RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE (*GOPHERUS AGASSIZII*): 2017 ANNUAL REPORTING

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Acknowledgements

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The original design for this project and considerations for optimizing it based on new information and experience were first set out in Anderson and Burnham (1996) and Anderson et al. (2001). Estimation methods were further refined during a 2008 workshop for distance sampling held by S. Buckland, L. Thomas, T. Marques, E. Rexstad, and D. Harris in Marshall, California.

Personnel from Kiva Biological Consulting (California) led by L. Mjos and C. Stirling, and from the Great Basin Institute (Nevada, the Beaver Dam Slope of Utah and Arizona, and Gold Butte in Arizona) led by T. Christopher conducted the field surveys. The field monitors from these teams who did the hard work of collecting and verifying the data were:

R. Adhar, J. Bain, M. Bassett, C. Barker, K. Black, B. Blosser, C. Boulden, M. Burke, G. Carlile, T. Chizinski, S. Clegg, T. Corwin, R. Crawford, J. Deane, T. Dee, I. Diaz , A. Drummer, A. d'Epremesnil, D. Essary, K. Forgrave, B. Guttung, J. Fowler, C. Shirley, C. Hackbarth, K. Hayes, J. Hunt, A. Jones, C. Lehnen, J. Macnaughton, A. Marciano, C. Michaud, L. Mjos, J. Moines, M. Mokaysh, C. Nagle, S. Nelson, A. Robinson, B. Sandstrom, B. Scavone, D. Schneider, A. Spenceley, C. Stirling, S. Trageser, M. Whitmer, A. Wiley, C. Wilhite, A. Wiscovitch, A. Zaidemen.

B. Sparks (GBI) provided specialized training instruction for field crews. R. Patil (GBI) updated the electronic data-collection forms and procedures. D. Fernbach (GBI) ran first-level quality assurance/quality control of data submitted by both field groups. M. Brenneman (Topoworks) provided independent review and post-processing of data, developed GIS tools for correctly reflecting transect paths, developed GIS tools for generating field maps, and developed the final databases.

EXECUTIVE SUMMARY

The recovery program for Mojave desert tortoises (*Gopherus agassizii*) throughout their range 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) for estimating range-wide desert tortoise density. From 2001 to 2005 and 2007 to 2017, the USFWS has coordinated the distance sampling monitoring program for desert tortoises in 4 of the 5 recovery units. (The Upper Virgin River Recovery Unit is monitored by Utah Division of Wildlife Resources (UDWR; McLuckie et al., 2016).)

This report describes quality assurance steps and final results for the 2017 monitoring effort. During the first years of the project, survey effort was directed annually at all 16 long-term monitoring strata. After agency funding was severely curtailed in 2012, the decision was made to survey only in well-funded strata to generate robust estimates rather than attempting to cover more strata in a less satisfactory manner, and this approach continued as funding has steadily increased again through 2017, when crews completed 694 transects (7420.1 km) between 9 March and 12 May. In the course of these surveys, they reported 468 live tortoises, 403 of which were at least 180 mm midline carapace length (MCL) and used to generate density estimates.

In 2017, the two strata in the Northeastern Mojave had very low density estimates (1.3 tortoises/km^2 in Beaver Dam Slope and 1.9 tortoises/km^2 in Gold Butte-Pakoon). The highest estimated density was in the Colorado Desert in Chocolate Mountains Aerial Gunnery Range (9.4 tortoises/km^2), where densities were over four times higher in the northern part of critical habitat than in the southern part. The encounter rate averaged 18.4 km for each adult tortoise that was observed.

RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE 2017

INTRODUCTION

The Mojave Desert population of the desert tortoise 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 *Gopherus 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 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), as determined through a rigorous program of long-term monitoring. This report describes implementation of monitoring and presents the analysis of desert tortoise density in 2017. A more thorough description of the background of the monitoring program, as well as estimation of population trends using data through 2014, is provided in USFWS (2015). Trends will be reevaluated after the 2019 season.

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 where tortoise recovery will be evaluated. These areas are called “tortoise conservation areas” (TCAs) in the recovery plan to describe designated critical habitat as well as contiguous areas with potential tortoise habitat and compatible management. The area associated with each critical habitat unit (CHU) is generally 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). New recovery units were established under the revised recovery plan (USFWS, 2011), so while making the corresponding changes to our databases we also separated the Piute and Eldorado Valleys into 2 distinct strata which are in different recovery units. Fenner Valley is in the same recovery unit but is a distinct stratum from Piute Valley to simplify reporting by state. 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.

In 2017, surveys were conducted in California in AG, CK, FK, JT, OR, PT, and SC strata; and in BD, EV, GB, and PV in Nevada, Arizona, and Utah. 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 stratum (Anderson and Burnham, 1996; Buckland et al., 2001). 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).

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 density 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. The target CV is achieved based on the number of tortoises that might be encountered there (some strata have higher densities than others). Operationally for this species, this typically entails surveying sufficient kilometers to encounter approximately 30 tortoises in each stratum.

The actual number of transects assigned in each stratum was a function of the optimal numbers described above, as well as on available funding. Transects were selected from among a set of potential transects laid out systematically across strata, with a random origin that was established in 2007 for the lattice of transects. Systematic placement provides more even coverage of the entire stratum, something that may not occur when strictly random placement of transects is used. Once the number of transects to survey in each stratum was determined, these were selected using randomization procedures; since 2013 R software has been used to implement the Generalized Random Tesselated Stratified (GRTS) spatially balanced survey design procedure (R Core Team, 2015; Kincaid and Olsen, 2016). The US Environmental Protection Agency developed GRTS as a means to generate a spatially balanced, random sample (Stevens and Olsen, 2004). Each year GRTS was used to select planned transects with these qualities and to select a set of alternative transects that would contribute to the final sample having the same spatially representative and random properties if any planned transects were replaced due to field logistics. Because the same set of potential transects has been used since 2007, some transects are repeated between years but others may not have been selected in the past.

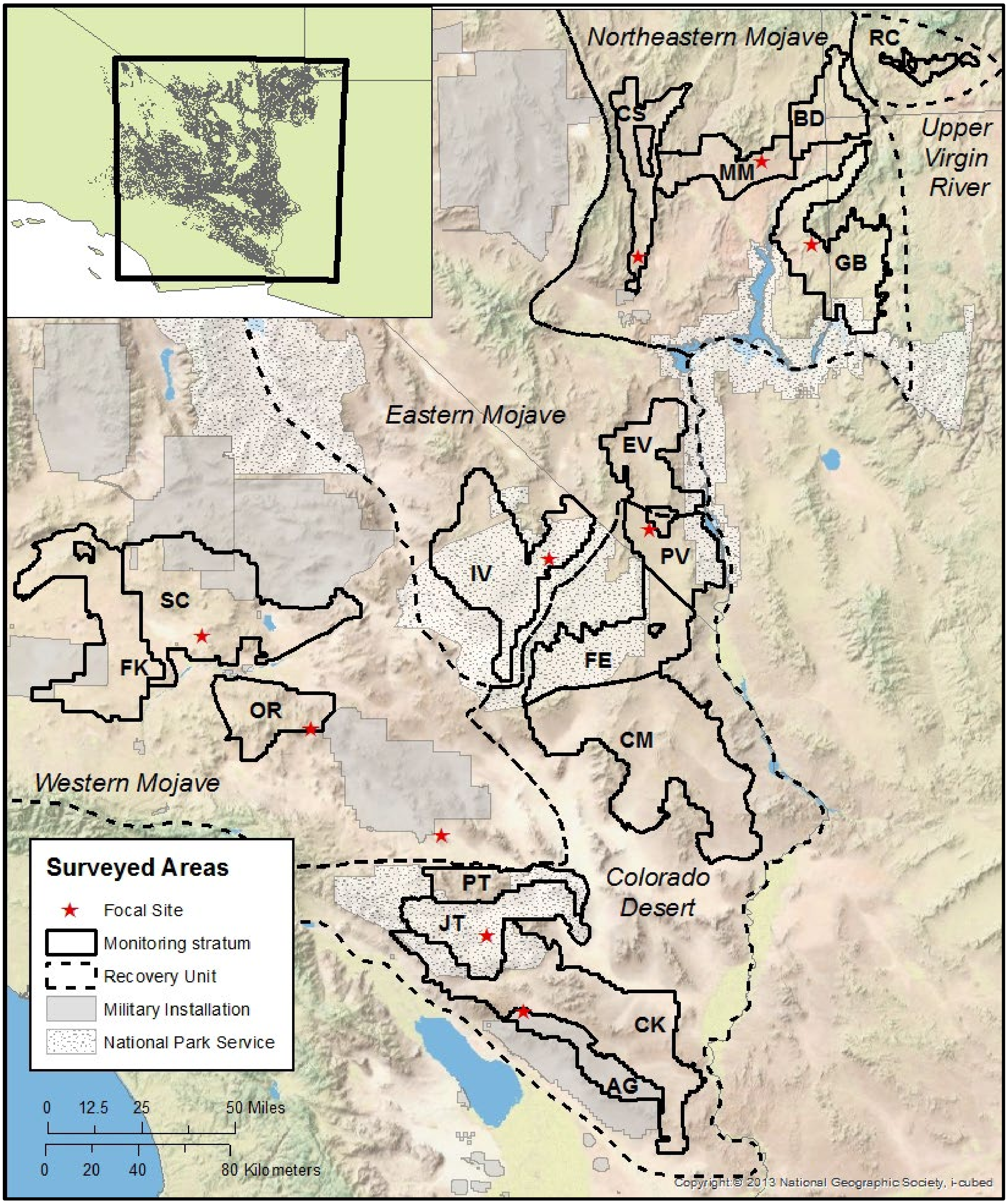

Figure 1. Long-term monitoring strata (n=17) corresponding to tortoise conservation areas (USFWS, 2011) in each recovery unit.
Stratum abbreviations are given in Table 6. Potential habitat (Nussear et al., 2009) is overlain on the southwestern United States in the extent indicator.

