

**RANGE-WIDE MONITORING OF THE
MOJAVE DESERT TORTOISE
(*GOPHERUS AGASSIZII*):
2022 ANNUAL REPORTING**

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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:

L. Anderson, T. Andrews, C. Arthur, M. Bassett, H. Buccowich, E. Buttram, S. Clegg, T. Cole, A. Colunga, J. Cooper, A. Cruz Valencia, J. Danielson, Q. DeCoursey, C. Dollen, A. Drummer, G. Gitschier, J. Gonzales, K. Hayes, C. Haywood, K. Hotchkiss, I. Jones, K. Kaiser, A. Kalyn, K. Keely, K. Kuhlmann, A. Li, A. Markowski, R. Masayesva, N. Mendelsohn, S. Mendoza, A. Moreland, J. Muntz, C. Olson, H. Rolph, R. Rubenthaler, A. Russell, A. Sanjar, J. Sanzo, B. Scavone, T. Schaeffer, E. Settle, P. Sharp-Garcia, C. Sharrow, E. Smith, T. Solorzano, S. Sonnenberg, K. Stemp, E. Sudbeck, P. Sweeney, S. Till, C. Veety, D. Weaver, M. Welc, R. Wester-Ebbinghaus, S. Williams, L. Yang, A. Yawdoszyn, N. Zuber.

R. Patil (GBI) updated the electronic data-collection forms and procedures. J. Cash and M. Spangler (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 2022, 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 2022 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 2022, when crews completed 604 transects (6415.2 km) in 9 strata between 6 March and 16 May. In the course of these surveys, they reported 185 live tortoises, 166 of which were at least 180 mm midline carapace length (MCL) and used to generate density estimates.

In 2022, we surveyed 9 of the 16 strata. Although the southern portion of the Chocolate Mountain Aerial Gunnery Range had densities similar to those in other strata (2.1 adults/km²), the northern portion had much higher densities (7.4 adults/km²), a pattern that was also seen in past years of these surveys. Other strata surveyed in 2022 (and the estimated density of adults/km²) were Chemhuevi (4.5), Piute Valley (3.1), Beaver Dam Slope (2.8), Coyote Springs Valley (4.5), Gold Butte-Pakoon (2.6), and Mormon Mesa (2.6). Over all strata, the encounter rate averaged 34.7 km for each adult tortoise that was observed.

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.

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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 in 2022. 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 2022, surveys were conducted in California in the Chocolate Mountain Aerial Gunnery Range (AG), Chemehuevi (CM), and Superior-Cronese (SC) strata; and in Beaver Dam Slope (BD), Coyote Springs Valley (CS), Eldorado Valley (EV), Gold Butte-Pakoon (GB), Mormon Mesa (MM), and Piute Valley (PV) in Nevada, Utah, and Arizona. 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. 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 2022). 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, but others may not have been selected in the past.

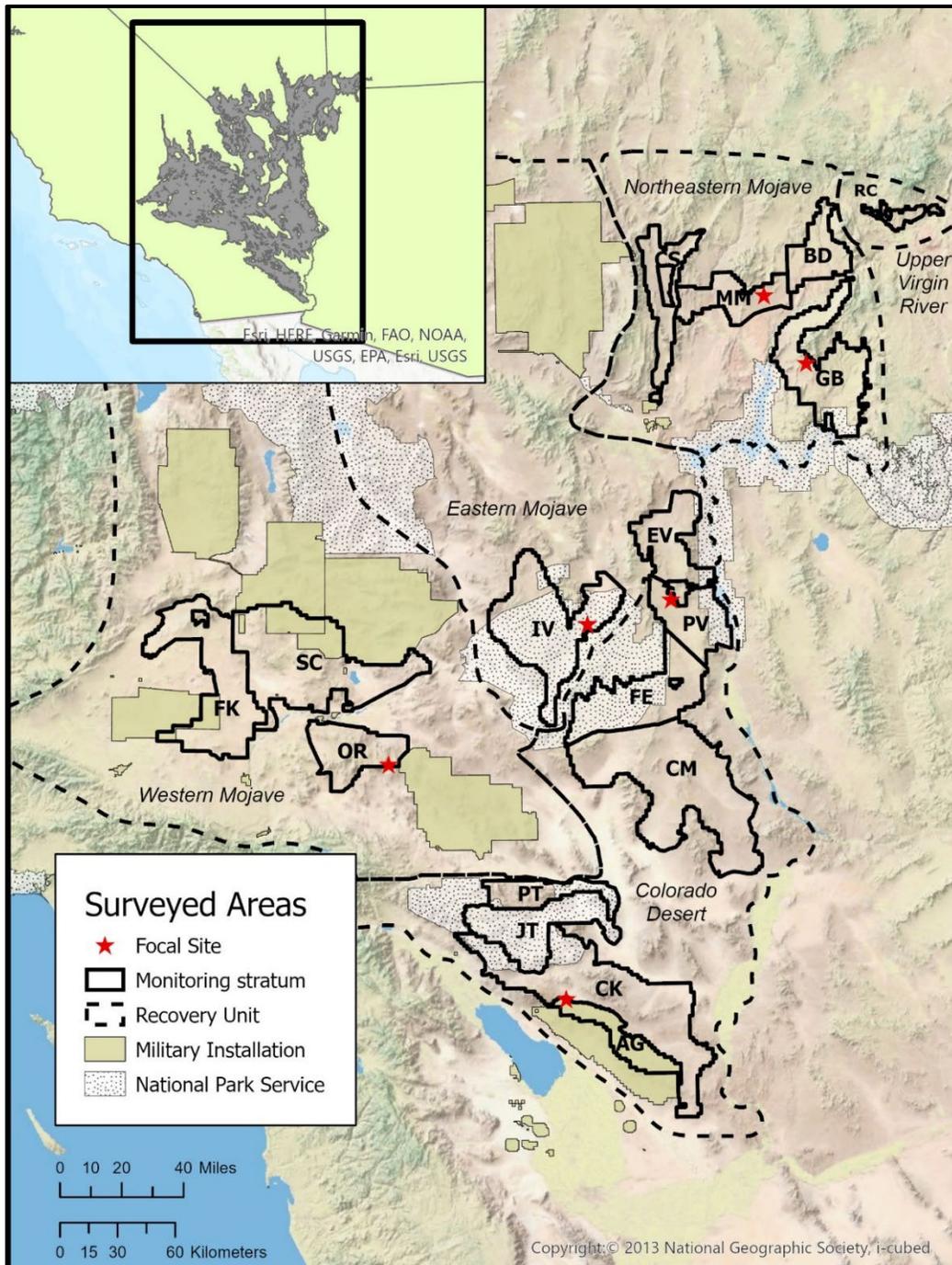


Figure 1. Long-term monitoring strata (n=17) corresponding to tortoise conservation areas (TCAs; USFWS 2011) in each recovery unit. TCAs and their codes are Chocolate Mountains Aerial Gunnery Range (AG), Beaver Dam Slope (BD), Chuckwalla (CK), Chemehuevi (CM), Coyote Springs Valley (CS), Eldorado Valley (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=6). Potential habitat (Nussear et al. 2009) is overlain on the southwestern United States in the extent indicator.

Distance sampling transect completion

One adaptation that tortoises have for living in the desert is to restrict surface activity to fairly narrow windows of time during the year. In general, tortoises emerge from 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 2024).

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 6 focal sites throughout the Mojave and Colorado deserts (Figure 1). Five of the focal sites, including Chuckwalla (CK), Gold-Butte (GB), Halfway Wash (HW), Piute-Mid (PM), and Superior-Cronese (SC) were used in 2022 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 2022). All candidate models included stratum as a fixed effect. In addition, mixed effect models where day was accounted for as a nested random effect 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 2022). 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 fundamental part of quality assurance for this project. This training includes instruction as well as required practice time on skills such as tortoise handling, walking practice transects, and developing detection and distance-measuring techniques on a training course with tortoise models in measured locations. Chapters of the monitoring handbook are updated as needed and posted to the Desert Tortoise Recovery Office website (<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. 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 3 of 48 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/km²).

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 2022 for Kiva transect crews.

Date	Activity	Location	Instructors
5 March	Transects methods overview	Chuckwalla ACEC, CA	Hayes/Bassett
	iPads – Transect database	Chuckwalla ACEC, CA	Hayes/Bassett
	Short transect (6 km) practice	Chuckwalla ACEC, CA	Hayes/Bassett
15 March	Training Lines 1 (8 km)	BLM Desert Tortoise Management Area (DTMA)	Allison
16 March	Review training line 1 results	GBI Field Station	Allison
	Tortoise handling	GBI Field Station	Bassett/ Hayes
	Tortoise visibility examples	GBI Field Station	Allison
	Review Chuckwalla ACEC practice transect results	GBI Field Station	Allison/Cash
17 March	Training Lines 2 (8 km)	BLM DTMA	Allison
18 March	Review training line 2 results	GBI Field Station	Allison
	Monitoring on public lands	GBI Field Station	Allison
	GPS and compass use for tortoise monitoring	GBI Field Station	Allison
	Wrap up discussion	GBI Field Station	Allison

Table 2. Training schedule for 2022 for GBI group 1 transect crews.

