RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE (*GOPHERUS AGASSIZII*): 2023 ANNUAL REPORTING

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ACKNOWLEDGEMENTS

Funding was provided to this collaborative project in 2023 by the U.S. Department of the Navy, Marine Corps Air Station, Yuma.

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. No data were collected in Nevada, Utah, or Arizona during the 2023 field season. 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, T. Corwin, M. Fossum, K. Hayes, L. Hupp, J. MacNaughton, B. Scavone, E. Smith, S. Till, and C. Veety.

R. Patil (GBI) updated the electronic data-collection forms and procedures. J. Cooper (GBI) ran first-level quality assurance/quality control of data. USFWS conducted 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 2023, 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 2023 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 2023. Due to a lack of available funding and staff changes within the USFWS Desert Tortoise Recovery Office in 2022, limited monitoring occurred this year within a single stratum. Crews completed 35 transects (379.3 km) in the Chocolate Mountain Aerial Gunnery Range between 1-12 March. In the course of these surveys, they reported 52 live tortoises, 46 of which were at least 180 mm midline carapace length (MCL) and used to generate density estimates.

The southern portion of the Chocolate Mountain Aerial Gunnery Range had estimated densities similar to those in other strata (1.9 adults/km^2) across the range in recent years, however, the northern portion continues to have much higher estimated densities (12.5 adults/km^2), a pattern seen in past years of these surveys. Overall, the encounter rate averaged 8.8 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 estimates in 2023. 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 2023, surveys were only conducted in California in the Chocolate Mountain Aerial Gunnery Range TCA (AG). 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 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, but others may not have been selected in the past.