Distance sampling 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 8am during March (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 completed transects during this optimal period each day. Start times were decided a week in advance, so crews arrived at transects at similar times on a given morning. However, completion times will be more variable, as a consequence of terrain, number of tortoises encountered, etc. Under normal conditions, each team walked one 12-km square transect each day. Teams were comprised of two 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 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 approximate 500 m intervals (waypoints) along the transect and/or whenever the transect bearing changed. Leader and follower each 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, 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, it was handled enough to measure midline carapace length (MCL), to determine its sex, assess its body condition (USFWS, 2012c), 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 at least 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 transects to avoid obstacles associated with human infrastructure or jurisdictions (large roads, private inholdings, administrative boundaries, etc.), or 2) shortening transects in rugged terrain (USFWS, 2012a). 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.

If it was anticipated that fewer than 6 km could be walked due to difficult terrain, the transect was replaced with a transect from the alternate list that were also selected using the GRTS procedure. It was assumed that the proportion of the area that was unwalkable was the same as the proportion of total planned kilometers (12 X number of planned transects) that were unwalkable. Specifics of how transect paths were to be modified for rugged terrain (shortened) or for administrative boundaries (reflected) can be found online in the current version of the handbook (USFWS, 2017b).

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

Basing 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 was incorporated in estimate of adult tortoise density to correct this bias.

We used telemetry to locate radio-equipped tortoises that were visible as well as those that were otherwise undetectable in deep burrows or well-hidden in dense vegetation. To quantify the proportion that were available for detection (visible), telemetry technicians used a VHF radio receiver and directional antenna to locate 7-14 radio-equipped G_0 tortoises in each of 6 focal 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. 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.

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 on a training course with tortoise models in measured locations. Chapters of the monitoring handbook are updated as needed and posted to the Desert Tortoise Recovery Office website (http://www.fws.gov/nevada/desert_tortoise/reports).

Kiva Biological (Kiva) supplied crews for monitoring in California strata. Great Basin Institute (GBI) supplied crews for monitoring in strata in Nevada, Arizona, and Utah. Thirteen of 24 personnel for Kiva had previous transect experience with this monitoring program. Only five of 20 surveyors for GBI had prior experience in this program. The two teams were trained separately by the same USFWS instructor for consistency. To accommodate logistics on Chocolate Mountain Aerial Gunnery Range, California surveys started approximately one month earlier than those in Nevada, so it was not practical to overlap the training schedules (Table 1).

Telemetry training

The primary goals of G_0 training include 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, skills training, field demonstrations, and practice transects to complete (Table 1). Ultimately each team was evaluated based on performance on a field arena outfitted with polystyrene tortoise models placed in measured locations (Anderson et al., 2001), as well as on performance meeting protocol requirements on full-day staged transects.

Polystyrene desert tortoise models were set out on the training course each year using placement instructions (vegetation or open placement, tape-measured distance along training line, and tape-measured 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 detected 80% of all tortoises that are found, the assumption was that the follower detected 80% of the tortoises that were missed by the leader. In this example, the pair together would detect 0.80 + (0.80 X (1 – 0.80)) = 0.96 of all tortoises on the centerline. 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 range-wide field surveys began.

Table 1. Training schedule for 2017 for a) Kiva transect crew, b) GBI transect crews, and c) GBI telemetry trainees.

1a. Training schedule for 2017 for Kiva transect crews

Date	Activity	Location	Instructors
Friday, 3 March	Transect methods overview	GBI Field Station	Allison
	Tortoise handling	GBI Field Station	Mjos
	Compass work	GBI Field Station	Mjos
	Introduction to Nexus phones for training lines	GBI Field Station	Allison
4 March	Training Lines I (8km)	BLM Desert Tortoise Mgmt Area (DTMA)	Allison
	Phones – Transect database	GBI Field Station	Allison
5 March	Full transects (12km)	Large Scale Translocation Study Area (LSTS)	Allison
	Review training line I results	GBI Field Station	Allison / Fernbach
6 March	Training Lines II (8km)	BLM DTMA	Allison
	Wrap up discussion	GBI Field Station	Allison
7 March	Training Lines II (8km)	BLM DTMA	Allison

Table 1b. Training schedule for GBI transect crews.

Date	Activity	Location	Instructors
Friday, 17 March	Transect methods overview	GBI Field Station	Allison
	Compass work	GBI Field Station	Christopher
	Intro to Nexus phones for training lines	GBI Field Station	Allison
20 March	Training Lines I (8km)	BLM DTMA	Allison
21 March	Tortoise handling	GBI Field Station	Dr. Johnson
	Review training line I results	GBI Field Station	Allison / Fernbach
22 March	Training Lines II (16km)	BLM DTMA	Christopher
23 March	Training Lines II (continued)	BLM DTMA	Christopher
27 March	Search image for tortoises	River Mtns, NV	Christopher/Sparks
	Phones – Transect database	GBI Field Station	Allison
28 March	Tortoise Handling	GBI Field Station	Christopher
	Training line results – Trial II	GBI Field Station	Allison
29 March	Full transects (12km) interrupted for terrain	LSTS	Allison
30 March	Tortoise Handling	GBI Field Station	Allison
	Review LSTS transects	GBI Field Station	Allison
	Wrap up discussion	GBI Field Station	Allison
31 March	Full transects (12km) reflected for highway	LSTS	Christopher

Table 2c. Training schedule for GBI telemetry technicians.

Date	Activity	Location	Instructors
Tuesday, 7 March	Introduction to distance sampling	GBI Field Station	Allison
	Visibility descriptions	GBI Field Station	Allison
8 March	Introduction to tortoise telemetry	Boulder City Conservation Easement (BCCE)	Sparks
9 March	Telemetry practice	BCCE	Sparks
16 March	Telemetry practice	BCCE	Sparks
17 March	Transect methods overview	GBI Field Station	Allison
20 March	Telemetry practice	BCCE	Sparks
21 March	Tortoise handling	GBI Field Station	Dr. Johnson
23 March	Telemetry practice	Halfway Wash focal site	Sparks
27 March	Search image for tortoises	River Mountains, Nevada	Christopher/Sparks
28 March	Tortoise Handling	GBI Field Station	Christopher
29 March	Telemetry practice	Piute-Mid focal site	Sparks
30 March	Tortoise Handling	GBI Field Station	Allison
31 March	Telemetry practice	Piute-Mid focal site	Sparks

Data management, quality assurance, and quality control
Two sets of data tables were maintained through the field season, organizing data collected on transects and at the G_0 focal sites. Collection data forms, paper datasheets, and databases were designed to minimize data entry errors and facilitate data verification and validation. Data were collected in both electronic and paper formats by the separate survey organizations, then combined into a single database by a single data manager provided by GBI. Data were submitted to the USFWS for evaluation at 7- 14-day intervals over the course of surveys. Data were evaluated for completeness and correctness but also for consistency among crews and between

field teams. Written review of the datasets was provided by USFWS to the field teams, who worked with the Phase I data manager to address and/or clarify any identified inconsistencies in the data and to ensure all crews applied the field protocols consistently.

Data quality assurance and quality control (data QA/QC, also known as verification and validation) was performed during the data collection (Phase I, described above), data integration, and data finalization phases. In each phase, processing steps were also implemented. For instance, in Phase I, datasheets were scanned and named to be easily associated with their electronic records. During the data integration phase (II), additional attribute fields were added to enable data from different UTM zones to be utilized simultaneously, and all fields were formatted for final processing. The third phase, data finalization (III), involved generation of final spatial and non-spatial data products used for analysis. Because processing steps can introduce errors, each phase of QA/QC included checks of collection but also of processing information. Figure 2 describes the overall data flow.