Date	Activity	Location	Instructors
14 March	Mojave Desert & tortoise ecology presentation	GBI Field Station	Christopher
	Compass introduction	GBI Field Station	Cash
17 March	Distance estimation presentation	GBI Field Station	Allison
	Training lines presentation & practice	GBI Field Station	Allison/Christopher
	Compass course 1	GBI Field Station	Ekholm
	Practice epoxy for tag attachment	GBI Field Station	Christopher
	Survey123 presentation & practice	GBI Field Station	Cash
18 March	Training lines 1 (8 km)	BLM DTMA	Allison/Cash
21 March	Review training line 1 results	GBI Field Station	Allison/Cash

Date	Activity	Location	Instructors
21 March (continued)	Biosecurity presentation	GBI Field Station	Johnson
	Tortoise handling practice 1	GBI Field Station	Johnson/Cash/ Christopher/Allison
22 March	Training lines 2 (16 km)	BLM DTMA	Christopher/Cash
23 March	Training lines 2 (continued)	BLM DTMA	Christopher/Cash
24 March	Search image for tortoises & sign	River Mountains, NV	Sparks
25 March	Tortoise handling practice 2	GBI Field Station	Christopher/Cash
	Recognizing tortoise sign presentation	GBI Field Station	Christopher
	Scoring tortoise visibility presentation	GBI Field Station	Christopher
	Compass course 2	GBI Field Station	Cash
	Practice epoxy for tag attachment 2	GBI Field Station	Christopher
28 March	Review training lines 2	GBI Field Station	Christopher/Cash
	Standard protocol & non-standard transects, interruptions exercise	GBI Field Station	Christopher
	GPS and compass use for tortoise monitoring	GBI Field Station	Cash
	Survey123 presentation & exercise	GBI Field Station	Cash
29 March	Full 12-km practice transect 1 with interruption for terrain	Large Scale Translocation Site (LSTS)	Christopher/Cash
30 March	Review practice transect 1	GBI Field Station	Christopher/Cash
	Monitoring on public lands Presentation	GBI Field Station	Christopher
	Non-standard transects & reflections exercise	GBI Field Station	Christopher
	Navigation presentation	GBI Field Station	Cash
31 March	Tortoise handling practice 3	GBI Field Station	Christopher/Cash
1 April	Full 12-km practice transect 2 with reflection	LSTS	Christopher/Cash
4 April	Review practice transect 2	GBI Field Station	Christopher/Cash

Table 3. Training schedule for 2022 for GBI group 2 transect crews.

Date	Activity	Location	Instructors
14 March	Mojave Desert & tortoise ecology presentation	GBI Field Station	Christopher
	Compass introduction	GBI Field Station	Cash
17 March	Distance estimation presentation	GBI Field Station	Allison
	Training lines presentation & practice	GBI Field Station	Allison/Christopher
	Compass course 1	GBI Field Station	Danielson
	Practice epoxy for tag attachment	GBI Field Station	Christopher
	Survey123 presentation & practice	GBI Field Station	Cash
18 March	Search image for tortoises and sign	River Mountains, NV	Sparks/Christopher
21 March	Training lines I (8 km)	BLM DTMA	Allison/Cash
22 March	Biosecurity presentation	GBI Field Station	Johnson
	Tortoise handling practice 1	GBI Field Station	Johnson/Cash/ Christopher/Allison
	Scoring tortoise visibility presentation	GBI Field Station	Allison
23 March	Tortoise handling practice 2	GBI Field Station	Christopher/Cash
24 March	Tortoise handling practice 3	GBI Field Station	Christopher/Cash

Date	Activity	Location	Instructors
24 March (continued)	Compass course 2	GBI Field Station	Ekholm
	Practice epoxy for tag attachment 2	GBI Field Station	Christopher
	Review training line 1 results	GBI Field Station	Christopher/Cash
25 March	Training line 2 (16 km)	BLM DTMA	Christopher/Cash
28 March	Training line 2 (continued)	BLM DTMA	Christopher/Cash
29 March	Review training lines 2	GBI Field Station	Christopher/Cash
	Standard protocol & non-standard transects, interruptions exercise	GBI Field Station	Christopher
	GPS and compass use for tortoise monitoring	GBI Field Station	Cash
	Survey123 presentation & exercise	GBI Field Station	Cash
30 March	Full 12-km practice transect 1 with interruption for terrain	LSTS	Christopher/Cash
31 March	Review practice transect 1	GBI Field Station	Christopher/Cash
	Monitoring on public lands Presentation	GBI Field Station	Christopher
	Non-standard transects & reflections exercise	GBI Field Station	Christopher
	Navigation presentation	GBI Field Station	Cash
	Recognizing tortoise sign presentation	GBI Field Station	Christopher
1 April	Full 12-km practice transect 2 with reflection	LSTS	Christopher/Cash
4 April	Review practice transect 2	GBI Field Station	Christopher/Cash
	Navigation presentation	GBI Field Station	Cash
	Recognizing tortoise sign presentation	GBI Field Station	Christopher
1 April	Full 12-km practice transect 2 with reflection	LSTS	Christopher/Cash
4 April	Review practice transect 2	GBI Field Station	Christopher/Cash

Table 4. Training schedule for 2022 for GBI telemetry technicians.

Date	Activity	Location	Instructors
28 February	Survey123 presentation & practice	GBI Field Station	Cash
1 March	Telemetry training	GBI Field Station	Sparks
2 March	Telemetry practice	Boulder City Conservation Easement (BCCE)	Sparks
3 March	Telemetry practice	BCCE	Sparks
7 March	Telemetry practice	BCCE	Sparks
8 March	Telemetry practice	BCCE	Sparks
9 March	Telemetry practice	Halfway Wash, NV	Sparks
10 March	Avenza training presentation	GBI Field Station	Cash
11 March	Telemetry practice	Piute-Mid focal site	Sparks
14 March	Mojave Desert & tortoise ecology presentation	GBI Field Station	Christopher
17 March	Telemetry practice	BCCE	Sparks
	Distance estimation presentation	GBI Field Station	Allison
18 March	Telemetry practice	River Mountains, Nevada	Sparks
21 March	Biosecurity presentation	GBI Field Station	Johnson

Date	Activity	Location	Instructors
21 March (continued)	Tortoise handling practice 1	GBI Field Station	Johnson/Cash Christopher/Allison
22 March	Telemetry practice	BCCE	Sparks
23 March	Telemetry practice	BCCE	Sparks
24 March	Telemetry practice	River Mountains, NV	Sparks
25 March	Tortoise handling practice 2	GBI Field Station	Christopher/Cash
	Scoring tortoise visibility presentation	GBI Field Station	Christopher
	Recognizing tortoise sign presentation	GBI Field Station	Christopher
28 March	Telemetry practice	Gold Butte focal site, NV	Sparks
29 March	Telemetry practice	BCCE	Sparks
30 March	Telemetry practice	BCCE	Sparks
31 March	Tortoise handling practice 3	GBI Field Station	Christopher/Cash
1 April	Telemetry to derive start times	Piute-Mid focal site, NV	Sparks
4 April	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 single 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.

