RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE (*GOPHERUS AGASSIZII*): 2025 ANNUAL REPORTING AND 2001-2025 POPULATION TRENDS

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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 field surveys in California, while data in Nevada, Utah, and Arizona were collected by Great Basin Institute (GBI) led by T. Christopher, T. Cornell, 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:

> M. Bassett, S. Clegg, A. d'Epremesnil, A. Drummer, S. Galati, K. Garcia, E. Garman, M. Goodmuth, J. Goshen, E. Haney, K. Hayes, M. Hellebrandt, K. Hotchkiss, N. Ingle, A. Kalyn, A. Karpenok, A. Keir-Rodriguez, C. Killian, E. King, M. Leake, A. Lesniewski, E. Luttrell, J. Macias, K. Mayeda, T. Melville, N. Mendelsohn, S. Milan, A. Miller, S. Nelson, C. Patron, B. Scavone, E. Smith, R. Thoennes, R. Vance, C. Veety, and K. Wood.

R. Patil (GBI) updated the electronic data-collection forms and procedures. T. Cornell (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*, tortoise) throughout most of their range in the Mojave and Colorado deserts (USFWS 2011) requires range-wide, long-term monitoring to enable a data driven process for recovery action prioritization and to determine whether recovery goals are met. In 1999, the Desert Tortoise Management Oversight Group endorsed the use of line distance sampling (Buckland et al. 2001) for estimating tortoise density north and west of the Colorado River. From 2001 to 2025, except 2006, USFWS has coordinated the distance sampling monitoring program for 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 results for the 2025 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 for these areas rather than attempting to cover more strata in a less satisfactory manner. This approach continued in 2025, with crews completing 405 transects (4144.9 km) in 6 strata between 6 March and 28 May. In the course of these surveys, they reported 137 live tortoises, 118 (86%) of which were at least 180 mm midline carapace length (MCL) and used to generate density estimates.

In 2025, we surveyed 6 of the 16 long-term strata across Arizona, California, Nevada, and Utah. The highest estimated density in 2025 was in the Colorado Desert in the Chocolate Mountains Aerial Gunnery Range (10.2 adults/km^2), where densities were higher in the north (16.1 adults/km^2) than in the south (5.3 adults/km^2), a pattern previously seen. Other long-term strata surveyed in 2025 (and the estimated density of adults/km^2) were Eldorado Valley (1.6), Joshua Tree (3.0), Mormon Mesa (2.2), Gold Butte-Pakoon (1.5), and Superior-Cronese (2.5). Overall, the encounter rate averaged 35.1 km for each adult tortoise observed 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. Therefore, the most accurate stratum-level density estimates are currently 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. Trends from the beginning of the monitoring program in 2001 through 2020 were previously reported in Zylstra et al. (2023). To incorporate the full 25-year dataset, from 2001 to 2025, the hierarchical model was adapted, and those results are provided in this report.

RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE
2025 ANNUAL REPORTING AND 2001-2025 POPULATION TRENDS

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 2025. A more thorough description of the background of the monitoring program is provided in USFWS (2015), and previous use of annual density estimates to describe population trends from 2004-2014 is available in Allison and McLuckie (2018) and 2001-2020 in Zylstra et al. (2023). To incorporate the full 25-year dataset, from 2001 to 2025, the hierarchical model described in Zylstra et al. (2023) was adapted, and updated adult density trends are provided in this report.

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 these areas. 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 2025, surveys were conducted in California in the Chocolate Mountains Aerial Gunnery Range (AG), Joshua Tree (JT), and Superior-Cronese (SC) strata; and in Eldorado Valley (EV), Gold Butte-Pakoon (GB), and Mormon Mesa (MM) in Nevada and Arizona. Before surveys began in 2025, the Superior-Cronese stratum boundaries were altered to remove portions of the Western Training Area at the National Training Center and Fort Irwin due to planned expansion of training activities and ongoing translocation of tortoises from these areas (USFWS 2021).

The optimal number of transects completed 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). 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, however, was assigned with respect to the optimal numbers described above and 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. 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.

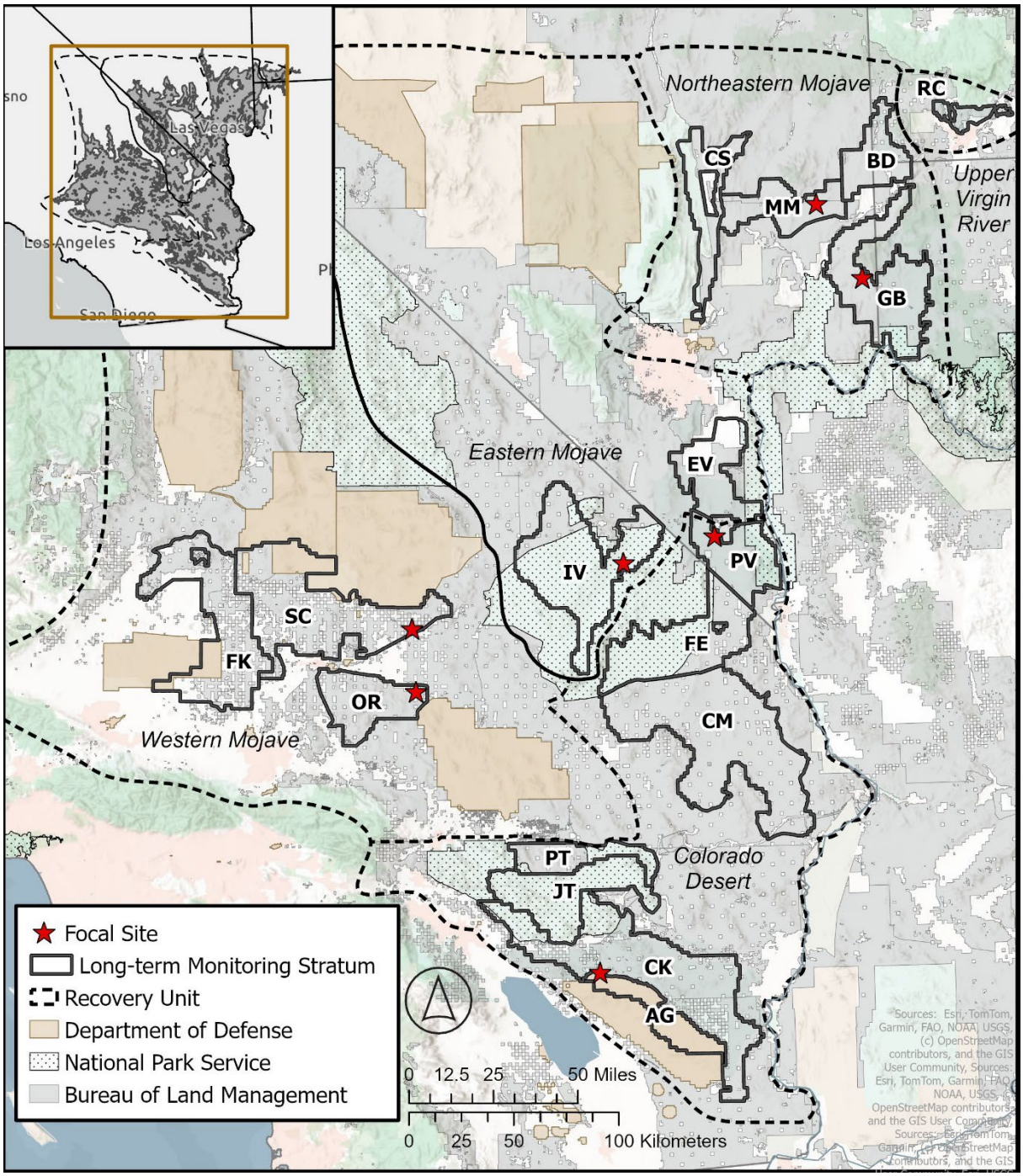


Figure 1. Long-term monitoring strata (n=17; dark gray outlined polygons) corresponding to tortoise conservation areas (TCAs; USFWS 2011) in each recovery unit. TCAs and their codes are Chocolate Mountains Aerial Gunnery Range (AG), Beaver Dam Slope (BD), Chuckwalla (CK), Chemehuevi (CM), Coyote Springs 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). 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 peak 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). Peak active periods coincide with production of their preferred food plants, suitable operative temperatures, and annual mating cycles. The annual range-wide monitoring effort is scheduled to match the spring peak 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 experience, we expect tortoises to become most active after 8:00 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 are assigned 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, which is used to indicate the transect centerline, maintain the appropriate spacing between the two observers, and facilitate measurement of the local transect bearing when a tortoise or carcass was detected. 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 distances from the transect centerline to tortoises are 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 to measure midline carapace length (MCL), determine its sex, record general health information, and apply a small alphanumeric 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 inclusion 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 4:00 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 2025, 5 focal sites, including Chuckwalla, Gold Butte, Halfway Wash, Piute-Mid, and Superior-Cronese were used, which correspond to the strata monitored this year. 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 for 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 transect experience with this monitoring program. Only 8 of 22 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 assigned practice transects (Table 1- 3). Ultimately each team was evaluated based on performance on a training course 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 during range-wide field surveys.

Table 1. Training schedule for 2025 for Kiva transect crews.

Date	Activity	Location	Instructors
28 February	Training lines 1 (8 km)	BLM Desert Tortoise Management Area (DTMA)	Mitchell
1 March	Review training line 1 results	GBI Field Station	Mitchell/Cornell
	Biosecurity and tortoise handling	GBI Field Station	Hayes/Bassett
	Scoring tortoise visibility presentation	GBI Field Station	Mitchell
	Survey123 presentation & practice	GBI Field Station	Mitchell/Cornell
2 March	Training lines 2 (8 km)	BLM DTMA	Mitchell
3 March	Review training line 2 results	GBI Field Station	Mitchell/Cornell
	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
	Wrap up discussion	GBI Field Station	Mitchell
4 March	Short practice transect (6 km) 1 with interruption for terrain and 1 reflection	Large Scale Translocation Site (LSTS)	Cornell/Hayes/ Bassett
5 March	Review practice transect	GBI Field Station	Mitchell/Cornell

Table 2. Training schedule for 2025 for GBI transect crews.

