RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE (*GOPHERUS AGASSIZII*): 2021 ANNUAL REPORTING

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Funding was provided to this collaborative project in 2021 by Clark County Desert Conservation Program; Arizona State BLM; the BLM California Desert District; MCAGCC Twentynine Palms; and the Marine Corps Air Station, Yuma. Data collected under contract to Wildlands, Inc. were also incorporated into this analysis.

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).

Personnel from Kiva Biological Consulting (California) led by M. Bassett and K. Hayes conducted the field surveys in California, while data in Nevada and Arizona were collected by Great Basin Institute (GBI) led by Terry Christopher and Mark Spangler. 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, J. Ciarcia, S. Clegg, E. Ceplecha, N. Cram, P. Delisle, A. d'Epremesnil, A. Drummer, E. Evangelist, J. Fox, M. Grubb, J. Haack, K. Hayes, M. Hellebrandt, K. Hotchkiss, A. Kalyn, K. Koller, B. Laliberte, N. Langlois, S. Mendoza, J. Merlo-Coyne, S. Meyer, E. Phipps, I. Ramirez, M. Rothrock, R. Russell, B. Scavone, E. Smith, S. Stobaugh, S. Till, N. Trager, E. Trimpe, C. Veety, C. Welch.

R. Patil (GBI) updated the electronic data-collection forms and procedures. 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 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 2021, 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., 2018) and will not be further addressed herein.)

This report describes quality assurance steps and final results for the 2021 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 2021, when crews completed 533 transects (5743.8 km) in 8 strata between 6 March and 19 May. In the course of these surveys, they reported 278 live tortoises, 243 of which were at least 180 mm midline carapace length (MCL) and used to generate density estimates.

In 2021, we surveyed 8 of the 16 strata. Piute Valley and Ivanpah both had estimated densities less than 2.0 adult tortoises/km^2. Although the southern portion of the Chocolate Mountain Aerial Gunnery Range had densities similar to those in other strata (2.2 adults/km^2), the northern portion had much higher densities (7.2 adults/km^2), a pattern that was also seen in past years of these surveys. Other strata surveyed in 2021 (and the estimated density of adults/km^2) were Chuckwalla (2.6), Fenner (5.3), Gold Butte-Pakoon (2.4), and Mormon Mesa (5.2). Over all strata, the encounter rate averaged 23.7 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. The most accurate existing density estimates for each stratum are therefore those based on trend estimates through 2014 (USFWS 2015); an updated analysis with more recent years of data is planned in 2022. The update is delayed a year because coronavirus mitigation measures meant it took longer to collect enough years of data in the eastern part of the range.

RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE 2021

INTRODUCTION

The Mojave Desert population of the desert tortoise was listed as threatened under the Endangered Species Act in 1990. This group of desert tortoises north and west of the Colorado River are now recognized as the species *Gopherus agassizii*, separate from *G. morafkai* south and east of the Colorado River (Murphy et al., 2011). The revised recovery plan (USFWS, 2011) designates five recovery units to which decisions about continued listing status should be applied. The recovery plan specifies that consideration of delisting should only proceed when populations in each recovery unit have increased for at least one tortoise generation (25 years), as determined through a rigorous program of long-term monitoring. This report describes implementation of monitoring and presents the analysis of desert tortoise density in 2021. 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).

