RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE (*GOPHERUS AGASSIZII*): 2024 ANNUAL REPORTING

PREPARED BY COREY MITCHELL
DESERT TORTOISE MONITORING COORDINATOR
U.S. FISH AND WILDLIFE SERVICE

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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). Linda Allison continued to develop and refine the project design and data collection protocol in her role as the Desert Tortoise Monitoring Coordinator with U.S. Fish and Wildlife Service from 2006-2022. L. Allison was instrumental in every phase of the project from project design and initiation through data collection.

Personnel from Kiva Biological Consulting (California) led by M. Bassett and K. Hayes conducted the field surveys in California, while data in Nevada, Utah, and Arizona were collected by Great Basin Institute (GBI) led by T. Christopher, J. Cash, and B. Sparks. The survey in Chocolate Mountains Aerial Gunnery Range was conducted by BioResource Consultants, Inc. The field monitors from these teams who did the hard work of collecting and verifying the data were:

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R. Patil (GBI) updated the electronic data-collection forms and procedures. T. Cornell, A. Markowski, and S. Martin (GBI) ran first-level quality assurance/quality control of data. M. Brenneman (Topoworks) provided independent review and post-processing of data and developed the final databases.

EXECUTIVE SUMMARY

The recovery program for Mojave desert tortoises (*Gopherus agassizii*) throughout most of 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 2024, except 2006, 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. 2020) and will not be further addressed herein.)

This report describes quality assurance steps and final results for the 2024 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 again in 2024, when crews completed 528 transects (5801.3 km) in 8 strata between 21 February and 13 May. In the course of these surveys, they reported 202 live tortoises, 169 of which were at least 180 mm midline carapace length (MCL) and used to generate density estimates.

In 2024, we surveyed 6 of the 16 long-term strata across Arizona, California, Nevada, and Utah as well as 2 short-term strata (Pahrump and Amargosa Valley) within the greater Amargosa Valley region of Nevada. The highest estimated density in 2024 was in the Colorado Desert in the Chocolate Mountains Aerial Gunnery Range (7.4 adults/km^2), where densities were higher in the northern portion (8.0 adults/km^2) than in the southern portion (7.0 adults/km^2), a pattern seen in past years of these surveys. Other long-term strata surveyed in 2024 (and the estimated density of adults/km^2) were Beaver Dam Slope (1.7), Coyote Springs (2.7), Fremont-Kramer (1.8), Piute Valley (4.0), and Ord-Rodman (2.7). Both short-term strata had estimated densities less than 2.0 adults/km^2: 1.1 adults/km^2 in Amargosa Valley and 1.9 adults/km^2 in Pahrump. Overall, the encounter rate averaged 26.6 km for each adult tortoise that was observed within long-term strata and 77.7 km for each adult tortoise observed within the two short-term strata surveyed this year.

These surveys are reported annually, corresponding to the reporting requirements for annual funding. However, the survey effort is not planned for precise and accurate annual density estimates; it is directed at accurately describing population trends by using multiple years of density estimates in each monitored stratum. Based on data from many years, we can thereby provide an estimate of the density in any one of those years that is more accurate than a single annual density estimate such as those in this report. Therefore, the most accurate existing density estimates for each stratum are currently those based on trend estimates from a spatially explicit hierarchical model developed by Zylstra et al. (2023) that accounts for both variation in detection probability and availability across surveys over a 20 year-period, from the beginning of the monitoring program in 2001 through 2020.

Range-Wide Monitoring of the Mojave Desert Tortoise
2024 Annual Reporting

Introduction

The Mojave Desert population of the desert tortoise was listed as threatened under the Endangered Species Act (ESA) in 1990 (USFWS 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). However, populations of *G. agassizii* (hereafter tortoise) do occur east of the Colorado River (USFWS 2011) but are not covered under the 1990 ESA listing. 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 estimates in 2024. A more thorough description of the background of the monitoring program is provided in USFWS (2015), and use of annual density estimates to describe population trends from 2004-2014 is provided in Allison and McLuckie (2018) with updated analysis from 2001-2020 available in Zylstra et al. (2023).

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 revised recovery plan to describe designated critical habitat as well as contiguous areas with high potential for tortoise habitat (Nussear et al. 2009) 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), which led to separating the Piute and Eldorado Valleys into two 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 tortoises in Joshua Tree National Park (JTNP). The national park designation and its 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 2024, surveys were conducted in California in the Chocolate Mountains Aerial Gunnery Range (AG), Fremont-Kramer (FK), and Ord-Rodman (OR) strata; and in Beaver Dam Slope (BD), Coyote Springs Valley (CS), and Piute-Valley (PV) in Nevada, Utah, and Arizona. In addition to long-term strata, two short-term strata were developed and surveyed in Clark County and Nye County, Nevada: Amargosa Valley (AV) and Pahrump (PA). Boundaries for these short-term strata were developed based on current BLM land ownership data and desert tortoise habitat suitability (Nussear et al. 2009). 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 sampling and inherent error or "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 within long-term range-wide strata or for the new survey areas outside long-term strata, established in 2008 where boundaries overlapped those from a previous study in Pahrump, NV or in 2024 for new survey areas. 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 were determined, transects were selected randomly based on a Generalized Random Tessellation Stratified (GRTS) spatially balanced survey design procedure which was executed using R statistical software and the spsurvey package (Kincaid et al. 2019, R Core Team 2023). The US Environmental Protection Agency developed GRTS as a means to generate a spatially balanced, random sample (Stevens and Olsen 2004). 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 within long-term monitoring strata, but others may not have been selected in the past.

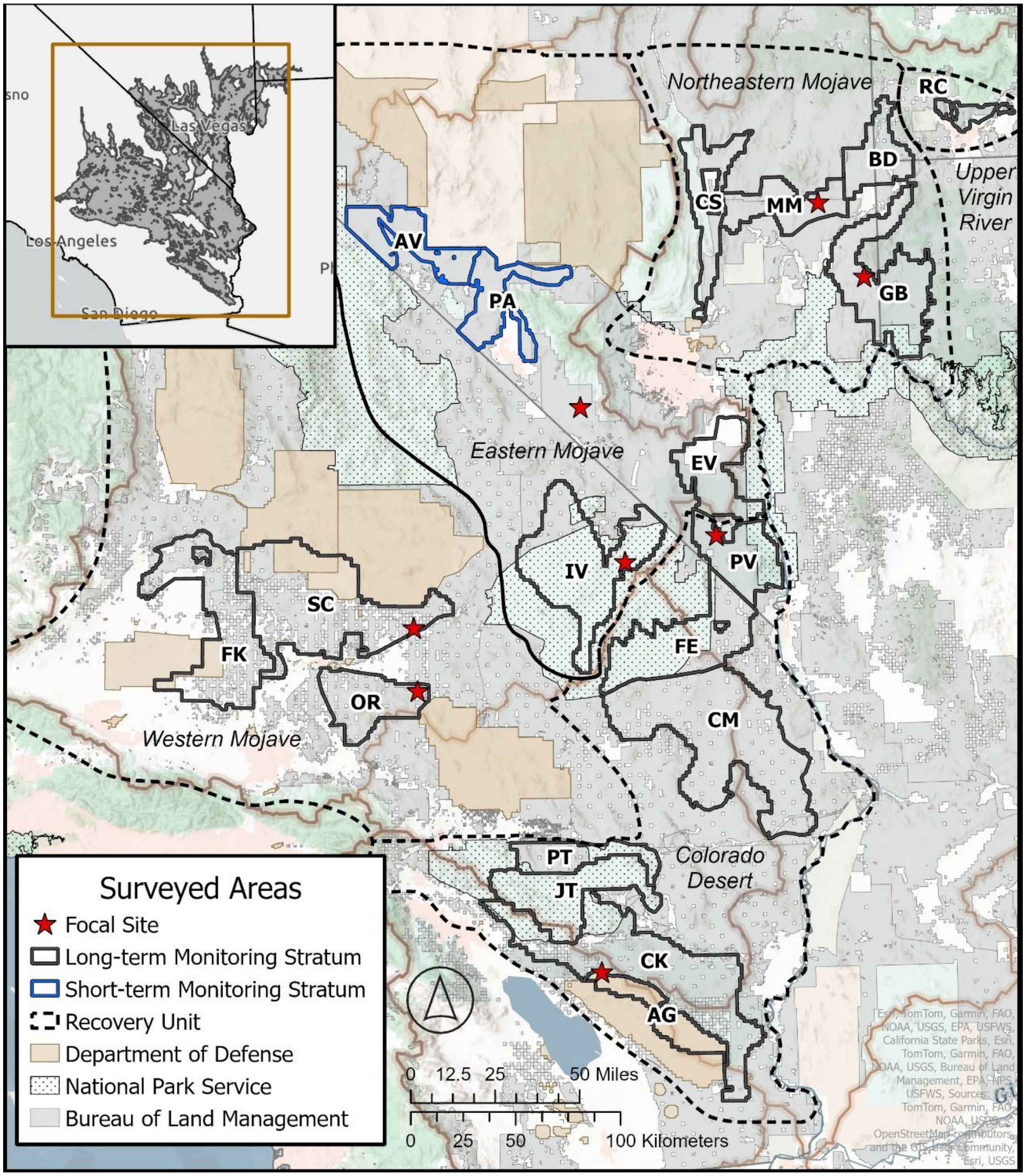

Figure 1. Long-term monitoring strata (n=17; dark gray outlined polygons) corresponding to tortoise conservation areas (TCAs; USFWS 2011) in each recovery unit. TCAs and their codes are Chocolate Mountains Aerial Gunnery Range (AG), Beaver Dam Slope (BD), Chuckwalla (CK), Chemehuevi (CM), Coyote Springs Valley (CS), Eldorado Valley (EV), Fenner (FE), Fremont-Kramer (FK), Gold Butte-Pakoon (GB), Ivanpah (IV), Joshua Tree (JT), Mormon Mesa (MM), Ord-Rodman (OR), Pinto Mountains (PT), Piute Valley (PV), Red Cliffs (RC), Superior-Cronese (SC). Short-term monitoring strata (n=2; blue outlined polygons) surveyed in 2024 and their codes are Amargosa Valley (AV) and Pahrump (PA). Observations to estimate visibility are made using populations of radio-equipped tortoises at regional focal sites (n=8; red stars). 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 winter hibernacula (shelter sites) in the early spring and are active mid-March through May and then again in the fall (Nussear et al. 2007). These periods coincide with production of their preferred food plants and with annual mating cycles. The annual range-wide monitoring effort is scheduled to match the spring activity period for tortoises.

Even so, not all tortoises are above ground or visible in burrows during this season. 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 8 am 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 afternoon temperatures to limit tortoise above-ground activity.

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 (3-km sides). 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-meter 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-meter 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-meter 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), determine its sex, record general health information, and 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 (an adult), 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 daily window of time, so 3) transects could be shortened to enable completion before 4 pm 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. 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 2024a).