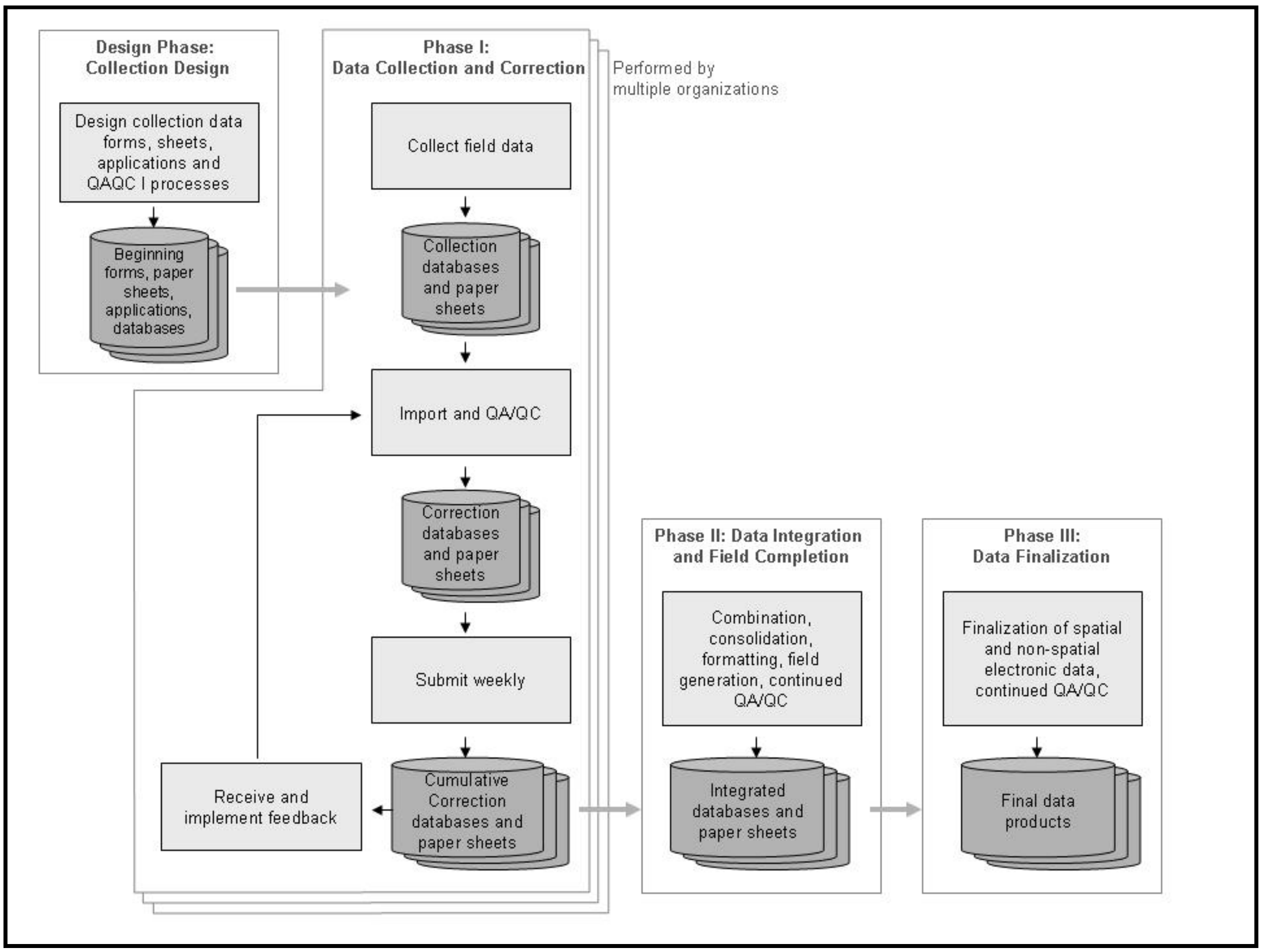

Figure 2. Data flow from collection through final products.

Tortoise encounter rate and development of detection functions

The number of tortoises seen in each stratum and their distances from the line were used to estimate the encounter rate (tortoises seen per kilometer walked) and the detection rate (proportion of available tortoises that are detected out to a certain distance from the transect centerline). 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). I expected to develop one detection curve for each field team each year because each of the pairs on a team contributes the same number of transects to the effort, and because each team works in geographically different sites. The encounter rate is less sensitive to small sample sizes, so it was estimated for each stratum separately.

Program DISTANCE, Version 6, Release 2 (Thomas et al., 2010) was used to fit appropriate detection functions, to estimate the encounter rate of tortoises in each stratum, and to calculate the associated variances. Analysis was applied to all live tortoises at least 180 mm MCL. Transects were packaged into monitoring strata ("regions" in Program DISTANCE).

Observations were truncated to improve model fit as judged by the simplicity (reasonableness) of the resulting detection function estimate (Buckland et al., 2001:15-16) as well as fit diagnostics near the transect centerline**.** Any observations that were not used to estimate detection functions were also not 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 tht truncation was applied conservatively to maximize the number of observations per stratum. Using truncated data, I considered 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). To determine whether a single detection curve might be used for both survey teams, AIC was also used to compare separate models to a single one that included a factor for field team to modify the shape of the curve.

Between April 9-15, 325 adult tortoises were translocated into OR as part of base expansion at 29 Palms Marine Corps Air Gunnery Command Center (MCAGCC). These animals were individually marked then translocated just before distance surveys were conducted in OR, and another 105 were translocated to OR before surveys ended. For this report, encounter rates were calculated in OR with all encountered animals and then again separately to report on only resident animals. The latter density captures the population status before translocations.

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

Transects were conducted by two-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; and thereby provides a test of the assumption 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 two-pass removal or double-observer 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 near 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 and is the basis for one of the training metrics.

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.

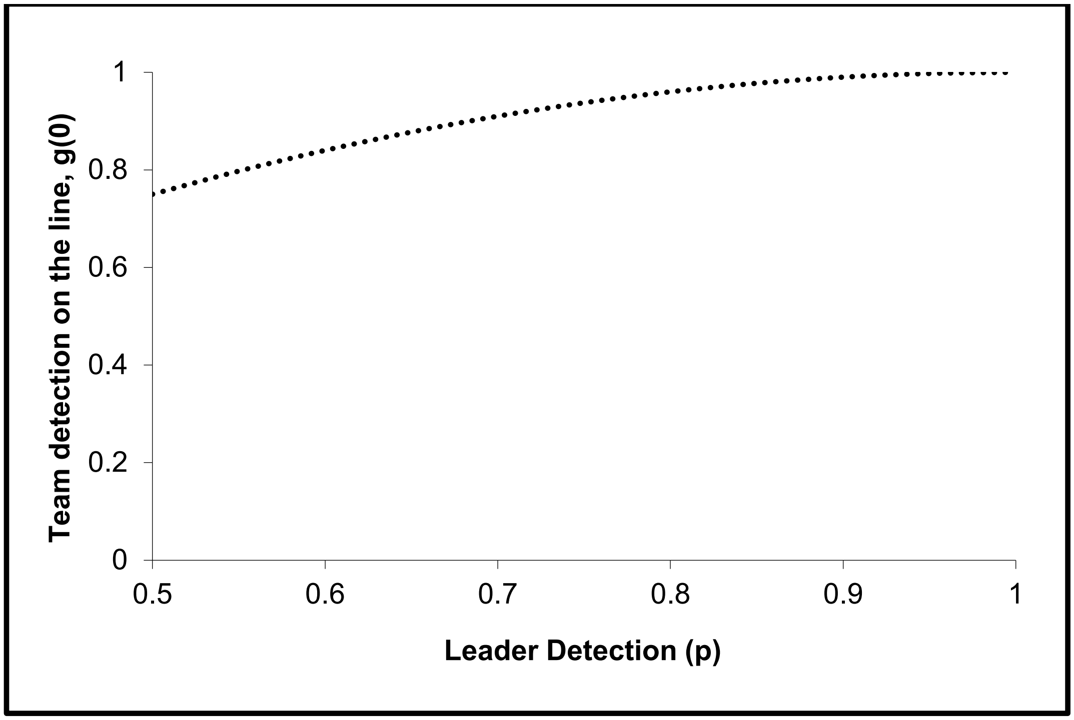

Figure 3. Relationship between single-observer detections (by the leader, *p*) and dual-observer (team) detections, *g(0)*.

Estimates of tortoise density

Each year, the density of tortoises is estimated at the level of the stratum. 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 distance assumptions in Program DISTANCE. The encounter rate (n/L) and its variance were estimated in Program DISTANCE for each stratum. Calculation of D required estimation of n/L, P_a, G_0, and $g(0)$, so the variance of D depended on the variance of these quantities as well.

Proportion of available tortoises was estimated for all strata near each G_0 site and the proportion of available tortoises detected on the transect centerline ($g(0)$) was estimated jointly for all strata. 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 2017, the two teams had very different detection patterns, so separate curves were developed for each. A schematic of the process leading to density estimates is given in Figure 4. Each of the four left-hand columns represent one estimate that contributed to the final density estimates, and the rows in each column show 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.