METHODS

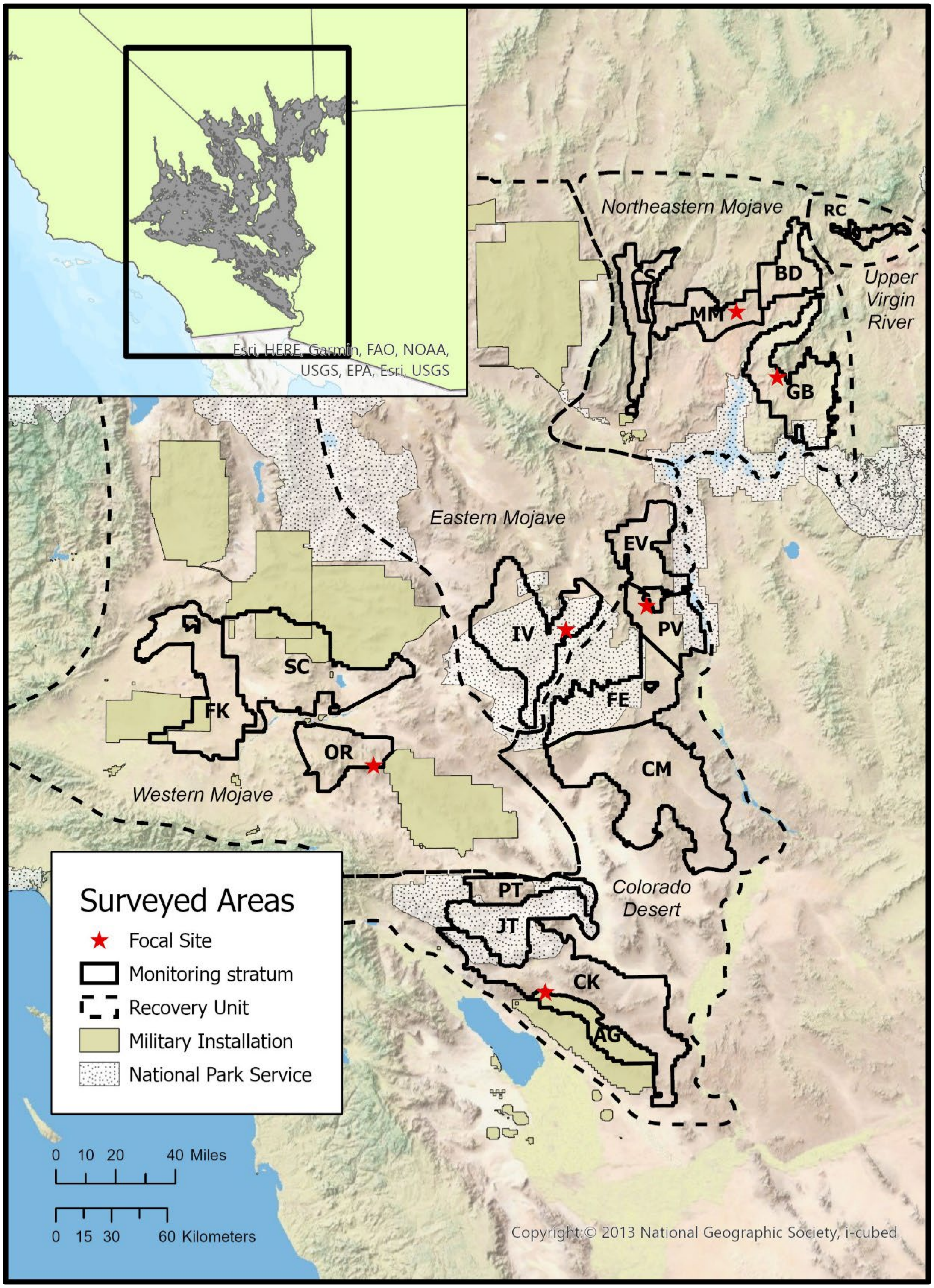
Study areas and transect locations

Long-term monitoring strata (Figure 1) will be used over the life of the project to describe population trends in areas where tortoise recovery will be evaluated. These areas are called "tortoise conservation areas" (TCAs) in the recovery plan to describe designated critical habitat as well as contiguous areas with potential tortoise habitat and compatible management. The area associated with each critical habitat unit (CHU) is generally treated as one monitoring stratum, although the portion of Mormon Mesa CHU that is associated with Coyote Springs Valley is treated as a separate stratum. Chuckwalla CHU is also treated as dual monitoring strata, with potentially unequal sampling effort in the areas managed by the Department of Defense (Chocolate Mountain Aerial Gunnery Range, CMAGR) and by the Bureau of Land Management (BLM). New recovery units were established under the revised recovery plan (USFWS, 2011), which led to separating the Piute and Eldorado Valleys into 2 distinct strata which are in different recovery units. Fenner Valley is in the same recovery unit but is a distinct stratum from Piute Valley to simplify reporting by state. The Joshua Tree stratum does not encompass all suitable habitat for desert tortoises in Joshua Tree National Park (JTNP). The national park designation and 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 2021, surveys were conducted in California in AG, CK, FE, IV, and OR strata; and in GB, MM, and PV in Nevada 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 was determined, these were selected using randomization procedures; since 2013 R software has been used to implement the Generalized Random Tesselated Stratified (GRTS) spatially balanced survey design procedure (R Core Team, 2020; Kincaid and Olsen, 2017). The US Environmental Protection Agency developed GRTS as a means to generate a spatially balanced, random sample (Stevens and Olsen, 2004). Each year GRTS was used to select planned transects with these qualities and to select a set of alternative transects that would contribute to the final sample having the same spatially representative and random properties if any planned transects were replaced due to field logistics. Because the same set of potential transects has been used since 2007, some transects are repeated between years but others may not have been selected in the past.



Stratum abbreviations are given in Table 6. Potential habitat (Nussear et al., 2009) is overlain on the southwestern United States in the extent indicator.

Distance sampling transect completion

One adaptation that tortoises have for living in the desert is to restrict surface activity to fairly narrow windows of time during the year. In general, tortoises emerge from deep within shelters (burrows) from mid-March through mid-May and then again (less predictably) in the fall. These periods coincide with flowering of their preferred food plants (in spring) and with annual mating cycles (in fall). The annual range-wide monitoring effort is scheduled to match the spring activity period for tortoises.