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) by a different but undetermined amount in each location, each year. To account for this, we used telemetry to estimate the proportion of tortoises available for sampling, G_0 ("gee-sub-zero"), which was incorporated in estimates of adult tortoise density to correct this bias.

To quantify the proportion of tortoises that were available for detection (visible), radio-telemetry technicians used a very high frequency (VHF) radio-telemetry receiver and directional antenna to locate 9-16 radio-equipped G_0 tortoises that were visible as well as those that were otherwise undetectable in deep burrows or well-hidden in dense vegetation in each of 8 focal sites throughout the Mojave and Colorado deserts (Figure 1). In 2024, 7 focal sites, including Chuckwalla, Halfway Wash, Ivanpah, Ord Rodman, Piute-Mid, Stump Springs, and Superior-Cronese were used corresponding to the monitored strata. Each time a radio-equipped 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.

Estimates of G_0 were developed with generalized linear mixed-models in R using the stats and lme4 packages to account for repeated measures of individual tortoises (Bates et al. 2015, R Core Team 2023). All candidate models included stratum as a fixed effect. In addition, mixed-effect models where day and tortoise identification number were accounted for as nested random effects were compared to linear models with no specified random effect. Model predictions and standard errors were generated with the stats, bootpredictlme4, and jtools packages (Long 2022, Duursma 2023, R Core Team 2023). Candidate models were compared based on model convergence, model fit, and Akaike information criterion (AIC).

Field observer training

Training for careful data collection and consistency between crews is a fundamental part of quality assurance for this project. This training generally includes classroom 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, provided to field crews, and posted to the Desert Tortoise Recovery Office website (https://www.fws.gov/media/2024-mojave-desert-tortoise-monitoring-handbook).

Kiva Biological (Kiva) supplied crews for monitoring in California strata. Great Basin Institute (GBI) supplied crews for monitoring in strata in Nevada, Utah, and Arizona. All 10 of the personnel with the Kiva team had previous tortoise field experience and all but 1 had previous transect experience with this monitoring program. This allowed us to accommodate logistics on Chocolate Mountain Aerial Gunnery Range, where surveys were completed under contract to BioResource Consultants, Inc. before formal review training (Tables 1-4) for surveys in the remaining strata. Only 6 of 36 surveyors in the GBI team had prior experience in this program. The two teams were trained separately by the same USFWS and data specialist instructors for consistency.

Distance sampling training

Transect walkers were given classroom instruction, skills training, field demonstrations, and practice transects to complete (Tables 1-4). 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 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 meters behind the leader, with the opportunity to detect models not found by the leader. If the leader detected 80% of all tortoises that were 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 $0.80 + (0.80 \times (1 - 0.80)) = 0.96$ 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 2024 for Kiva transect crews.

Date	Activity	Location	Instructors
20 February	Transects methods overview	Chuckwalla ACEC, California	Hayes/Bassett
	iPads – Transect database	Chuckwalla ACEC, California	Hayes/Bassett
	Short transect (6 km) practice	Chuckwalla ACEC, California	Hayes/Bassett
11 March	Training lines 1 (8 km)	BLM Desert Tortoise Management Area (DTMA)	Mitchell
12 March	Review training line 1 results	GBI Field Station	Mitchell/Markowski
	Biosecurity and tortoise handling	GBI Field Station	Hayes/Bassett
	Scoring tortoise visibility presentation	GBI Field Station	Mitchell
	Survey123 presentation & practice	GBI Field Station	Mitchell/Markowski
	Review Chuckwalla ACEC practice transect results	GBI Field Station	Mitchell/Markowski
13 March	Training lines 2 (8 km)	BLM DTMA	Mitchell
14 March	Review training line 2 results	GBI Field Station	Mitchell/Cash/ Markowski
	Monitoring on public lands presentation	GBI Field Station	Mitchell
	GPS and compass use for tortoise monitoring	GBI Field Station	Mitchell
	Standard and non-standard transect protocol	GBI Field Station	Mitchell
	Short transect (6 km) practice with interruption for terrain and reflection	BLM DTMA	Mitchell
	Wrap up discussion	GBI Field Station	Mitchell

Table 2. Training schedule for 2024 for GBI Range-wide transect crews.

Date	Activity	Location	Instructors
11 March	Mojave Desert & tortoise ecology presentation	GBI Field Station	Christopher
	Compass introduction	GBI Field Station	Cash/Markowski
14 March	Distance estimation presentation	GBI Field Station	Mitchell

Date	Activity	Location	Instructors
14 March (continued)	Training lines presentation & practice	GBI Field Station	Mitchell/ Christopher
	Compass course 1	GBI Field Station	Markowski
	Practice epoxy for tag attachment	GBI Field Station	Christopher
	Survey123 presentation & practice	GBI Field Station	Cash
17 March	Training lines 1 (8 km)	BLM DTMA	Cash/Markowski
18 March	Search image for tortoises & sign	River Mountains, NV	Sparks
19 March	Review training line 1 results	GBI Field Station	Mitchell/Cash/ Markowski
	Biosecurity presentation	GBI Field Station	Dr. Johnson
	Tortoise handling practice 1	GBI Field Station	Dr. Johnson/Cash/ Christopher/ Mitchell
20 March	Tortoise handling practice 2	GBI Field Station	Christopher/ Markowski
	Recognizing tortoise sign presentation	GBI Field Station	Mitchell
	Scoring tortoise visibility presentation	GBI Field Station	Mitchell
	Compass course 2	GBI Field Station	Markowski
	Practice epoxy for tag attachment 2	GBI Field Station	Markowski
22 March	Training lines 2 (16 km)	BLM DTMA	Cash/Markowski
23 March	Training lines 2 (continued)	BLM DTMA	Cash/Markowski
25 March	Review training line 2 results	GBI Field Station	Mitchell/Cash/ Markowski
	Standard protocol & non-standard transects, interruptions exercise	GBI Field Station	Mitchell/Cash/ Markowski
	GPS & compass presentation	GBI Field Station	Cash/Markowski
	Survey123 presentation & exercise	GBI Field Station	Cash/Markowski
26 March	Full 12-km practice transect 1 with interruption for terrain	Large Scale Translocation Site (LSTS)	Cash
	Training lines 3 (2 teams)	BLM DTMA	Markowski
27 March	Review practice transect 1	GBI Field Station	Mitchell/Cash/ Markowski
	Review training line 3 results	GBI Field Station	Mitchell/Cash/ Markowski
	Monitoring on public lands presentation	GBI Field Station	Mitchell
	Non-standard transects & reflections exercise	GBI Field Station	Mitchell/Cash/ Markowski
	Tortoise handling practice 3	GBI Field Station	Mitchell/Cash/ Markowski
28 March	Full 12-km practice transect 2 with reflection	LSTS	Markowski
29 March	Review practice transect 2	GBI Field Station	Mitchell/Cash/ Markowski

Table 3. Training schedule for 2024 for GBI Amargosa Valley transect crews.

Date	Activity	Location	Instructors
11 March	Mojave Desert & tortoise ecology presentation	GBI Field Station	Christopher
	Compass introduction	GBI Field Station	Cash/Martin
14 March	Distance estimation presentation	GBI Field Station	Mitchell
	Training lines presentation & practice	GBI Field Station	Mitchell/ Christopher
	Compass course 1	GBI Field Station	Martin
	Practice epoxy for tag attachment	GBI Field Station	Christopher
	Survey123 presentation & practice	GBI Field Station	Cash
15 March	Training lines I (8 km)	BLM DTMA	Cash/Martin
18 March	Review training line 1 results	GBI Field Station	Mitchell/Cash/ Martin
	Training lines 2 (16 km)	BLM DTMA	Cash/Martin
19 March	Training lines 2 (continued)	BLM DTMA	Cash/Martin
20 March	Biosecurity presentation	GBI Field Station	Dr. Johnson
	Tortoise handling practice 1	GBI Field Station	Dr. Johnson/Cash/ Christopher/ Mitchell
	Recognizing tortoise sign presentation	GBI Field Station	Mitchell
	Scoring tortoise visibility presentation	GBI Field Station	Mitchell
	Compass course 2	GBI Field Station	Martin
	Practice epoxy for tag attachment 2	GBI Field Station	Martin
21 March	Search image for tortoises & sign	River Mountains, NV	Sparks
22 March	Tortoise handling practice 2	GBI Field Station	Christopher/Martin
	Review training line 2 results	GBI Field Station	Mitchell/Cash/ Martin
25 March	Standard protocol & non-standard transects, interruptions exercise	GBI Field Station	Mitchell/Cash/ Martin
	GPS and compass presentation	GBI Field Station	Cash/Martin
	Survey123 presentation & exercise	GBI Field Station	Cash/Martin
26 March	Full 12-km practice transect 1 with interruption for terrain	LSTS	Cash/Martin
	Training lines 3 (4 teams)	BLM DTMA	Cash/Martin
27 March	Tortoise handling practice 3	GBI Field Station	Christopher
	Review practice transect 1	GBI Field Station	Mitchell/Cash/ Martin
	Review training line 3 results	GBI Field Station	Mitchell/Cash/ Martin
	Monitoring on public lands presentation	GBI Field Station	Mitchell
	Non-standard transects & reflections exercise	GBI Field Station	Mitchell/Cash/ Martin
28 March	Full 12-km practice transect 2 with reflection	LSTS	Cash/Martin
29 March	Review practice transect 2	GBI Field Station	Mitchell/Cash/ Martin

Table 4. Training schedule for 2024 for GBI telemetry technicians.

Date	Activity	Location	Instructors
6 March	Survey123 presentation & practice	GBI Field Station	Cash
11 March	Mojave Desert & tortoise ecology presentation	GBI Field Station	Christopher
14 March	Telemetry training	GBI Field Station	Sparks
	Distance estimation presentation	GBI Field Station	Mitchell
	Compass course 1	GBI Field Station	Martin
	Practice epoxy for tag attachment 1	GBI Field Station	Christopher
15 March	Telemetry training	GBI Field Station	Sparks
18 March	Telemetry practice	River Mountains, NV; Piute-Mid Focal Site, NV	Sparks/Richardson
19 March	Telemetry practice	Boulder City Conservation Easement (BCCE)	Sparks
20 March	Biosecurity presentation	GBI Field Station	Dr. Johnson
	Tortoise handling practice 1	GBI Field Station	Dr. Johnson/Cash Christopher/ Mitchell
	Scoring tortoise visibility presentation	GBI Field Station	Mitchell
	Recognizing tortoise sign presentation	GBI Field Station	Mitchell
	Compass course 2	GBI Field Station	Martin
	Practice epoxy for tag attachment 2	GBI Field Station	Martin
21 March	Telemetry practice	BCCE and Halfway Wash Focal Site, NV	Sparks/Richardson
22 March	Tortoise handling practice 2	GBI Field Station	Christopher/Cash/ Mitchell
25 March	Telemetry practice	BCCE	Sparks/Richardson
26 March	Telemetry practice	Stump Springs and Trout Canyon, NV	Sparks/Richardson
27 March	Tortoise handling practice 3	GBI Field Station	Christopher/Cash/ Mitchell
	Monitoring on public lands Presentation	GBI Field Station	Mitchell
28 March	Telemetry to derive start times	Halfway Wash, Piute-Mid, and Stump Springs Focal Sites, NV	Sparks
29 March	Telemetry to derive start times	Halfway Wash, Piute-Mid, and Stump Springs Focal Sites, NV	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 data manager provided by GBI. Data were compiled 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 based on templates created by USFWS were provided by the Phase I data manager to the field teams, who then worked with the teams 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 Universal Transverse Mercator (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.