<table>
<tr><th>Tortoise encounter rate</th><th>Proportion that are visible, G_0</th><th>Detection rate, P_a</th><th>Proportion seen on the line, g(0)</th><th>Density</th><th></th></tr>
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<tr><td>CK</td><td>CK</td><td>CK</td><td>Colorado Desert</td></tr>
<tr><td>JT</td><td>MC2</td><td>JT</td><td>Colorado Desert</td></tr>
<tr><td>PT</td><td>MC2</td><td>PT</td><td>Colorado Desert</td></tr>
<tr><td>OR</td><td>OR</td><td rowspan="7">GBI</td><td>OR</td><td>Western Mojave</td></tr>
<tr><td>FK</td><td>SC</td><td>FK</td><td>Western Mojave</td></tr>
<tr><td>SC</td><td>SC</td><td>SC</td><td>Western Mojave</td></tr>
<tr><td>EV</td><td>PM</td><td>EV</td><td>Eastern Mojave</td></tr>
<tr><td>PV</td><td>PM</td><td>PV</td><td>Colorado Desert</td></tr>
<tr><td>BD</td><td>HW</td><td>BD</td><td>Northeastern Mojave</td></tr>
<tr><td>GB</td><td>HW</td><td>GB</td><td>Northeastern Mojave</td></tr>
</table>

Figure 4. Process for developing density estimates in 2017. For each type of estimate, the full set of data was factored as indicated by columns.

RESULTS

Field observer training

Training in 2017 lasted from 3 – 31 March (Table 1). Tests of field detection abilities occurred toward the end of each period.

Proportion of tortoises detected at distances from the transect centerline

Table 2 reports the proportion of models that were available and were detected over 16 km of transects by each team at 1-, 2-, and 5-m from the transect centerline. Teams were tested after a trial run on the detection lines or after returning crews walked practice transects to refresh the search pattern. The target for detection on the centerline is 100%, and half of the crews achieved this. Table 4 reports further statistics for each team on the evaluation lines. Measurement accuracy reported in Table 4 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 were used for this estimate, and capture two different sources of inaccuracies: 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 increased if crew path diverged from the measured line 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 was 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 was expected for the team.

Although some individual metrics were below-par (gray cells in Tables 2 and 3), all teams performed well overall so after corrective instruction to fine tune search techniques of specific crews, no pairs were rebuilt or retested. During training, detection curves were fit to each crew’s set of tortoise model observations. In no case was the best-fitting model a negative exponential one without a “shoulder” describing detections near the centerline. The best-fitting detection curves were fit to the data to generate density estimates in Table 3. In Figure 5 and 6 all of the crew detection curves for each field team are overlaid. Crews were not evaluated on their ability to match teammates; however, 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).

In 2017, 11 of the 24 Kiva surveyors were new trainees. All 4 of the teams comprised only of new trainees met the target metrics and certainly matched the performance of experienced teams. Three teams (2, 7, and 12) had a wider detection shoulder than the others (Figure 5), but this was not associated with compromised detection near the line.

Four of the GBI surveyors had previous experience with this project, and a fifth one had surveyed for tortoises without using distance sampling. Within the GBI crews, teams 21, 26, and 27 had the most anomalous curves (broadest shoulders) in Figure 6. The usual concern when crews are successful searching farther from the line is that they will focus less on areas close to the line; only team 27 was slightly below standard in detections within 2 m from the centerline but this team also improved greatly during training and reported the highest encounter rate for GBI during the field season. These teams were coached on tightening their search pattern to better match other teams, but the patterns were not of concern.

Table 2. Proportion of tortoise models detected in 2017 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	0.87
2	1.00	0.93	0.96
3	0.86	0.92	0.91
4	0.93	0.93	0.87
5	1.00	0.93	0.94
6	1.00	1.00	1.00
7	0.93	0.96	0.93
8	0.93	0.95	0.95
9	1.00	1.00	0.96
10	0.93	0.96	0.94
11	1.00	0.88	0.86
12	0.93	0.93	0.93
21	1.00	1.00	0.94
22	1.00	0.93	0.85
23	1.00	0.96	0.96
24	1.00	0.92	0.91
25	0.93	0.92	0.90
26	0.87	0.88	0.84
27	0.87	0.93	0.90
28	1.00	0.93	0.88
29	0.87	0.85	0.82
30	0.87	0.83	0.74
Kiva	**0.959**	**0.949**	**0.926**
GBI	**0.940**	**0.916**	**0.931**
Overall	**0.950**	**0.934**	**0.902**

Table 3. Diagnostics for individual teams after training in 2017.

Team	Available models detected		Measured v. exact model distance (m)	Estimated abundance	95% confidence interval	
	Within 2m of centerline by leader	Within 2m of centerline by team			Lower limit	Upper limit
1	0.90	1.00	0.87	500	401.6	622.0
2	0.86	0.93	1.00	432	372.0	502.3
3	0.88	0.92	0.78	421	307.5	577.4
4	0.81	0.93	0.91	448	324.4	619.0
5	0.93	0.93	0.63	441	279.4	695.7
6	1.00	1.00	0.81	477	363.3	627.3
7	0.85	0.96	0.67	363	322.3	408.8
8	0.91	0.95	0.99	474	392.4	572.0
9	0.91	1.00	1.02	483	383.4	609.8
10	0.96	0.96	0.74	431	373.1	498.6
11	0.75	0.88	1.30	419	298.9	586.1
12	0.82	0.93	0.94	413	353.3	483.2
21	0.93	1.00	0.86	423	386.4	485.9
22	0.86	0.93	0.89	410	348.1	483.4
23	0.88	0.96	0.75	481	405.0	570.6
24	0.88	0.92	1.18	449	365.2	411.9
25	0.85	0.92	0.93	448	372.6	537.9
26	0.88	0.88	0.74	276	223.3	340.7
27	0.86	0.93	0.93	422	352.2	504.9
28	0.87	0.93	1.04	426	313.6	479.4
29	0.81	0.85	1.01	638	304.7	445.1
30	0.79	0.83	0.72	339	266.6	430.2
Kiva	**0.882**	**0.949**	**0.888**	**442**	**347.6**	**566.8**
GBI	**0.861**	**0.916**	**0.905**	**404**	**332.0**	**779.0**
Overall	**0.873**	**0.934**	**0.896**	**425**	**340.5**	**526.9**

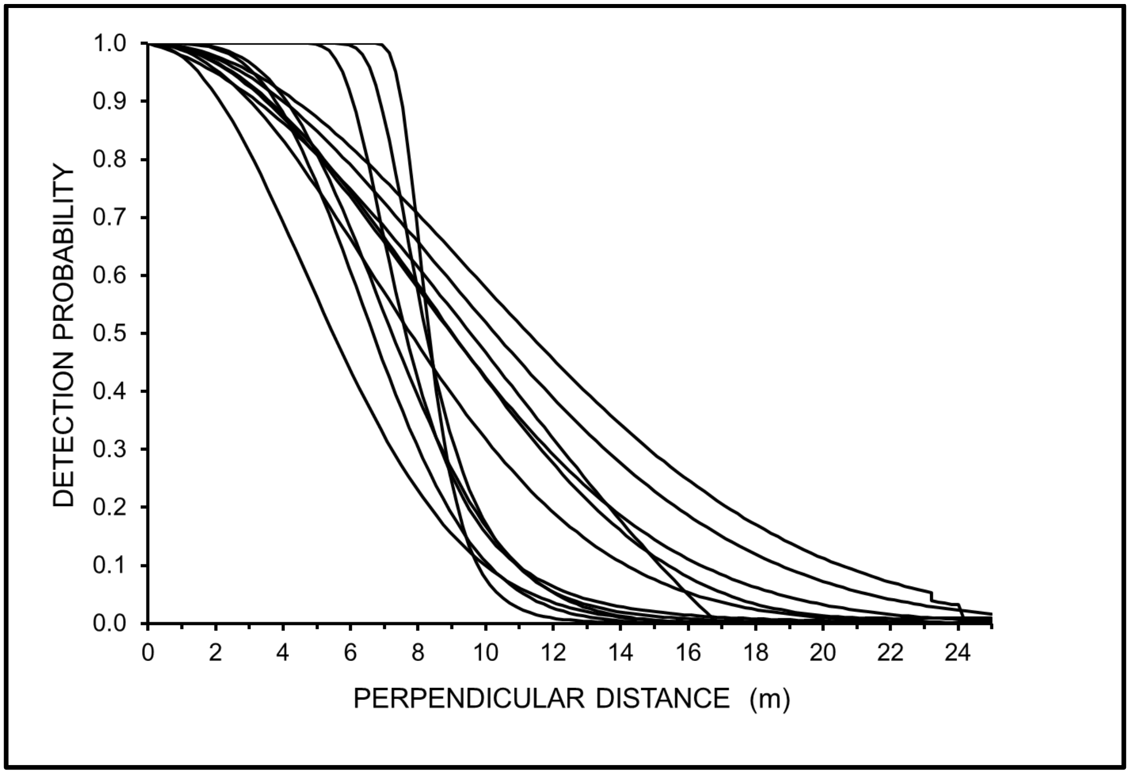

Figure 5. Detection curves for each of the 2017 Kiva teams during training. Each curve is based on a 16 km trial with approximately 100 detections.