During this season, not all tortoises are above ground or visible in burrows. To encounter as many tortoises as possible, monitoring is scheduled for early in the day and to be completed before the hottest time of day. Because tortoises are located visually, monitoring is restricted to daylight hours. Based on past experience, we expect tortoises to become most active after 8am during March (it is usually too cool before this time), but to emerge earlier and earlier until their optimal activity period includes sunrise by the beginning of May. In May, we also expect 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. Teams were comprised of two field personnel who switched lead and follow positions at each corner of each transect, so they each spent an equal amount of time in the leader and follower positions. The leader walked on the designated compass bearing while pulling a 25 m length of durable cord; the walked path is also the transect centerline and was indicated by the location of the cord. The length of cord also spaced the two observers, guiding the path of the follower; when the cord was placed on the ground after a tortoise or carcass was detected, it facilitated measurement of the local transect bearing. The walked length of each transect was calculated as the straight-line distance between GPS point coordinates that were recorded at approximate 500 m intervals (waypoints) along the transect and/or whenever the transect bearing changed. Leader and follower each scanned for tortoises independently without leaving the centerline, and the role of the crew member finding each tortoise was recorded in the data. Although the leader saw most of the tortoises, the role of the follower was to see any remaining tortoises near the centerline, crucial to unbiased estimation of tortoise densities.

Distance sampling requires that distance from the transect centerline to tortoises is measured accurately. When a tortoise was observed, crews 1) used a compass to determine the local transect bearing based on the orientation of the 25 m centerline, 2) used a compass to determine the bearing from the point of observation to the tortoise, and 3) used a measuring tape to determine the distance from the observer to the tortoise. These data are sufficient to calculate the perpendicular distance from the observed tortoise to the local transect line. If the tortoise was outside of a burrow, it was handled enough to measure midline carapace length (MCL), to determine its sex, assess its body condition (USFWS, 2019a), and to apply a small numbered tag to one scute. If a tortoise could not be measured because it was in a burrow, because temperatures precluded handling, or for any other reason, crews attempted to establish by other means whether the animal was at least 180 mm MCL, the criterion for including animals in density estimates.