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). Because each of the pairs on a team typically contributes the same number of transects to the effort, and because each field team works in geographically different sites, one detection curve for each field team each year is developed. The encounter rate is less sensitive to small sample sizes, so it was estimated for each stratum separately.

The Distance package in R (Miller et al. 2019) 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 with an MCL of at least 180 mm. Transects were packaged into monitoring strata (“regions” in Distance).

Observation data were truncated to remove outliers and improve model fit as judged by the shape 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 that truncation was applied conservatively to maximize the number of observations per stratum. AIC was used to compare detection-function models (uniform, half normal, and hazard-rate) and key function/series expansions (none, cosine, simple polynomial, hermite polynomial) at the same truncation distance (Buckland et al. 2001).

Because Chocolate Mountains Aerial Gunnery Range is a heavily scheduled training facility, tortoise surveys are timed to coincide with closure and Explosive Ordinance Disposal (EOD) clearance of the south, followed by the north range. There are therefore two separate survey periods used to cover both ranges, so density estimates are calculated separately for each range and then combined for reporting the range density.

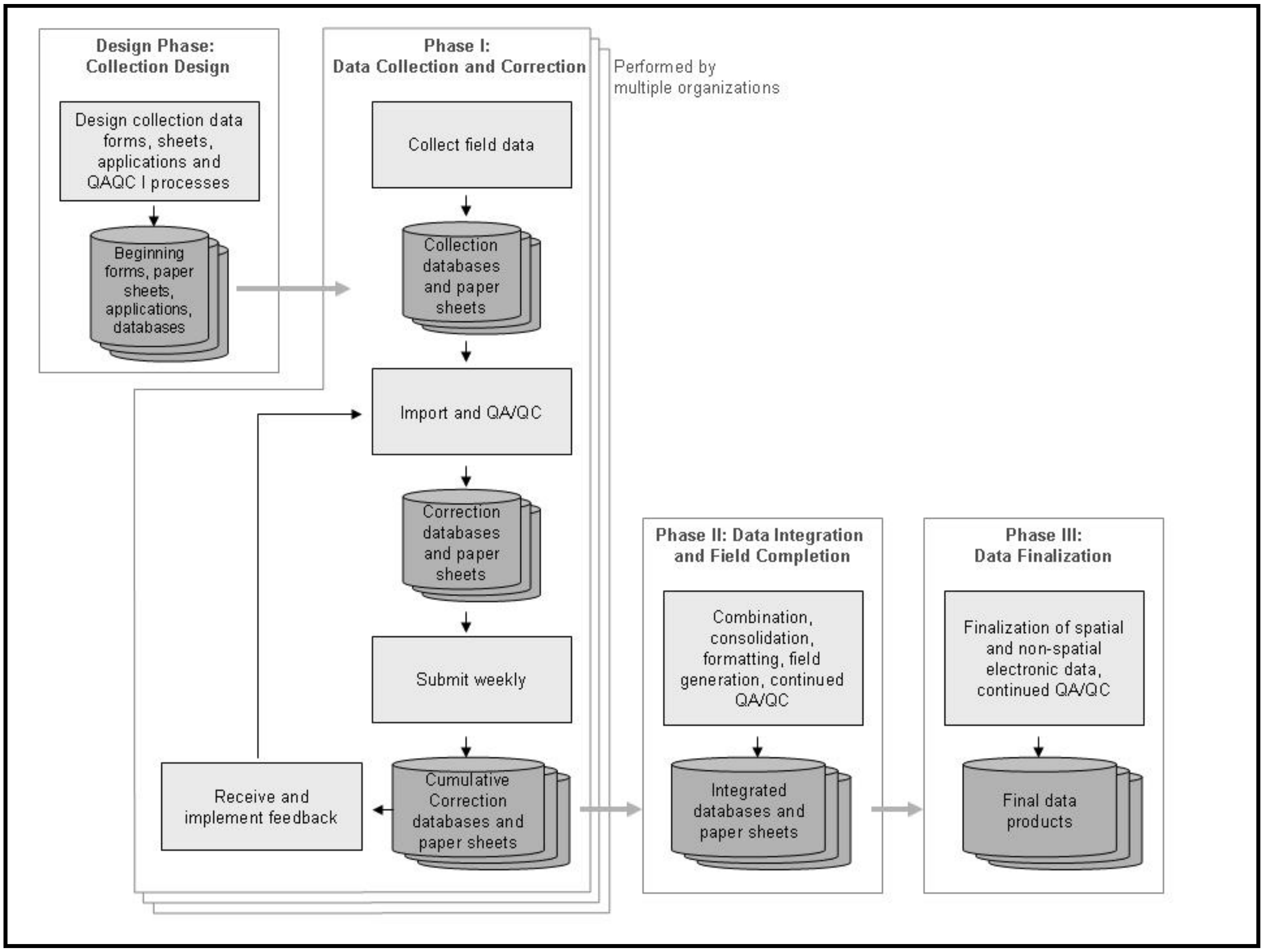

Figure 2. Data flow from collection through final products.

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 meters 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): $p = (\text{lead}-\text{follow})/\text{lead}$, where lead = the number of tortoises first seen by the observer in the leading position and follow = the number of tortoises seen by the observer in the follower position. The corresponding proportion detected near the line by two observers was estimated by $g = 1 - q^2$, where $q = 1 - p$. Figure 3 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 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 meter on each side of the transect line) results in few observations to precisely estimate $g(0)$. Instead, a 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 meter of the transect centerline, and the variance of $g(0)$ is estimated as twice the variance of p.

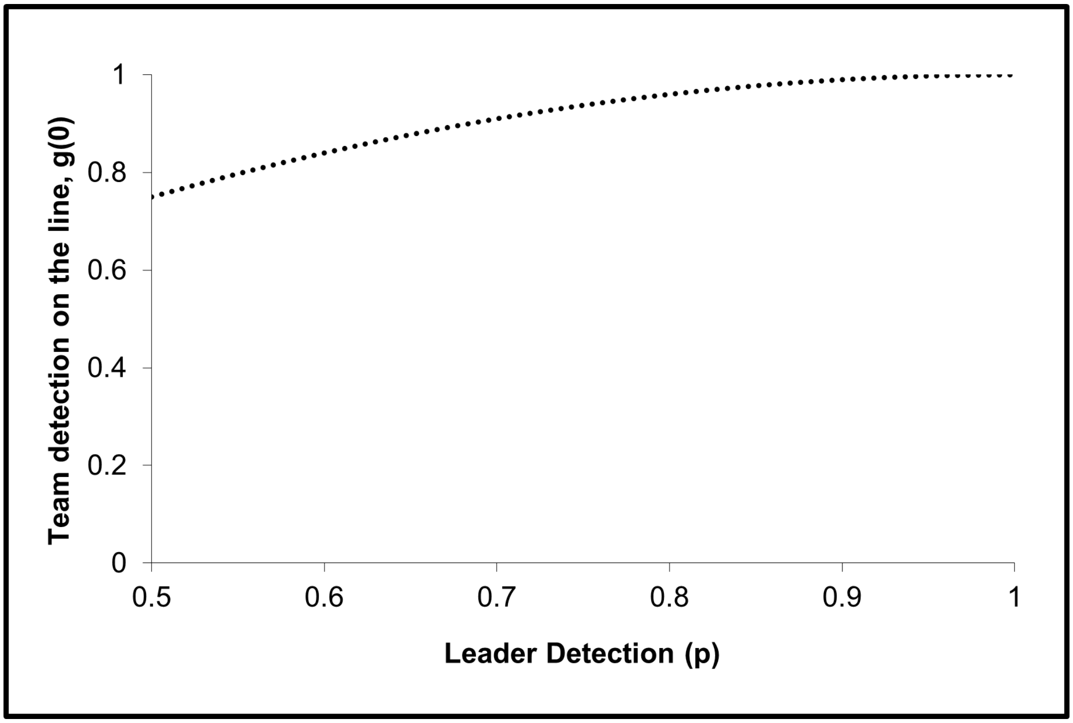

Figure 3. Relationship between single-observer detections (by the leader, *p*) and dual-observer (team) detections, *g(0)*.

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, 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 the Distance package in R. The encounter rate (n/L) and its variance were estimated 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, was estimated jointly for all survey pairs due to low detections per pair. A schematic of the process leading to density estimates is given in Table 5. Each of the four right-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 are combined from left to right to generate stratum density estimates.

Table 5. Process for developing density estimates in 2024. For each estimate (one for each of the four right-hand columns), the full set of data were factored as indicated by divisions within the columns.

<table>
<tr><th></th><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></tr>
<tr><td>Recovery Unit</td><td>Stratum</td><td>Neighboring G_0 Sites</td><td>Data Collection Group</td><td>Overall</td></tr>
<tr><td rowspan="2">Eastern Mojave</td><td>Amargosa Valley</td><td rowspan="2">Stump Springs</td><td rowspan="5">Great Basin Institute</td><td rowspan="8">All data</td></tr>
<tr><td>Pahrump</td></tr>
<tr><td rowspan="2">Northeastern Mojave</td><td>Beaver Dam Slope</td><td rowspan="2">Halfway Wash</td></tr>
<tr><td>Coyote Springs</td></tr>
<tr><td rowspan="2">Colorado Desert</td><td>Piute Valley</td><td>Piute-Mid</td></tr>
<tr><td>Chocolate Mountain Aerial Gunnery Range</td><td>Chuckwalla</td><td rowspan="3">Kiva</td></tr>
<tr><td rowspan="2">Western Mojave</td><td>Fremont-Kramer</td><td>Superior-Cronese</td></tr>
<tr><td>Ord-Rodman</td><td>Ord Rodman</td></tr>
</table>

Results

Field observer training

Training in 2024 lasted from 20 February – 29 March (Tables 1-4). Tests of field detection abilities occurred toward the end of each period, as indicated in the schedules.

Proportion of tortoises detected at distances from the transect centerline

Table 6 reports the proportion of models that were available and were detected over 8-16 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 11 of the 22 crews achieved this.