Date	Activity	Location	Instructors
11 March	Mojave Desert & tortoise ecology presentation	GBI Field Station	Christopher
	Compass introduction	GBI Field Station	Cornell
12 March	Distance estimation presentation	GBI Field Station	Mitchell
	Training lines presentation & practice	GBI Field Station	Mitchell/ Christopher
	GPS & compass presentation	GBI Field Station	Cornell

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

Table 3. Training schedule for 2025 for GBI telemetry technicians.

Date	Activity	Location	Instructors
11 March	Mojave Desert & tortoise ecology presentation	GBI Field Station	Christopher
	Compass introduction	GBI Field Station	Cornell

Date	Activity	Location	Instructors
12 March	Distance estimation presentation	GBI Field Station	Mitchell
	GPS & compass presentation	GBI Field Station	Cornell
	Compass course 1	GBI Field Station	Cornell
	Practice epoxy for tag attachment	GBI Field Station	Christopher
	Telemetry training	GBI Field Station	Sparks
	Survey123 presentation & practice	GBI Field Station	Cornell
13 March	Scoring tortoise visibility presentation	GBI Field Station	Mitchell
	Recognizing tortoise sign presentation	GBI Field Station	Mitchell
	Telemetry practice	Piute-Mid Focal Site, NV	Sparks
14 March	Biosecurity presentation	GBI Field Station	Dr. Johnson
	Tortoise handling practice 1	GBI Field Station	Mitchell/Cornell
17 March	Telemetry practice	Halfway Wash Focal Site, NV	Sparks
18 March	Telemetry practice	Gold Butte Focal Site, NV	Sparks
19 March	Search image for tortoises & sign	River Mountains, NV	Sparks/Cornell
24 March	Telemetry practice	GBI Field Station	Sparks
25 March	Telemetry practice	Boulder City Conservation Easement (BCCE), NV	Sparks
26 March	Monitoring on public lands presentation	GBI Field Station	Mitchell
	Practice epoxy for tag attachment 2	GBI Field Station	Mitchell/ Christopher
	Tortoise handling practice 2	GBI Field Station	Mitchell/Cornell/ Christopher
27 March	Telemetry practice	BCCE, NV	Sparks
28 March	Tortoise handling practice 3	GBI Field Station	Christopher/Cornell
	Telemetry to derive start times	Piute-Mid Focal Site, 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 typically 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.

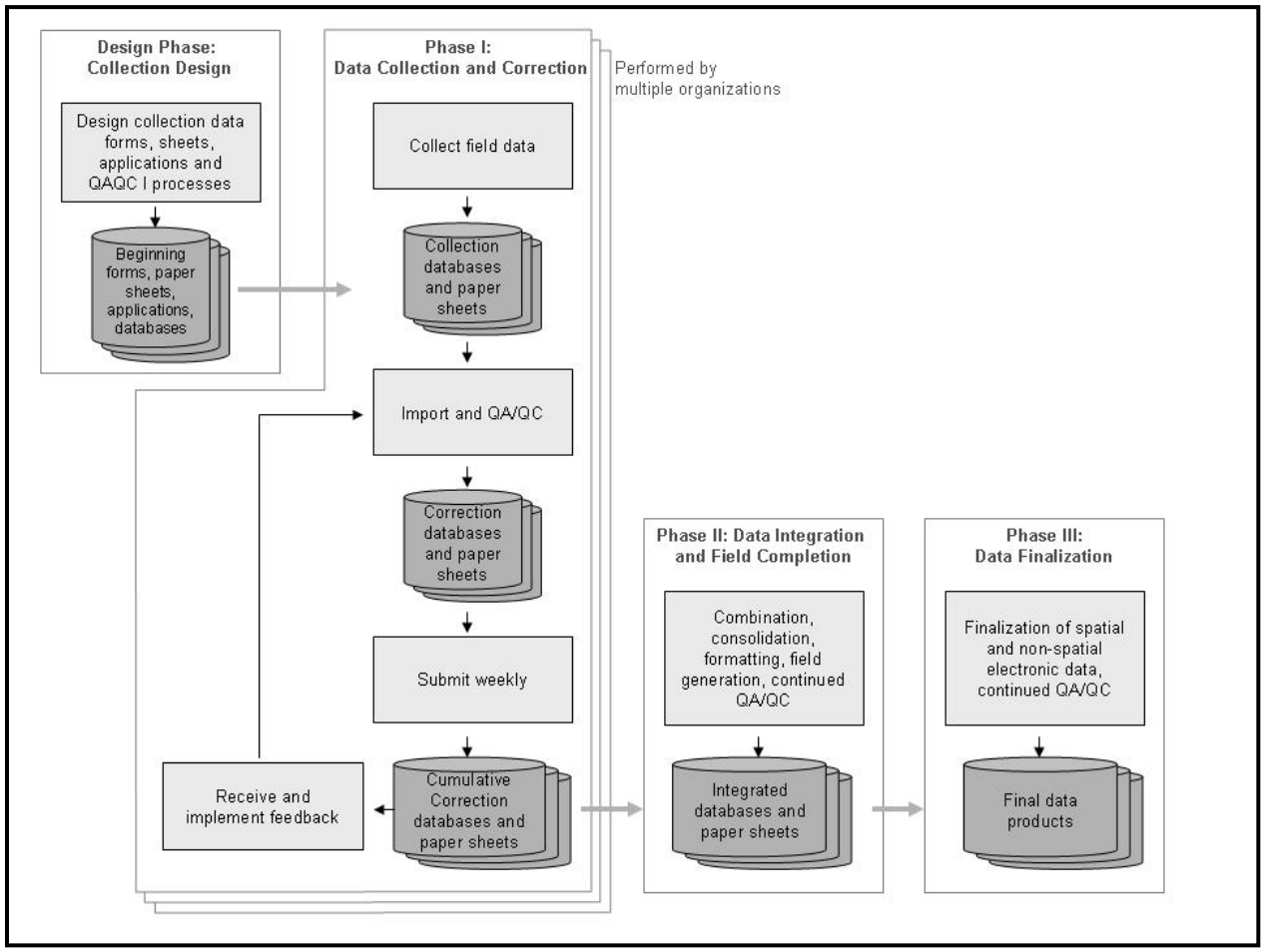


Figure 2. Data flow from collection through final products.

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

Transects were conducted by two-person crews using the method adopted 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 available for detection 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 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 crew 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 available for detection 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.

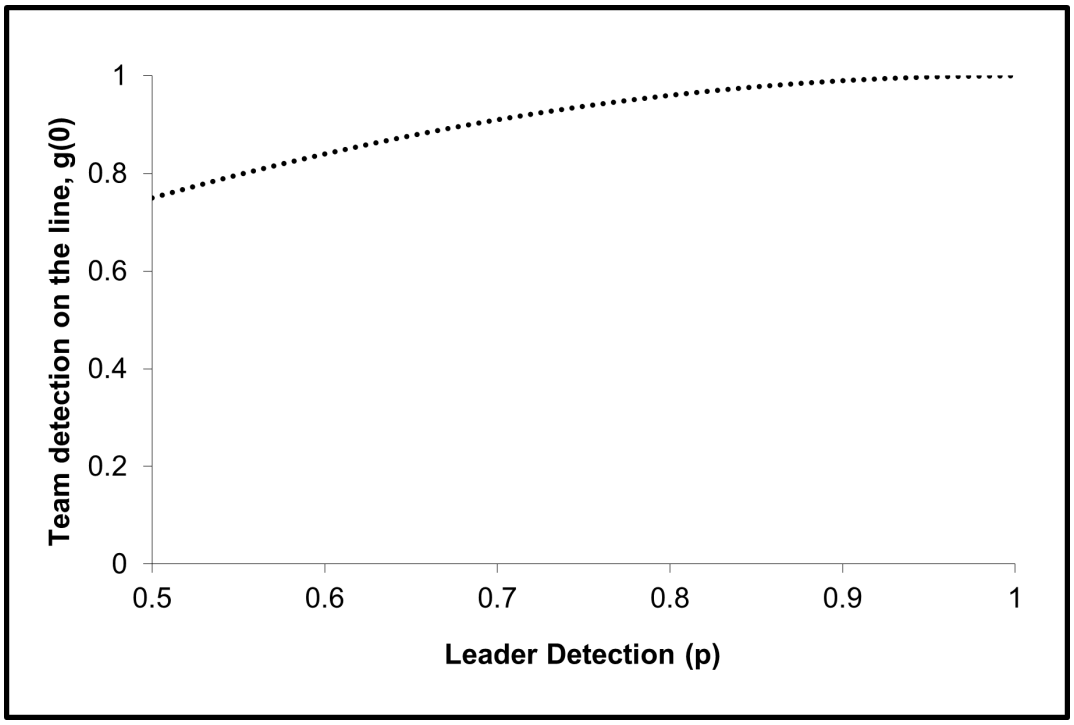


Figure 3. Relationship between single-observer detections (by the leader, *p*) and dual-observer (team) detections, *g(0)*.

