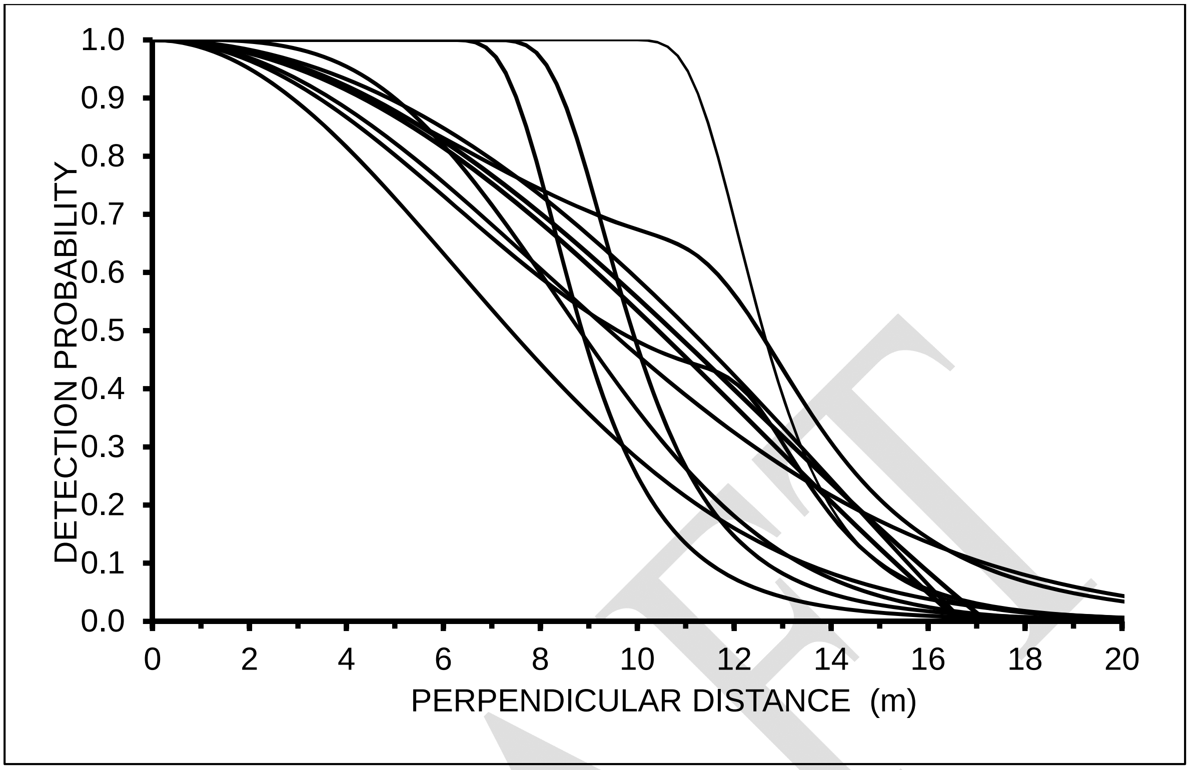

Figure 6. Detection curves for each of the 2011 GBI teams during training. Curves are based on 16 km trials with approximately 100 detections.

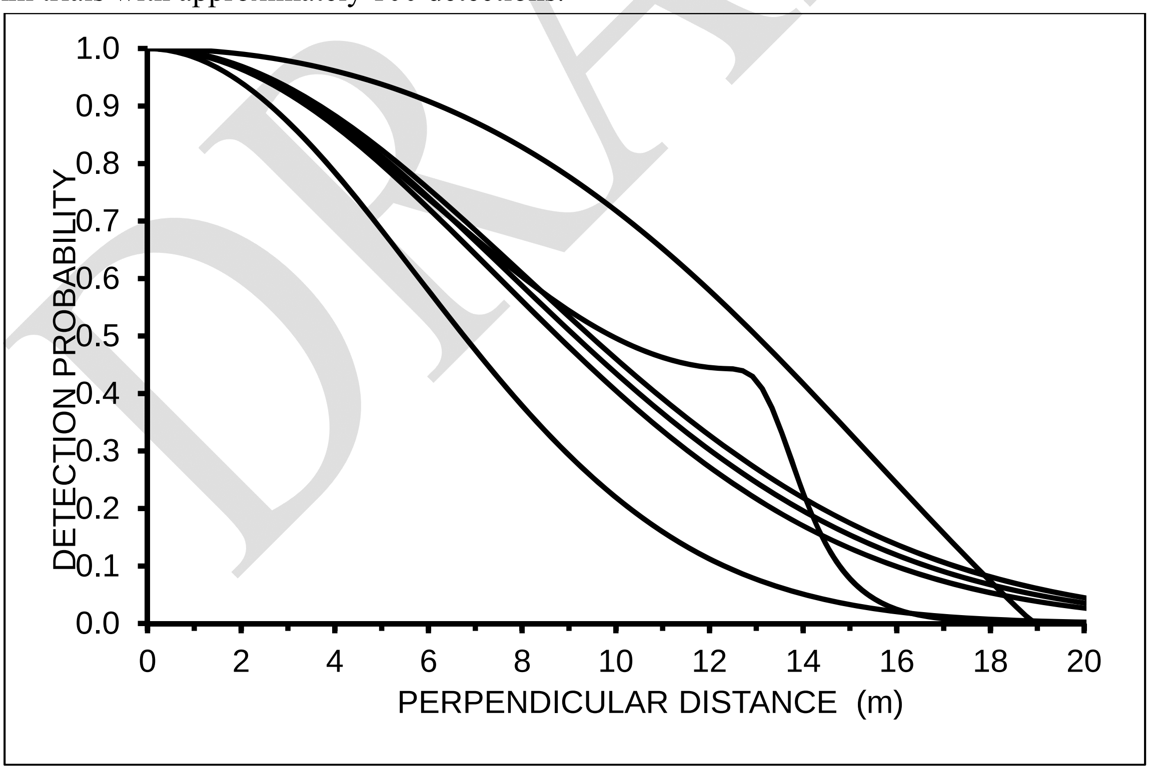

Figure 7. Detection curves for each of the 2011 IWS trainee teams. Curves are based on 16 km trials with approximately 100 detections.