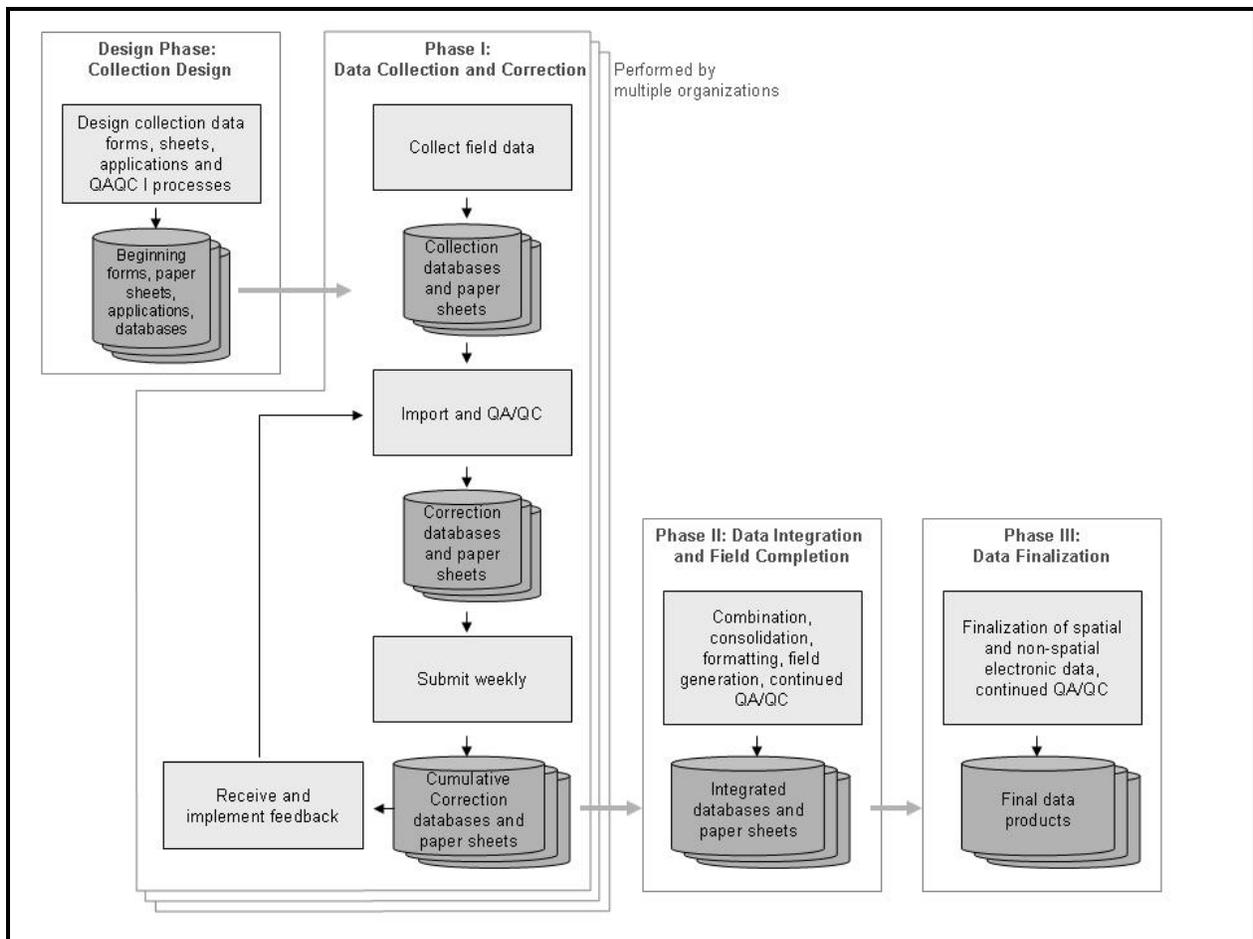


Figure 2. Data flow from collection through final products.

Tortoise encounter rate and development of detection functions

The number of tortoises seen in each stratum and their distances from the line were used to estimate the encounter rate (tortoises seen per kilometer walked) and the detection rate (proportion of available tortoises that are detected out to a certain distance from the transect centerline). Detection function estimation is “pooling robust” under most conditions (Buckland et al. 2001). This property holds as long as factors that cause variability in the curve shape are represented proportionately (Marques et al. 2007). Factors that can affect curve shape include vegetation that differentially obscures vision with distance and different detection protocols used by individual crews (pairs). Because each of the pairs on a team 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 simplicity (reasonableness) of the resulting detection function estimate (Buckland et al. 2001:15-16) as well as fit diagnostics near the transect centerline. Any observations that were not used to estimate detection functions were also not used to estimate the encounter rate (tortoises detected per kilometer walked). In distance sampling applications for many other species, encounter rate can be estimated with relatively high precision, but tortoise encounter rates are low enough 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.

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 .

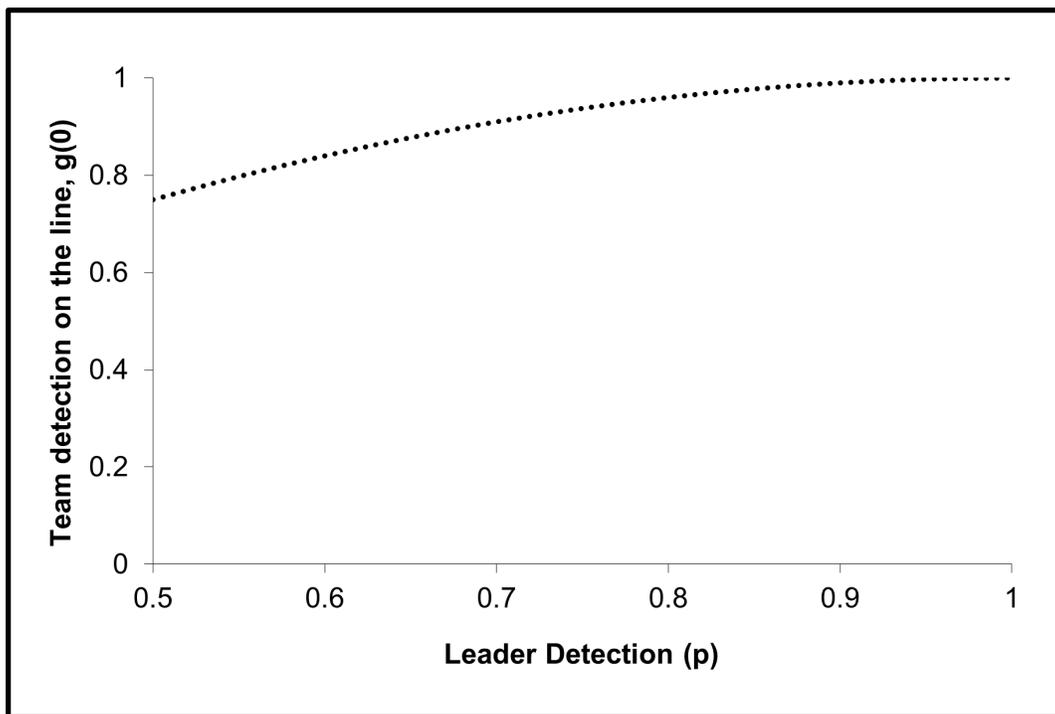


Figure 3. Relationship between single-observer detections (by the leader, p) and dual-observer (team) detections, $g(0)$.

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:

$$D = \frac{n}{2wLP_{\alpha}G_0g(0)}$$

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 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 2022. 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.

	Tortoise Encounter Rate	Proportion that Are Visible, G_0	Detection Rate, P_a	Proportion Seen on the Line, $g(0)$
<i>Recovery Unit</i>	<i>Stratum</i>	<i>Neighboring G_0 Sites</i>	<i>Data Collection Group</i>	<i>Overall</i>
Northeastern Mojave	Beaver Dam Slope	Halfway Wash	Great Basin Institute	All data
	Coyote Springs Valley			
	Mormon Mesa			
	Gold Butte-Pakoon	Gold Butte		
Eastern Mojave	Eldorado Valley	Piute-Mid	Kiva	
Colorado Desert	Piute Valley	Chuckwalla		
	Chocolate Mountain Aerial Gunnery Range			
	Chemehuevi			
Western Mojave	Superior-Cronese	Superior-Cronese		

RESULTS

Field observer training

Training in 2022 lasted from 5 March – 4 April (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 12 of the 29 crews achieved this.

Table 6. Proportion of tortoise models detected in 2022 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	0.94	0.96	0.91
2	1.00	1.00	0.88
3	1.00	1.00	0.96
4	1.00	1.00	0.97
5	1.00	1.00	0.96
10	1.00	1.00	1.00
11	0.86*	0.93	0.92
12	0.93	0.93	0.90
13	0.93	0.96	0.89
14	0.93	0.96	0.93
15	0.93	0.96	0.90
16	0.86*	0.92	0.90
17	1.00	1.00	0.94
18	1.00	0.96	0.93
19	0.87*	0.90	0.90
20	0.93	0.97	0.91
21	0.86*	0.93	0.92
22	0.94	0.96	0.91
23	0.86*	0.92	0.94
24	0.86*	0.93	0.94
25	0.94	0.96	0.93
26	1.00	1.00	0.94
27	0.93	0.96	0.93
28	0.93	0.93	0.87
29	1.00	0.92	0.91
30	1.00	1.00	0.97

Crew Number	1 m	2 m	5 m
31	1.00	0.93	0.94
32	0.93	0.96	0.96
33	1.00	1.00	0.89
Kiva	0.99	0.99	0.94
GBI	0.94	0.95	0.92
Overall	0.95	0.96	0.93

*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 2022. 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	0.96	0.58	393.1	338.3	456.9
2	0.97	1.00	0.75	362.9	319.1	412.7
3	0.97	1.00	0.77	411.8	366.3	463.0
4	0.89	1.00	0.63	388.5	347.5	434.2
5	1.00	1.00	0.62	438.0	329.3	582.5
10	1.00	1.00	0.64	380.8	313.2	463.1
11	0.89	0.93	0.70	411.8	352.4	481.2
12	0.83	0.93	0.97	399.9	336.5	475.3
13	0.85	0.96	0.77	402.4	342.8	472.4