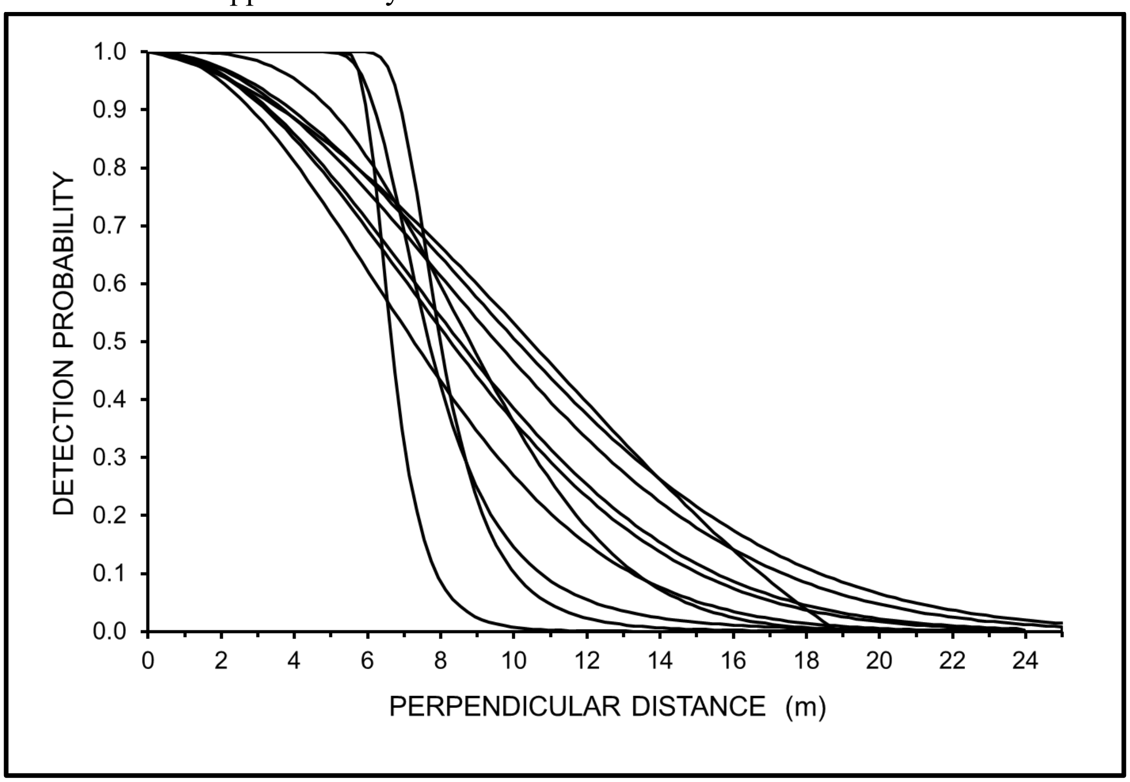

Figure 6. Detection curves for each of the 2017 GBI teams during training. Each curve is based on a 16 km trial with approximately 100 detections.

Quality assurance and quality control

There were 18,852 transect records and 2297 G_0 records associated with the monitoring effort in 2017. The first data specialist worked with the field teams to resolve 3045 cases with fields that were inconsistent with constraints and expectations. After this phase of QA/QC had finished verifying and validating the information in these databases, Phase II provided independent review, repackaged tables into their final configuration, and added some spatial information. An additional 604 issues remained or were discovered in the third (final) phase of QA/QC. Only 254 were errors created by the field crews (sometimes faulty equipment or crews otherwise entering electronic data after the transect was completed, other times data entry error), of which all but 37 were corrected with recourse to paper datasheets. The remaining errors in 2017 indicated a failure to comply with protocols (e.g., ID tags not attached because epoxy tube broke), not because the data were erroneous.

Data for these and previous years are available at http://psw.databasin.org/galleries/af8e55a0197a4c95a3120b278075a2b1.

Transect completion

Table 4 reports the number of assigned and completed transects in each stratum in 2017. Pending a Department of Interior review of modifications to existing cooperative agreements. Kiva Biological was instructed to postpone surveys after 2 May. The remaining work was approved after tortoises were no longer active above-ground, so 3 assigned transects in FK were not completed and surveys in CM, FE, and IV were not initiated.

Table 4 also indicates the number of assigned transects that could be completed as standard square 12-km transects or by reflecting around property boundaries and infrastructure (column 4). An additional number (column 5) were shortened and represent more rugged terrain. Finally, some transects were considered unwalkable (column 6). Figures 7 to 10 show locations of transects and observations of live tortoises.

Table 4. Number and completion of transects in each stratum in 2017.

Stratum	Assigned transects	Assigned and alternate transects completed	Assigned, completed 12k	Assigned, completed shortened	Assigned, judged unwalkable*
BD	33	33	18	13	2
GB	72	72	26	29	17
EV	86	86	49	28	9
PV	50	50	33	9	8
GBI	241	241	126	79	36
AG	36	36	18	8	1
CK	120	120	58	36	26
JT	60	60	22	17	21
PT	50	50	11	29	10
FK	60	57	44	6	4
OR	60	60	28	11	21
SC	70	70	46	18	6
Kiva	456	453	227	125	89
Total	697	694	353	204	125

*Assigned transects that were not walked were to be replaced by alternates. In addition to transects that were unwalkable due to terrain and counted in the far right column above, nine walkable assigned transects in AG were replaced due to planning considerations on military installations.

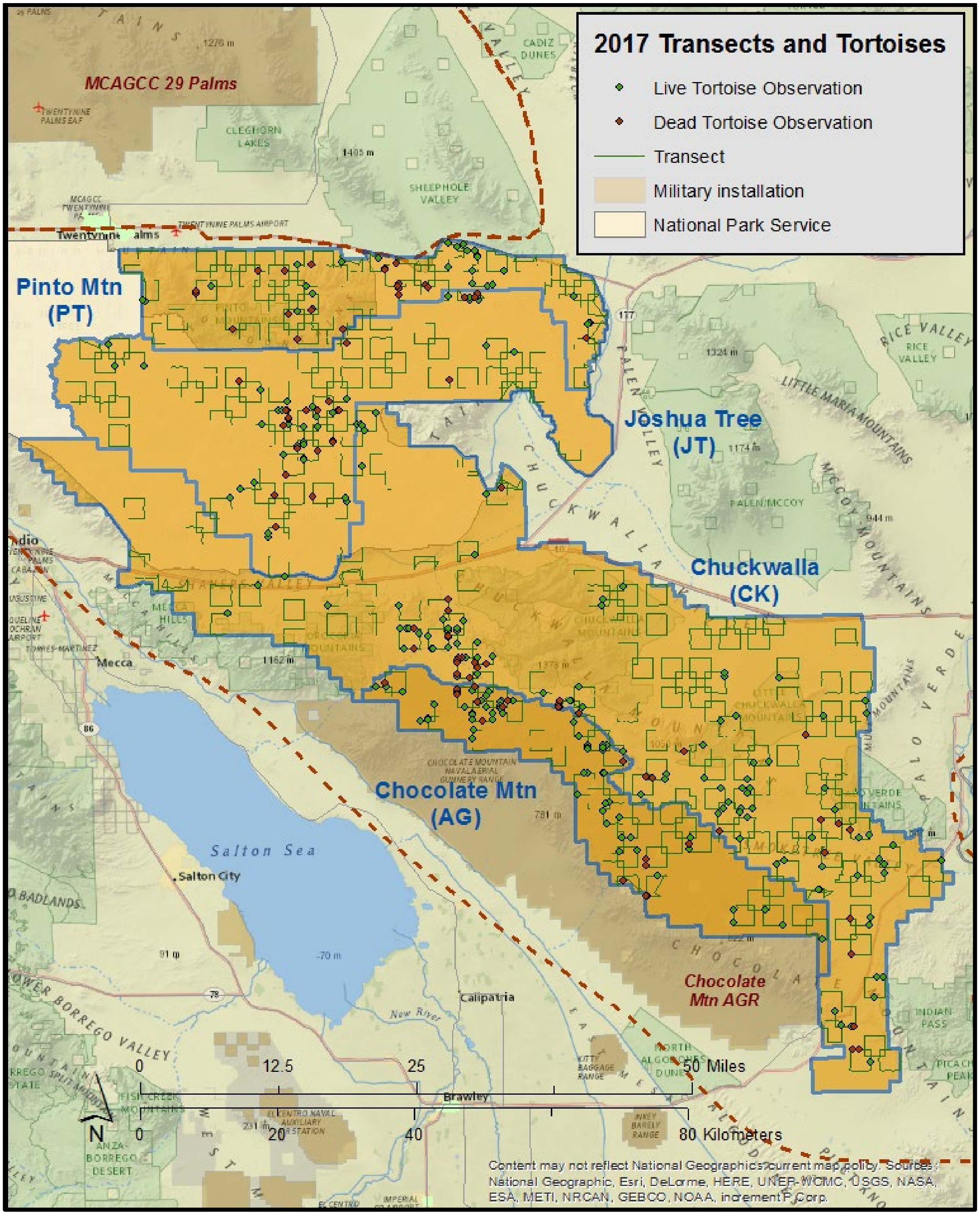

Figure 7. Distribution of distance sampling transects and live tortoise observations in 2017 in the southern part of the Colorado Desert Recovery Unit.