Table 6. Proportion of tortoise models detected in 2024 by crews within 1-, 2-, or 5-m of the transect centerline. Crews 1-6 surveyed for Kiva Biological; the remaining crews surveyed for Great Basin Institute.

Crew Number	1 m	2 m	5 m
1	1.00	1.00	0.91
2	1.00	1.00	0.97
4	1.00	1.00	0.95
5	1.00	1.00	0.94
6	0.93	0.92	0.93
10	1.00	1.00	0.86
11	0.92	0.92	0.87
12	1.00	1.00	0.94
13	0.93	0.92	0.87
14	0.83*	0.86*	0.88
15	0.86*	0.83*	0.79
17	1.00	1.00	0.93
18	0.92	0.96	0.80
19	0.86*	0.93	0.86
20	0.93	0.92	0.92
21	1.00	1.00	0.91
22	1.00	1.00	0.91
23	1.00	0.96	0.90
24	1.00	0.96	0.94
25	0.92	0.96	0.91
26	0.87*	0.89*	0.88
27	1.00	0.96	0.93
39	0.94	0.96	0.91
Kiva	**0.99**	**0.98**	**0.94**
GBI	**0.94**	**0.95**	**0.89**
Overall	**0.95**	**0.95**	**0.90**

*Values that scored below the target 0.90 at 1- (column 2) and 2-m (column 3) (also highlighted gray).

Table 7 gives the average [absolute] difference between the expected and measured perpendicular distances from the model to the walked line. All measurements for all models detected out to 25 m during the evaluated 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 within 2 m of centerline 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 the leader was 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.

Table 7. Diagnostics for individual crews after training in 2024. Column 2 represents the proportion of all models within 2 m of the transect line that were found by the leader. Column 3 represents the proportion of models within 2 m of the transect line that were found by the team (leader and follower). Column 4 represents the average absolute difference in meters between the expected and measured perpendicular distances from the model to the transect line based on all models detected out to 25 m. Column 5 represents the total number of models estimated based on the best-fitting detection model selected for each team with 95% lower and upper confidence intervals for abundance estimates represented by the columns 6 and 7, respectively.

Crew Number	Proportion available models within 2 m of centerline by leader	Proportion available models within 2 m of centerline by team	Measured versus exact distance (m)	Estimated Abundance	95% CI Lower limit	95% CI Upper limit
1	1.00	1.00	0.56	395.4	339.9	459.9
2	0.92	1.00	0.62	400.6	354.0	453.3
4	0.96	1.00	0.63	413.4	313.7	544.7
5	0.96	1.00	0.72	424.5	317.6	567.2
6	0.85	0.92	0.61	388.1	345.9	435.4
10	0.89	1.00	1.10*	470.1	381.0	580.0
11	0.77*	0.92	0.99	397.1	347.1	454.2
12	0.86	1.00	1.02*	453.8	297.4	692.3
13	0.81	0.92	0.58	356.8	315.6	403.4
14	0.86	0.86*	1.02*	382.9	317.2	462.2
15	0.83	0.83*	0.63	370.5	275.0	499.2
17	0.89	1.00	0.75	403.1	325.1	499.8
18	0.93	0.96	0.80	398.8	324.4	485.9
19	0.93	0.93	0.68	425.1	322.9	559.6
20	0.88	0.92	0.91	407.3	286.7	578.4
21	0.93	1.00	0.96	407.4	319.8	519.1
22	0.85	1.00	0.77	407.5	325.3	510.6
23	0.96	0.96	0.65	376.3	330.9	428.0

Crew Number	Proportion available models within 2 m of centerline by leader	Proportion available models within 2 m of centerline by team	Measured versus exact distance (m)	Estimated Abundance	95% CI Lower limit	95% CI Upper limit
24	0.86	0.96	0.85	370.3	337.3	406.5
25	0.96	0.96	1.04*	462.1	375.3	569.0
26	0.86	0.89*	0.71	378.6	327.6	437.7
27	0.96	0.96	0.56	380.3	331.6	436.0
39	0.88	0.96	0.97	488.8	403.9	591.4
Kiva	**0.94**	**0.98**	**0.63**	**406.9**	**331.1**	**503.2**
GBI	**0.88**	**0.95**	**0.83**	**407.6**	**330.2**	**506.3**
Overall	**0.90**	**0.95**	**0.79**	**406.9**	**331.1**	**503.2**

*Values that scored below the target 0.8 at 2-m by the leader (column 2), 0.90 at 2-m by the team (column 3), or above the target 1.0 m for measured distance (column 4) (also highlighted gray).

Although some individual metrics were below-target (gray cells in Tables 6 and 7), all teams performed well overall so after corrective instruction to fine tune search techniques of specific crews, no pairs were rebuilt. During training, detection curves were fit to each crew's set of tortoise model observations. In no case was the best-fitting model one without a "shoulder" describing detections near the centerline. The best-fitting detection curves for each team are plotted in Figures 4 and 5, and were used to generate abundance estimates in Table 7. Crews were not evaluated on their ability to match curves of teammates; however, such overlays were used to focus field personnel to 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).

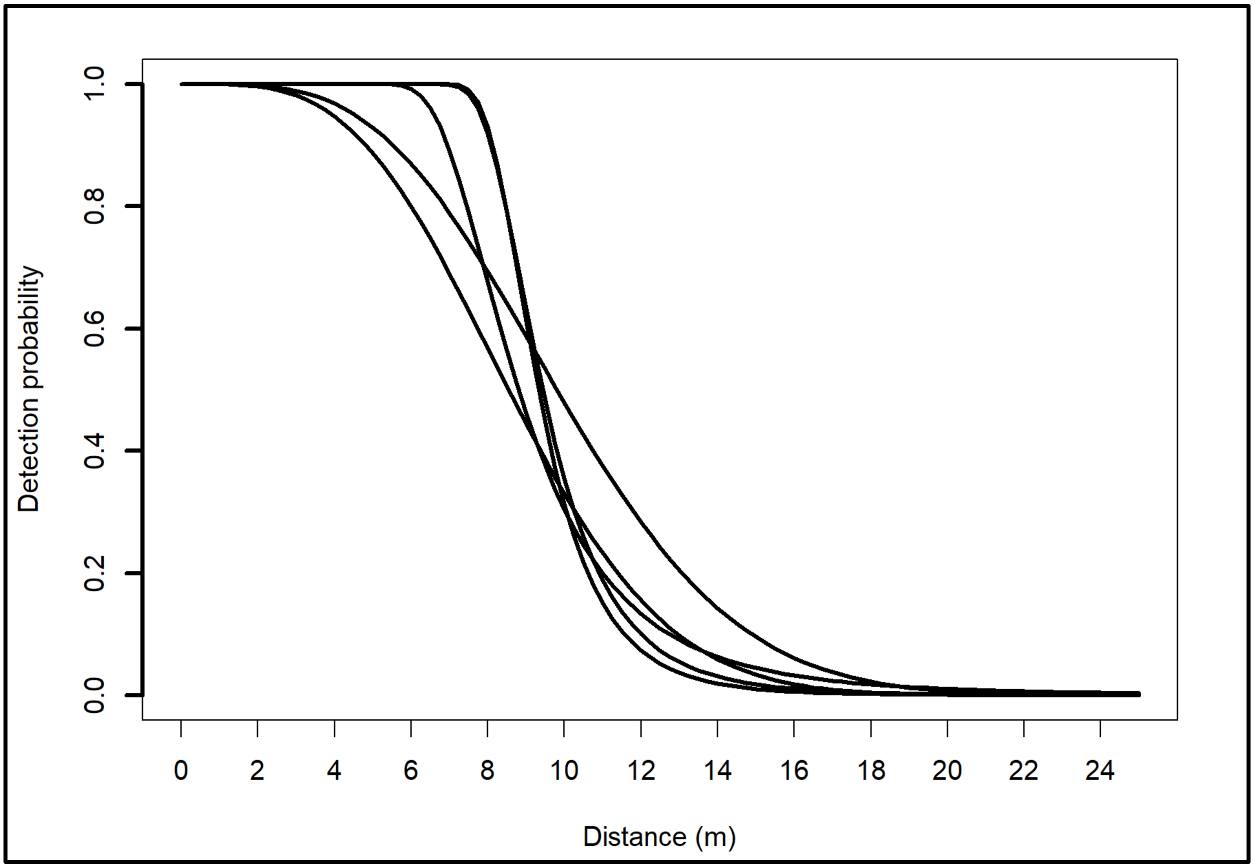

Figure 4. Detection curves for each of the 2024 Kiva crews during training. Each curve is based on a 16 km trial for one team with an average of 123 detections.

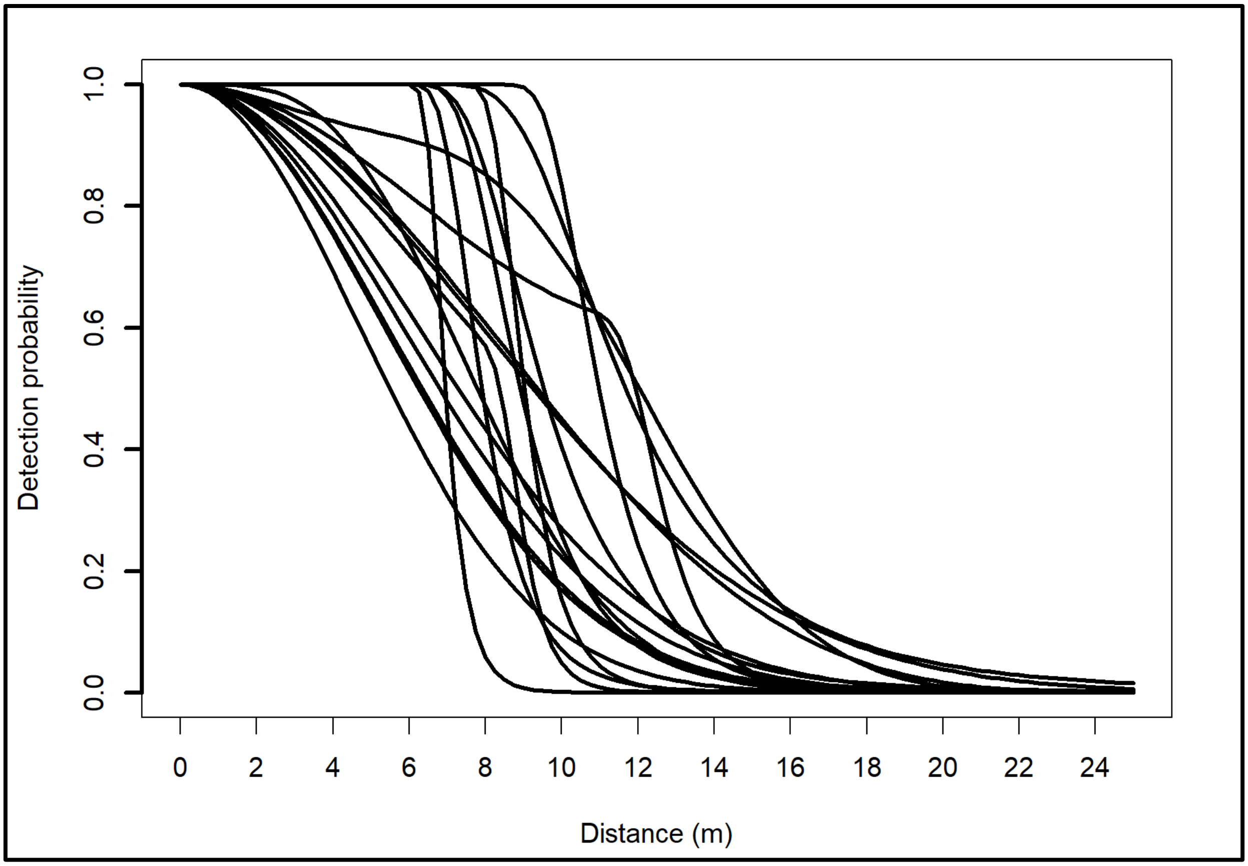

Figure 5. Detection curves for each of the 2024 GBI crews during training. Each curve is based on an 8-16 km trial for one team with an average of 105 detections.