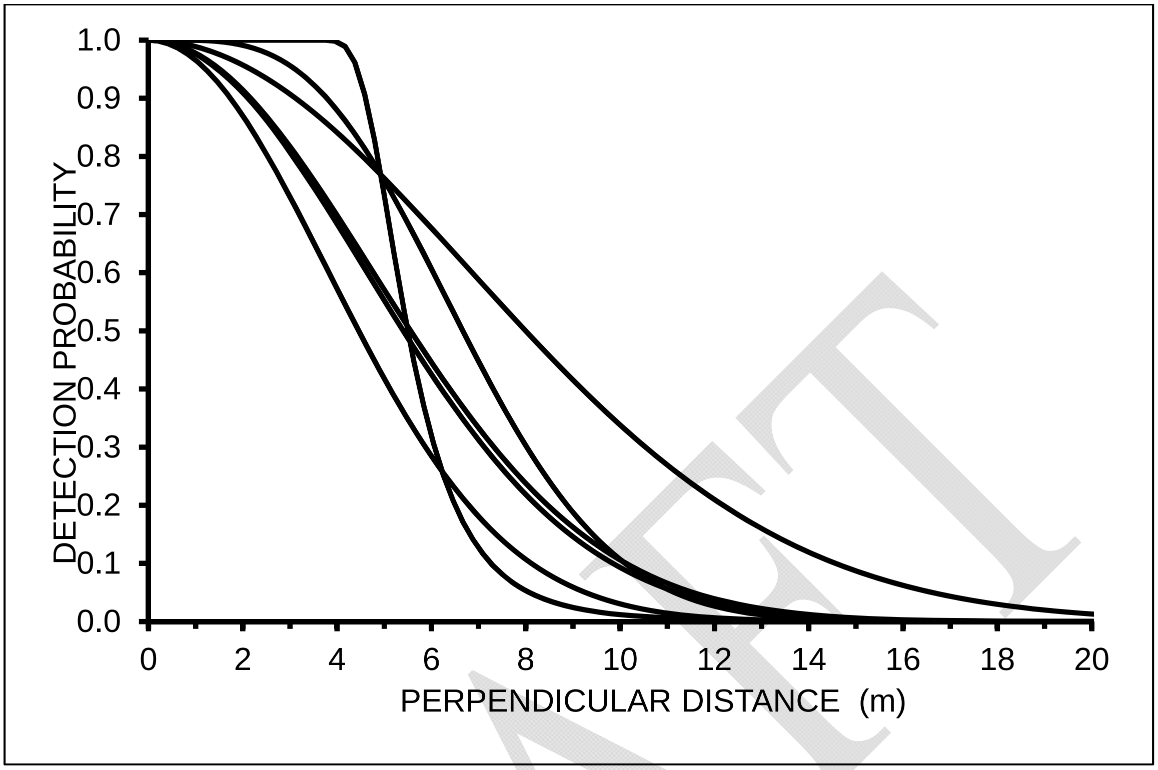

Figure 8. Detection curves for each of the 2011 Kiva trainee teams. Curves are based on 16 km trials with approximately 100 detections.

Quality assurance and quality control

There were 18,294 transect records and 5647 G0 records associated with the monitoring effort in 2011. After data specialists with the field teams had finished verifying and validating the information in these 2 databases, there were 673 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.) Relatively few (378) were errors created by the field crews (sometimes faulty equipment, other times data entry error), of which 128 could not be corrected with recourse to paper datasheets. Most of the uncorrected errors involved inability to retrieve time information when data are entered manually after-the-fact. Somewhat surprisingly, some of the new Trimble Juno units would unexpectedly run out of battery power, so there was more manual data entry and overall more equipment-related errors that anticipated, given the purchase this year of a new set of units. Another 115 errors were “processing” errors. Processing steps are associated with correcting other errors (perhaps the correct entry is mis-entered), 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. Some entries violate QA/QC rules but are extreme or explicable entries; there were 244 of these exceptions which require time to research and are one of the costs of QA/QC.

Transect completion

Table 4 reports the number of assigned and completed transects in each stratum. No transects were inadvertently completed twice by different crews. Kiva was assigned 160 transects and walked an additional transect. They consistently replaced any assigned but unwalkable transects with alternates in the same strata. All assigned transects were completed or replaced by IWS, although one unwalkable transect in the Eldorado Valley was replaced by an alternate in neighboring Piute Valley. The Great Basin Institute completed 380 transects, replacing any assigned but unwalkable transects with alternates in the same strata. Great Basin Institute used base-camping in route-less areas to provision crews with supplies, including water, to enable crews to complete 17 transects without returning over large or difficult distances to their vehicles.

Table 4 indicates the number of assigned transects that could be completed as standard square 12km transects or by reflecting around property boundaries and infrastructure (column 4). These transects represent flatter topography. An additional number (column 5) were completed as 6km squares (GBI) or shortened (IWS and Kiva), and represent more rugged terrain. Finally, some transects were considered unwalkable (column 6). Figures 9 through 12 show locations of transects and observations of live tortoises.

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

Stratum	Assigned transects	Assigned and alternate transects completed*	Assigned, completed 12k	Assigned, completed shortened	Assigned, judged unwalkable
BD	70	70	48	13	9
CK	25	26	13	7	5
CM	30	30	27	2	1
CS	90	90	60	17	13
EV	31	30	20	7	4
FE	15	15	14	1	0
FK	22	22	20	1	1
GB	100	100	52	22	26
IV	35	35	31	4	0
JT	15	15	6	5	4
MM	120	120	70	33	17
OR	15	15	9	3	3
PT	12	12	3	6	3
PV	20	21	13	5	2
SC	70	70	53	13	4
Total	670	671	439	139	92
GBI	380	380	230	85	65
IWS	131	131	105	19	7
Kiva	159	160	104	35	20