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
14	0.88	0.96	0.95	373.5	323.3	431.6
15	0.92	0.96	0.83	402.7	336.4	482.2
16	0.73*	0.92	0.88	423.8	300.6	597.4
17	0.93	1.00	0.66	493.1	365.3	665.7
18	0.93	0.96	1.05*	430.0	367.2	503.5
19	0.86	0.90	0.84	418.3	370.5	472.2
20	0.90	0.97	0.72	404.4	348.6	469.0
21	0.93	0.93	1.30*	462.2	373.0	572.9
22	0.85	0.96	0.76	351.8	298.8	414.2
23	0.83	0.92	1.04*	381.4	326.4	445.6
24	0.80	0.93	0.71	392.8	287.1	537.3
25	0.65*	0.96	1.27*	345.7	304.9	391.9
26	1.00	1.00	0.64	426.2	355.6	540.8
27	0.85	0.96	0.86	387.2	287.5	521.4
28	0.93	0.93	0.79	375.8	270.4	522.4
29	0.92	0.92	0.65	379.7	317.8	453.6
30	1.00	1.00	1.04*	393.2	316.4	488.6
31	0.93	0.93	0.55	402.7	331.2	489.7
32	0.85	0.96	0.65	372.7	309.7	448.5
33	1.00	1.00	0.89	568.1	407.4	792.0
Kiva	0.95	0.94	0.67	398.9	340.1	469.9
GBI	0.89	0.95	0.84	407.5	331.0	505.5
Overall	0.90	0.96	0.81	406.0	332.5	499.4

*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).

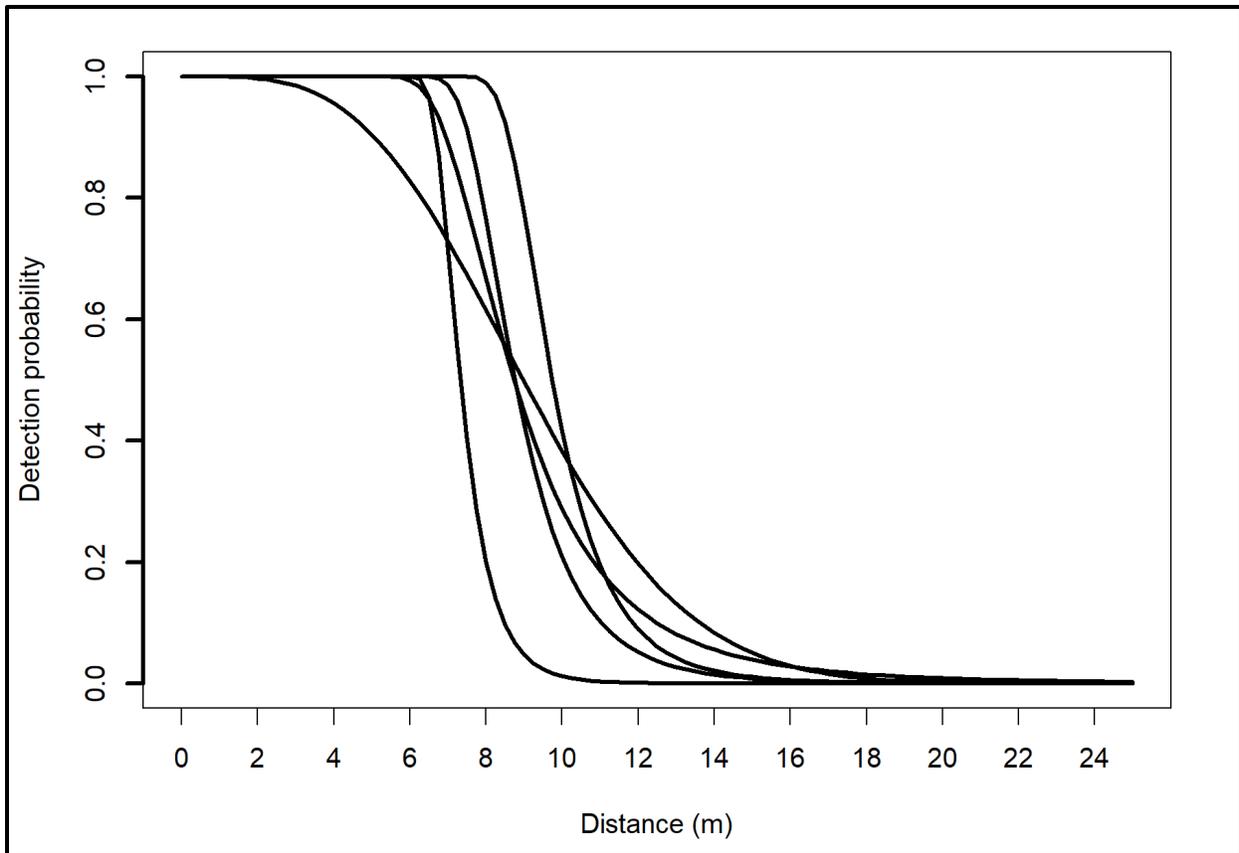


Figure 4. Detection curves for each of the 2022 Kiva crews during training. Each curve is based on a 16 km trial for one team with approximately 115 detections.

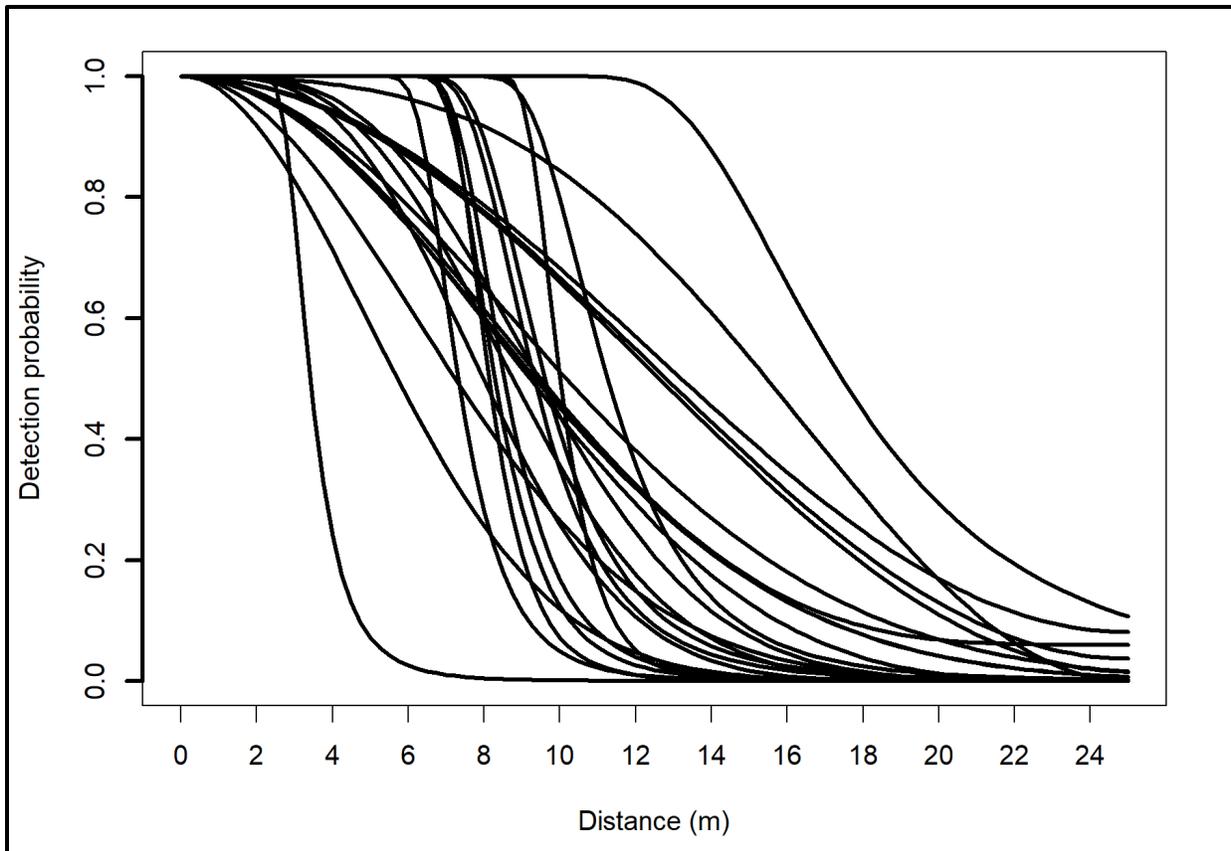


Figure 5. Detection curves for each of the 2022 GBI crews during training. Each curve is based on an 8-16 km trial for one team with approximately 100 detections.