Because transects are 3 km on one side, it is not unusual for that path to cross through varied terrain or even be blocked by an obstacle such as an interstate highway. In the first years of this program, smaller transects in inconvenient locations were shifted or replaced, but this compromised the representative nature of the sample. Since 2007, the basic rules for modifying transects involve 1) reflecting transects to avoid obstacles associated with human infrastructure or jurisdictions (large roads, private inholdings, administrative boundaries, etc.), or 2) shortening transects in rugged terrain (USFWS, 2012b). 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 4pm each day.

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

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. Instead, we use telemetry to estimate the proportion of tortoises available for sampling, G_0 (“gee-sub-zero”), which was incorporated in estimate of adult tortoise density to correct this bias.

We used telemetry to locate radio-equipped tortoises that were visible as well as those that were otherwise undetectable in deep burrows or well-hidden in dense vegetation. To quantify the proportion that were available for detection (visible), telemetry technicians used a VHF radio receiver and directional antenna to locate 9-16 radio-equipped G_0 tortoises in each of the 6 focal sites throughout the Mojave and Colorado deserts (Fig. 1). The Chuckwalla, Gold-Butte, Halfway, Ivanpah, Ord-Rodman, and Piute-Mid focal sites were used in 2021 corresponding to the monitored strata.

Each time a transmittered tortoise was located, the observer determined whether the tortoise was visible (*yes* or *no*). Through careful coordination, observers at telemetry sites monitored visibility during the same daily time period when field crews were walking transects in the same region of the desert. Observers completed a survey circuit of all focal animals as many times as possible during the allotted time, recording visibility each time. I estimated G_0 using a mixed model in R (R Core Team 2020), treating day as a random factor and including this source of error in the standard error.

Field observer training

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

Kiva Biological (Kiva) supplied crews for monitoring in California strata. Great Basin Institute (GBI) supplied crews for monitoring in strata in Nevada and Arizona. All of the 10 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 (Table 1) for surveys in the remaining 4 strata. Only 3 of 20 surveyors in the GBI team had prior experience in this program. The two teams were trained separately by the same USFWS instructor for consistency.

Distance sampling training

Transect walkers were given classroom instruction, skills training, field demonstrations, and practice transects to complete (Table 1). Ultimately each team was evaluated based on performance on a field arena outfitted with polystyrene tortoise models placed in measured locations (Anderson et al., 2001), as well as on performance meeting protocol requirements on full-day staged transects.

Polystyrene desert tortoise models were set out on the training course each year using placement instructions (vegetation or open placement, tape-measured distance along training line, and tape-measured distance perpendicular from training line). This course was used to determine whether 1) individual teams are able to detect all models on the transect centerline, 2) whether their survey techniques yield useful detection functions, and 3) whether they can accurately report the distance of each model from the transect centerline. For each purpose, many opportunities must be provided, so the course is populated at a very high density of models (410/km^2).

Crews were sent on transects and training lines as paired, independent observers. That is, the follower was 25 m behind the leader, with the opportunity to detect models not found by the leader. If the leader detected 80% of all tortoises that 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 X (1 – 0.80)) = 0.96 of all tortoises on the centerline. These data on models were used to evaluate and correct crew performance before the field season, but were not used in any way to estimate densities of live tortoises once range-wide field surveys began.

Table 1. Training schedule for 2021 for 1) Kiva transect crews, b) GBI transect crews, and c) GBI telemetry trainees.

1a. Training schedule for 2021 Kiva transect crews

Date	Activity	Location	Instructors
Friday, 5 March	Transect methods overview	Chuckwalla ACEC, California	Hayes/Bassett
	Phones – Transect database	Chuckwalla ACEC, California	Hayes/Bassett
	Short transect (6 km) practice	Chuckwalla ACEC, California	Hayes/Bassett
16 March	Training Lines I (8km)	BLM Desert Tortoise Mgmt Area (DTMA)	Allison
17 March	Review training line I results	GBI Field Station	Allison / Spangler
	GPS and compass use for tortoise monitoring	GBI Field Station	Allison
	Tortoise handling	GBI Field Station	Bassett/ Hayes
	Tortoise visibility examples	GBI Field Station	Allison
18 March	Training Lines II (8km)	BLM DTMA	Allison
19 March	Review training line II results	GBI Field Station	Allison / Spangler
	Review Chuckwalla ACEC practice transect results	GBI Field Station	Allison / Spangler