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:

$$D = \frac{n}{2wLP_aG_0g(0)}$$

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 4. 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 4. Process for developing density estimates in 2025. 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>Eastern Mojave</td><td>Eldorado Valley</td><td>Piute-Mid</td><td rowspan="3">Great Basin Institute</td><td rowspan="6">All data</td></tr>
<tr><td rowspan="2">Northeastern Mojave</td><td>Gold Butte-Pakoon</td><td>Gold Butte</td></tr>
<tr><td>Mormon Mesa</td><td>Halfway Wash</td></tr>
<tr><td rowspan="2">Colorado Desert</td><td>Chocolate Mountain Aerial Gunnery Range</td><td rowspan="2">Chuckwalla</td><td rowspan="3">Kiva</td></tr>
<tr><td>Joshua Tree</td></tr>
<tr><td>Western Mojave</td><td>Superior-Cronese</td><td>Superior-Cronese</td></tr>
</table>

Population trend estimation: 2001-2025

Zylstra et al. (2023) developed a spatially explicit hierarchical distance-sampling model for the tortoise that accounts for both variation in detection probability and availability across surveys. The authors used the model to analyze data collected from the beginning of the monitoring program in 2001 through 2020 and reported density trends across most of the range over this period. To incorporate the 25-year line distance dataset, collected from 2001 to 2025, the hierarchical model was adapted, and those results are provided in this report. Methods described in Zylstra et al. (2023) were followed, however, when necessary, covariate layers were updated or substituted.

Due to a lag in in the release of Daymet precipitation data (Thornton et al. 2022) for the current year, high-resolution PRISM monthly precipitation data (PRISM Group, accessed 4 Feb 2026) were substituted and used to calculate the precipitation totals for each segment and telemetry site during the six month period preceding each survey (October to March) for the entire time series (2001-2025). PRISM monthly precipitation data were also used in lieu of Daymet precipitation data to obtain mean precipitation totals for October-March over a recent 30-year period (1981-2010) for each location, then the annual precipitation totals were divided by this value and used as a measure of whether winters were wetter or drier than normal as described in Zylstra et al.

(2023). Similarly, PRISM monthly precipitation data were used to obtain 30-year normals over the same period for winter (November-April) and summer (May-October) mean precipitation. In addition, raster layers representing impervious surfaces were created for 2024 by reclassifying developed land cover classes from the National Land Cover Database (USGS 2024) and recalculated for 2001 (LaMotte 2016) using the same processing methods. Impervious surfaces >40% in 2001 and 2024 were excluded for predicting densities in 2001 and 2025, respectively.

The model predictions reported in Zylstra et al. (2023) for 2001 may differ marginally from those outlined here, due to minor variations in precipitation data sources. Nevertheless, the credible intervals for these parameters overlap, indicating that the estimates are comparable. For further information regarding modeling methodologies and additional covariates, please refer to Zylstra et al. (2023).

RESULTS

Field observer training

Training in 2025 lasted from 28 February – 28 March (Table 1- 3). 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 5 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 7 of the 16 crews achieved this goal.

Table 5. Proportion of tortoise models detected in 2025 by crews within 1-, 2-, or 5-m of the transect centerline. Crews 1-5 surveyed for Kiva Biological; the remaining crews surveyed for Great Basin Institute.

Crew Number	1 m	2 m	5 m
1	0.86*	0.88*	0.86
2	1.00	1.00	0.90
3	1.00	1.00	0.97
4	0.92	0.96	0.87
5	0.85*	0.92	0.94
12	1.00	1.00	0.97
13	1.00	1.00	0.94
14	0.86*	0.88*	0.90
15	0.86*	0.92	0.87
16	0.92	0.96	0.90
17	0.85*	0.93	0.94
18	1.00	1.00	0.96
19	1.00	1.00	0.96
20	1.00	1.00	0.90
21	0.92	0.96	0.90
22	0.92	0.93	0.81
Kiva	**0.93**	**0.95**	**0.91**
GBI	**0.94**	**0.96**	**0.91**
Overall	**0.94**	**0.96**	**0.91**

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

Table 6. Diagnostics for individual crews after training in 2025. 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	0.91	0.88*	0.67	380.9	327.5	443.0
2	0.96	1.00	0.68	443.6	332.3	592.2
3	0.89	1.00	0.58	438.4	329.5	583.2
4	1.00	0.96	0.70	407.5	332.9	498.9
5	0.96	0.92	0.80	396.5	336.6	467.0
12	0.80	1.00	0.76	393.8	345.4	448.9
13	1.00	1.00	0.96	405.6	356.0	462.0
14	0.95	0.88*	0.96	364.0	315.7	419.7
15	0.83	0.92	0.84	392.6	302.6	509.4
16	0.93	0.96	0.94	381.6	316.2	460.4
17	0.92	0.93	0.81	417.8	308.3	566.2
18	0.96	1.00	0.85	390.1	342.1	444.9
19	0.92	1.00	0.82	434.0	327.1	576.0
20	0.88	1.00	0.77	366.2	297.4	451.0
21	1.00	0.96	0.94	382.3	331.6	440.8
22	1.00	0.93	0.74	401.7	324.4	497.4
Kiva	**0.94**	**0.95**	**0.69**	**413.4**	**331.8**	**516.9**
GBI	**0.93**	**0.96**	**0.85**	**393.6**	**324.3**	**479.7**
Overall	**0.93**	**0.96**	**0.80**	**399.8**	**326.6**	**491.3**

*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).

The average [absolute] difference between the expected and measured perpendicular distances from the model to the walked line is summarized in Table 6. 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.

Although some individual metrics were below-target (gray cells in Table 5 and Table 6), 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 Figure 4 and Figure 5, and were used to generate abundance estimates in Table 6. 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).

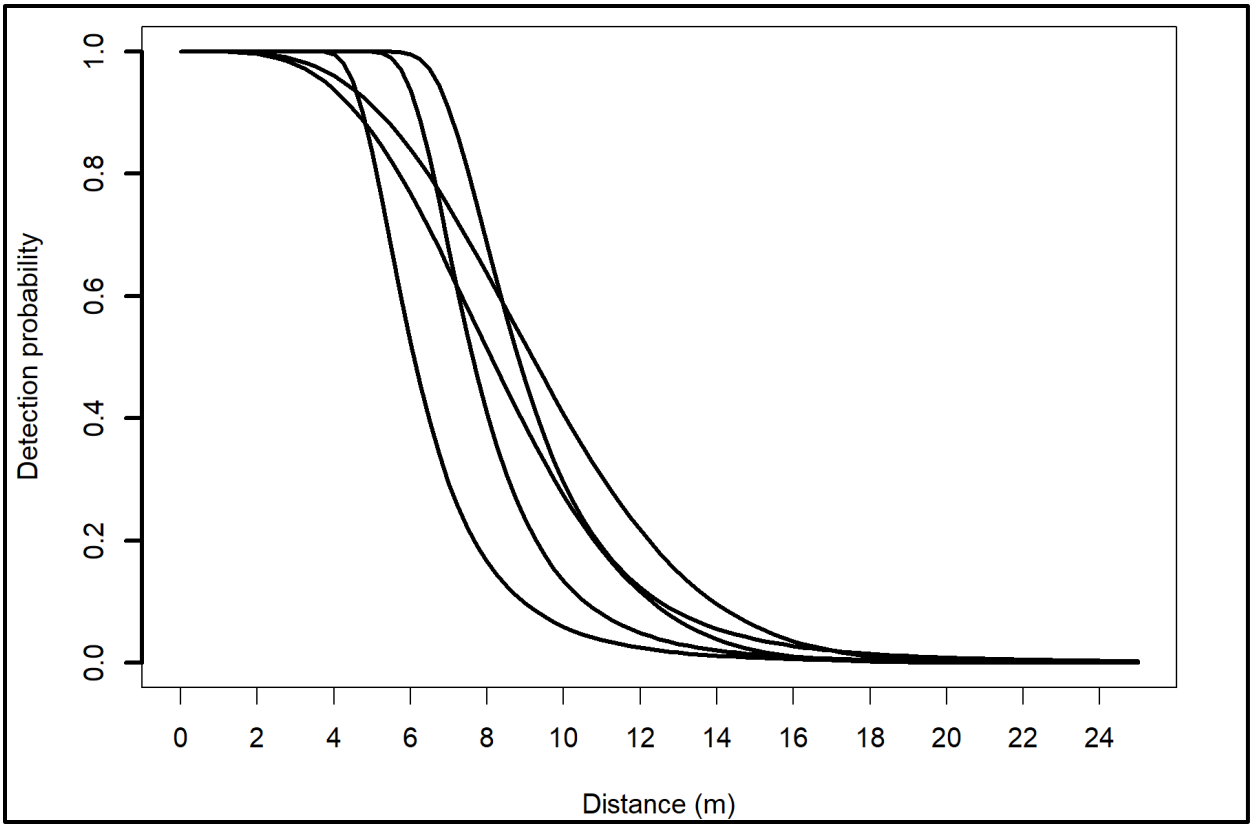


Figure 4. Detection curves for each of the 2025 Kiva crews during training. Each curve is based on a 16 km trial for one team with an average of 111 detections.