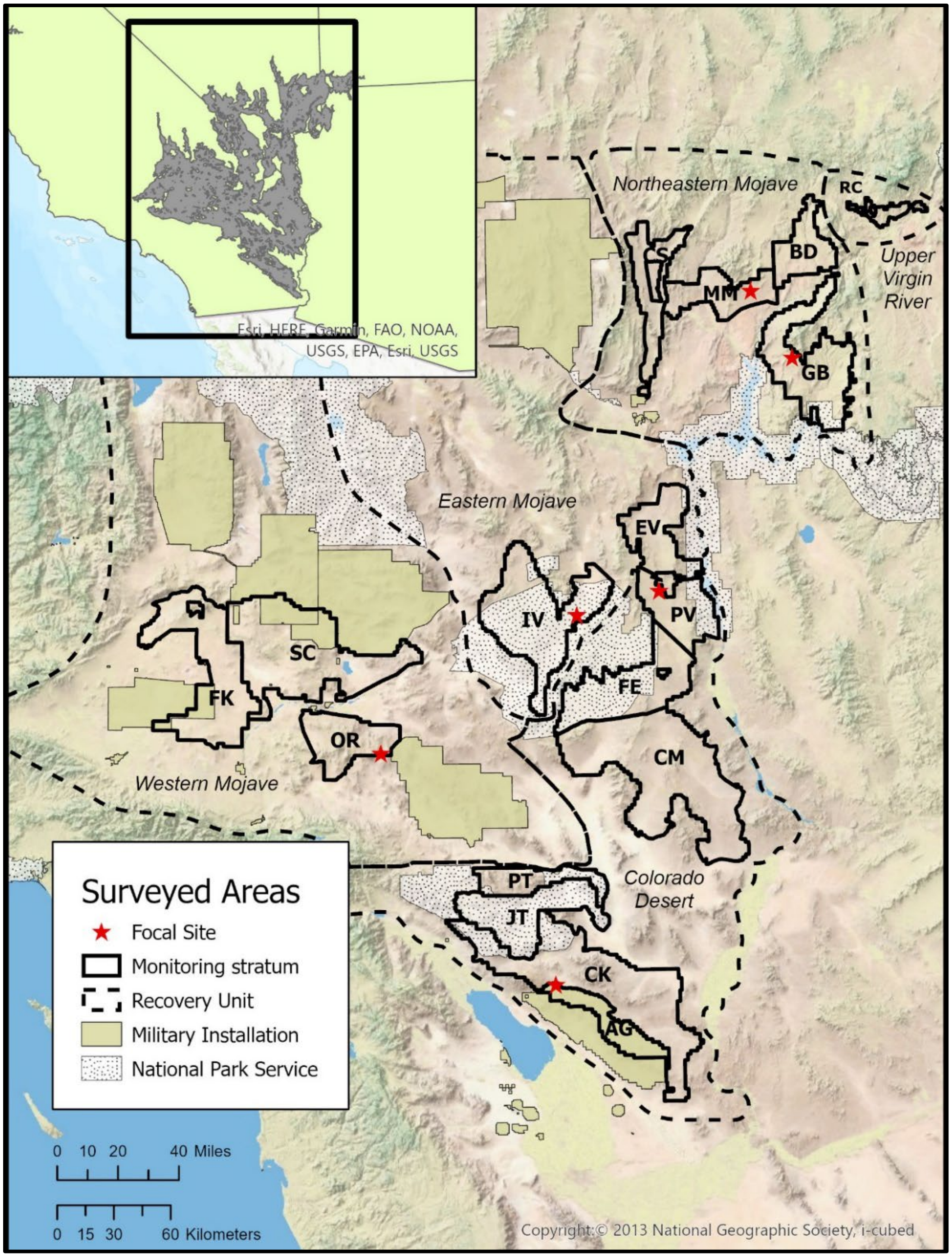

Figure 1. Long-term monitoring strata (n=17) corresponding to tortoise conservation areas (TCAs; USFWS 2011) in each recovery unit. TCAs and their codes are Chocolate Mountains Aerial Gunnery Range (AG), Beaver Dam Slope (BD), Chuckwalla (CK), Chemehuevi (CM), Coyote Springs Valley (CS), Eldorado Valley (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 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 6 focal sites throughout the Mojave and Colorado deserts (Figure 1). In 2023, the Chuckwalla (CK) focal site was used corresponding to the monitored strata (AG). Each time a radio-equipped tortoise was located, the observer determined whether the tortoise was visible (*yes* or *no*). Through careful coordination, observers at telemetry sites monitored visibility during the same daily time period when field crews were walking transects in the same region of the desert. Observers completed a survey circuit of all focal animals as many times as possible during the allotted time, recording visibility each time.

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

Field observer training

Training for careful data collection and consistency between crews is a fundamental part of quality assurance for this project. This training generally includes classroom instruction as well as required practice time on skills such as tortoise handling, walking practice transects, and developing detection and distance-measuring techniques on a training course with tortoise models in measured locations. Chapters of the monitoring handbook are updated as needed, provided to field crews, and posted to the Desert Tortoise Recovery Office website (https://www.fws.gov/media/2024-mojave-desert-tortoise-monitoring-handbook).

Kiva Biological (Kiva) supplied crews for monitoring in 2023. All 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 are completed under contract to BioResource Consultants, Inc. typically before formal review training is scheduled. Since no additional strata were scheduled to be surveyed in 2023, no formal classroom instruction was conducted this year; however, a field based refresher training took place before crews walked transects and collected data (Table 1).

Table 1. Training schedule for 2023 for Kiva transect crews.

Date	Activity	Location	Instructors
28 Feb	Transects methods overview	Chuckwalla ACEC, CA	Mitchell/Hayes/Bassett
	Tortoise handling review		
	Survey123 and data collection protocols		
	Short transect (6 km) practice		

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.

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 shape of the resulting detection function estimate (Buckland et al. 2001:15-16) as well as fit diagnostics near the transect centerline**.** Any observations that were not used to estimate detection functions were also not used to estimate the encounter rate (tortoises detected per kilometer walked). In distance sampling applications for many other species, encounter rate can be estimated with relatively high precision, but tortoise encounter rates are low enough that truncation was applied conservatively to maximize the number of observations per stratum. AIC was used to compare detection-function models (uniform, half normal, and hazard-rate) and key function/series expansions (none, cosine, simple polynomial, hermite polynomial) at the same truncation distance (Buckland et al. 2001).