Quality assurance and quality control

There were 16,355 transect records and 1,934 G_0 records associated with the monitoring effort in 2022. The first data specialist worked with the field teams to resolve 975 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 154 issues remained or were discovered in the third (final) phase of QA/QC. Only 26 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 13 were corrected with recourse to paper datasheets. The remaining errors in 2022 indicated a failure to comply with protocols (e.g., first timestamps indicating the transect record was initiated the night before the survey), not because the data were erroneous.

Transect completion

Table 8 reports the number of assigned and completed transects in each stratum in 2022. 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 to 9 show locations of transects and observations of live and dead tortoises.

Table 8. Number and completion of transects in each stratum in 2022.

Stratum	Assigned transects	Assigned and alternate transects completed	Assigned, completed 12-km	Assigned, completed shortened	Assigned, completed with a major reduction*
BD	70	70	49	17	4
CS	72	72	37	31	4
EV	75	75	46	26	3
GB	81	83	38	32	13
MM	65	65	37	25	3
PV	58	59	41	11	7
GBI	421	424	248	142	34
AG	35	35	24	6	5
CM	70	70	53	15	2
SC	75	75	63	10	2
Kiva	180	180	140	31	9
Total	601	604	388	173	43

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

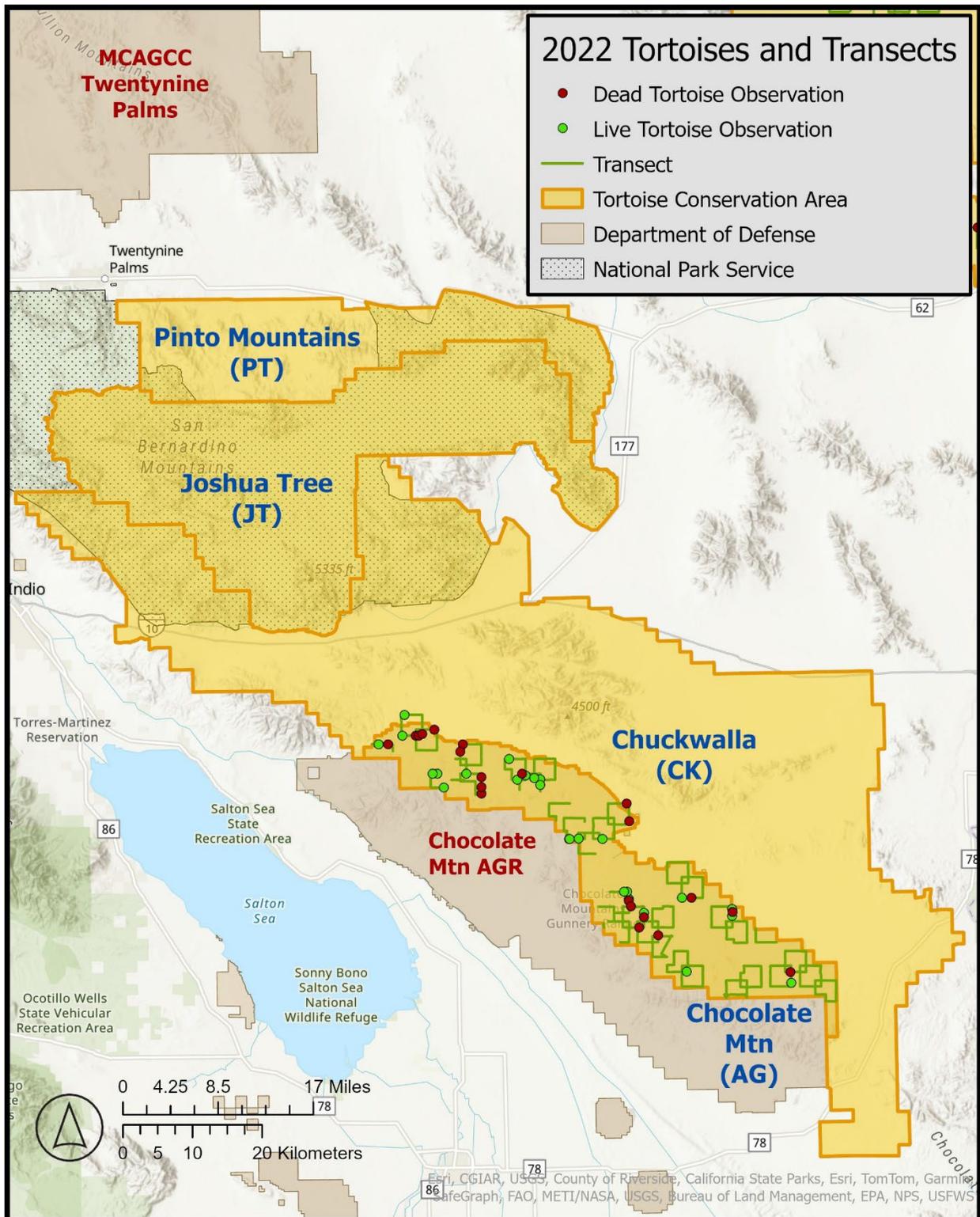


Figure 6. Distribution of distance sampling transects and tortoise observations in 2022 in Chocolate Mountain Aerial Gunnery Range in the southern part of the Colorado Desert Recovery Unit.

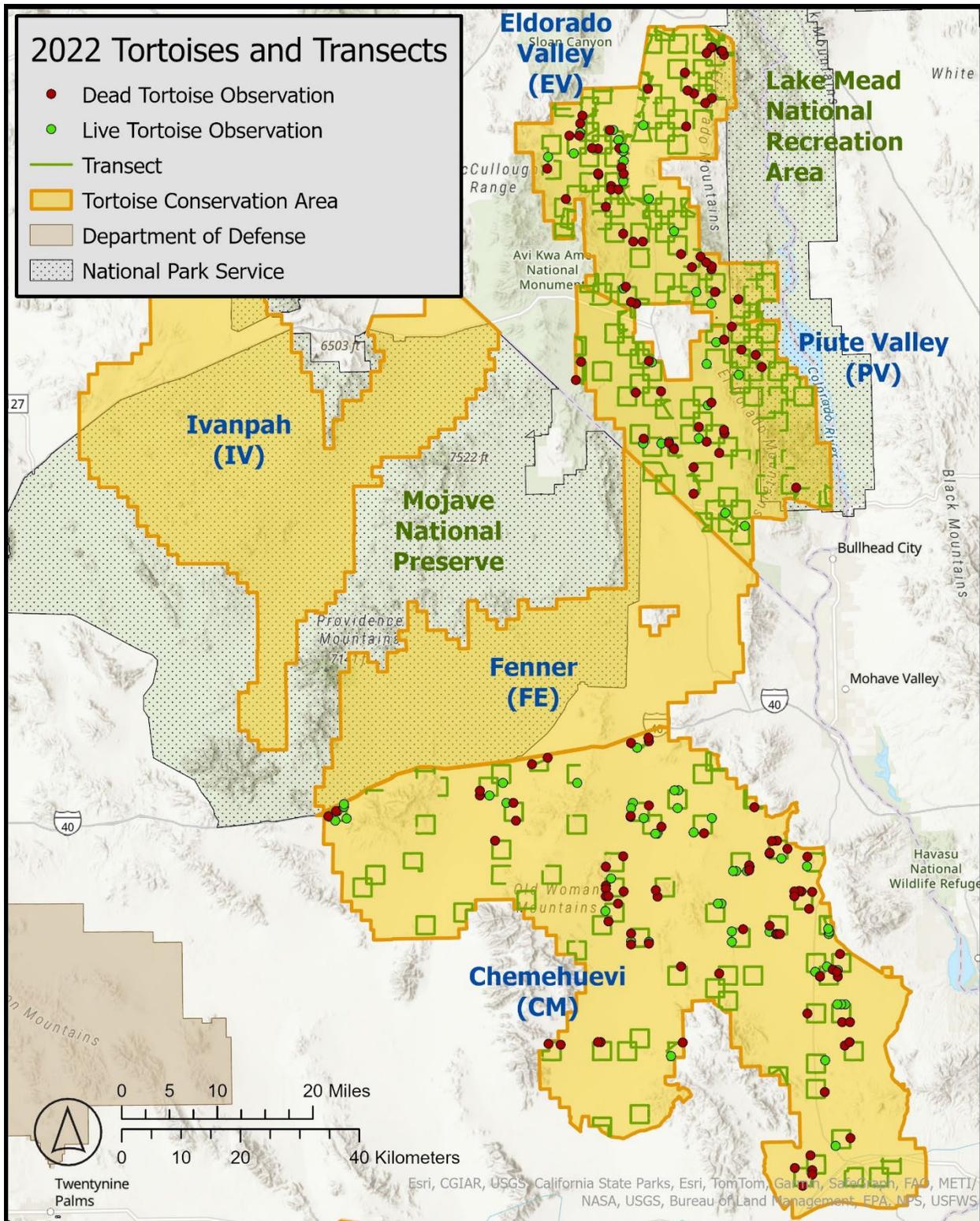


Figure 7. Distribution of distance sampling transects and tortoise observations in 2022 in the Eldorado Valley stratum of the Eastern Mojave Recovery Unit and in the Chemehuevi and Piute Valley strata of the Colorado Desert Recovery Unit.