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

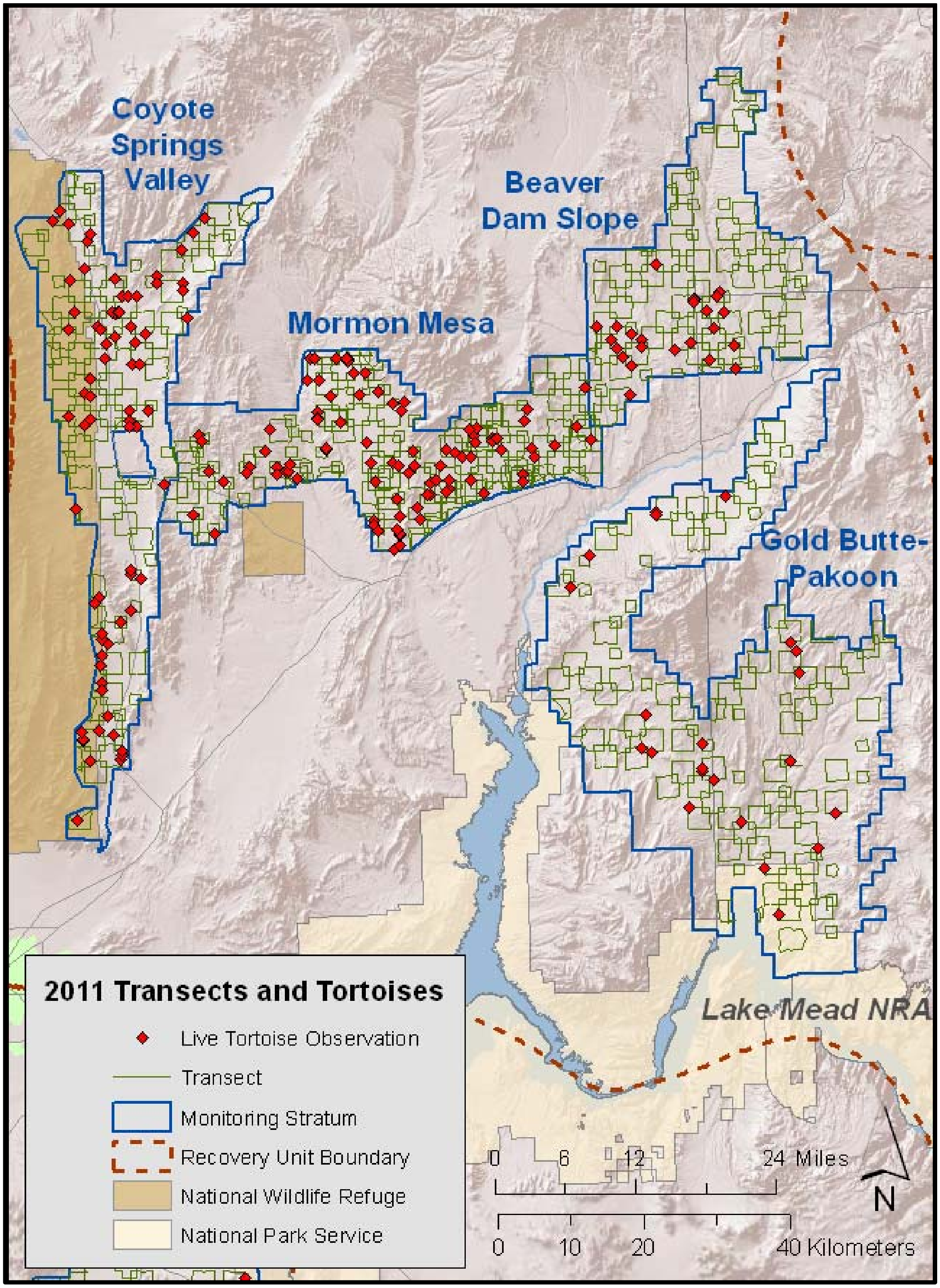

Figure 9. Distribution of distance sampling transects and live tortoise observations in the Northeastern Mojave Recovery Unit (Coyote Springs Valley, Mormon Mesa, Beaver Dam Slope, and Gold Butte-Pakoon monitoring strata).

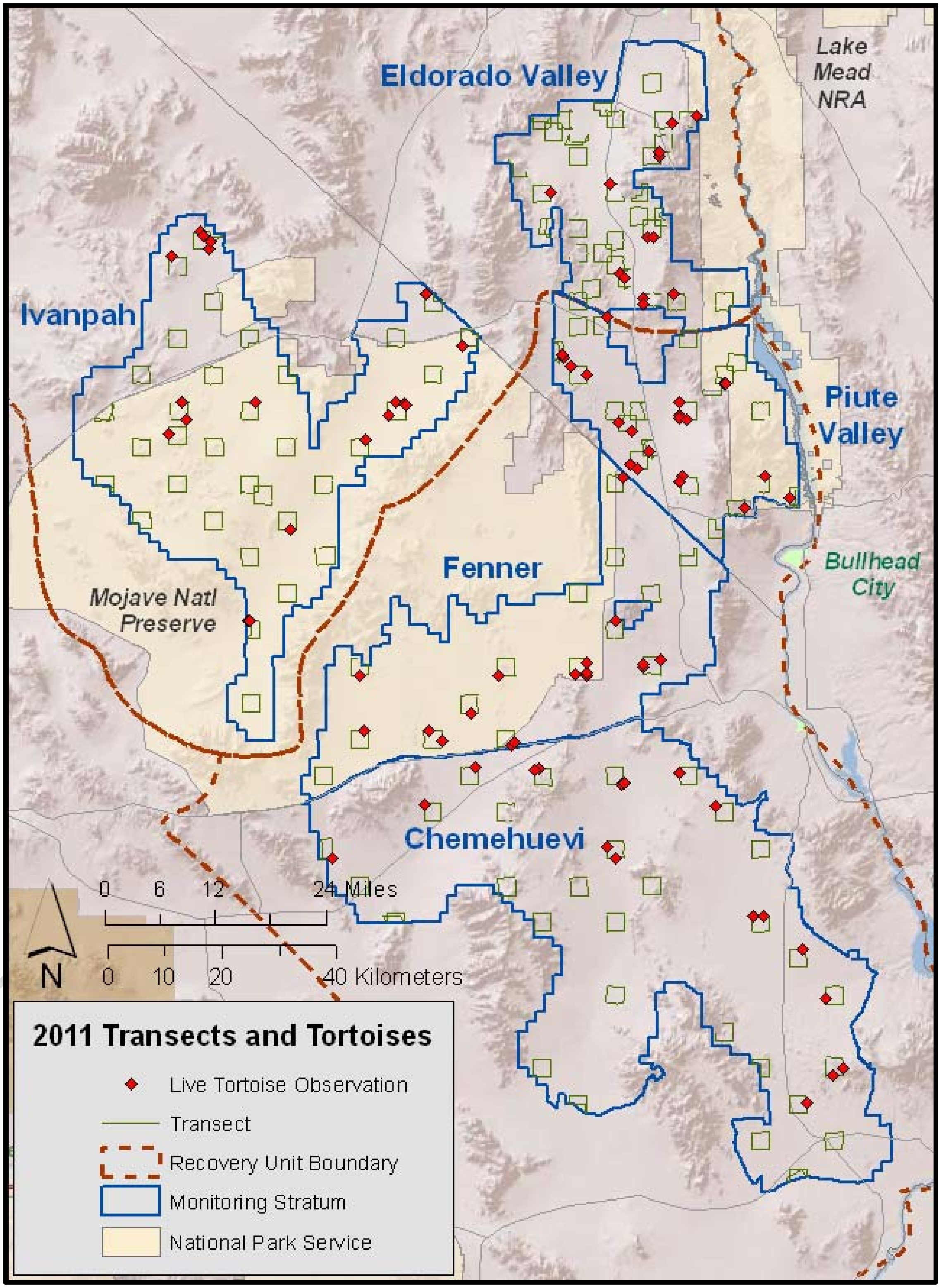

Figure 10. Distribution of distance sampling transects and live tortoise observations in the Eastern Mojave Recovery Unit (Eldorado Valley and Ivanpah monitoring strata) and the eastern part of the Colorado Desert Recovery Unit (Fenner, Piute Valley, and Chemehuevi monitoring strata).