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

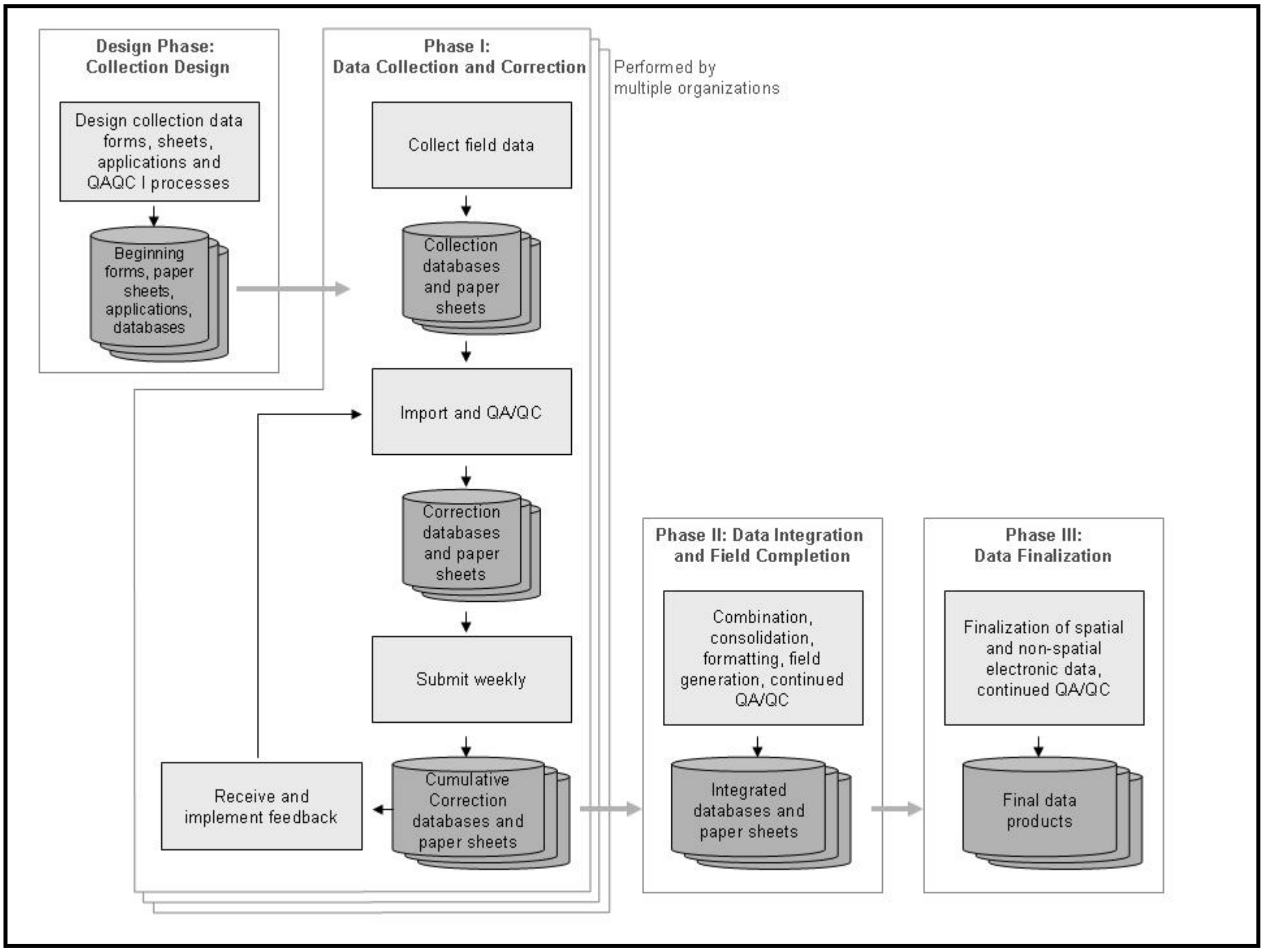

Figure 2. Data flow from collection through final products.

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

Transects were conducted by two-person crews using the method adopted beginning in 2004 (USFWS 2006). Transects were walked in a continuous fashion, with the lead crew member walking a straight line on a specified compass bearing, trailing about 25 meters of line, and the second crew member following at the end of the line. This technique involves little lateral movement off the transect centerline, where attention is focused. Use of two observers allows estimation of the proportion of tortoises detected on the line; and thereby provides a test of the assumption that all tortoises on the transect centerline are recorded ($g(0) = 1$). The capture probability (p) for tortoises within increasing distances from the transect centerline was estimated as for a two-pass removal or double-observer estimator (White et al. 1982): p = (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 crews (pairs) are expected to detect 96% of all models within 1 m of the transect centerline. This corresponds to the leader being responsible for at least 80% of the team's detections near the centerline in order to meet this standard and is the basis for one of the training metrics.