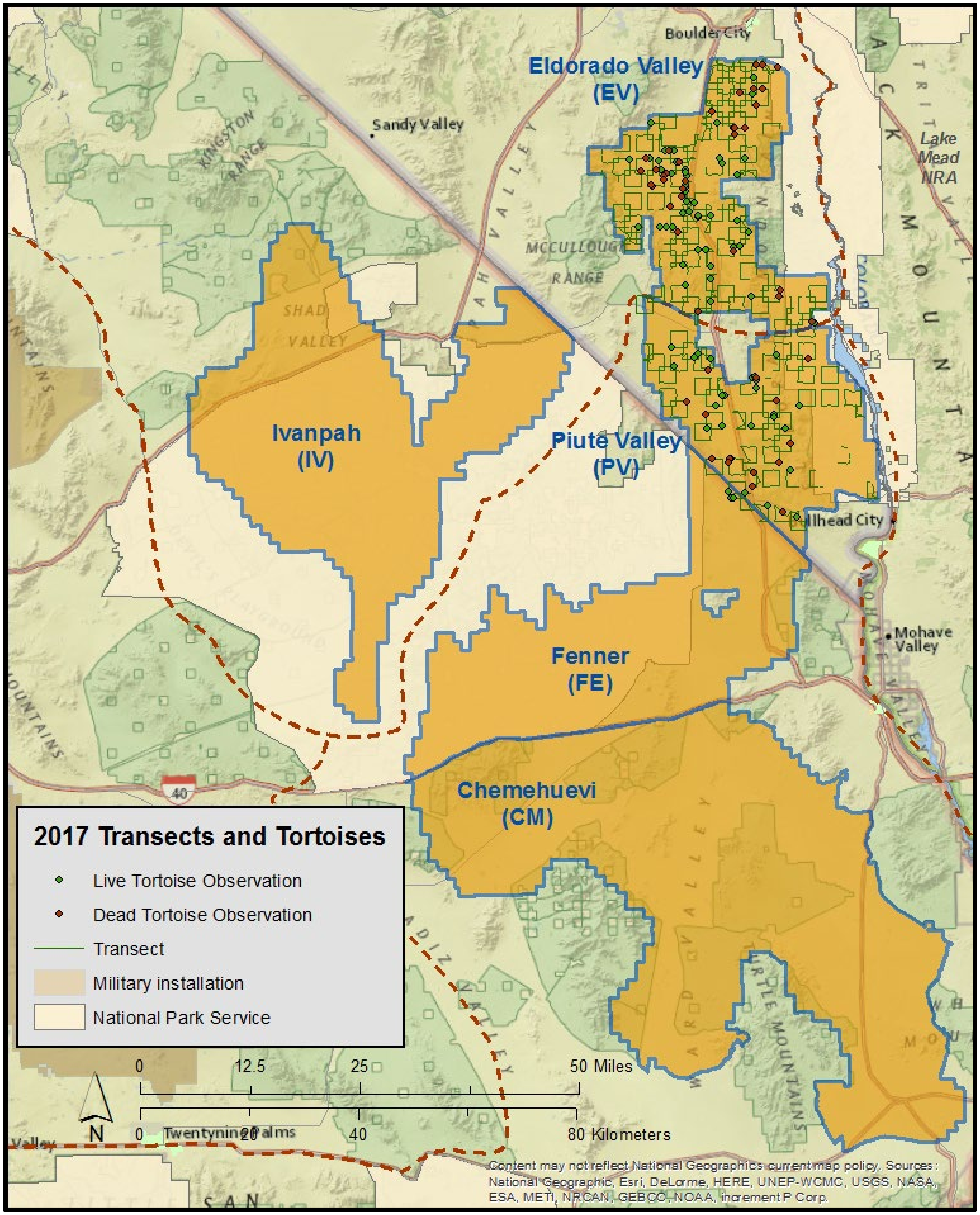

Figure 8. Distribution of distance sampling transects and live tortoise observations in 2017 in the Eldorado Valley stratum of the Eastern Mojave Recovery Unit and in the Piute Valley stratum of the Colorado Desert Recovery Unit.

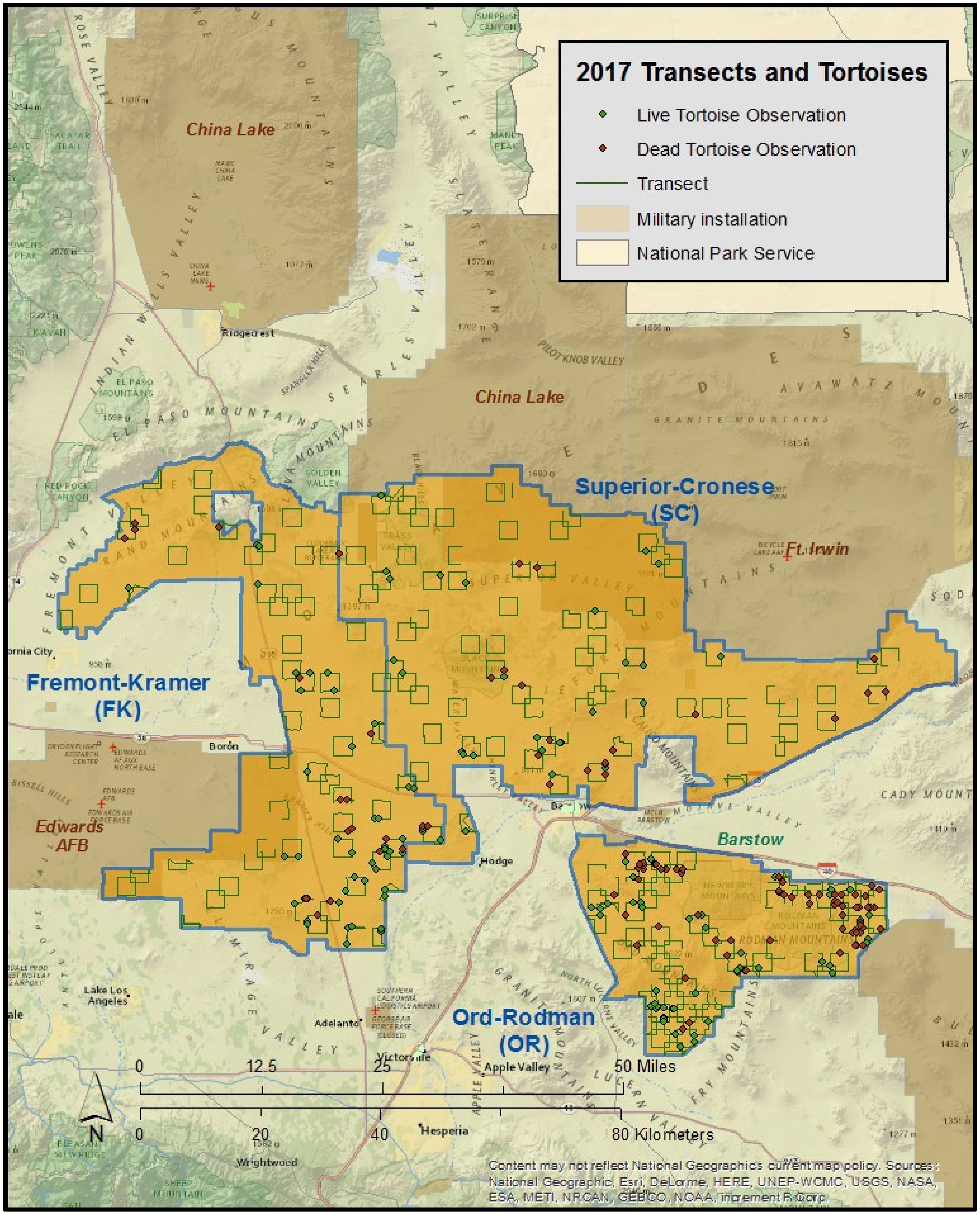

Figure 9. Distribution of distance sampling transects and live tortoise observations in 2017 in the Western Mojave Recovery Unit.