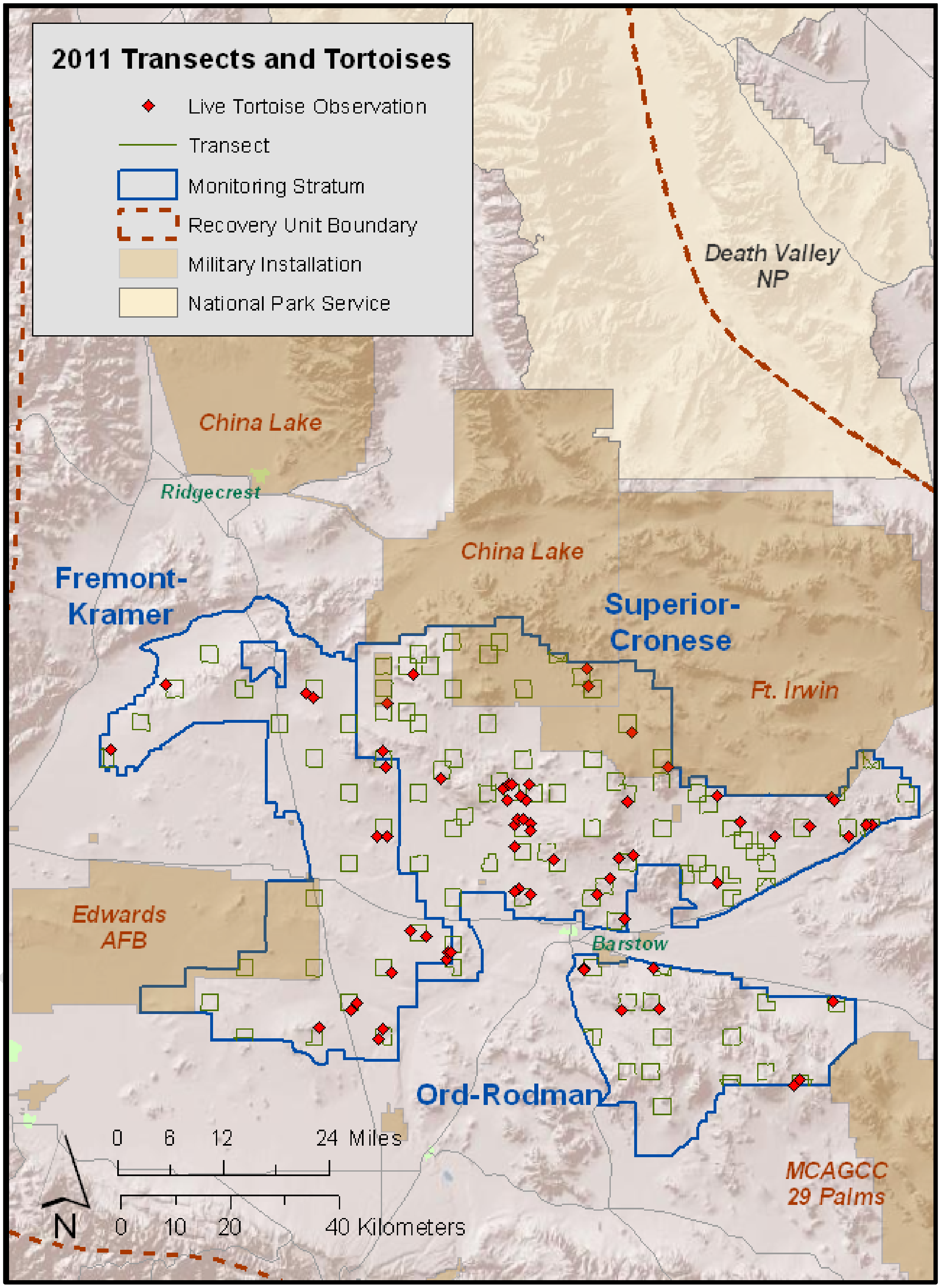

Figure 11. Distribution of distance sampling transects and live tortoise observations in the Western Mojave Recovery Unit (Fremont-Kramer, Superior-Cronese, and Ord-Rodman monitoring strata).

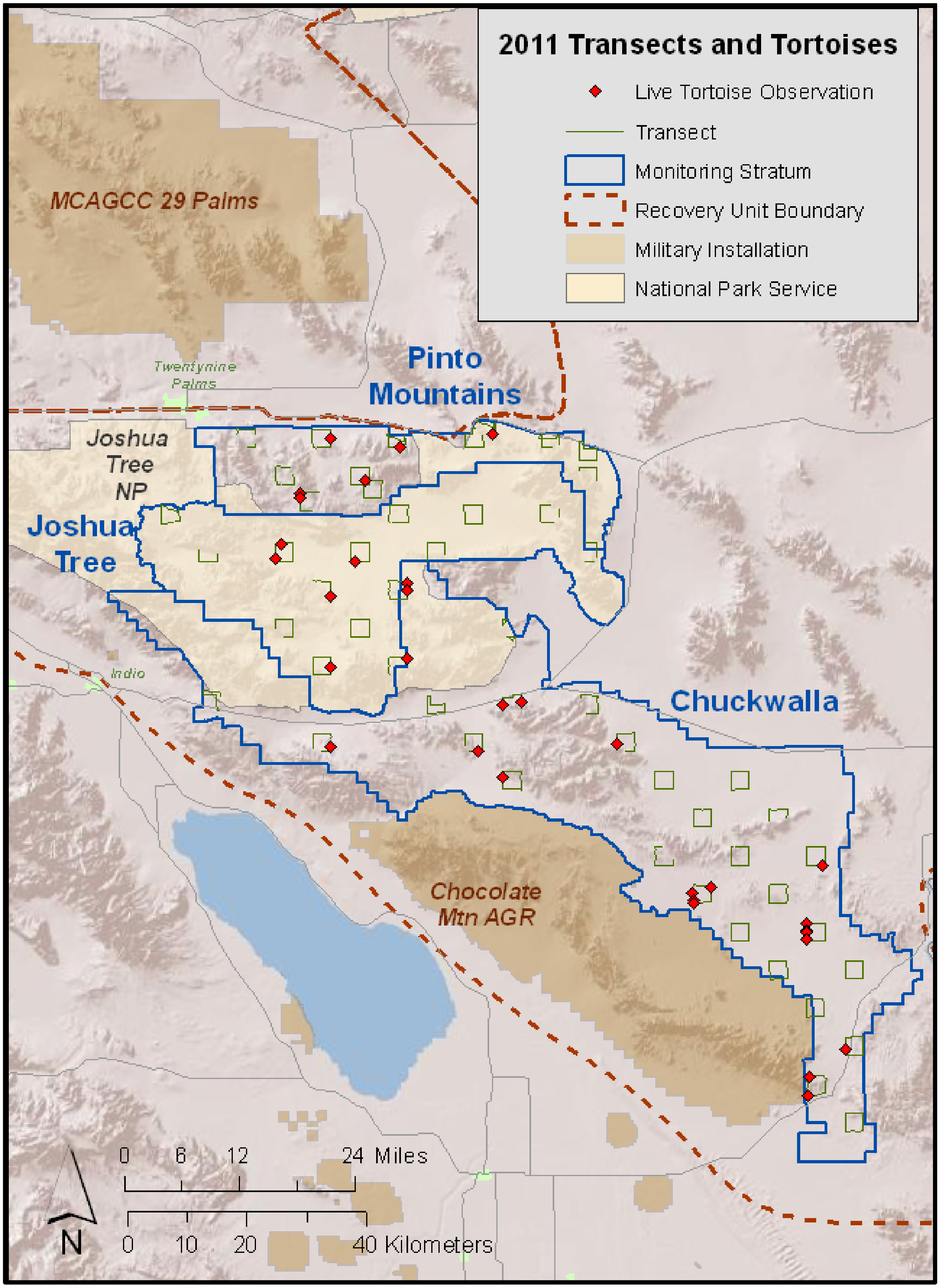

Figure 12. Distribution of distance sampling transects and live tortoise observations in the western portion of the Colorado Desert Recovery Unit (Pinto Mountains, Joshua Tree, and Chuckwalla monitoring strata). Chocolate Mountain AGR was not surveyed in 2011.