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

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

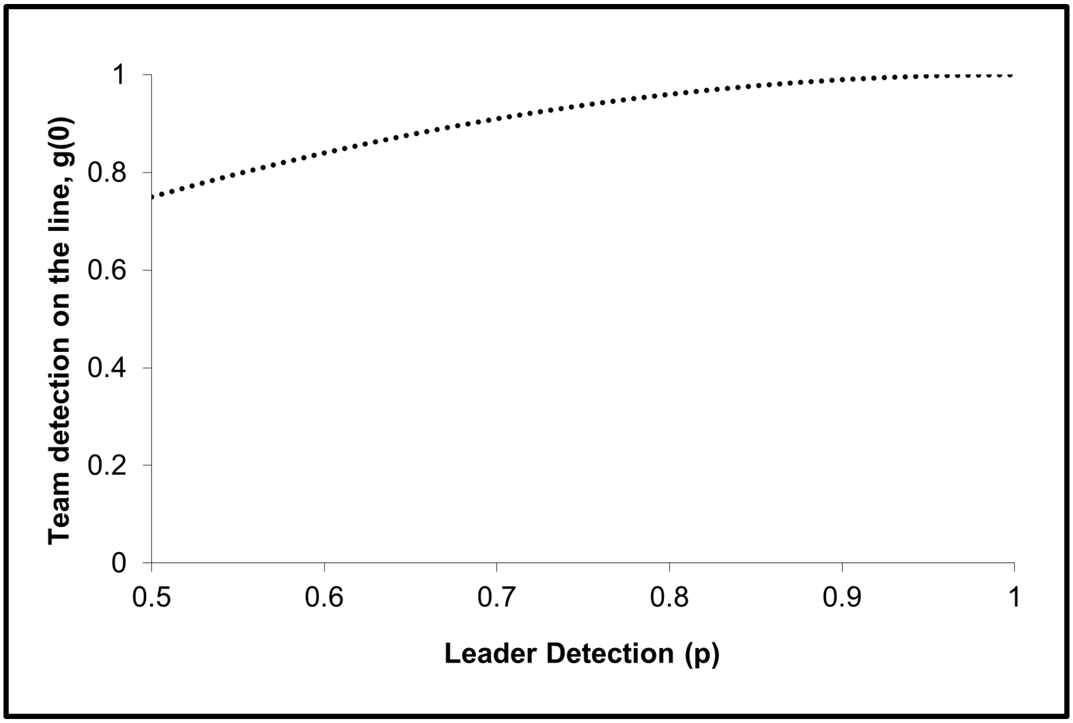

Figure 3. Relationship between single-observer detections (by the leader, *p*) and dual-observer (team) detections, *g(0)*.

Estimates of tortoise density

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

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

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

Proportion of available tortoises was estimated for all strata near each G_0 site and the proportion of available tortoises detected on the transect centerline ($g(0)$) was estimated jointly for all strata. The detection function, which comes into the above equation as P_a, was estimated jointly for all survey pairs due to low detections per pair. A schematic of the process leading to density estimates is given in Table 2. 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 2. Process for developing density estimates in 2023. 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, $g(0)$**
Recovery Unit	*Stratum*	*Neighboring G_0 Sites*	*Data Collection Group*	*Overall*
Colorado Desert	Chocolate Mountain Aerial Gunnery Range (also separated into north and south range estimates)	Chuckwalla	Kiva	All Data

RESULTS

Field observer training

Due to the short field season, training in 2023 was abbreviated and took place in the field on 28 February (Table 1). All eight surveyors for Kiva were returners to the project, having completed and passed formal review training in prior years. In lieu of formal classroom instruction, training in 2023 was focused on field data collection protocols as well as a review of transect methods and tortoise handling led by the current monitoring coordinator and field leads from Kiva.

Quality assurance and quality control

There were 989 transect records and 245 G_0 records associated with the monitoring effort in 2023. The first data specialist worked with the field teams to resolve 639 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 17 issues remained or were discovered in the third (final) phase of QA/QC. Only 6 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 were corrected with recourse to paper datasheets. The remaining errors in 2023 were data processing errors (e.g., incorrect datasheet naming convention), not that the data were erroneous.