Date	Activity	Location	Instructors
	Wrap up discussion	GBI Field Station	Allison

1b. Training schedule for 2021 for GBI transect crews

Date	Activity	Location	Instructors
Tuesday, 16 March	Transect methods overview	GBI Field Station	Allison
	Phones – Training database	GBI Field Station	Spangler
	Review protocol and goals on training lines	GBI Field Station	Allison
	Compass use for measuring tortoise distance from line	GBI Field Station	Spangler
	Practice styrotort protocol and data entry	GBI Field Station	Christopher
17 March	Training Lines I (8km)	BLM DTMA	Allison
22 March	Review training line I results	GBI Field Station	Allison / Spangler
	Monitoring on public lands	GBI Field Station	Allison
	Phones – Transect database	GBI Field Station	Spangler
	Practice epoxy for tag attachment	GBI Field Station	Christopher
23 March	Training Lines II (16km)	BLM DTMA	Allison
24 March	Training Lines II (continued)	BLM DTMA	Allison
25 March	Tortoise sign	GBI Field Station	Allison
	Tortoise visibility examples	GBI Field Station	Allison
	Biosecurity	GBI Field Station	Dr. Johnson

Date	Activity	Location	Instructors
	Tortoise handling practice 1	GBI Field Station	Dr. Johnson / Spangler
26 March	Search image for tortoises and sign	River Mtns, NV	Christopher/Sparks
29 March	Review training line II results	GBI Field Station	Allison / Spangler
	Standard protocol and nonstandard transects, start point and reflection exercise	GBI Field Station	Allison
	GPS and compass use	GBI Field Station	Allison
30 March	Full 12km transect 1 with interruption for terrain	Large Scale Translocation Site	Christopher
31 March	Review LSTS 1 practice	GBI Field Station	Allison / Spangler
	Handling practice 2	GBI Field Station	Christopher
1 April	Full 12km transect 2 with reflection	Large Scale Translocation Site	Christopher
2 April	Review LSTS 2 practice	GBI Field Station	Allison / Spangler
	Wrap up discussion	GBI Field Station	Allison
	Handling practice 3	GBI Field Station	Christopher

1c. Training schedule for GBI telemetry technicians.

Date	Activity	Location	Instructors
2 March	Tortoise and tortoise sign	GBI Field Station	Allison
	Telemetry instruction and practice	GBI Field Station	Sparks

Date	Activity	Location	Instructors
3 March	Telemetry practice	BCCE	Sparks
4 March	Telemetry practice	BCCE	Sparks
5 March	Introduction to distance sampling	GBI Field Station	Allison
	Visibility descriptions	GBI Field Station	Allison
	Telemetry practice	BCCE	Sparks
8 March	Telemetry practice	BCCE	Sparks
9 March	Telemetry practice	BCCE	Sparks
10 March	Telemetry practice	Piute-Mid focal site	Sparks
15 March	Telemetry practice	BCCE	Sparks
16 March	Telemetry practice	Halfway Wash	Sparks
17 March	Telemetry practice	BCCE	Sparks
22 March	Telemetry practice	BCCE	Sparks
23 March	Telemetry practice	Gold Butte focal site	Sparks
24 March	Telemetry practice	BCCE	Sparks
25 March	Telemetry practice	River Mountains, Nevada	Sparks
20 March	Telemetry practice	River Mountains, Nevada	Sparks
25 March	Tortoise visibility	GBI Field Station	Allison
	Biosecurity	GBI Field Station	Dr. Johnson
	Tortoise handling practice	GBI Field Station	Dr. Johnson
26 March	Surveyor search image for tortoises	River Mountains, Nevada	Spangler / Sparks