Tortoise encounter rates and detection functions

In 2011, all pairs worked together from the beginning to the end of the season. Each Kiva crew walked on average 27 transects and overall they detected 106 tortoises over 180 mm MCL; GBI crews walked a median of 35 transects and detected 180 tortoises; and IWS crews had considerably lower effort, with a median of 22 transects (days of work). However, each IWS observer subsequently walked 1-person distance transects in a separate study at the Large Scale Translocation Site near Jean, Nevada; altogether IWS personnel completed 30 days of work and the team observed 140 tortoises, and the LSTS encounters were used to model the overall IWS detection probability illustrated in Fig. 14. Even when crews have similar levels of effort, if there are sufficient observations to generate separate detection curves for each team, that is preferred to also account for differences in vegetation and other regional differences that may alter detection probabilities.

Figures 13 to 15 are histograms of the observed number of tortoises seen at increasing distance from the transect centerline. There is one histogram for each team (Kiva, IWS, and GBI). 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 (Buckland et al. 2001). Each figure indicates the customized truncation distance that was applied. 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. Truncation was conservative to maximize the number of observations per stratum.

Kiva crews reported an unusually high number of detections around 8 m from the centerline. The result was that some attempts to fit models were unsuccessful, especially with truncations inside 16 m. In part for this reason, but also to be conservative and keep truncation closer to 5% of observations, all observations were incorporated out to 16 m from the centerline. At this distance, the half-normal model with no adjustments performed best (Fig. 15).

For GBI, truncation at 20 m represented loss of about 5% of the observations and provided a curve fit that did not fit the tail of the curve at the expense of good fit near the centerline. Otherwise, it would have been necessary to truncate to 14 m to further simplify the model, and at the cost of a loss in precision and of 12 observations (2 each in CS and GB, 8 in MM). The 20 m truncation distance was used (Fig. 13), for which the hazard rate model with 2 parameter estimates but no adjustments fit the data best, and indicate a shoulder of about 2.5m – just about 10% of the width.

For IWS, the 5% truncation came in at about 20 m. At 10m truncation distance finally simplifies the model to one parameter for half normal, but at the cost of the most distance 26 observations. Using either 10- or 20-m truncation, models run separately for LSTS and the rest of IWS sum to a higher AIC (ΔAIC ~2) than that model with all IWS data together. This may result from the very low number of observations at LSTS. Combining all data, the hazard rate model performed better than half-normal or uniform models. The shoulder is very narrow, and in fact the best negative exponential model had an AIC only slightly larger than (indistinguishable from) that of the best hazard rate model.

The area below the curves in Figs. 13-15 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 42.9% of the visible tortoises within 20 m of the centerline (CV=0.102). The corresponding estimate of P_a for strata surveyed by IWS was 31.9% (CV=0.186) within 20 m, and for Kiva was 53.2% (CV=0.080) within 16 m.

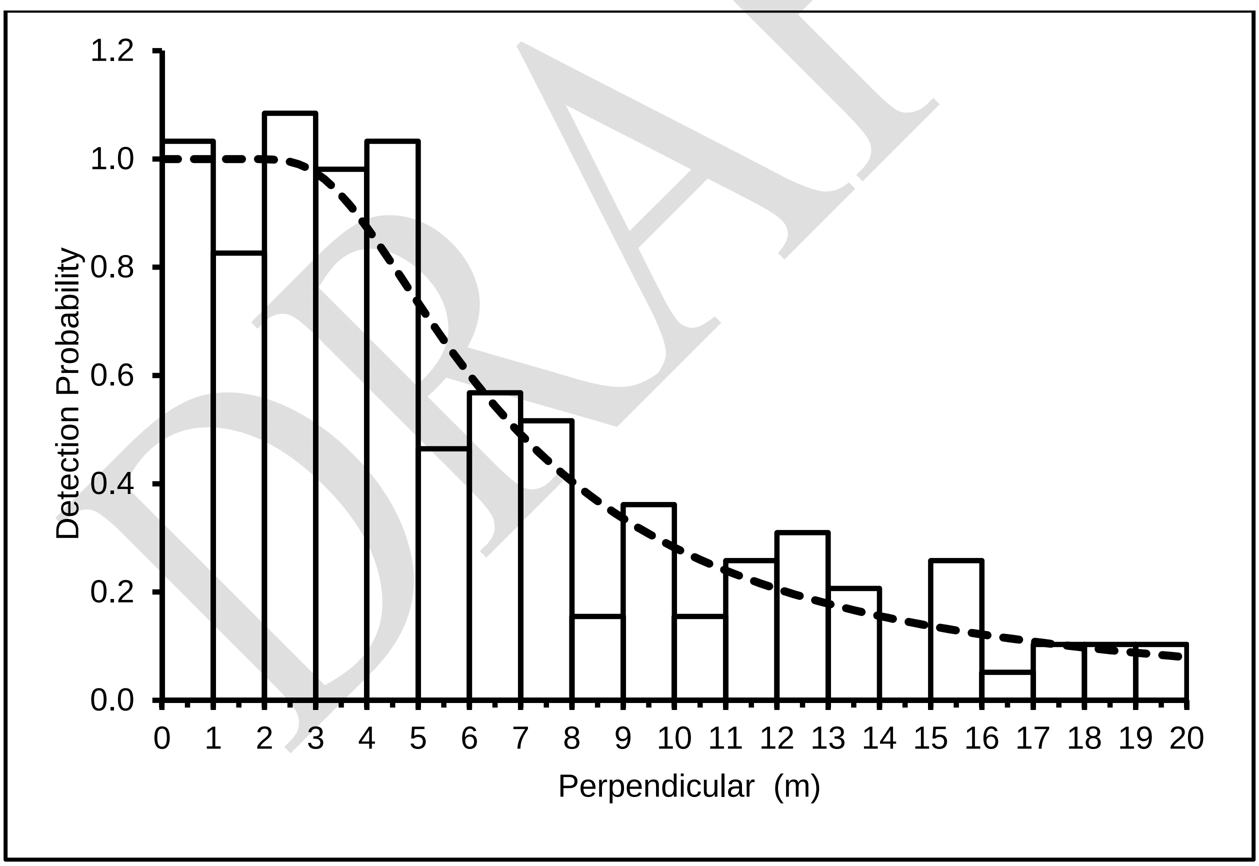

Figure 13. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by GBI. This curve uses only the 166 observations found within 20 m of the line.