Transect completion

Table 3 reports the number of assigned and completed transects in each stratum in 2023. Table 3 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). Figure 4 shows locations of transects and observations of live and dead tortoises.

Table 3. Number and completion of transects in each stratum in 2023.

Stratum	Assigned transects	Assigned and alternate transects completed	Assigned, completed 12-km	Assigned, completed shortened	Assigned, completed with a major reduction*
AG N	15	17	7	9	1
AG S	20	18	15	3	0
Total	35	35	22	12	1

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

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

For predicting 2023 estimates of G_0, the best performing model was a generalized linear mixed-effects model which included stratum as a fixed effect and date as well as tortoise number as nested random effects. The fitted mixed-effects model which only included date as a nested random effect had a singular fit, which may be the result of overfitting (Bates et al. 2015). Estimates of G_0 for the focal sites used for the 2023 sampling effort are included in Table 4.

Table 4. Availability of tortoises (G_0) when transects were walked in 2023 in the same or in neighboring strata.

G_0 site	Stratum	Dates	Days	G_0 (Std Error)
Chuckwalla	Chocolate Mountain South	1 Mar – 5 Mar	5	0.63 (0.33)
Chuckwalla	Chocolate Mountain North	7 Mar – 12 Mar	6	0.73 (0.33)

Tortoise encounter rates and detection functions

All survey pairs worked together from the beginning to the end of the season. Kiva crews surveyed a median 10-11 transects and overall they detected 46 tortoises larger than 180 mm MCL (adults). Kiva's detection pattern best fit a hazard-rate curve with no adjustments based on 5% truncation of the furthest observations from the centerline. Figure 5 is a histogram of the observed number of tortoises seen at increasing distance from the transect centerline. Truncation distance for Kiva removed 3 of the most distant observations and resulted in good fit overall and near the centerline. The detection rate for Kiva crews within 18 m of the transect centerline was 61.3% (CV=0.108).