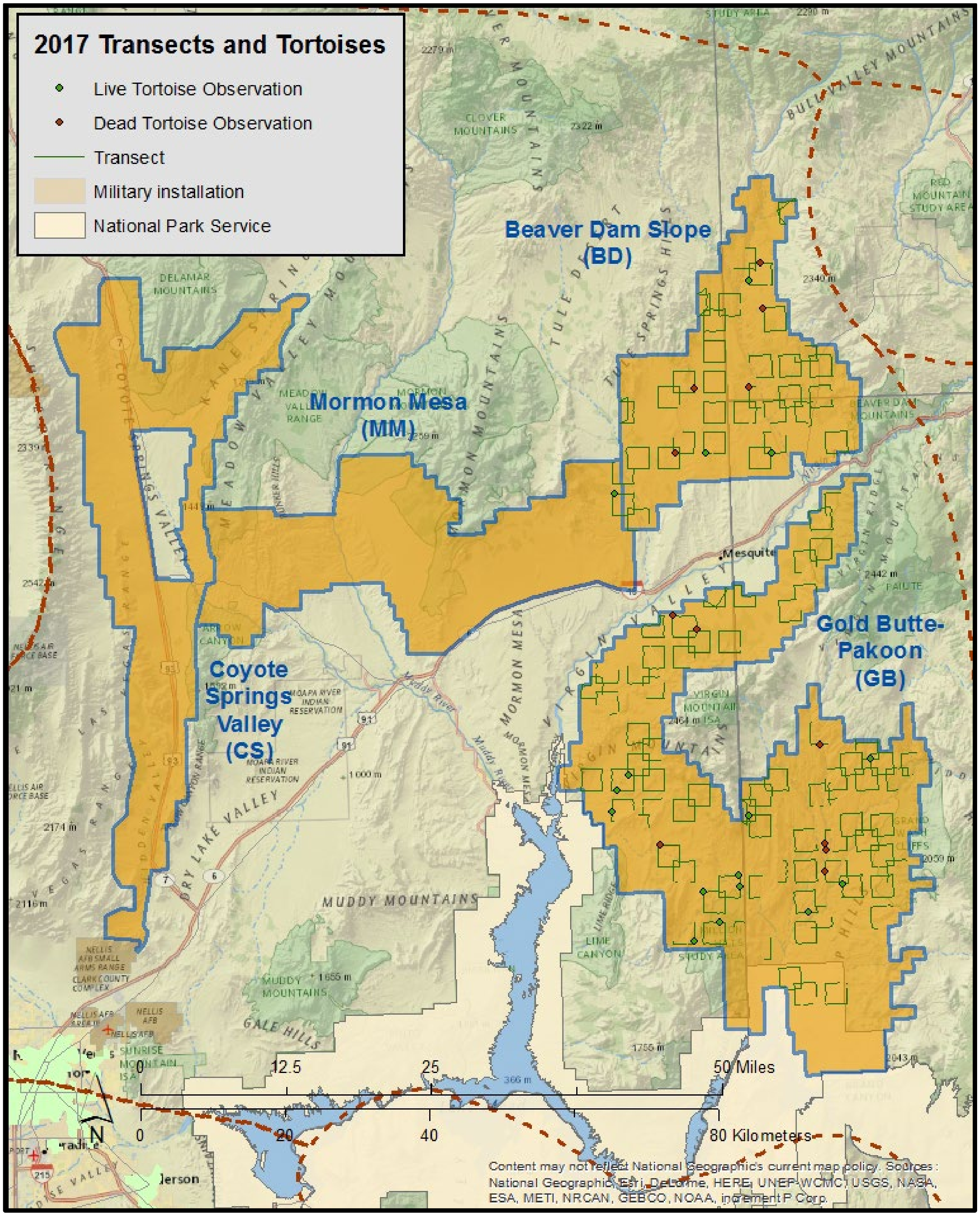

Figure 10. Distribution of transects and live tortoise observations in 2017 in the Beaver Dam Slope and Gold Butte-Pakoon strata of the Northeastern Mojave Recovery Unit.

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

In general, telemetry sites and associated strata 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. Visibility from the Chuckwalla telemetry site is usually highest in March and early April, consistent with the estimates for the given dates in 2017 (Table 5). Tortoise activity in the eastern part of the range is generally lower than in the west, which is clearly seen comparing G_0 estimates from sites in California to those in Piute-Mid and then to Halfway Wash which is farther east.

Table 5. Availability of tortoises (G_0) when transects were walked in 2017 in the same or in neighboring strata.

G_0 site	Stratum	Dates	Days	G_0 (Std Error)
Chuckwalla	Chuckwalla (BLM)	9 Mar – 23 Mar 2017	15	0.96 (0.053)
Chuckwalla	Chocolate Mtn south	12 Mar – 14 Mar 2017	3	0.95 (0.052)
Chuckwalla	Chocolate Mtn north	15 Mar – 17 Mar 2017	3	0.99 (0.023)
Piute-Mid	Piute Valley	3 Apr – 11 Apr 2017	9	0.74 (0.116)
MCAGCC 2	Joshua Tree	7 Apr – 11 Apr 2017	5	0.96 (0.042)
MCAGCC 2	Pinto Mountains	12 Apr – 15 Apr 2017	4	1.00 (0.000)
Piute-Mid	Eldorado Valley	12 Apr – 24 Apr 2017	13	0.78 (0.124)
Ord-Rodman	Ord-Rodman	16 Apr – 20 Apr 2017	5	0.97 (0.04)
Superior-Cronese	Superior-Cronese	22 Apr – 27 Apr 2017	6	0.96 (0.076)
Halfway Wash	Gold Butte-Pakoon	24 Apr – 8 May 2017	15	0.65 (0.167)
Superior-Cronese	Fremont-Kramer	28 Apr – 2 May 2017	5	0.94 (0.091)
Halfway Wash	Beaver Dam Slope	9 May – 12 May 2017	4	0.63 (0.195)

Tortoise encounter rates and detection functions

All survey pairs worked together from the beginning to the end of the season. Each Kiva crew walked on a median 38 transects (one team walked 35) and overall they detected 310 tortoises larger than 180 mm MCL. GBI surveyors walked a median 25 transects each with one team finishing after 16 transects due to injury.

Because GBI did not have a large number of observations on which to base their detection curve, a single detection curve was tested against separate curves for each group, but at several truncation distances, the separate curves were more strongly supported. Kiva's detection pattern best fit a uniform model with cosine adjustment and using all observations up to 24 m from the centerline. GBI best fit a hazard rate curve with hermite adjustment (although the negative exponential model was within 0.30 AIC units). Figure 11 and 12 are histograms of the observed number of tortoises seen at increasing distance from the transect centerline. Truncation distances for both teams was conservative to maximize the number of observations per stratum and resulted in detections with good fit near the centerline and minimum adjustment terms to fit the handful of observations in the tails. The detection rate for Kiva crews within 20 m of the transect centerline was 42.5% (Kiva; CV=0.045) and for GBI crews within 25 m of the centerline it was 21.6% (CV=0.164).

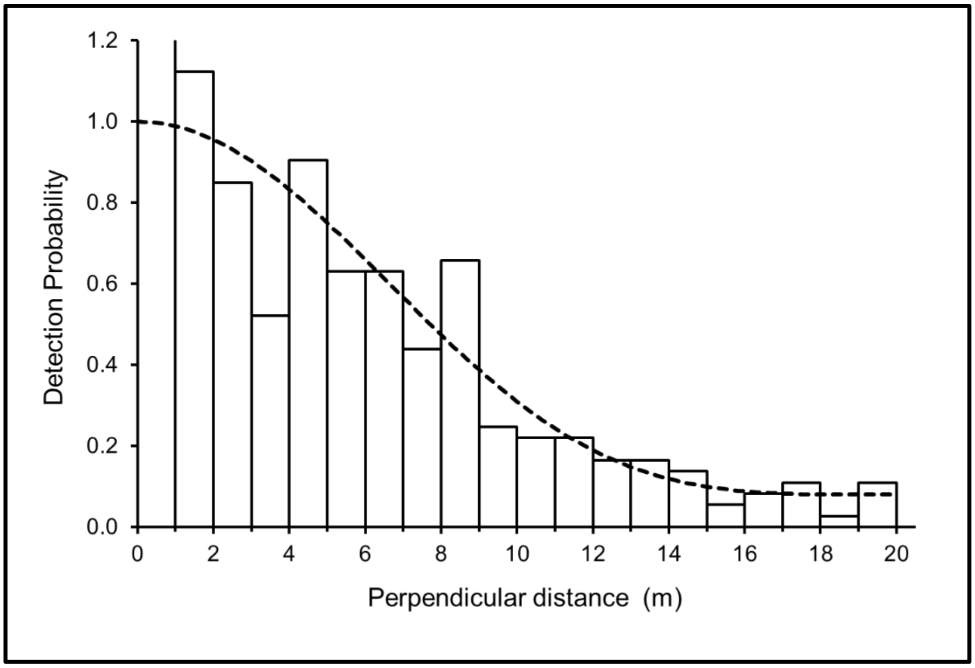

Figure 11. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by Kiva in 2017. This curve uses only the n=310 observations found within 20 m of the line.