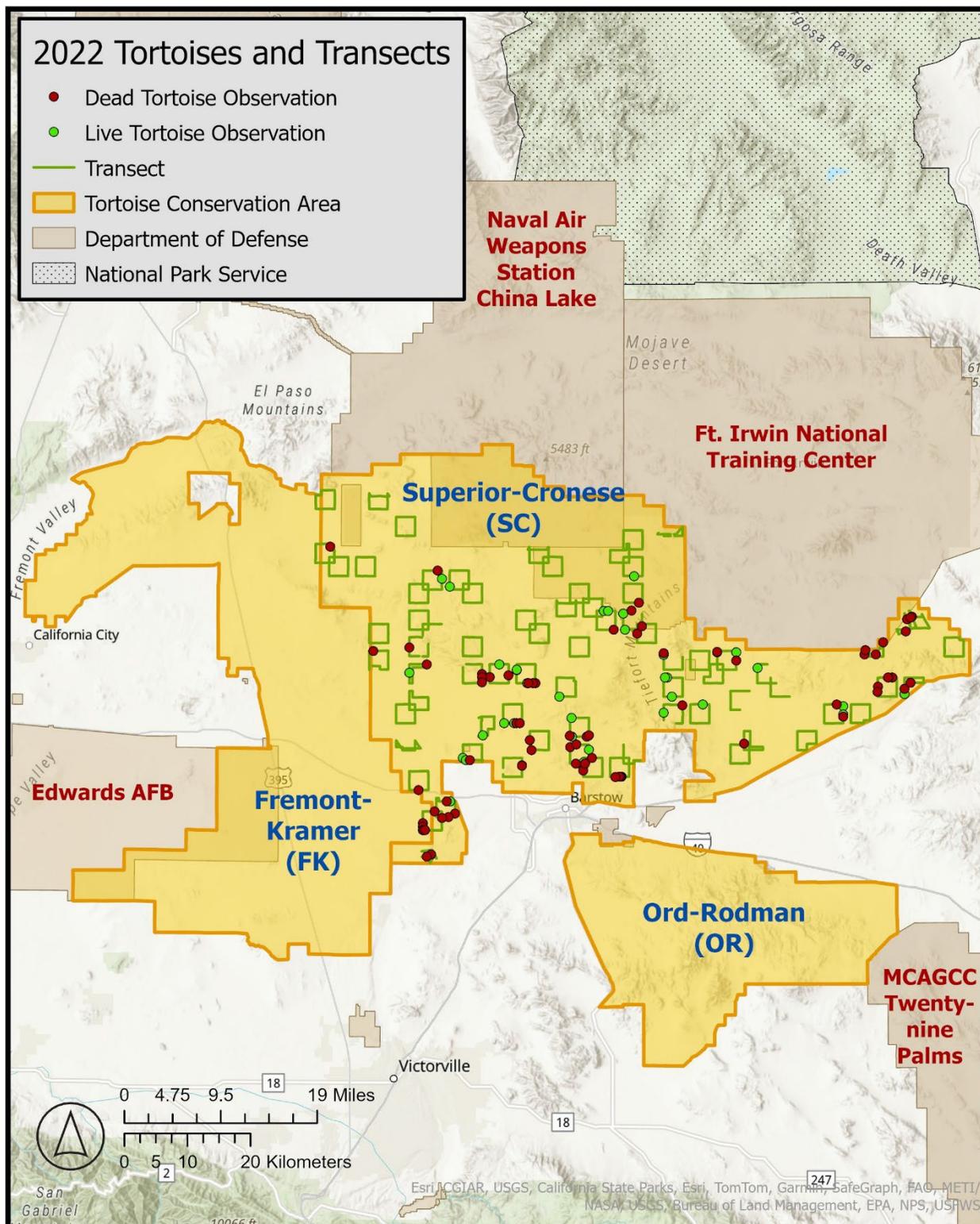


Figure 8. Distribution of transects and tortoise observations in 2022 in the Superior-Cronese stratum of the Western Mojave Recovery Unit.

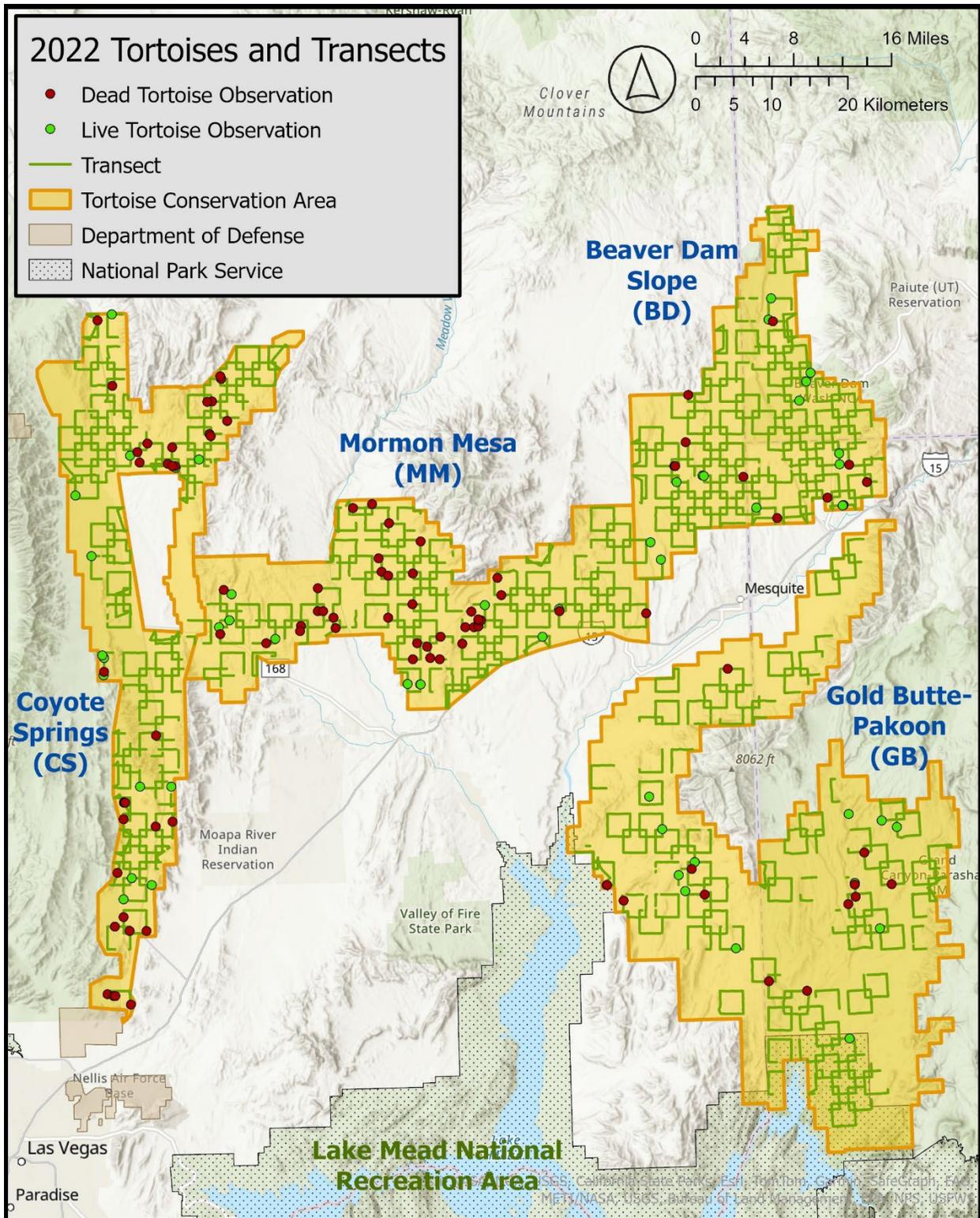


Figure 9. Distribution of transects and tortoise observations in 2022 in the Coyote Springs Valley, Mormon Mesa, Beaver Dam Slope, and Gold Butte-Pakoon strata of the Northeastern Mojave Recovery Unit.

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

For predicting 2022 estimates of G_0 , the best performing model was a generalized linear model which included stratum as a fixed effect. The fitted mixed effects model which also included day as a nested random effect had a singular fit, which may be the result of overfitting (Bates et al. 2015). A comparison of model outputs demonstrated that removing day as a random effect had no influence on the resulting estimates. Estimates of G_0 for the focal sites used for the 2022 sampling effort are included in Table 9.