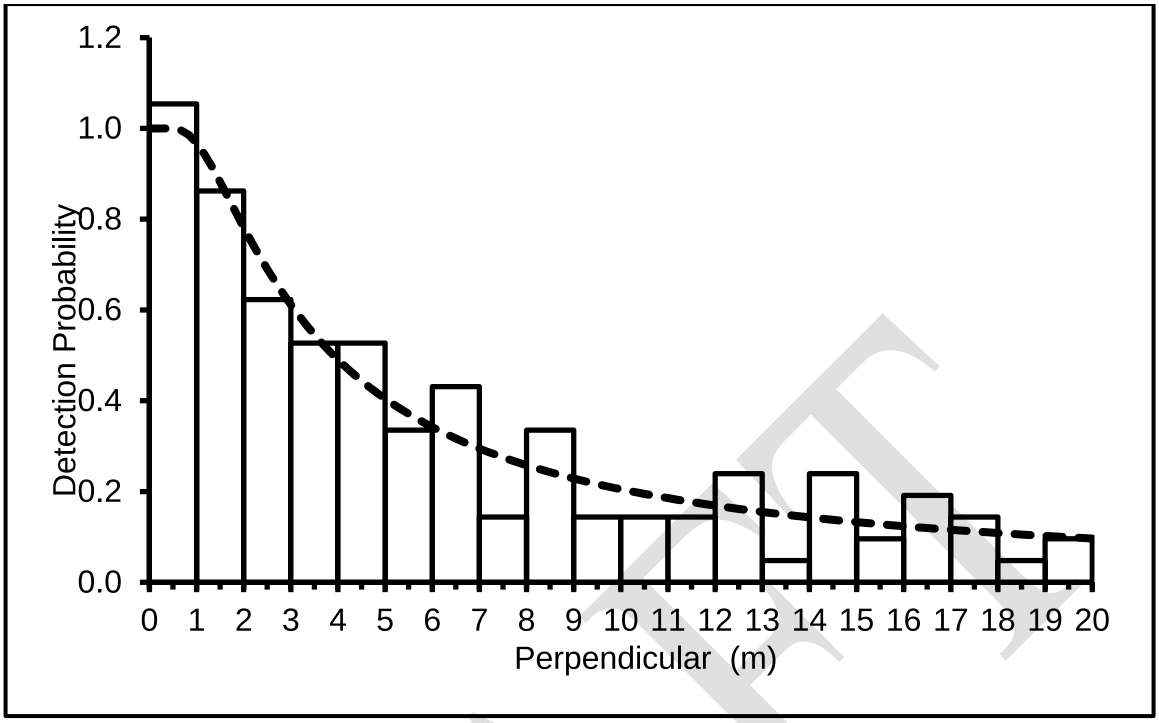

Figure 14. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180 mm found by IWS. This curve uses only the 133 observations found within 20 m of the line.

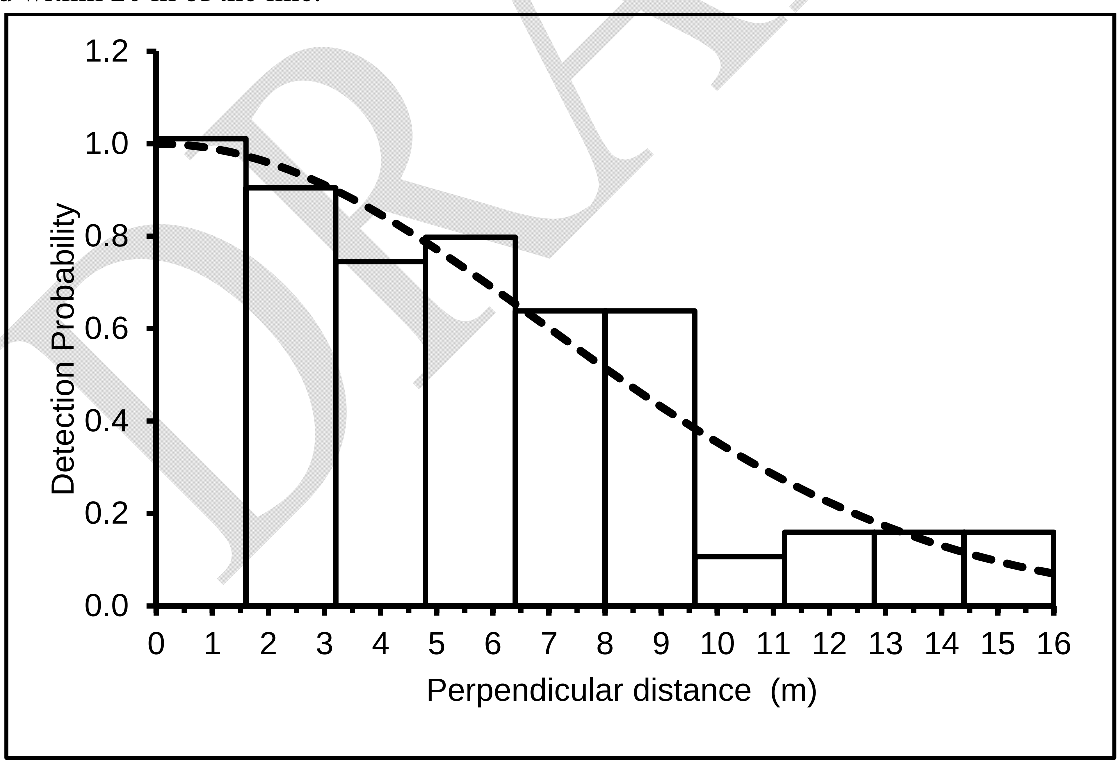

Figure 15. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by Kiva. This curve uses only the 100 observations found within 16 m of the line.

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

In general, telemetry sites and associated transects were completed sequentially, from south to north. This pattern corresponds to the expected timing of tortoise activity; peaking first in the south, later in the north. In 2011, to accommodate access dates on Chocolate Mountain, strata in the northern Western Mojave Recovery Unit were completed before those in the western portion of the Colorado Desert. Dates, total days monitored, and G_0 estimates are given in Table 5.

Strata in the western part of the range were apparently sampled during a very active period, reflected in high G_0 estimates. In the eastern part of the range, G_0 remained relatively lower, only increasing slightly in Coyote Springs Valley which was monitored later in the field season.

Table 5. Availability of tortoises (G_0) during the period in 2011 when transects were walked in each group of neighboring strata.

G_0 sites	Strata	Dates	Days	G_0 (Std Error)
Gold Butte	Gold Butte	6 Apr - 19-Apr	14	0.65 (0.155)
Halfway Wash	Beaver Dam Slope, Mormon Mesa	20 Apr – 12 May	23	0.55 (0.152)
Coyote Springs Valley	Coyote Springs	13May – 27 May	15	0.79 (0.093)
Piute/ Ivanpah/ Chemehuevi	Chemehuevi, Eldorado Valley, Fenner, Ivanpah, Piute Valley	30 Mar – 28 Apr	30	0.84 (0.152)
Joshua Tree/ Chuckwalla	Chocolate Mtn, Chuckwalla, Joshua Tree, Pinto Mtns	14 Apr – 22 Apr	9	0.90 (0.103)
Ord-Rodman/ Superior Cronese	Fremont-Kramer, Ord-Rodman, Superior Cronese	25 Mar – 11 Apr	18	0.95 (0.067)

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

Because they are cryptic, even tortoises that are visible (not covered by dense vegetation or out of sight in a burrow) may not be detected. For 41 detections of tortoises within 1 m of the transect centerline, 39 were found by the observer in the lead position and 2 by the follower, so that the probability of detection by single observer, $p = 0.949$, and the proportion detected using the dual observer method, $g(0 \text{ to } 1 \text{ m}) = 0.997$ (SE = 0.04). Figure 16 shows that $g(0)$ was converging on 1.0, indicating the assumption of perfect detection on the centerline was met; consequently, no adjustment was made to the final density estimate. The curves since dual observers were first used in 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 (USFWS 2009, 2012a, 2012b).