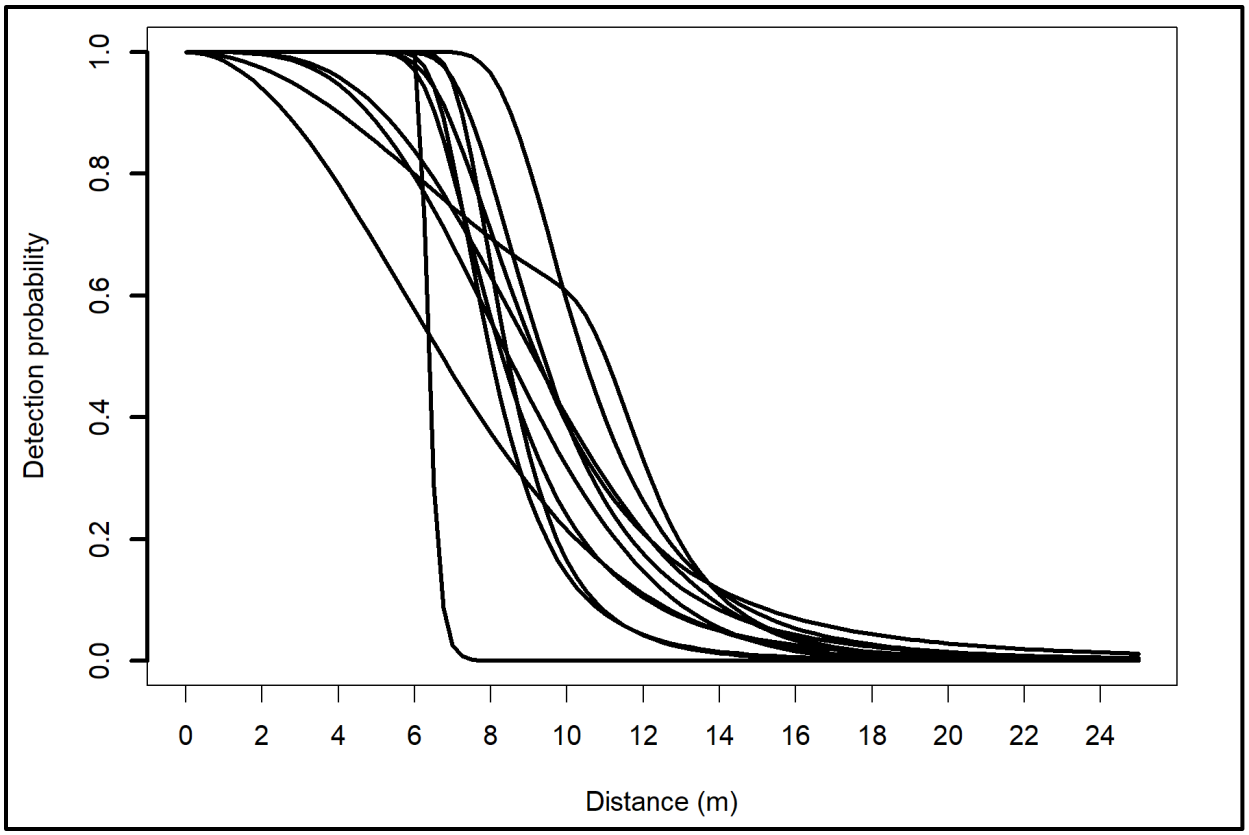


Figure 5. Detection curves for each of the 2025 GBI crews during training. Each curve is based on a 16 km trial for one team with an average of 113 detections.

Quality assurance and quality control

There were 10,805 transect records and 1594 G_0 records associated with the monitoring effort in 2025. The first level data specialist worked with the field teams to resolve 340 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 416 issues remained or were discovered in the third (final) phase of QA/QC. Only 53 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 6 were corrected with recourse to paper datasheets. The remaining errors in 2025 were data processing errors (e.g., incorrect datasheet naming convention), not that the data were erroneous.

Transect completion

The number of assigned and completed transects in each stratum in 2025 is reported in Table 7. Table 7 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- 9 show locations of transects and observations of live and dead tortoises.

Table 7. Number of assigned and completed transects in each stratum during 2025.

Stratum	Assigned transects	Assigned and alternate transects completed	Assigned, completed 12-km	Assigned, completed shortened	Assigned, completed with a major reduction*
EV	80	80	44	31	5
GB	93	93	43	47	3
MM	70	70	41	28	1
GBI	243	243	128	106	9
AG	35	32	16	14	2
JT	55	55	21	29	5
SC	75	75	47	24	4
Kiva	165	162	84	67	11
Total	408	405	212	173	20

*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

To estimate G_0 in 2025, 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 2025 sampling effort reported in Table 8.

Table 8. Availability of tortoises (G_0) when transects were walked in 2025 in the same or in neighboring strata.

G_0 site	Stratum	Dates	Days	G_0 (Std Error)
Chuckwalla	Chocolate Mountain South	6 Mar - 9 Mar	4	0.60 (0.059)
Chuckwalla	Chocolate Mountain North	11 Mar - 13 Mar	3	0.69 (0.065)
Piute-Mid	Eldorado Valley	31 Mar - 1 Apr	2	0.71 (0.029)
Gold Butte	Gold Butte-Pakoon	10 Apr - 29 Apr	20	0.63 (0.031)
Chuckwalla	Joshua Tree	20 Mar - 1 Apr	13	0.73 (0.028)
Halfway Wash	Mormon Mesa	28 Apr - 15 May	18	0.43 (0.029)
Superior-Cronese	Superior-Cronese	3 Apr - 18 Apr	16	0.96 (0.011)

Tortoise encounter rates and detection functions

All survey pairs worked together throughout the season. Kiva crews surveyed a total of 31-33 transects and detected 89 tortoises larger than 180 mm MCL (adults). GBI surveyors walked a median of 23 transects and reported 29 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. Several truncation distances were tested, and a global multiple-covariate detection function where detection was modeled as a function of group was

most strongly supported for the 2025 data. Thus, all observations were used to provide information about the shape of the detection curve, however, only observations collected by each particular group were used to fit the scale for that group. Kiva's and GBI's combined detection pattern best fit a hazard-rate curve with no adjustments based all observations up to 28 m from the centerline. Figure 10 shows a histogram of the observed number of tortoises seen at increasing distance from the transect centerline. Truncation distance removed two observations for Kiva and none for GBI and resulted in good fit overall and near the centerline. Most of the strata surveyed by Kiva had at least 20 observations, except for Joshua Tree where there were 19 observations. None of the strata surveyed by GBI had 20 observations before truncation (Table 9). The detection rate for Kiva crews within 28 m of the transect centerline was 30.5% (CV=0.155) and for GBI crews it was 20.4% (CV=0.282) within 28 m of the transect centerline.

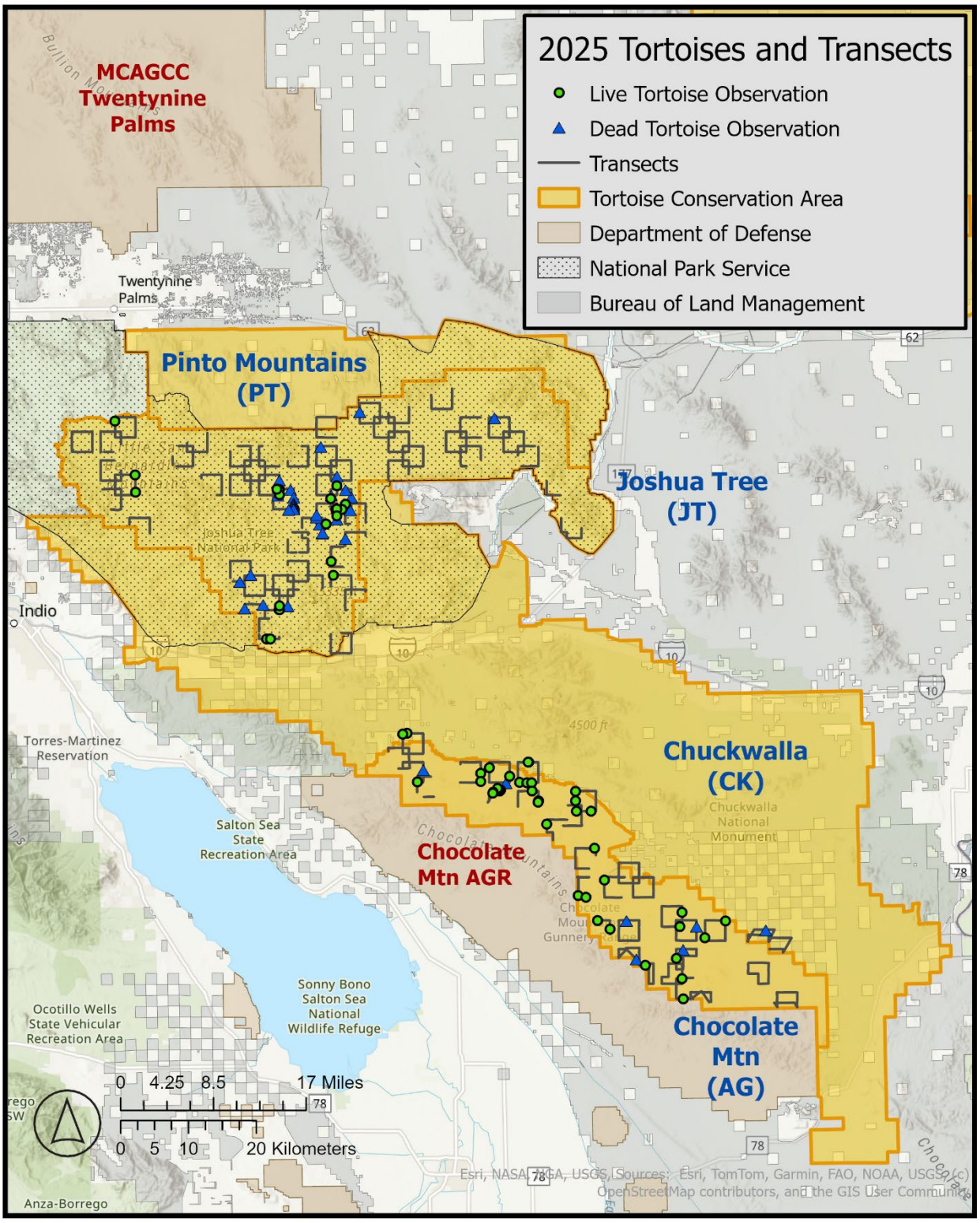


Figure 6. Distribution of distance sampling transects and tortoise observations in 2025 in the Chocolate Mountain Aerial Gunnery Range and Joshua Tree strata in the Colorado Desert Recovery Unit.