Quality assurance and quality control

There were 14,736 transect records and 2862 G_0 records associated with the monitoring effort in 2024. The first level data specialists worked with the field teams to resolve 2947 cases with fields that were inconsistent with constraints and expectations. Forty percent (1192 instances) of recorded issues in 2024 were caused by a programming bug in the Survey123 data collection software that changed time entries without user knowledge. 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 393 issues remained or were discovered in the third (final) phase of QA/QC. Only 165 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 33 were corrected with recourse to paper datasheets. The remaining errors in 2024 were data processing errors (e.g., incorrect datasheet naming convention), not that the data were erroneous.

Transect completion

Table 8 reports the number of assigned and completed transects in each stratum in 2024. Table 8 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 6-10 show locations of transects and observations of live and dead tortoises.

Table 8. Number and completion of transects in each stratum in 2024.

Stratum	Assigned transects	Assigned and alternate transects completed	Assigned, completed 12-km	Assigned, completed shortened	Assigned, completed with a major reduction*
AV	90	90	72	18	0
BD	75	75	54	21	0
CS	78	78	40	34	4
PA	90	90	58	32	0
PV	60	60	44	15	1
GBI	393	393	268	120	5
AG	35	35	23	10	2
FK	50	50	43	6	1
OR	50	50	28	21	1
Kiva	135	135	94	37	4
Total	528	528	362	157	9
In long-term strata	348	348	232	107	8

*More than half the 12-km transect could not be walked due to terrain, weather, access, or other obstacles.

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

For predicting 2024 estimates of G_0, the best performing model was a generalized linear model which included stratum as a fixed effect. Estimates of G_0 for the focal sites used for the 2024 sampling effort are included in Table 9.

Table 9. Availability of tortoises (G_0) when transects were walked in 2024 in the same or in neighboring strata.

G_0 site	Stratum	Dates	Days	G_0 (Std Error)
Chuckwalla	Chocolate Mountain South	21 Feb - 25 Feb	5	0.58 (0.049)
Chuckwalla	Chocolate Mountain North	16 Mar - 18 Mar	3	0.61 (0.060)
Halfway Wash	Beaver Dam Slope	25 Apr - 13 May	19	0.66 (0.023)
Halfway Wash	Coyote Springs	11 Apr - 26 Apr	16	0.69 (0.022)
Ord Rodman	Ord-Rodman	20 Mar - 30 Mar	11	0.94 (0.020)
Piute-Mid	Piute Valley	2 Apr - 11 Apr	10	0.29 (0.023)
Stump Springs	Amargosa Valley	22 Apr - 9 May	18	0.83 (0.018)
Stump Springs	Pahrump	1 Apr - 22 Apr	22	0.69 (0.027)
Superior-Cronese	Fremont-Kramer	1 Apr - 10 Apr	10	0.96 (0.017)

Tortoise encounter rates and detection functions

All survey pairs worked together from the beginning to the end of the season with the exception of one surveyor from team 5 and one from team 6 who formed team 3 for a week in February. All Kiva crews surveyed 23-28 transects and overall, they detected 103 tortoises larger than 180 mm MCL (adults). GBI surveyors walked a median 24 transects and reported 66 adult tortoises. 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, separate curves for each team were most strongly supported. Kiva's detection pattern best fit a hazard-rate curve with no adjustments based all observations up to 30 m from the centerline. GBI's detection pattern best fit a hazard-rate curve with no adjustments using observations up to 22 m from the centerline. Figures 11 and 12 are histograms of the observed number of tortoises seen at increasing distance from the transect centerline. Truncation distance for Kiva removed no observations and resulted in good fit overall and near the centerline. All strata surveyed by Kiva had at least 20 observations. Truncation distance for GBI removed 2 of the observations and had a simple shape (no adjustments). None of the strata surveyed by GBI had 20 observations before truncation (Table 10). The detection rate for Kiva crews within 30 m of the transect centerline was 43.5% (CV=0.088) and for GBI crews it was 27.2% (CV=0.205) within 22 m of the transect centerline.

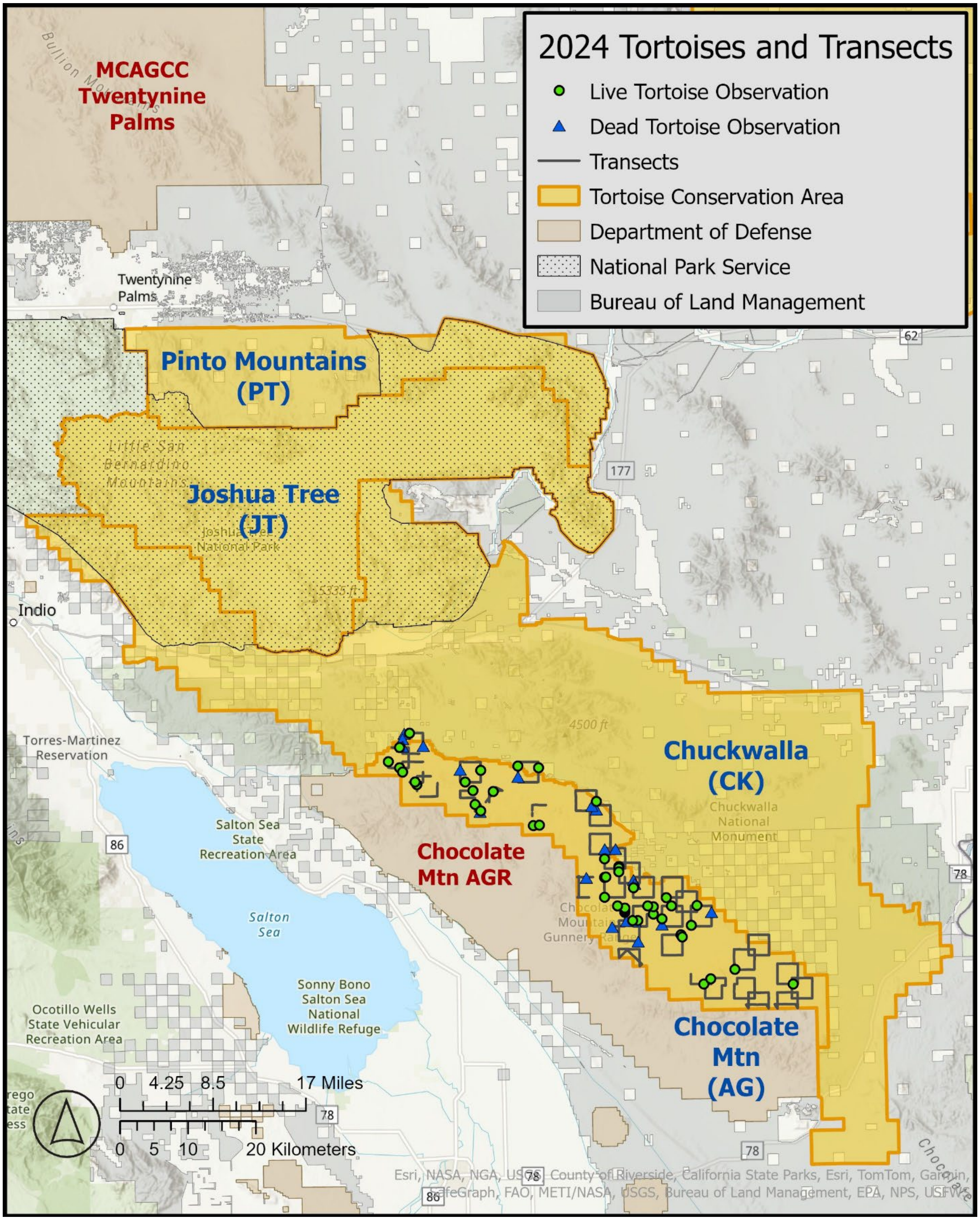

Figure 6. Distribution of distance sampling transects and tortoise observations in 2024 in Chocolate Mountain Aerial Gunnery Range stratum in the southern part of the Colorado Desert Recovery Unit.