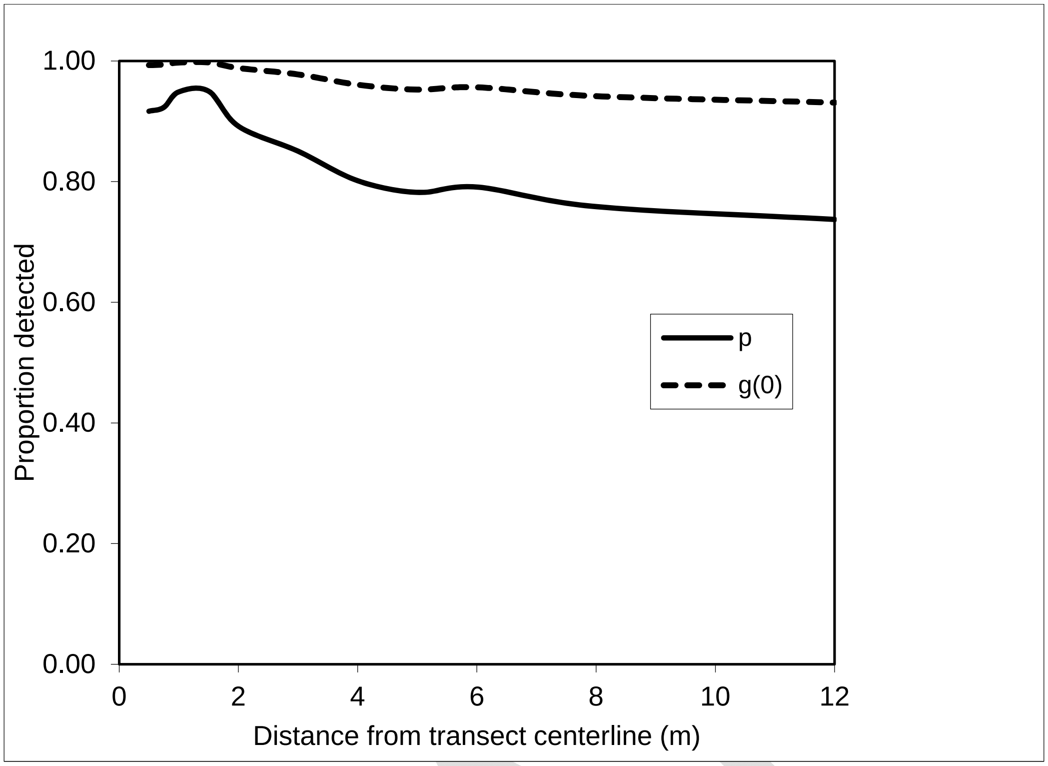

Figure 16. Detection pattern for the leader (*p*) and by the team (*g(0)*) based on all observations out to a given distance (*x*) from the centerline in 2011. Note convergence of *g(0)* on 1.0 as *x* goes to 0.

Estimates of tortoise density

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

When the annual estimates are imprecise, it should not be expected that there will be a close match from one year to the next. Over a period of many years, however, any underlying trend in the number of tortoises should be obvious through this "background noise." The CVs in 2011 represent an overall improvement in precision from previous years, a function of improved funding in this one year.

Table 6. Recovery unit and stratum-level encounters and densities in 2011 for tortoises with MCL ≥ 180mm.

Recovery Unit	Stratum		Area (km2)	Number of Transects	Total transect length (km)	Sampling Dates Begin	Sampling Dates End	Field Observers	*n* (tortoises observed)	CV(*n*)	Density (/km^2)	CV(Density)
Colorado Desert			**12776**	**119**	**1316**	**30-Mar**	**28-Apr**		**76**		**4.6**	**22.3**
	Chuckwalla	CK	3509	26	280	14-Apr	22-Apr	Kiva	17	31.6	3.9	34.60
	Chemehuevi	CM	4038	30	354	30-Mar	28-Apr	IWS	15	28.2	4.0	38.22
	Fenner	FE	1841	15	179	30-Mar	27-Apr	IWS	13	31.7	6.8	40.88
	Joshua Tree	JT	1567	15	147	14-Apr	22-Apr	Kiva	8	35.0	3.5	37.70
	Pinto Mountains	PT	751	12	118	14-Apr	22-Apr	Kiva	6	39.7	3.3	42.04
	Piute Valley	PV	1070	21	239	30-Mar	28-Apr	IWS	17	29.7	6.6	39.35
Eastern Mojave			**3720**	**65**	**746**	**30-Mar**	**28-Apr**		**30**		**4.0**	**34.8**
	Eldorado Valley	EV	1153	30	331	30-Mar	28-Apr	IWS	10	30.6	2.8	40.02
	Ivanpah	IV	2567	35	416	30-Mar	28-Apr	IWS	20	28.3	4.5	38.28
Northeastern Mojave			**4889**	**380**	**3984**	**6-Apr**	**27-May**		**164**		**3.4**	**21.3**
	Beaver Dam Slope	BD	828	70	751	20-Apr	10-May	GBI	23	22.8	3.3	37.24
	Coyote Springs Valley	CS	1117	90	967	13-May	27-May	GBI	52	15.7	4.0	22.11
	Gold Butte-Pakoon	GB	1977	100	1039	6-Apr	20-Apr	GBI	18	26.4	1.6	37.04
	Mormon Mesa	MM	968	120	1227	20-Apr	13-May	GBI	73	15.4	6.3	33.21
Western Mojave			**6873**	**107**	**1257**	**25-Mar**	**11-Apr**		**69**		**3.4**	**19.1**
	Fremont-Kramer	FK	2417	22	264	25-Mar	9-Apr	Kiva	15	29.6	3.5	31.46
	Ord-Rodman	OR	1124	15	174	27-Mar	10-Apr	Kiva	9	35.1	3.2	36.70
	Superior-Cronese	SC	3332	70	820	25-Mar	11-Apr	Kiva	45	20.7	3.4	23.30

Table 7. Estimated density of desert tortoises in monitored areas of each recovery unit in the Mojave and Colorado deserts in 2011.

Recovery Unit	Sampled area (km^2)	Kilometers walked	Tortoises detected	Density ($/km^2$)	Lower limit 95% CI (Density)	Upper limit 95% CI (Density)	%CV (Density)
Colorado Desert[a]	12776	1316	76	4.6	2.96	7.02	22.3
Eastern Mojave	3720	746	30	4.0	2.06	7.77	34.8
Northeastern Mojave	4889	3984	164	3.4	2.25	5.12	21.3
Western Mojave	6873	1257	69	3.4	2.36	4.96	19.1
Upper Virgin River[b]	114	310	113	18.2	14.3	23.1	12.2

[a] This density estimate applies to all areas except Chocolate Mountain, which was not surveyed in 2011.
[b] Data for Upper Virgin River from McLuckie et al. (2012)

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

Evaluating transect classification

In 2011, 73 of the 790 walked transects were not completed as predicted. Table 8 summarizes conclusions after examining these transects. Forty-five were reclassified based on crew experience. In some cases, this reflects discrepancy between interpretation of terrain from imagery; in many others, classification is ambiguous because over the course of a 12 km transect, terrain is so variable to that it was not a simple matter to evaluate the ability of a typical crew to complete it. The remaining 28 anomalous transects were not reclassified, because earlier experience indicated that most crews would use the original completion strategy. Anomalous completions represented 9.2 % of all transects in 2011. The 45 transects that were also reclassified represent only 1.8% of the 2464 transects evaluated since 2008, so this had very little impact on our estimate of the proportion of each stratum that is walkable.