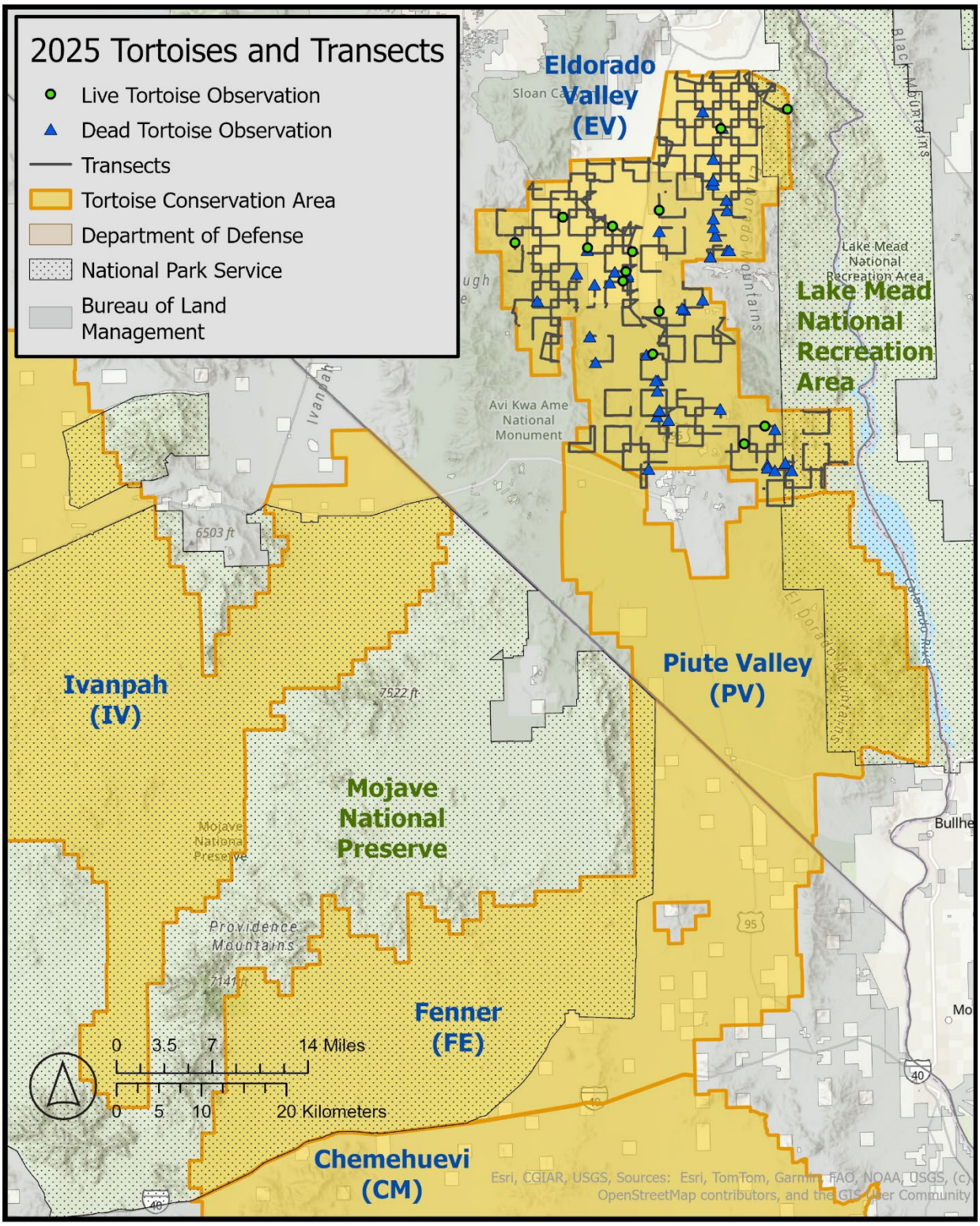


Figure 7. Distribution of distance sampling transects and tortoise observations in 2025 in the Eldorado Valley stratum of the Eastern Mojave Recovery Unit.

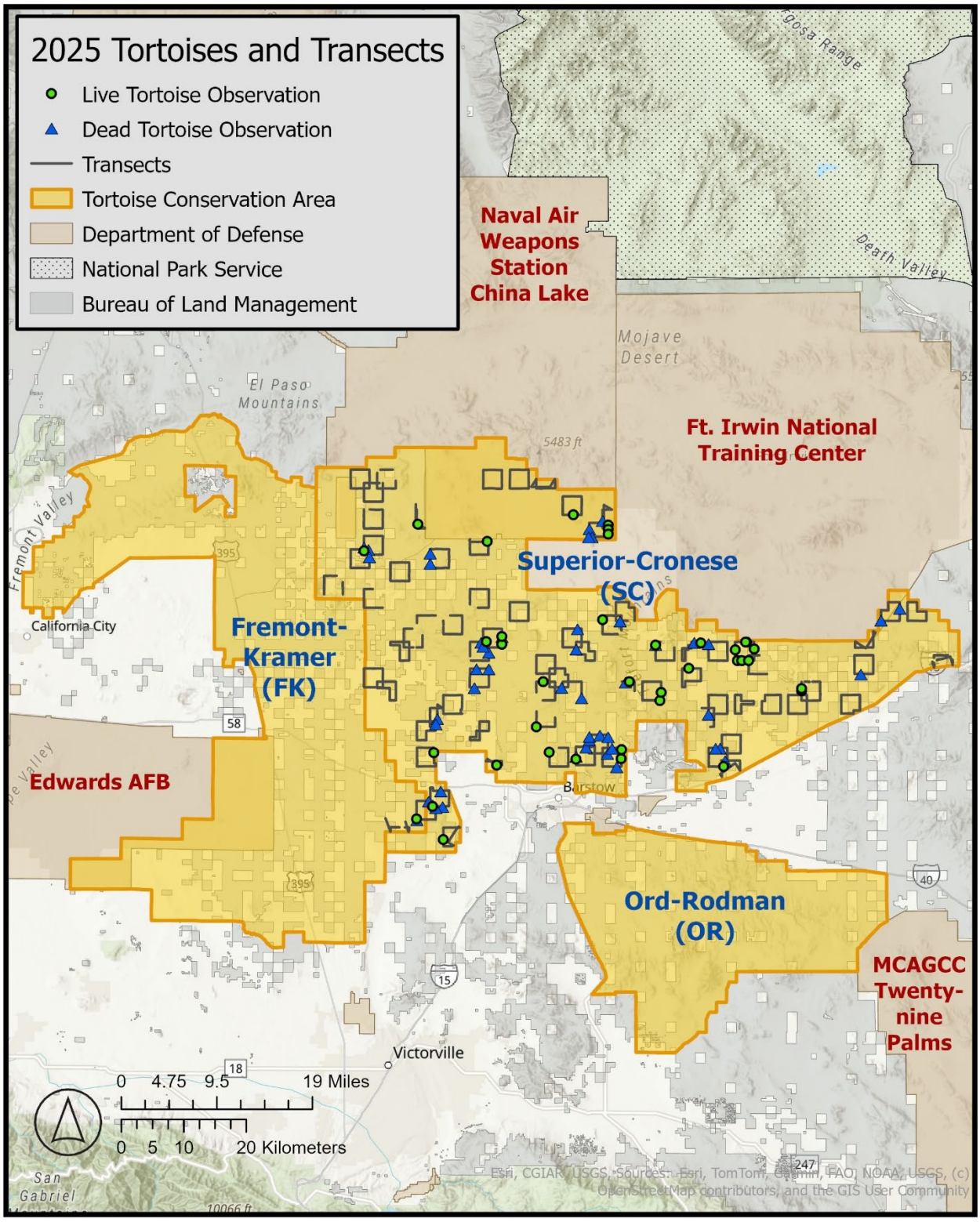


Figure 8. Distribution of distance sampling transects and tortoise observations in 2025 the Superior-Cronese stratum of the Western Mojave Recovery Unit.