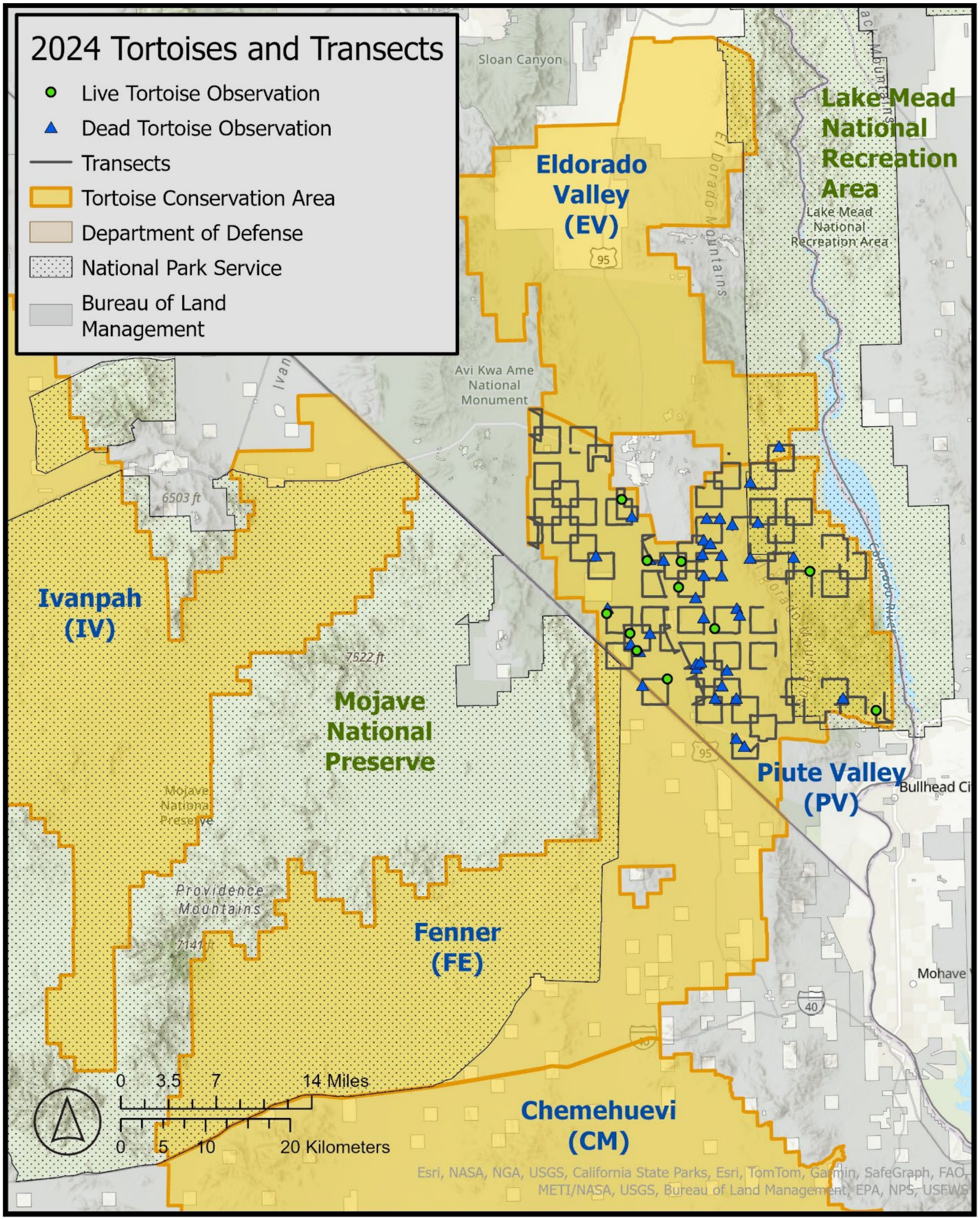

Figure 7. Distribution of distance sampling transects and tortoise observations in 2024 the Piute Valley stratum of the Colorado Desert Recovery Unit.

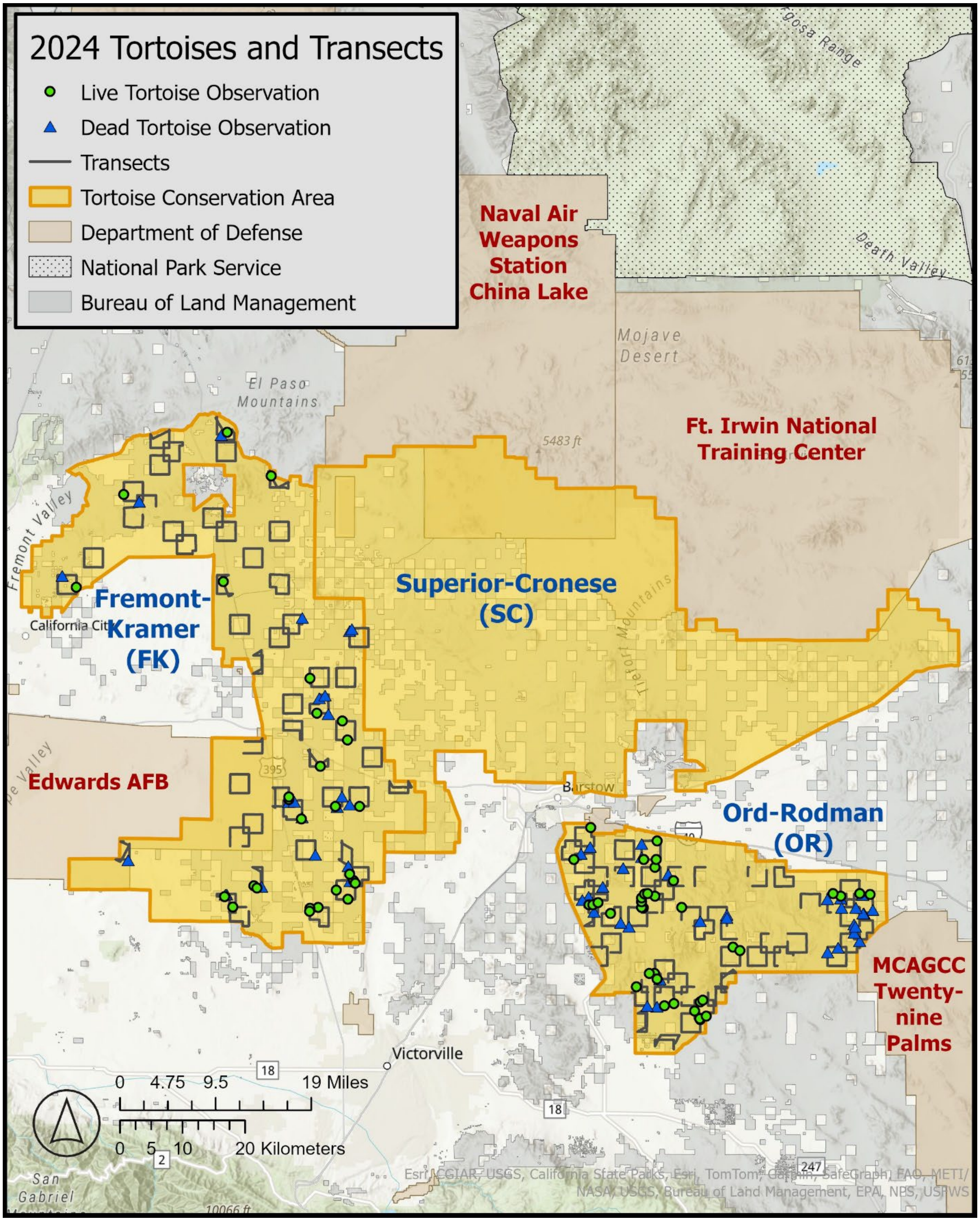

Figure 8. Distribution of distance sampling transects and tortoise observations in 2024 the Fremont-Kramer and Ord-Rodman strata of the Western Mojave Recovery Unit.

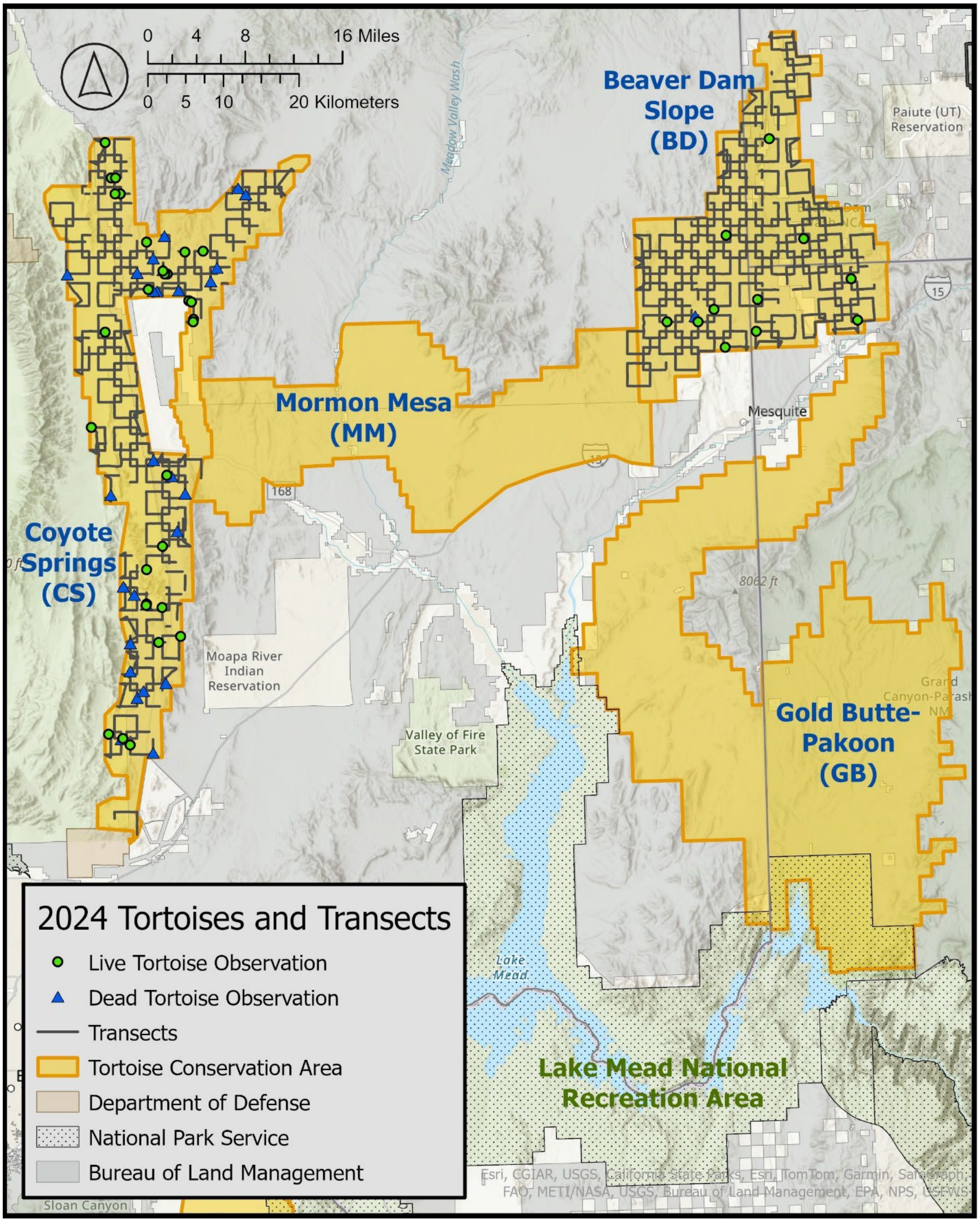

Figure 9. Distribution of distance sampling transects and tortoise observations in 2024 in the Coyote Springs Valley and Beaver Dam Slope strata of the Northeastern Mojave Recovery Unit.