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

Previous substratum	Situation	New substratum	Number of transects
12k	On-the-ground observation differs from imagery	Shortened	13
12k	Shortened in 2011, contradicting previous experience	12k	12
Shortened	On-the-ground observation differs from imagery	12k	22
Unwalkable	On-the-ground observation differs from imagery	12k	3
Unwalkable	On-the-ground observation differs from imagery	Shortened	4
Shortened	Lengthened in 2011, but other crews would shorten	Shortened	14
Unwalkable	Shortened in 2011, but other crews could not walk	Unwalkable	2
12k	Crew attempted the transect but couldn’t walk at least 6km	Unwalkable	1
Unwalkable	2010 shortening rules allowed at least 6 km completed, but earlier rules would have classified these as unwalkable	Shortened	2

Proportion of each stratum walked

The proportion of each stratum represented by distance sampling is calculated as the proportion of planned kilometers that can be walked (Column 3 in Table 9). This proportion is calculated based on all transects evaluated since 2008. Table 9 reports the area of each stratum, the proportion covered by our density estimates, and the associated estimate of tortoise abundance.

Table 9. Estimated tortoise abundance in sampled areas of each stratum

Stratum	Area (km^2)	Proportion sampled	SE(Prop. Sampled)	Sampled area	N (number of tortoises)	95% Confidence Interval	
						Lower Limit	Upper Limit
BD	828	0.89	0.032	738	2407	1184.3	4893.8
CK	3509	0.82	0.030	2890	11415	5885.3	22139.5
CM	4038	0.93	0.023	3755	14848	7190.2	30662.2
CS	1117	0.86	0.031	958	3807	2467.1	5873.4
EV	1153	0.87	0.030	999	2816	1319.3	6009.5
FE	1841	0.96	0.020	1770	12005	5551.0	25961.3
FK	2417	0.96	0.017	2328	8197	4484.9	14982.3
GB	1977	0.81	0.027	1604	2513	1241.3	5087.6
IV	2567	0.95	0.021	2442	10954	5300.2	22638.5
JT	1567	0.74	0.033	1159	4096	1995.2	8408.7
MM	968	0.86	0.034	836	5295	2797.2	10022.0
OR	1124	0.73	0.040	821	2631	1301.4	5319.6
PT	751	0.69	0.051	522	1728	775.1	3853.3
PV	1070	0.87	0.031	927	6152	2916.2	12977.8
SC	3332	0.95	0.015	3149	10705	6813.6	16818.3
Total	28258	0.881		24897	99568	69324.1	143007.1

Debriefing to identify strengths and weaknesses in preparation for future years

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

More centralization of information and discussions

We will move from use of ftp to Sharepoint. In addition to continuing use of a centralized site to share files, this will allow discussions to be captured on discussion boards rather than in separate email chains.

Training improvements to make more effective use of same time period

Part of the emphasis should be on integration of telemetry training with the schedule for training transect crews. For transect walkers and telemetry crews we should have one-page bulleted protocols for the daily routine and for methodically collecting all data on each live tortoise. For telemetry, existence of a step-by-step protocol will allow more targeted training and evaluation. This will also have the effect of shifting training emphasis from telemetry skills to protocol standardization. The training should also provide more opportunities to handle tortoises in the field on transects before the field season. Upfront coordination on training materials should ensure consistent themes and remove contradictions between trainers.

Use the off-season to test hardware to develop protocols to improve reliability
The new Trimble Juno units were more reliable that the units they replaced this year; however, battery life was highly variable and GPS grabs consistently timed out on certain units.

DISCUSSION

Sampling representatively in all monitoring strata

Since 2007, transects have been placed systematically in monitoring strata; the placement scheme itself had a random origin so that transects were located at random with respect to tortoises. The goal of systematic placement is to provide better coverage of sampled areas, yet the random aspect of this design also allows inference about the entire sampled area. Because the same set of potential transect locations will be used to sample from in future years, it is meaningful to collect information describing access and completion of each transect so that this information is available when planning to walk this transect location in future years. The current sampling design allows us to 1) estimate the actual area to which our density estimates apply; some areas are too rugged for humans to access, and therefore 2) also apply the density estimate to this sampled area to arrive at an abundance estimate in each monitoring stratum.

As various cooperating agencies move forward with recovery actions for the desert tortoise and/or the desert habitat in their jurisdiction, road closures are becoming more common and by restricting access are expected to increasingly affect our ability to sample representatively. In Mormon Mesa and Coyote Springs Valley, 17 less-accessible transects were completed using base-camping by which transect crews are supplied at a central location with food and water so that return to vehicles between transects is not necessary. It is anticipated that this approach to transect access will be required as Grand Canyon-Parashant National Monument moves forward with current road planning. In other areas, access has been blocked when private landowners gate roads through their properties; large areas of Mormon Mesa have been impacted by this.

Planning improvements

In addition to transect and telemetry data collection, each field group uses a separate database to report information about their ability to complete transects as planned and in the random order specified. The transect tracking database was integrated with GIS information this year, and both were provided centrally rather than having each field group generate their own transect layers. Topoworks created versions of the transect paths that were reflected for stratum boundaries and divided highways; this information could be further modified by mapmakers for each field team.

Quality control and quality assurance

In addition to purchase of new electronic data collection devices (reducing equipment-related errors), feedback to crews and to data specialists was much more extensive during training in 2011. This included an emphasis on review of paper datasheets, standardization of rules for modifying records and documenting these changes, and use of final data managers to train crews involved in data collection. When project rely on large numbers of relatively independent data collection crews, this sort of standardization reduces identifiable and unidentifiable errors in the final database. Although databases in 2010 were more error-free than previous years, the 2011 databases improved yet again, with a marked decrease in the number of errors passed through from the field teams to independent reviewers.

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, 2011). The priority for this and every field season is therefore to improve ability to detect trends in desert tortoise abundance at the recovery unit level.

Consequences of sufficient transects

Associated with the relatively low estimates of tortoise visibility (G_0) in the eastern part of the range, encounter rates were lower than in 2010, but adequate funding allowed for sufficient transects to nonetheless detect several tortoises per stratum. In 3 of the 15 surveyed strata, fewer than 10 tortoises were detected; this is a rough lower limit for the number of observations to develop an adequate density estimate (Buckland et al. 2001). In this case, none of the stratum estimates are meant to stand on their own, and will either be used in combination with other stratum estimates in the same recovery unit (in annual reports such as this one) or with other years of estimates from the same stratum to describe trends. Although Anderson and Burnham (1996) targeted CVs between 10 and 15% in each recovery unit, this would be unusually high precision for such an estimate of wildlife abundance. In 2011, 3 recovery units had CVs between 19 and 23% of the density estimate – satisfactory for an annual estimate. The Eastern Mojave Recovery Unit had a density estimate of lower precision (34.8 %), a reminder that lower funding amounts and unseasonable conditions can act separately to undermine our coordinated efforts for range-wide density estimates.

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