Date	Activity	Location	Instructors
29 March	Surveyor search image for tortoises	River Mountains, Nevada	Christopher/Sparks
30 March	Telemetry practice	BCCE	Sparks
31 March	Handling practice 2	GBI Field Station	Christopher
2 April	Telemetry to derive start times	Piute-Mid focal site	Sparks

Data management, quality assurance, and quality control

Two sets of data tables were maintained through the field season, organizing data collected on transects and at the G_0 focal sites. Collection data forms, paper datasheets, and databases were designed to minimize data entry errors and facilitate data verification and validation. Data were collected in both electronic and paper formats by the separate survey organizations, then combined into a single database by a single data manager provided by GBI. Data were submitted to the USFWS for evaluation at 7-14-day intervals over the course of surveys. Data were evaluated for completeness and correctness but also for consistency among crews and between field teams. Written review of the datasets was provided by USFWS to the field teams, who worked with the Phase I data manager to address and/or clarify any identified inconsistencies in the data and to ensure all crews applied the field protocols consistently.

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

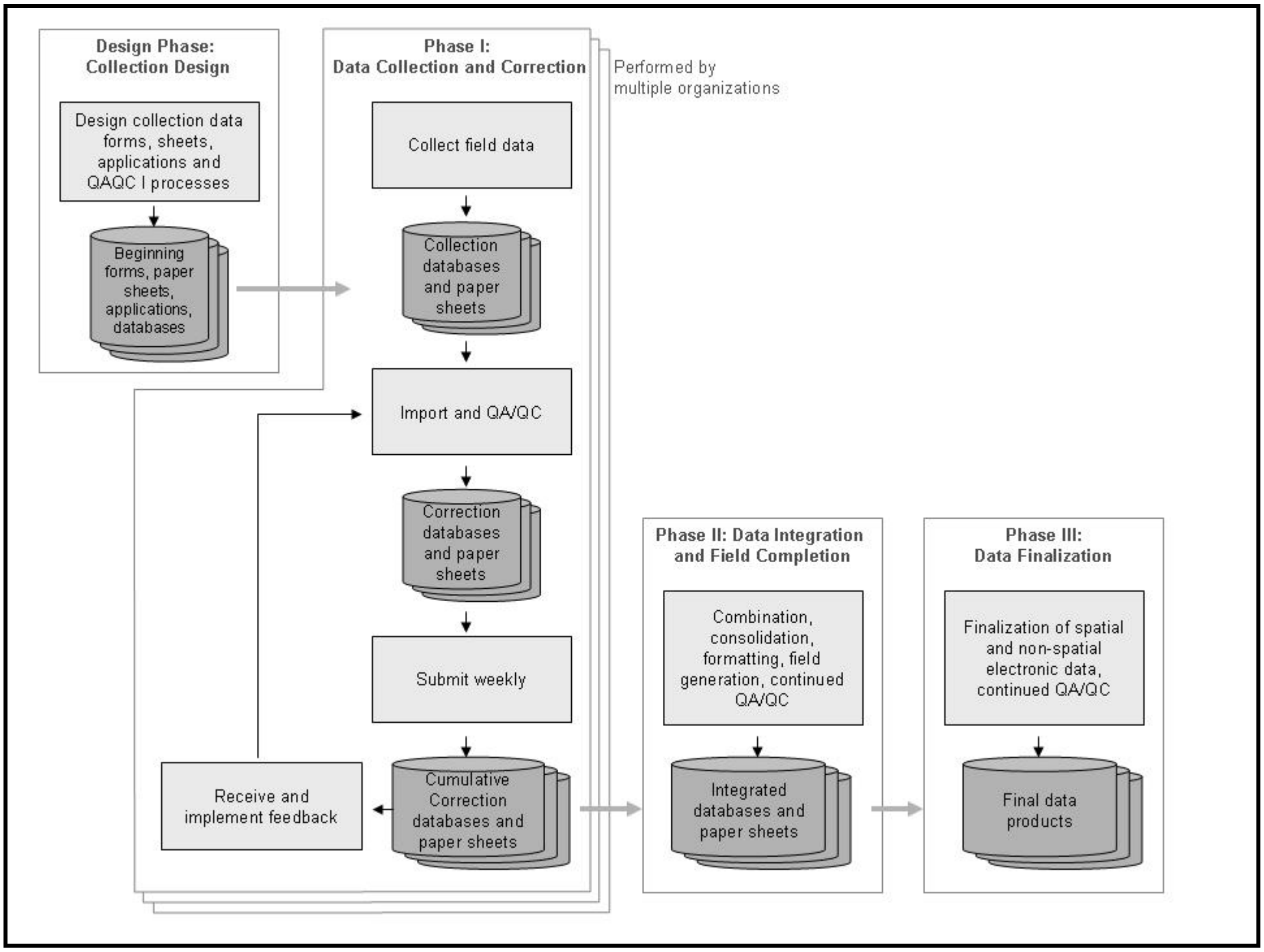


Figure 2. Data flow from collection through final products.

Tortoise encounter rate and development of detection functions

The number of tortoises seen in each stratum and their distances from the line were used to estimate the encounter rate (tortoises seen per kilometer walked) and the detection rate (proportion of available tortoises that are detected out to a certain distance from the transect centerline). Detection function estimation is "pooling robust" under most conditions (Buckland et al., 2001). This property holds as long as factors that cause variability in the curve shape are represented proportionately (Marques et al., 2007). Factors that can affect curve shape include vegetation that differentially obscures vision with distance and different