In general, telemetry sites and associated strata were completed sequentially across the range, from south to north. This pattern corresponds to the expected timing of tortoise activity, peaking first in the south, later in the north. Visibility was higher in the western part of the range than in the east during surveys in the spring of 2022 (Table 9). Given the ongoing drought throughout the desert southwest, it is not surprising that tortoises in some areas were sheltering deep in burrows, so not available for detection.

Table 9. Availability of tortoises (G_0) when transects were walked in 2022 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	0.80 (0.042)
Chuckwalla	Chocolate Mountain North	11 Mar – 13 Mar	3	0.78 (0.049)
Superior-Cronese	Superior-Cronese	20 Mar – 4 Apr	15	0.97 (0.010)
Piute-Mid	Piute Valley	5 Apr – 13 Apr	9	0.65 (0.023)
Piute-Mid	Eldorado Valley	5 Apr – 13 Apr	9	0.65 (0.023)
Piute-Mid	Chemehuevi	7 Apr – 21 Apr	14	0.64 (0.020)
Gold Butte	Gold Butte-Pakoon	19 Apr – 27 Apr	7	0.43 (0.029)
Halfway Wash	Coyote Springs Valley	28 Apr – 5 May	5	0.44 (0.035)
Halfway Wash	Mormon Mesa	28 Apr – 11 May	8	0.46 (0.028)
Halfway Wash	Beaver Dam Slope	9 May – 12 May	4	0.47 (0.040)

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 15 and one from team 26 who formed team 34 for a week in April, and one surveyor from team 31 and one from team 32 who formed team 35 for a week in May. All Kiva crews surveyed 35-37 transects and overall they detected 104 tortoises larger than 180 mm MCL (adults). GBI surveyors walked a median 18 transects and reported 62 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 half-normal curve with second-order cosine adjustment and using all observations up to 24 m from the centerline. GBI's detection pattern best fit a hazard rate curve using observations up to 20 m from the centerline. Figures 10 and 11 are histograms of the observed number of tortoises seen at increasing distance from the transect centerline. Truncation

distance for Kiva removed 2 of the most distant observations and resulted in good fit overall and near the centerline. All stratum surveyed by Kiva had at least 20 observations. Truncation distance for GBI removed only 1 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 24 m of the transect centerline was 40.0% (CV=0.045) and for GBI crews it was 22.0% (CV=0.177) within 20 m of the transect centerline.

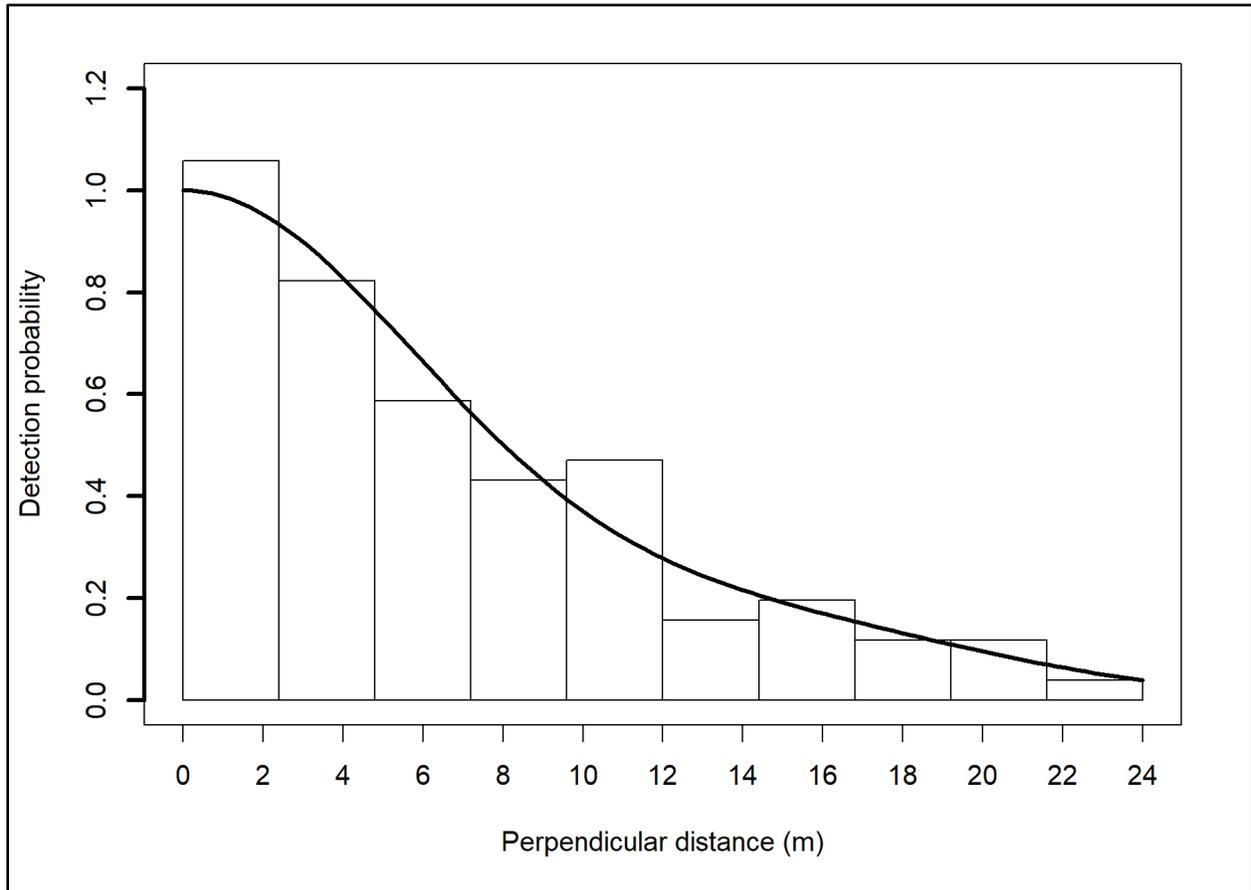


Figure 10. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL \geq 180 mm found by Kiva in 2022. This curve uses only the n=102 observations found within 24 m of the line.

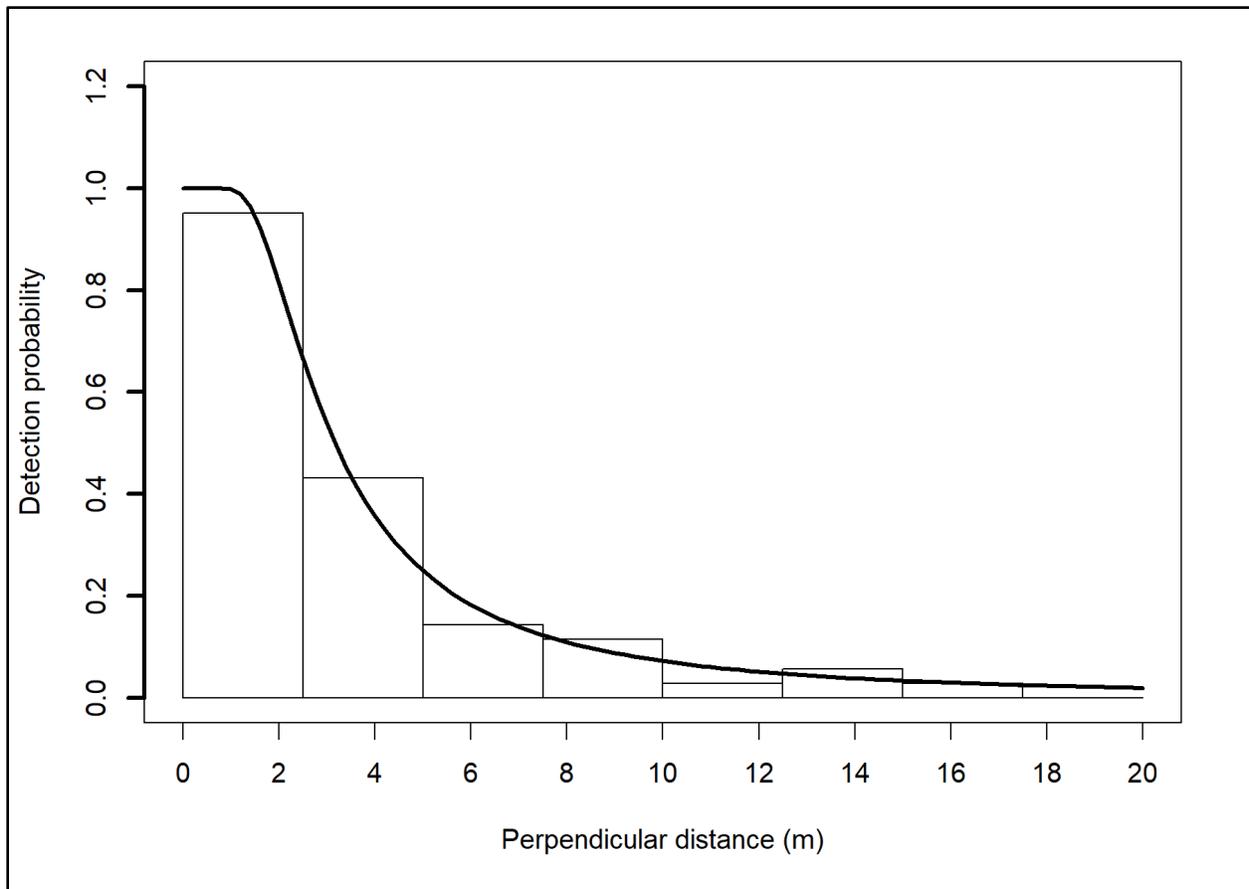


Figure 11. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with $MCL \geq 180$ mm found by GBI in 2022. This curve uses only the $n=61$ observations found within 20 m of the line.