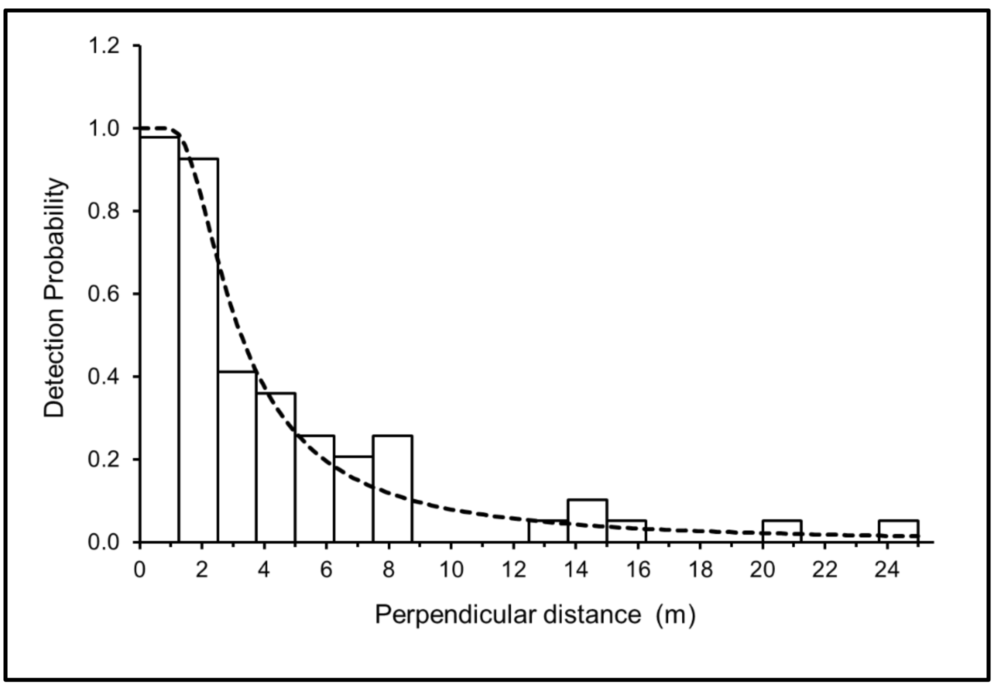

Figure 12. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by GBI in 2017. This curve uses only the n=72 observations found within 25 m of the line.

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) and close to the surveyor may not be detected. In 2017, for 220 detections of tortoises within 5 m of the transect centerline, 186 were found by the observer in the lead position and 34 by the follower, so that the probability of detection by single observer, $p = 0.817$, and the proportion detected using the dual observer method, *g(0 to 5 m)* = 0.967 (SE = 0.049). In Figure 13 shows that *g(0)* was converging on 1.0 in 2017, 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, 2013, 2014, 2015, 2016).

Estimates of tortoise density
Density estimates were generated separately for each monitoring stratum, and for OR they were generated based only on resident tortoises and then again after including marked animals that had been translocated (Table 6). The reported densities represent an increase of 608 (SE=107.2) tortoises/km^2, which may be an overestimate due to increased encounters with translocated animals that are more active than residents. We expect activity and encounter rates to stabilize in a couple years after translocations are completed in 2018 and the behavior of these animals has settled (Nussear et al. 2012, Farnsworth et al. 2015).

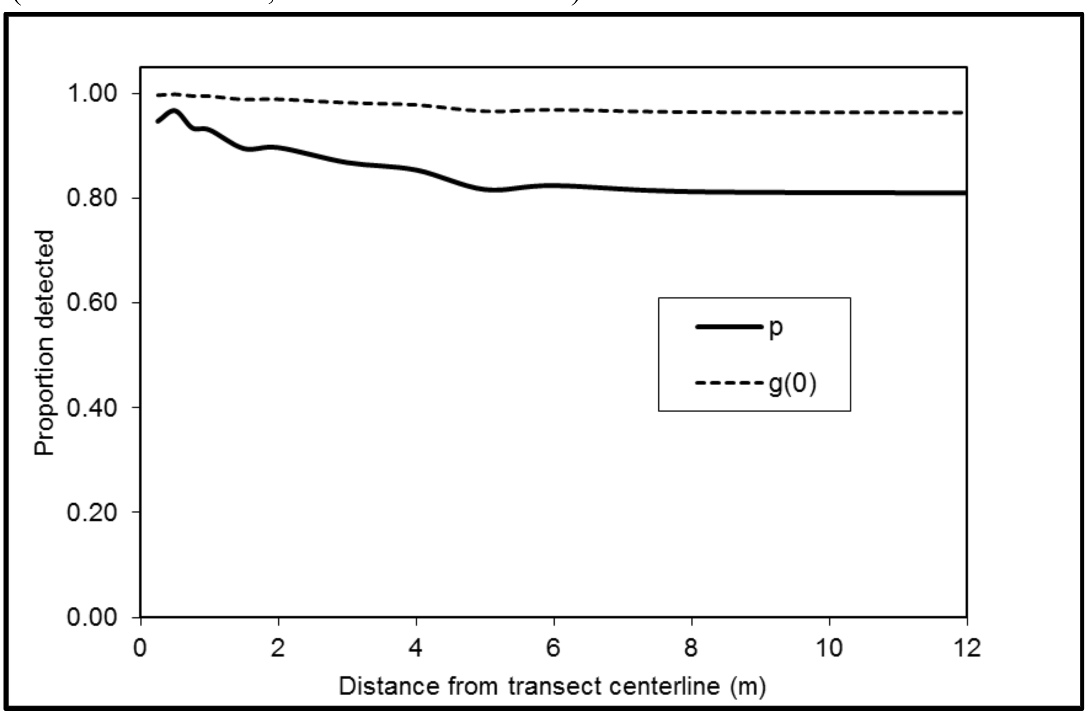

Figure 13. Detection pattern for the leader (*p*) and by the team (*g(0)*) based on all observations out to a given distance (*x*) from the centerline in 2017. Note convergence of *g(0)* on 1.0 as *x* goes to 0.

Table 6. Stratum-level encounters and densities in 2017 for tortoises of MCL ≥ 180 mm within 20 m of the centerline in California strata, otherwise within 25 m of the centerline. Coefficients of variation expressed as percentages.

Recovery Unit/ Stratum		Area (km2)	# Transects	Transect length (km)	Begin date	End date	*n* (torts observed)	CV*(n)*	Density (/km2)	CV(Density)
Western Mojave		**6873**	**187**	**2125**	**16-Apr**	**2-May**	**110**			
Fremont-Kramer	FK	2417	57	667	27-Apr	2-May	44	19.4	4.1	22.01
Ord-Rodman	OR	1124	60	678	16-Apr	22-Apr	44	18.9	3.9	19.84
OR – residents only	ORr	1124	60	678	16-Apr	22-Apr	36	18.1	3.2	19.04
Superior-Cronese	SC	3332	70	781	22-Apr	30-Apr	22	21.9	1.7	23.76
Colorado Desert		**7610**	**316**	**3284**	**9-Mar**	**16-Apr**	**223**			
Chocolate Mtn	AG	713	36	376	15-Mar	17-Mar	58	23.1	9.4	14.8
Chuckwalla	CK	3509	120	1270	12-Mar	14-Mar	88	14.0	4.3	15.70
Joshua Tree	JT	1567	60	615	12-Mar	17-Mar	36	21.6	3.6	22.52
Pinto Mtns	PT	751	50	452	9-Mar	23-Mar	18	32.4	2.3	32.70
Piute Valley	PV	1070	50	572	3-Apr	11-Apr	23	26.4	5.9	35.00
Eastern Mojave		**1153**	**86**	**940**	12-Apr	16-Apr	**38**			
Eldorado Valley	EV	1153	86	940	3-Apr	11-Apr	38	17.3	5.6	28.58
Northeastern Mojave		**2805**	**105**	**1071**	**11-Apr**	**27-Apr**	**11**			
Beaver Dam Slope	BD	828	33	365	11-Apr	27-Apr	3	56.0	1.3	65.64
Gold Butte-Pakoon	GB	1977	72	706	**25-Apr**	**12-May**	8	33.2	1.9	44.26

DISCUSSION

One priority for the next years will be to determine whether there is a pattern of tortoise activity moving to earlier in the season in any parts of the range. This will inform the optimal timing of surveys but is of course of more significance for interpreting other measures of biological response to climate change.

The annual stratum-level density estimates will be evaluated every five years with those since the beginning of the surveys in order to test for and describe population growth trajectories. The next evaluation of population trends is planned after the 2019 field season. Thorough surveys of each stratum at least every other year will be needed to develop accurate and precise population trend estimates.

Base expansion of 29 Palms MCAGCC affected many tortoises in 2017, and a large number of these were translocated to the Ord-Rodman critical habitat unit. Although this expansion negatively impacts tortoises and their habitat (USFWS 2017b), augmenting the resident population in OR with reproductive adults may result in population growth by increasing the number of juveniles produced each year. In conjunction with fencing, law enforcement, and other mitigation that is implemented in OR, population augmentation is a strategy that may accelerate the process of stabilizing this population (USFWS 2011). Other monitoring is in place to assess the success of the translocations measured as their survival, for instance, but the ongoing range-wide monitoring program will provide a composite view of the success of the suite of recovery activities that are now occurring in OR. This year, the program certainly captured an increase of hundreds of number of adult tortoises.

Monitoring of declining populations should be deeply integrated in conservation and recovery programs. Although these surveys were designed to provide a 25-year description of a positive population growth trend, this single purpose would be an underutilization of the program which can certainly address interim management questions (Nichols and Williams, 2006). Population recovery will necessitate accelerated, prioritized recovery activities (Darst et al., 2013). Targeted effectiveness monitoring (Lyons et al., 2008; Lindenmayer et al., 2010), where possible, will complement this larger monitoring program that provides a composite view of all recovery activities in each stratum. Both types of monitoring will be needed to characterize the effectiveness of recovery activities where the list of threats is so large and their interactive effects can be complex.

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