detection protocols used by individual crews (pairs). I expected to develop one detection curve for each field team each year because each of the pairs on a team contributes the same number of transects to the effort, and because each team works in geographically different sites. The encounter rate is less sensitive to small sample sizes, so it was estimated for each stratum separately.

Program DISTANCE, Version 7, Release 3 (Thomas et al., 2010) was used to fit appropriate detection functions, to estimate the encounter rate of tortoises in each stratum, and to calculate the associated variances. Analysis was applied to all live tortoises at least 180 mm MCL. Transects were packaged into monitoring strata ("regions" in Program DISTANCE).

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

Because Chocolate Mountains Aerial Gunnery Range is a heavily scheduled training facility, tortoise surveys are timed to coincide with closure and EOD clearance of the south, followed by the north range. There are therefore 2 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 m of line, and the second crew member following at the end of the line. This technique involves little lateral movement off the transect centerline, where attention is focused. Use of two observers allows estimation of the proportion of tortoises detected on the line; and thereby provides a test of the assumption that all tortoises on the transect centerline are recorded ($g(0) = 1$). The capture probability (p) for tortoises within increasing distances from the transect centerline was estimated as for a two-pass removal or double-observer estimator (White et al., 1982): p = (lead–follow)/lead, where lead = the number of tortoises first seen by the observer in the leading position and follow = the number of tortoises seen by the observer in the follower position. The corresponding proportion detected near the line by two observers was estimated by $g = 1 - q^2$, where $q = 1 - p$. Figure 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 on the centerline in order to meet this standard and is the basis for one of the training metrics.