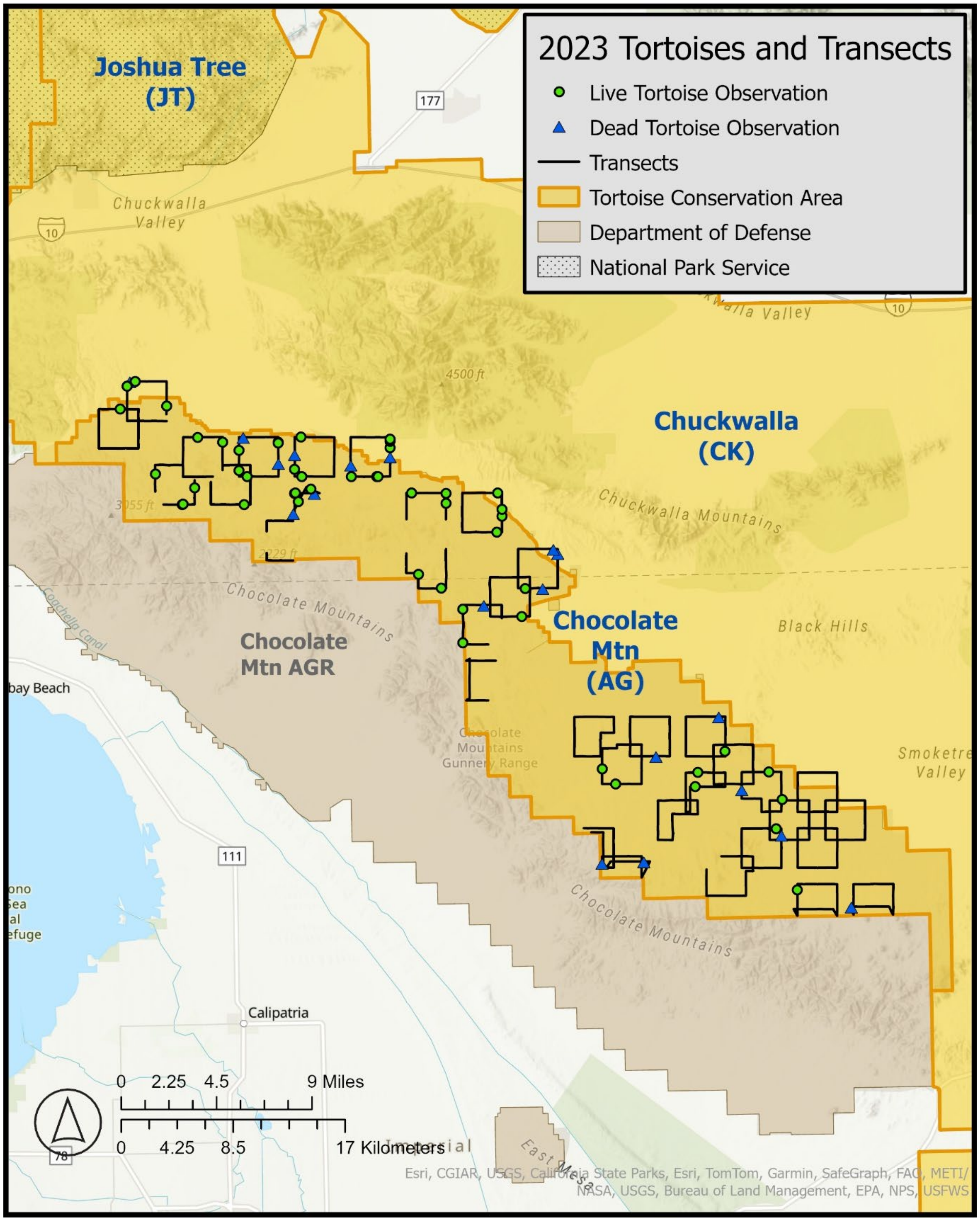

Figure 4. Distribution of distance sampling transects and tortoise observations in 2023 in Chocolate Mountain Aerial Gunnery Range in the southern part of the Colorado Desert Recovery Unit.