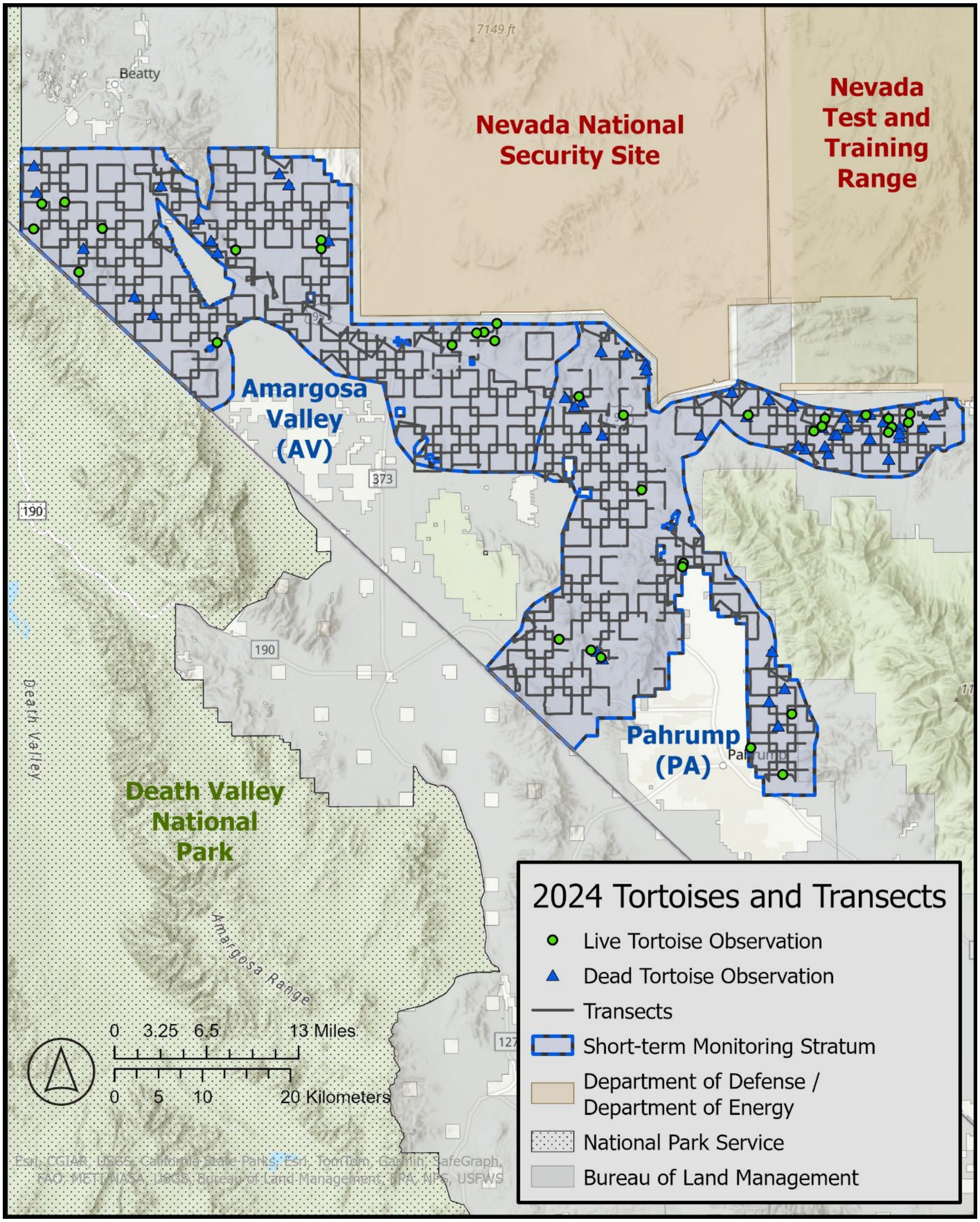

Figure 10. Distribution of distance sampling transects and tortoise observations in 2024 in Amargosa Valley and Pahrump short-term monitoring strata in the northern part of the Eastern Mojave Recovery Unit.

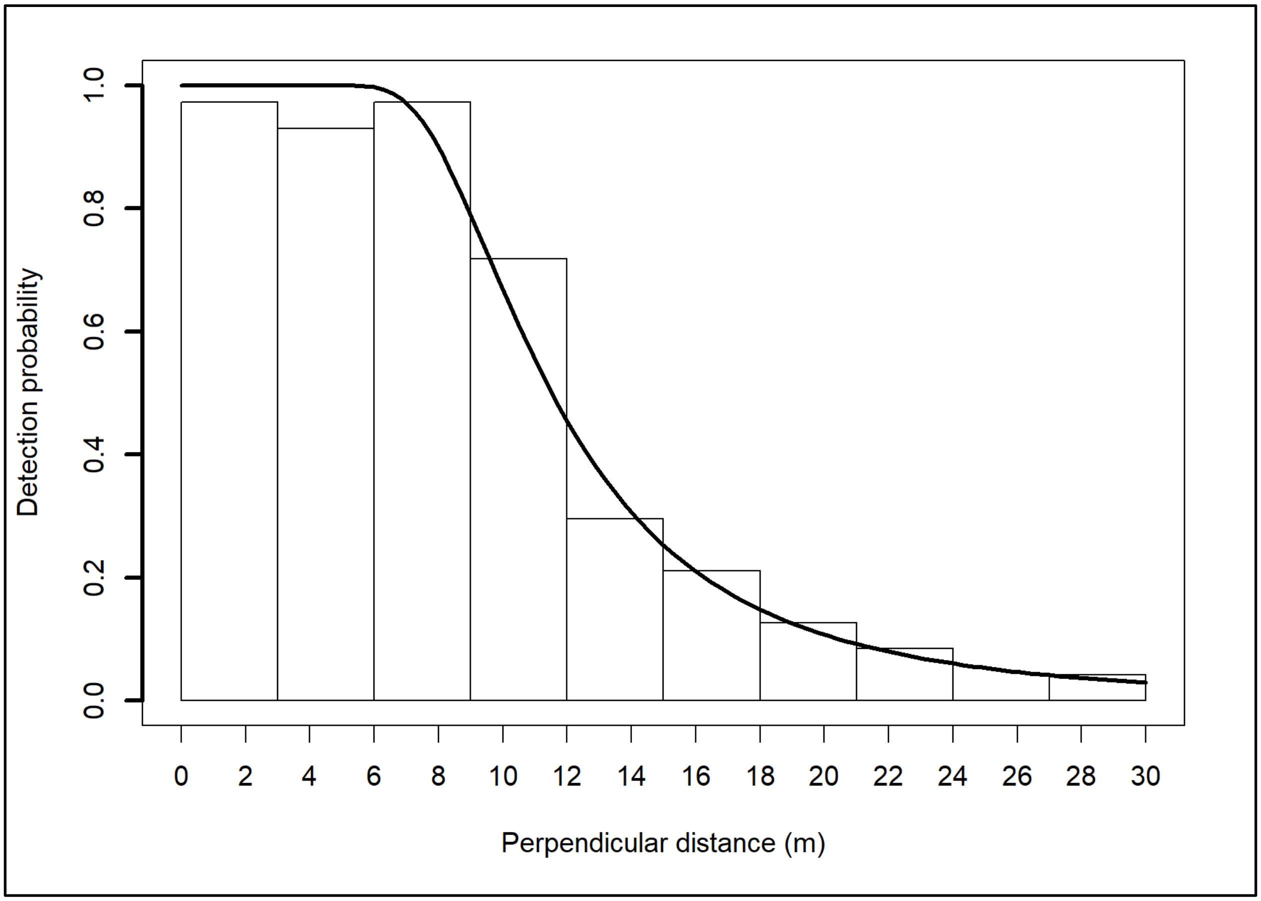

Figure 11. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180 mm found by Kiva in 2024. This curve uses the n=103 observations found within 30 m of the line.

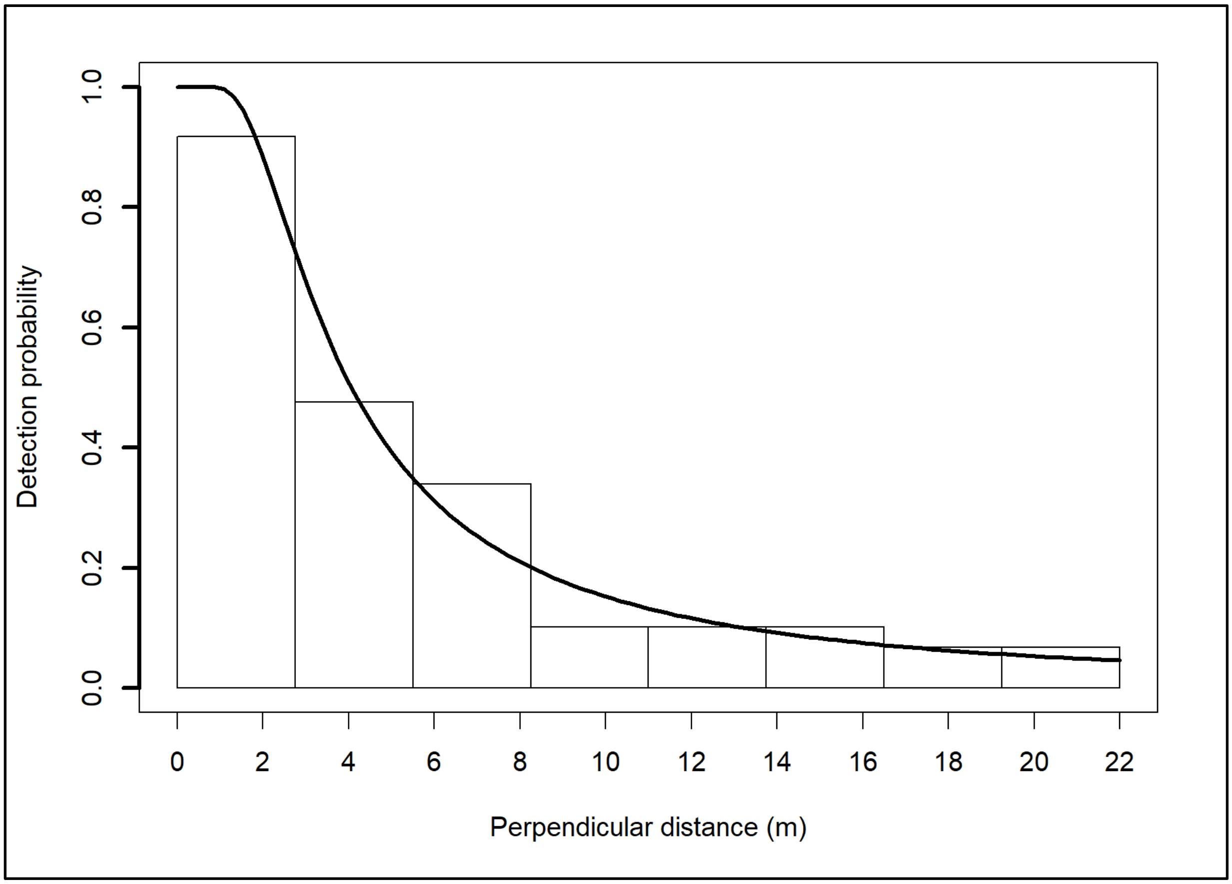

Figure 12. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180 mm found by GBI in 2024. This curve uses the n=64 observations found within 22 m of the line.