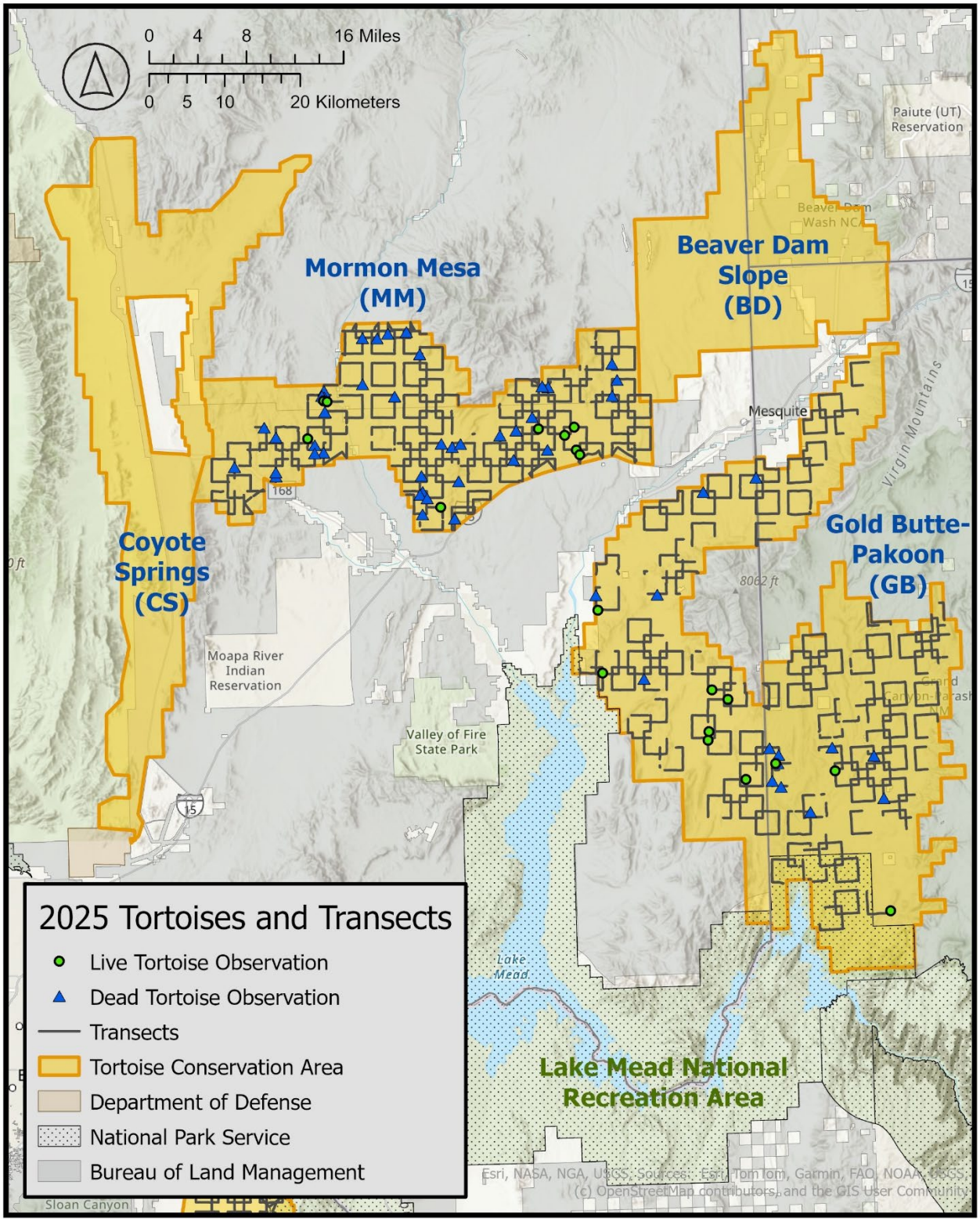


Figure 9. Distribution of distance sampling transects and tortoise observations in 2025 in the Gold Butte-Pakoon and Mormon Mesa strata of the Northeastern Mojave Recovery Unit.

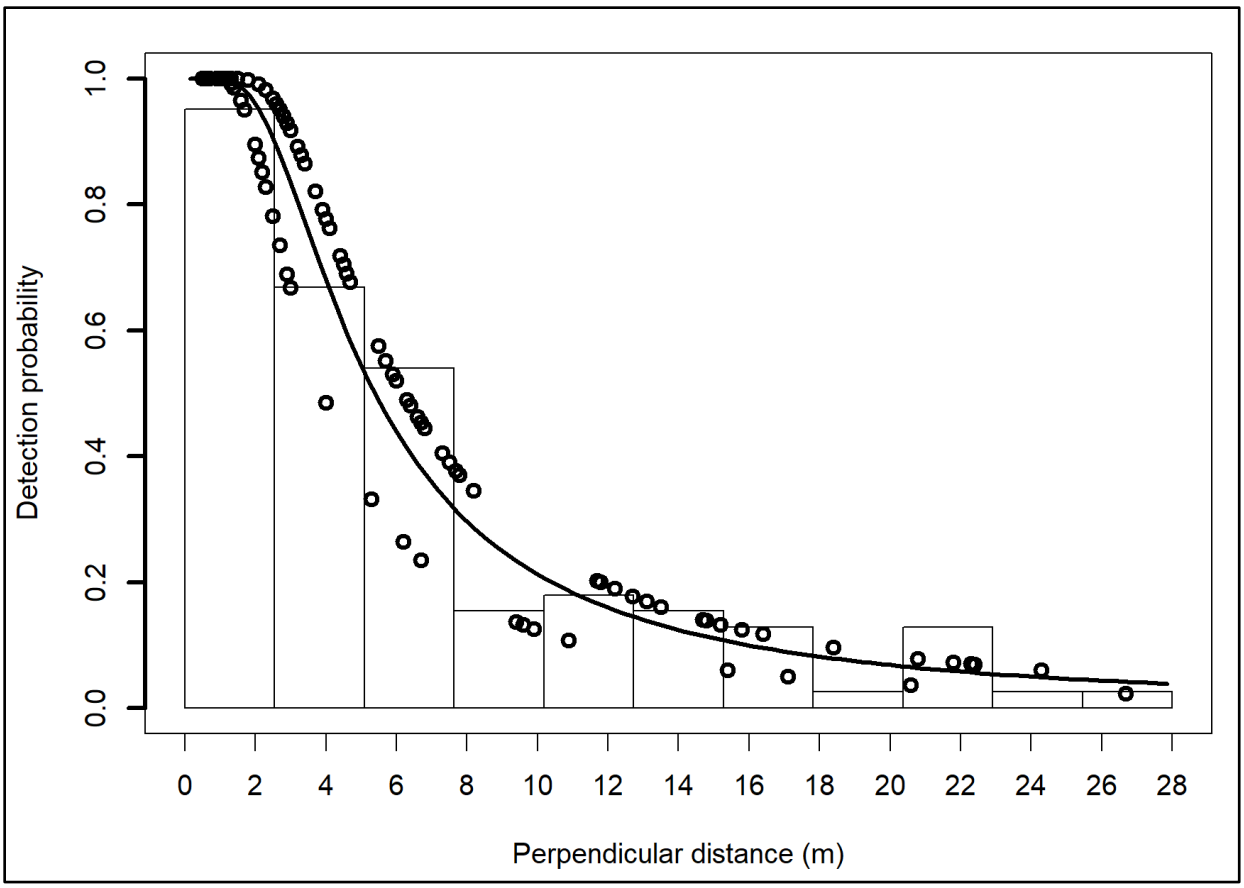


Figure 10. Observed detections (histogram) and the resulting detection function (smooth curve) with predicted values for detected live tortoises with MCL ≥ 180 mm found by Kiva (points above smooth curve) and GBI (points below smooth curve) in 2025. This curve uses the n=116 observations found within 28 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 2025, for 27 detections of adult tortoises within 2 m of the transect centerline, 22 were found by the observer in the lead position and 5 by the follower, so that the probability of detection by single observer, $p = 0.842$, and the proportion detected using the dual observer method, $g(0 \text{ to } 2 \text{ m}) = 0.975$ (SE = 0.140). Figure 11 shows that *g(0)* was converging on 1.0 in 2025. 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, 2025a, 2025b). Previous years of data and the pattern in Figure 11 indicate the assumption of perfect detection on the centerline was met; consequently, no adjustment was made to the final density estimate.

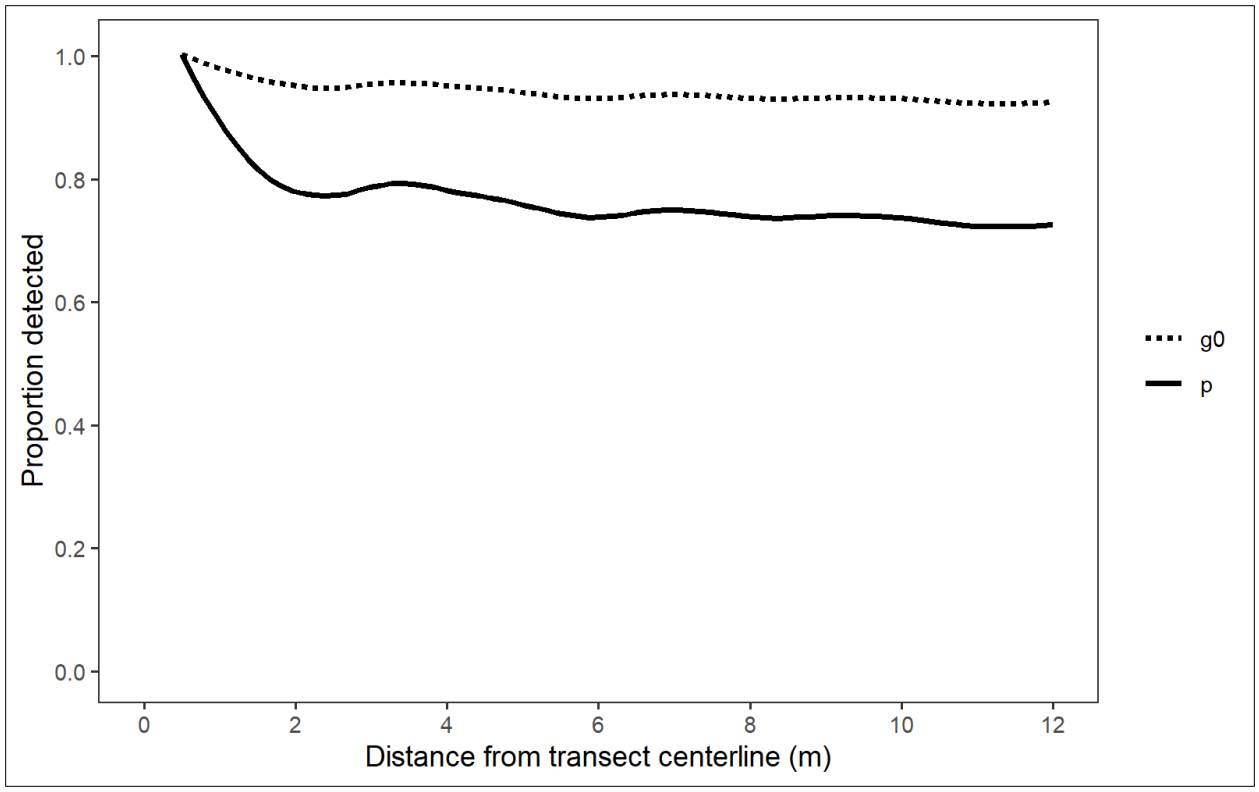


Figure 11. Detection pattern for the leader (*p*) and by the team (*g(0)*) based on all observations out to a given distance (*x*) from the centerline in 2025. Note convergence of *g(0)* on 1.0 as *x* goes to 0.