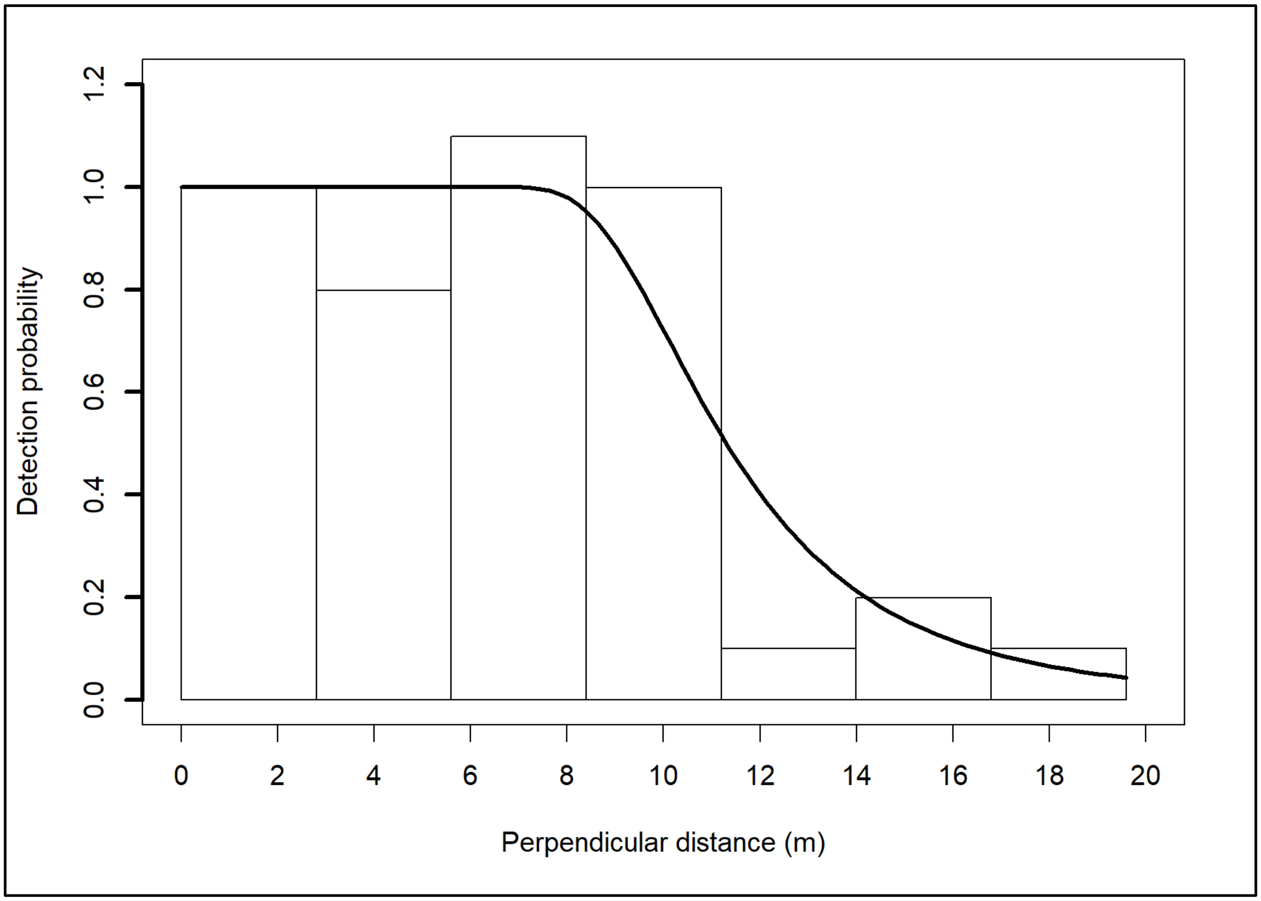

Figure 5. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180 mm found by Kiva in 2023. This curve is based on truncation of 5% of the most distant observations leaving only n=43 observations found within 18 m of the line.

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 2023, for 16 detections of adult tortoises within 5 m of the transect centerline, 13 were found by the observer in the lead position and 3 by the follower, so that the probability of detection by single observer, $p = 0.769$, and the proportion detected using the dual observer method, *g(0 to 5 m)* = 0.947 (SE = 0.214). Figure 6 shows that *g(0)* was converging on 1.0 in 2023. 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). Previous years of data and the pattern in Figure 6 indicate the assumption of perfect detection on the centerline was met; consequently, no adjustment was made to the final density estimate.