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 2024, for 38 detections of adult tortoises within 2 m of the transect centerline, 31 were found by the observer in the lead position and 7 by the follower, so that the probability of detection by single observer, $p = 0.774$, and the proportion detected using the dual observer method, *g(0 to 2 m)* = 0.949 (SE = 0.137). Figure 13 shows that *g(0)* was converging on 1.0 in 2024. 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, 2018, 2019, 2022a, 2022b, 2024b, 2025). Previous years of data and the pattern in Figure 13 indicate the assumption of perfect detection on the centerline was met; consequently, no adjustment was made to the final density estimate.

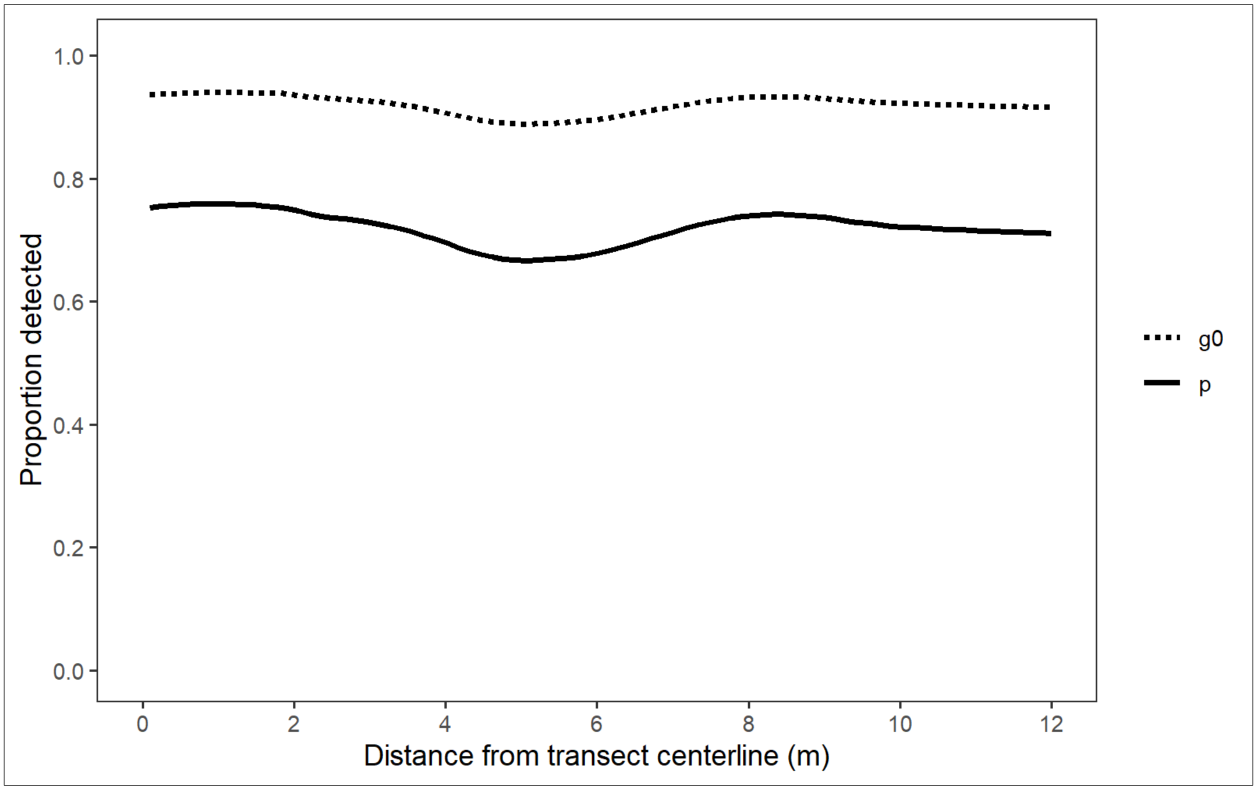

Figure 13. Detection pattern for the leader (*p*) and by the team (*g(0)*) based on all observations out to a given distance (*x*) from the centerline in 2024. Note convergence of *g(0)* on 1.0 as *x* goes to 0.

Estimates of tortoise density

Density estimates were generated separately for each monitoring stratum (Table 10). Because the north and south ranges of Chocolate Mountain Aerial Gunnery Range are surveyed consecutively, separate G_0 estimates were used to generate separate estimates for the north and south ranges before combining estimates proportional to their area.

Table 10. Stratum-level encounters and densities in 2024 for tortoises of MCL ≥ 180 mm.

Recovery Unit/ Stratum		Area (km^2)	n (tortoises observed)	# Transects	Transect length (km)	Begin date	End date	Tortoise density (/km^2)			
								Density	Lower limit, 95% CI	Upper limit, 95% CI	%CV
Western Mojave			**60**	**100**	**1102**	**20-Mar**	**10-Apr**				
Fremont-Kramer	FK	2417	26	50	583	1-Apr	10-Apr	1.8	1.1	2.9	25.54
Ord-Rodman	OR	1124	34	50	519	20-Mar	30-Mar	2.7	1.7	4.1	22.76
Colorado Desert			**52**	**95**	**1035**	**21-Feb**	**11-Apr**				
Chocolate Mtn north	AGN	351	19	15	149	16-Mar	18-Mar	8.0	4.7	13.7	27.76
Chocolate Mtn south	AGS	403	24	20	227	21-Feb	25-Feb	7.0	4.0	12.0	28.24
Chocolate Mtn	AG	755	43	35	377	21-Feb	18-Mar	7.4	4.9	11.1	20.77
Piute Valley	PV	1070	9	60	659	2-Apr	11-Apr	4.0	1.8	8.6	22.76
Northeastern Mojave			**29**	**153**	**1643**	**11-Apr**	**13-May**				
Beaver Dam Slope	BD	828	11	75	839	25-Apr	13-May	1.7	0.9	3.3	35.02
Coyote Springs Valley	CS	1025	18	78	804	11-Apr	26-Apr	2.7	1.3	5.6	37.95
Eastern Mojave			**26**	**180**	**2021**	**1-Apr**	**9-May**				
Amargosa Valley	AV	1047	11	90	1045	22-Apr	9-May	1.1	0.5	2.4	44.11
Pahrump	PA	1004	15	90	976	1-Apr	22-Apr	1.9	1.0	3.5	33.18

DISCUSSION

After an abbreviated effort in 2023, additionally funding allowed for range-wide monitoring efforts to ramp up again in 2024 and included surveys at six long-term strata as well as two new short-term strata located in an understudied area at the northern edge of the species' range. Since 2001, the desert tortoise range-wide monitoring effort has largely been focused on surveying in centralized core regions, predominantly within designated TCAs derived primarily from USFWS designated critical habitat for the desert tortoise as well as contiguous areas with high potential for tortoise habitat (Nussear et al. 2009) and compatible management (e.g. National Park Service, BLM Areas of Environmental Concern, Department of Defense installations, etc.). TCAs make-up over 7.1 million acres of tortoise habitat and this approach allows for efficient resource allocation and consistent long-term data collection across this vast landscape, however, outside these core zones, peripheral tortoise populations often remain critically understudied and population dynamics largely unknown.

The Amargosa Valley of Nevada is located at the northern edge of known desert tortoise occupancy and this region is experiencing increased infrastructure development related to utility-scale renewable energy and other anthropogenic activities. Line distance sampling was conducted in areas surrounding Pahrump, NV in 2008 as part of range-wide monitoring efforts (USFWS 2012a); however, contemporary estimates of desert tortoise population densities do not exist for the larger area. In the spring of 2024, with supplemental funding provided by the BLM, range-wide monitoring efforts were expanded outside core long-term monitoring areas to include two new short-term monitoring strata in the greater Amargosa Valley region: Amargosa Valley (AV) and Pahrump (PA; Figure 10). Crews detected 11 adult tortoises over 1045 km of transects in AV and 15 adults over 976 km in PA. Additionally, four juvenile tortoises were detected in AV and six in PA, ranging in size from 55-178 mm MCL, an indication that reproduction and recruitment are occurring. Resulting density estimates in both strata are low and below the species' minimum viable density threshold (3.9/km^2; USFWS 1994), however, based on the most recent trend analysis, estimates are in line with predicted densities for other core areas in the same Recovery Unit, the Eastern Mojave (Zylstra et al. 2023). Populations at the edges of a species' range, such as those in the greater Amargosa Valley, often experience different habitat and environmental conditions from those at the core and may harbor unique genetic traits and adaptations that may be essential for long-term resilience to environmental changes (Parandhaman 2023; Rehm et al. 2015). Furthermore, a northward shift of suitable habitat over time is predicted based on recent modeling efforts and maintaining intact habitat in this region could become increasingly important for future recovery efforts (Parandhaman 2023). While this survey effort provides important information on the status and distribution of this understudied population, given its potential future importance under shifting climatic conditions, further focused studies may be needed to help determine the most effective management strategies needed to maintain and support this population going forward.

After years of prolonged drought (Williams et al. 2022), the Mojave and Colorado desert regions experienced two normal to wet winters back-to-back leading to most of the region no longer under severe drought conditions in time for the spring 2024 monitoring effort. Additionally in early 2024, parts of the region were impacted by a powerful atmospheric river and crews surveying early in the season experienced signs of flooding along with rain on transects. The return to normal precipitation levels in the two winters preceding the spring 2024 surveys likely led to the improved encounter rates within long-term monitoring strata this year (26.6 km/adult) where crews detected more tortoises per each km surveyed than in 2022 (34.7 km/adult), a drought year. However, encounter rates and tortoise detections have not yet rebounded to rates observed on transects in years prior. This is likely because the effects that drought and extreme temperatures play in reducing encounter rates is twofold: an overall reduction in tortoise activity resulting in an immediate short-term effect of less tortoises above ground during a drought period (Duda et al. 1999, Freilich et al. 2000), and a longer-lasting effect of a decrease in tortoises on the landscape due to a reduction in survival. Drought, particularly prolonged drought, has been documented to negatively affect tortoise survival rates (Turner et al. 1984, Longshore et al. 2003, Lovich et al. 2023). While we observed that tortoise activity, as measured by G_0 correction factors, increased at many of the focal sites this year especially in the eastern portion of the range (except Piute-Mid where early in the season several tortoises remained under ground during surveys in the same area), tortoise populations have not yet rebounded, which may take many years and will require more winters with improved precipitation patterns similar to those experienced recently.

A similar range-wide monitoring survey effort is planned for 2025, with six TCAs scheduled to be surveyed: three in California and three in the Nevada and Arizona region. Additionally, supplemental surveys are planned in Nevada for the Stump Springs Regional Augmentation Site and Greater Trout Canyon Translocation Area.

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