Estimates of tortoise density

Density estimates were generated separately for each monitoring stratum (Table 9). 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 9. Stratum-level encounters and densities in 2025 for tortoises of MCL ≥ 180 mm with associated 95% confidence interval (CI).

Recovery Unit/ Stratum		Area (km^2)	n (tortoises observed)	# Transects	Transect length (km)	Begin date	End date	Adult tortoise density (/km^2)			
								Density	Lower limit, 95% CI	Upper limit, 95% CI	%CV
Western Mojave			**33**	**75**	**808**	**3-Apr**	**18-Apr**				
Superior-Cronese	SC	3061	33	75	808	3-Apr	18-Apr	2.5	1.4	4.3	28.52
Colorado Desert			**54**	**87**	**831**	**6-Mar**	**1-Apr**				
Chocolate Mtn north	AGN	351	25	15	132	11-Mar	13-Mar	16.1	8.8	29.6	31.67
Chocolate Mtn south	AGS	403	10	17	184	6-Mar	9-Mar	5.3	2.5	11.2	39.40
Chocolate Mtn	AG	755	35	32	316	6-Mar	13-Mar	10.2	5.8	17.8	29.08
Joshua Tree	JT	1567	19	55	515	20-Mar	1-Apr	3.0	1.5	5.8	34.71
Northeastern Mojave			**18**	**163**	**1673**	**10-Apr**	**15-May**				
Mormon Mesa	GB	1977	10	93	926	10-Apr	29-Apr	1.5	0.7	3.4	43.89
Gold Butte-Pakoon	MM	968	8	70	747	28-Apr	15-May	2.2	0.8	6.1	56.94
Eastern Mojave			**11**	**80**	**833**	**31-Mar**	**10-Apr**				
Eldorado Valley	EV	1153	11	80	833	31-Mar	10-Apr	1.6	0.7	3.6	41.95

Population trend estimation: 2001-2025

Over the past 25 years, annual range-wide monitoring survey efforts have varied in scale, both temporally and spatially. Figure 12 illustrates annual survey effort across strata, transects, and kilometers walked, as well as number of live tortoises detected within 20 meters of the transect centerline used to develop the trend estimates from 2001 to 2025 presented below. Shape and length of transects have varied over the life of the monitoring program as well; from 2001-2003 shorter transects (1.6 to 4-km) allowed surveyors to complete several per day, which is evident in Figure 12 where those years show a much higher number of transects compared to subsequent years. In 2004, the 12-km square transect currently used was adopted. Since monitoring began in 2001, a total of 15,048 transects have been surveyed, covering 134,163 kilometers, and resulting in 6,070 adult tortoises detected within 20 m of transect centerlines – averaging 0.05 adults encountered per km of transect surveyed.

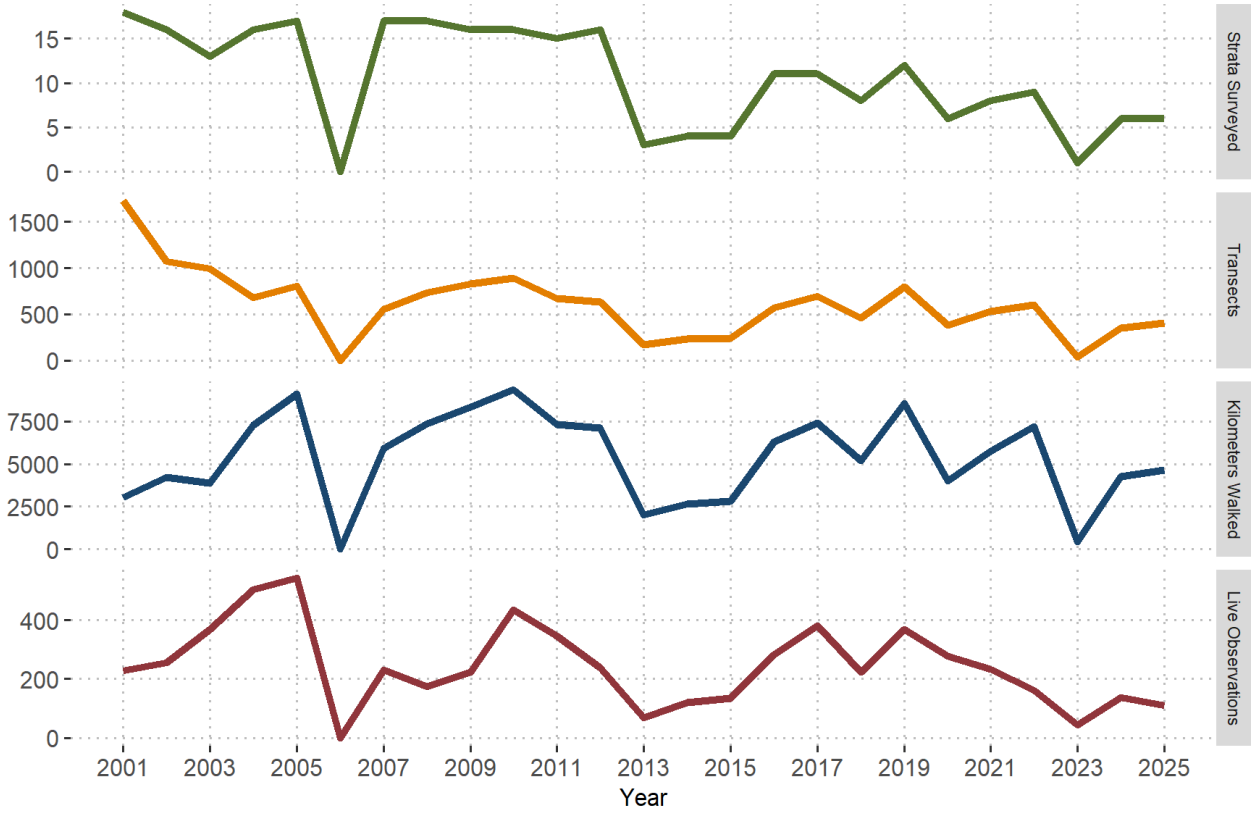


Figure 12. Annual counts of strata surveyed (top), line distance transects walked (second from top), surveyed kilometers (second from bottom), and live tortoises detected within 20 m of transect centerlines (bottom) over the last 25 years of the USFWS range-wide monitoring program. At the start of the program surveyors completed multiple shorter transects each day, however beginning in 2004, the 12 km square transect, which is still protocol today, was adopted (USFWS 2006; USFWS 2015).

Adult tortoise density was predicted across most of the species' range (excluding Upper Virgin Recovery Unit) and averaged 2.0/km^2 (95% CI = 0.0-5.3 adults/km^2) in 2025 in comparison to 3.7 (95% CI = 0.0-11.5 adults/km^2) predicted in 2001. As previously reported, predicted density varied appreciably among long-term monitoring strata (Table 10). Mean predicted densities in 2025 ranged from 1.26 adults/km^2 in Ivanpah Valley to 4.09 adults/km^2 in Fremont-Kramer. In line with results presented in Zylstra et al. (2023), average predicted densities were lowest in the Eastern Mojave and highest in the Western Mojave Recovery Unit, corresponding to higher winter and lower summer precipitation in the western portion of the range.

Table 10. Predicted density for tortoises of MCL ≥ 180 mm in each stratum in 2001 and 2025. Min and max estimates represent 95% lower and upper credible intervals, respectively.

Recovery Unit/ Stratum		Area (km^2)	Adult tortoise density (/km^2)					
			2001			2025		
			Mean	Min	Max	Mean	Min	Max
Colorado Desert								
Chocolate Mtn	AG	755	4.54	2.37	8.33	3.26	1.69	6.01
Chuckwalla	CK	3509	2.93	0.05	8.84	2.10	0.03	6.34
Chemehuevi	CM	4038	2.87	0.58	6.36	2.06	0.42	4.59
Fenner	FE	1841	3.65	0.38	6.22	2.63	0.27	4.48
Joshua Tree	JT	1567	2.29	0.05	5.50	1.64	0.03	3.94
Pinto Mountains	PT	751	2.47	0.25	3.81	1.78	0.18	2.75
Piute Valley	PV	1070	3.38	0.43	6.22	2.43	0.31	4.48
Eastern Mojave								
Eldorado Valley	EV	1153	2.01	0.29	3.49	1.45	0.21	2.50
Ivanpah Valley	IV	2567	1.75	0.06	4.45	1.26	0.04	3.22
Northeastern Mojave								
Beaver Dam Slope	BD	828	3.94	1.45	5.64	2.18	0.81	3.12
Coyote Springs	CS	1117	2.65	0.40	4.15	1.47	0.22	2.31
Gold Butte-Pakoon	GB	1977	2.41	0.01	3.87	1.34	0.01	2.15
Mormon Mesa	MM	968	2.85	0.35	3.80	1.58	0.19	2.12
Western Mojave								
Fremont-Kramer	FK	2417	8.98	0.58	17.05	4.09	0.27	7.75
Ord-Rodman	OR	1124	4.25	0.04	9.96	1.94	0.02	4.56
Superior-Cronese	SC	3061	5.93	0.55	13.17	2.71	0.26	5.97