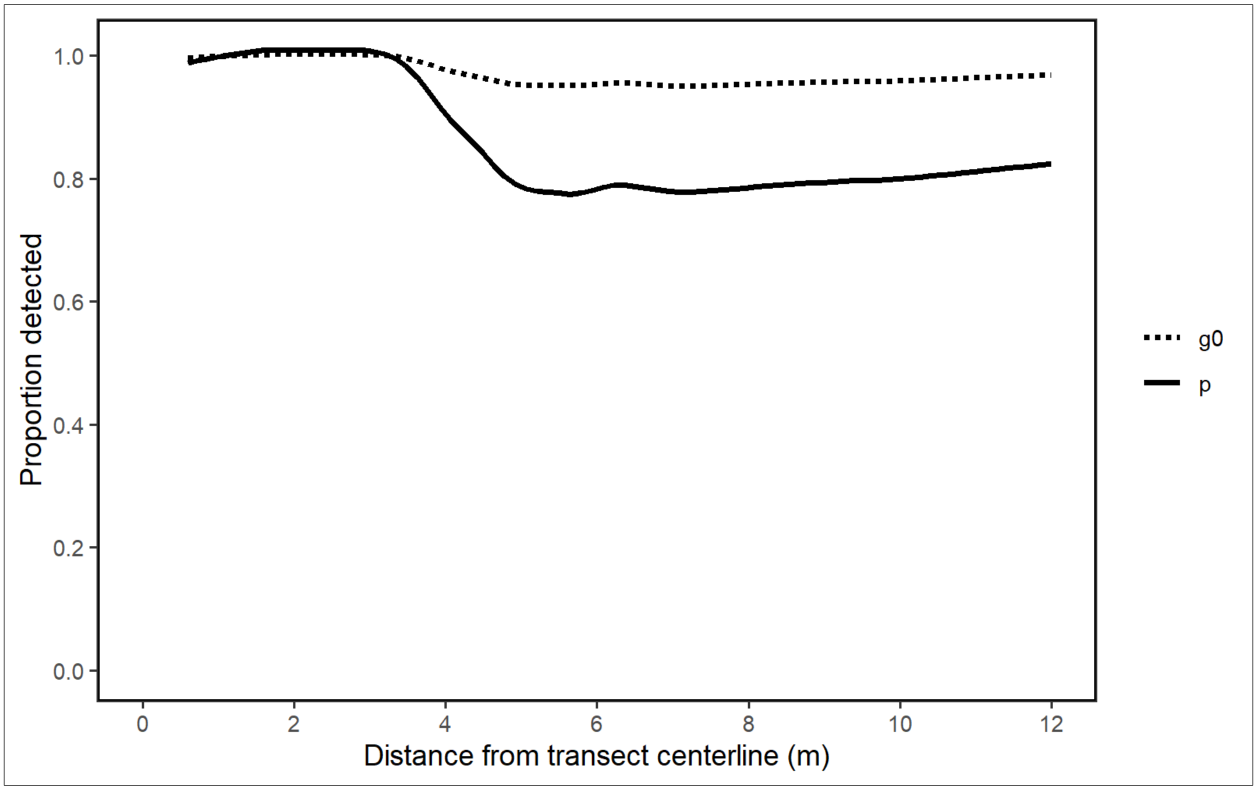

Figure 6. Detection pattern for the leader (*p*) and by the team (*g(0)*) based on all observations out to a given distance (*x*) from the centerline in 2023. Note convergence of *g(0)* on 1.0 as *x* goes to 0.

Estimates of tortoise density

Density estimates were generated separately for each monitoring stratum (Table 5). 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 5. Stratum-level encounters and densities in 2023 for tortoises of MCL ≥ 180 mm.

Recovery Unit/ Stratum		Area (km^2)	n (tortoises observed)	# Transects	Transect length (km)	Begin date	End date	Tortoise density (/km^2)			
								Density	Lower limit, 95% CI	Upper limit, 95% CI	%CV
Colorado Desert			**43**	**35**	**379**	**1-Mar**	**12-Mar**				
Chocolate Mtn North	AGN	351	37	15	168	7-Mar	12-Mar	12.5	5.04	31.02	48.95
Chocolate Mtn South	AGS	403	6	20	211	1-Mar	5-Mar	1.9	0.55	6.32	68.66
Chocolate Mtn	AG	755	43	35	379	1-Mar	12-Mar	6.9	2.55	18.37	53.69

Discussion

In 2023, desert tortoise range-wide monitoring efforts were abbreviated and limited to a single stratum in California, the Chocolate Mountains Aerial Gunnery Range. The short survey season was due to staff changes within the USFWS Desert Tortoise Recovery Office in 2022 as well as limited available funding for the monitoring program in 2023. 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 in long-term monitoring strata across the range; however, this is the first time since the program began that only a single stratum was surveyed over the course of the spring. Fortunately, the Chocolate Mountain Aerial Gunnery Range has continued to provide regular funding in support of the monitoring program, enabling range-wide surveys to occur on the installation 21 out of the last 23 years since the program began in 2001.

The years 2000 through 2021 were the driest 22-year period recorded in over 1200 years in this region (Williams et al. 2022), with the drought continuing well into 2022. Fortunately, this shifted during the winter preceding the 2023 field season and the region experienced substantially higher winter precipitation levels than in recent years. Survey crews in 2023 reported signs of sheet flow on transects in the Colorado Desert and even experienced rain while surveying in early spring. This ultimately led to a spring across the desert southwest with more annual biomass and cooler average temperatures than have been experienced in recent years. This also likely the reason more tortoises were encountered on transects than in recent years. On average survey crews encountered an adult tortoise every 8.8 km while surveying at the Chocolate Mountain Aerial Gunnery Range in 2023. In 2022 the average encounter rate during surveys in the same TCA was 15.7 km surveyed for each adult tortoise, with 2021 rates slightly higher at 17.5 km per adult. Compared to the last two years of surveys in this TCA crews in 2023 encountered adults nearly twice as frequently as they have during the previous two springs. Hopefully this is a trend that will continue across the range into next year.

A substantially larger range-wide monitoring survey effort is planned for 2024, with six TCAs scheduled to be surveyed: three in California and three in the Nevada, Utah, Arizona region. Additionally, supplemental surveys are planned within the northern portion of the range in under-studied areas within the greater Amargosa Valley area of Nevada.

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