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 2022, for 97 detections of adult tortoises within 5 m of the transect centerline, 73 were found by the observer in the lead position and 24 by the follower, so that the probability of detection by single observer, $p = 0.671$, and the proportion detected using the dual observer method, $g(0 \text{ to } 5 \text{ m}) = 0.892$ (SE = 0.116). Figure 12 shows that $g(0)$ was converging on 1.0 in 2022. 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). Previous years of data and the pattern in Figure 12 indicate the assumption of perfect detection on the centerline was met; consequently, no adjustment was made to the final density estimate.

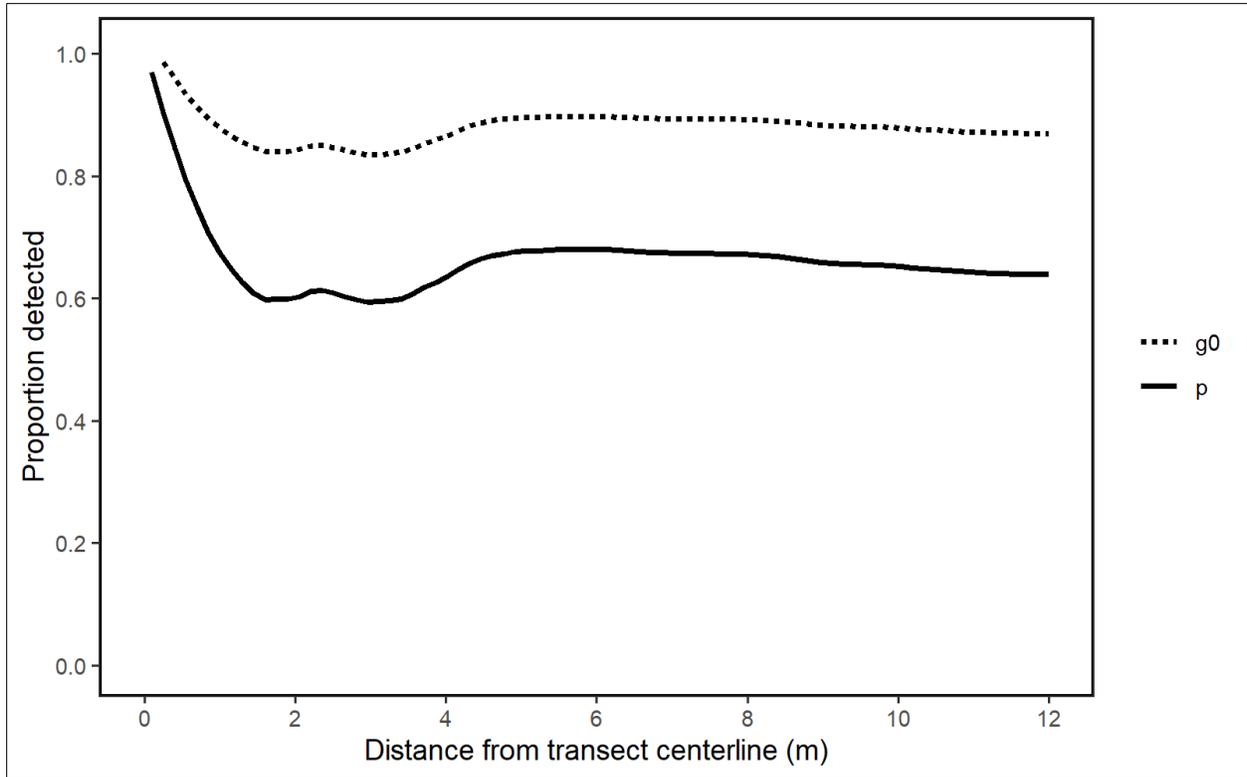


Figure 12. Detection pattern for the leader (p) and by the team ($g(\theta)$) based on all observations out to a given distance (x) from the centerline in 2022. Note convergence of $g(\theta)$ on 1.0 as x goes to 0.

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_θ 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 2022 for tortoises of MCL \geq 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		35	75	854	16-Mar	16-Mar					
Superior-Cronese	SC	1124	35	75	854	16-Mar	16-Mar	2.2	1.4	3.4	22.97
Colorado Desert		78	164	1777	6-Mar	13-Apr					
Chocolate Mtn north	AGN	351	16	15	145	12-Mar	14-Mar	7.4	4.0	13.6	31.79
Chocolate Mtn south	AGS	403	7	20	217	7-Mar	10-Mar	2.1	0.8	5.4	50.14
Chocolate Mtn	AG	755	23	35	362	7-Mar	14-Mar	4.2	2.4	7.3	28.84
Chemehuevi	CM	3509	44	70	796	6-Mar	7-Apr	4.5	2.9	7.0	22.97
Piute Valley	PV	1070	11	59	620	5-Apr	13-Apr	3.1	1.4	7.1	43.94
Northeastern Mojave		15	148	1488	15-Apr	18-May					
Beaver Dam Slope	BD	828	9	70	765	9-May	16-May	2.8	1.3	6.4	43.29
Coyote Springs Valley	CS	1025	13	72	740	26-Apr	5-May	4.5	2.1	9.5	39.27
Gold Butte-Pakoon	GB	1977	8	83	810	15-Apr	29-Apr	2.6	1.3	5.5	38.88
Mormon Mesa	MM	968	7	65	679	29-Apr	18-May	2.6	1.1	6.0	45.61
Eastern Mojave		13	75	790	20-Apr	8-May					
Eldorado Valley	EV	1153	13	75	790	20-Apr	8-May	2.9	1.5	5.8	36.44

DISCUSSION

During the spring of 2022, fewer tortoises were detected during range-wide line distance sampling across the entirety of the species' range than in years prior, resulting in decreased encounter rates in the majority of monitoring strata and G_0 correction factors showing that a large portion of the population remained below ground. In fact, at the focal telemetry sites several radio-transmitted tortoises were never recorded above ground during spring surveys which are strategically scheduled to match the spring activity period for tortoises.

The years 2000 through 2021 were the driest 22-year period recorded in over 1200 years in this region (Williams et al. 2022). The drought continued well into 2022 and the spring season was the third consecutive year in which extreme drought conditions were coupled with extreme temperatures across tortoise habitat. The effects that drought and extreme temperatures may have played in reducing encounter rates is twofold: an overall reduction in tortoise activity resulting in less tortoises above ground and a decrease in tortoises on the landscape due to a reduction in survival. During periods of drought there is typically a reduction in plant foods and available water yielding a down-regulation of metabolism and physiology for tortoises. In response to these conditions, tortoises will often decrease surface activity and increase the amount of time spent underground (Duda et al. 1999, Freilich et al. 2000), decreasing the likelihood of detecting individuals on a survey. Additionally, drought, particularly prolonged drought, has been documented to negatively affect survival rates (Turner et al. 1984, Longshore et al. 2003, Lovich et al. 2023). During drought periods, tortoise survival is affected both directly through dehydration and starvation, and indirectly via increased predation due to predators such as coyotes switching prey to tortoises when populations of more favorable prey species are in decline (Cypher et al. 2018, Esque et al. 2010), reducing the total number of animals available to be detected on the landscape.

Not surprisingly, encounter rates in 2022 were considerably lower than surveys in previous years across the range. At Eldorado Valley, Gold Butte-Pakoon, and Piute Valley, encounter rates decreased between 0.002–0.013 tortoises encountered per kilometer surveyed between 2019 and 2022, resulting in 0.6–3.8 fewer adult tortoises encountered for every 25 12-km line distance transects completed. Additional monitoring strata in Arizona, Nevada, and Utah saw a much larger reduction in encounter rates, resulting in 3.5–5.6 fewer tortoises encountered for every 25 transects surveyed. A few monitoring strata in California have seen slight increases in encounter rates since 2019 (Fenner, Pinto Mountains, and Superior-Cronese) but overall, encounter rates have decreased in this part of the range as well. Given the multi-year drought, this decrease in encounter rates across the range is not unexpected.

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