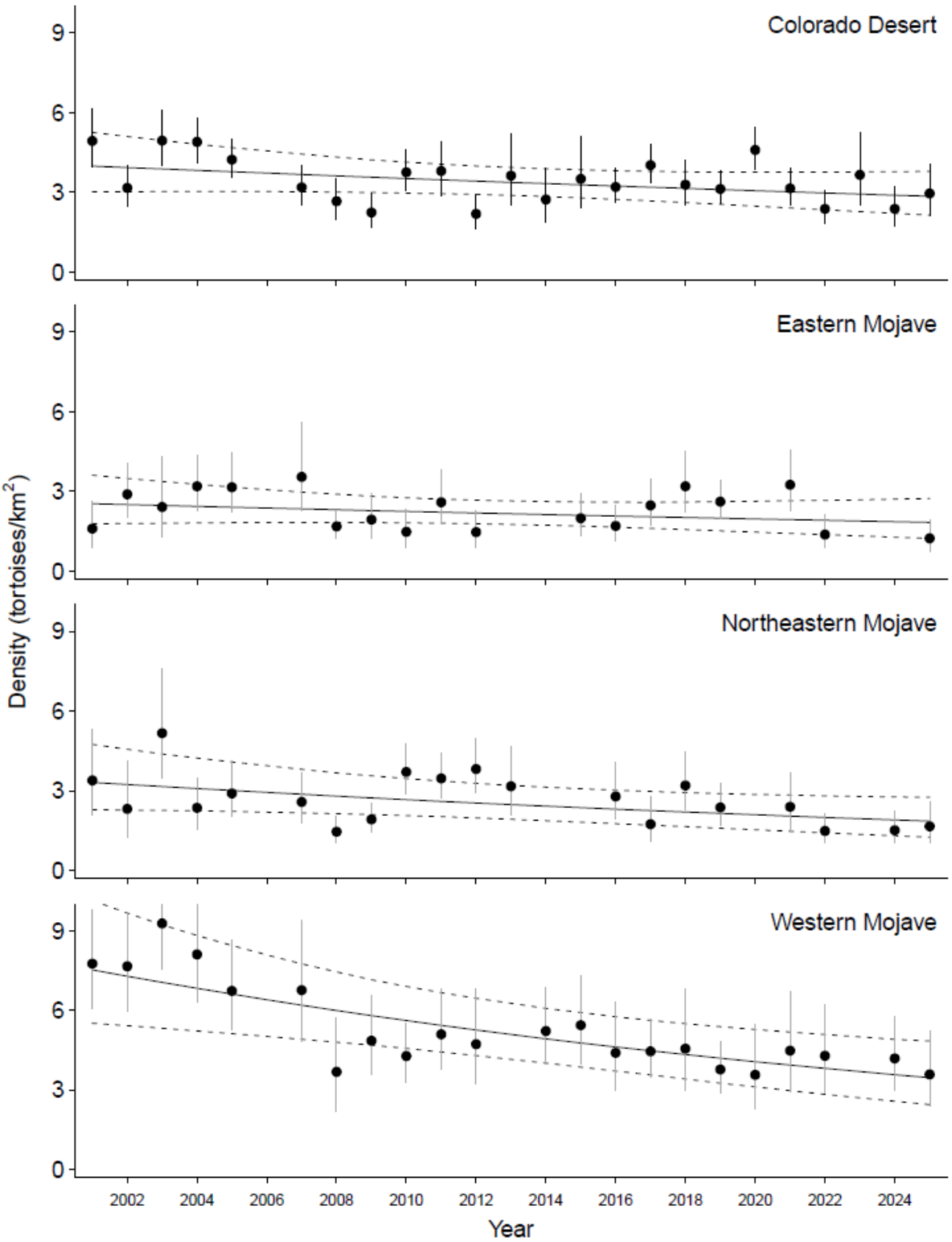


Figure 13. Estimates of density for adult tortoises (posterior medians [circles] and 95% credible intervals [CIs]) in each year a recovery unit was surveyed, with fitted log-linear trends (solid line) and 95% CIs for trends (dashed lines) in each recovery unit adapted from Zylstra et al. (2023).

Consistent with earlier tortoise population trend analyses from Allison and McLuckie (2018) and Zylstra et al. (2023), adult tortoise densities have steadily declined across the range. Between 2001 and 2025, density declined by an average 2.2% on an annual basis (95% CI = -1.0% to -3.4%) with the steepest declines continuing to be reported for the Western Mojave (Table 11; Figure 13). In addition, steeper declines than previously reported are now predicted in both the Eastern Mojave and Northeastern Mojave Recovery Units (Figure 13). Within long-term monitoring strata, predicted densities fell by roughly 27–28% within the Colorado Desert and Eastern Mojave Recovery Units, about 44% in the Northeastern Mojave Recovery Unit, and approximately 54% in the Western Mojave Recovery Unit (Table 10). An estimated loss of approximately 244,000 adults is predicted to have occurred between 2001 to 2025 with most of that loss predicted in the Western Mojave alone.

Table 11. Predicted abundance and associated standard error of adult tortoises within the modeled area of four recovery units in 2001 and 2025, and percent change between years with associated 95% credible interval [2.5%, 97.5%].

Recovery Unit	2001		2025		Percent change in abundance
	Area (km^2)	Abundance	Area (km^2)	Abundance	
Colorado Desert	30,921	103,576 (19,290)	30,802	72,412 (13,300)	-29.72 [-58.17, 9.22]
Eastern Mojave	39,593	64,452 (12,334)	39,289	45,900 (9483)	-29.41 [-56.53, 30.60]
Northeastern Mojave	19,443	39,187 (7474)	19,299	21,586 (4560)	-44.57 [-67.07, -4.91]
Western Mojave	50,902	321,131 (89,285)	50,590	146,374 (43,006)	-54.48 [-73.02, -26.65]
Total	140,859	533,182 (104,291)	139,980	287,634 (53,319)	-45.75 [-60.31, -25.49]

DISCUSSION

This year marked the 25th year of line distance sampling and the tortoise range-wide monitoring program. However, despite multiple decades of management and conservation efforts, population trend analyses derived from this effort indicate that adult tortoise populations have continued to decline across the range over this time period, with the steepest declines reported for the Western Mojave Recovery Unit. Steep declines are now also being predicted in the Northeastern Mojave Recovery Unit, which was previously reported as having an increasing density trend (Allison and McLuckie 2018), as well as the Eastern Mojave Recovery Unit. Additionally, recent analyses suggest that most monitoring strata may be below the minimum viable population threshold (3.9 adult tortoises/km^2; USFWS 2011; Allison and McLuckie 2018).

During the first years of the project, survey effort was directed annually at all 16 long-term monitoring strata. Since agency funding was severely curtailed in 2012 the range-wide monitoring program has not had the opportunity to complete surveys every year or even every other year within long-term monitoring strata in parts of the range. Sampling efforts within the eastern and northern portions of the range (Arizona, Nevada, and Utah) have continued to be implemented on a regular basis with strata in these areas generally being surveyed every other year (except 2023). However, since 2020, sampling efforts have continued to decline in the western and southern portions of the range and most strata in California (with exception to the Chocolate Mountain Aerial Gunnery Range stratum) have only been surveyed once in the last five years mainly due to lack of funding for surveys. The annual effort historically has not been planned for precise and accurate annual estimates. Instead, it is directed at accurately describing trends by using multiple years of density estimates in each stratum. Because the trend estimates derived from line distance sampling depend on these annual efforts, a reduction in annual effort across the range could result in less reliable trend estimates, representing a potential limitation for these estimates.

Over the last 25 years, the range-wide monitoring program has primarily employed line distance sampling to estimate tortoise density within TCAs across the range. While line distance has been a very important tool for understanding population trends across the range, this approach provides only coarse-scale estimates of density for adult tortoises and does not allow for estimation of density for smaller age classes or provide information on other important demographic parameters needed to manage the species. In addition, it is subject to bias due to tortoise behaviors that violate statistical assumptions, can be strongly influenced by spatiotemporal and environmental conditions, and requires a targeted number of detections to produce meaningful estimates. As tortoise populations decline or sampling areas are reduced, as we are seeing across the range, distance sampling and other traditional survey approaches may

not produce reliable density estimates or provide accurate information on population status and trends. Furthermore, as described above, the capacity of range-wide monitoring has been limited in recent years by inadequate funding necessary to sufficiently survey suitable tortoise habitat throughout the contemporary range.

In an effort to improve the efficacy of range-wide monitoring for the tortoise and help address these limitations, in partnership with the U.S. Geological Survey Western Ecological Research, we are working on a spatially explicit approach to tortoise monitoring. Our goals with this novel approach are to build on the foundation established by distance sampling and the range-wide monitoring program, while promoting statistically robust density estimates for multiple size classes, as well as direct estimates of other critical demographic parameters. In contrast to conventional density estimation methods, spatially explicit capture-recapture (SCR) models have the potential to alleviate bias in estimates of density and other demographic parameters associated with assumption violations of previously employed methods, including line distance sampling (Goessling et al. 2025; Murphy et al. 2026; Royle and Young 2008). SCR models have previously been used in multiple studies to improve density estimation and estimate tortoise demographics within multiple recovery units (Doyle et al. 2025; Mitchell et al. 2021; Murphy et al. 2026); however, the survey designs implemented for these studies were not originally developed in the SCR framework. We recently developed a novel tortoise specific multi-area search-encounter survey design that was founded on established theory and recommendations for designs in the SCR framework (Sun et al. 2014, Clark 2019, Paterson et al. 2019) and in 2025, we successfully applied this new design to a survey in Nevada, covering the Stump Springs Regional Augmentation Site and the Greater Trout Canyon Translocation Area.

We are continuing to refine and field-test this novel SCR design to improve density and vital rate estimates for the desert tortoise with the goal of implementing it at the range-wide scale if feasible. However, it's still under development and for the time being, line distance sampling will continue being implemented across the range dependent on the availability of funding. In 2026, a similar monitoring effort is planned for Nevada, where three TCAs are scheduled for survey. California will likely have a reduced effort, with only one TCA slated for survey.

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