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

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

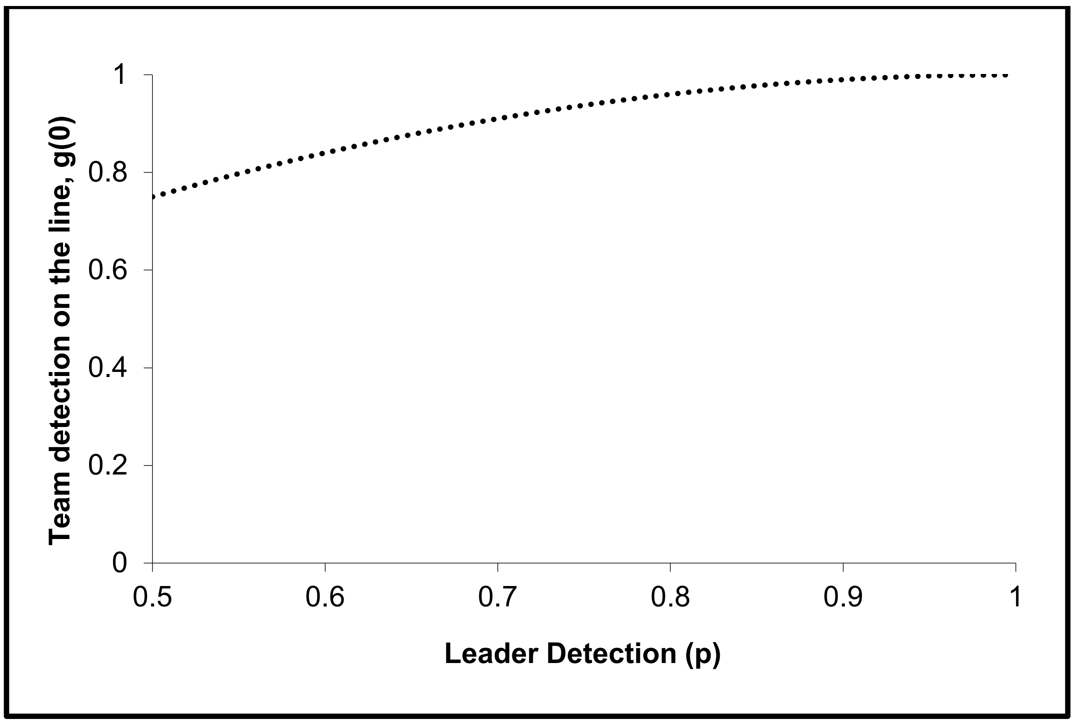


Figure 3. Relationship between single-observer detections (by the leader, *p*) and dual-observer (team) detections, *g(0)*.

Estimates of tortoise density

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

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

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

Proportion of available tortoises was estimated for all strata near each G_0 site and the proportion of available tortoises detected on the transect centerline ($g(0)$) was estimated jointly for all strata. The detection function, which comes into the above equation as P_a, 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 Figure 4. Each of the four left-hand columns represent one estimate that contributed to the final density estimates, and the rows in each column show the subsets of the data on which they are based. These estimates combined from left to right to generate stratum and recovery unit density estimates.

<table>
<tr><th></th><th>Tortoise encounter rate</th><th>Proportion that are visible, G0</th><th>Detection rate, P_a</th><th>Proportion seen on the line, g(0)</th></tr>
<tr><td>Recovery unit</td><td>Stratum</td><td>Neighboring G0 sites</td><td>Data collection group</td><td>Overall</td></tr>
<tr><td rowspan="2">Northwestern Mojave</td><td>GB</td><td>GB</td><td rowspan="3">GBI</td><td rowspan="8">All data</td></tr>
<tr><td>MM</td><td>HW</td></tr>
<tr><td rowspan="4">Colorado Desert</td><td>PV</td><td>PM</td></tr>
<tr><td>AG</td><td rowspan="2">CK</td><td rowspan="5">Kiva</td></tr>
<tr><td>CK</td></tr>
<tr><td>FE</td><td rowspan="2">IV</td></tr>
<tr><td>Eastern Mojave</td><td>IV</td></tr>
<tr><td>Western Mojave</td><td>OR</td><td>OR</td></tr>
</table>

Figure 4. Process for developing density estimates in 2021. For each estimate (one per column), the full set of data was factored as indicated by divisions within the columns.

RESULTS

Field observer training

Training in 2021 lasted from 12 – 17 March (Table 1). 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 2 reports the proportion of models that were available and were detected over 16 km of transects by each team at 1-, 2-, and 5-m from the transect centerline. Teams were tested after a trial run on the detection lines or after returning crews walked practice transects to refresh the search pattern. The target for detection on the centerline is 100%, and 10 of the 15 crews achieved this.

Table 2. Proportion of tortoise models detected in 2021 by crews within 1-, 2-, or 5-m of the transect centerline.
Values that scored below the target of 0.90 at 1- and 2-m are highlighted. Crews 1-5 surveyed for Kiva Biological; the remaining crews surveyed for Great Basin Institute.

Crew Number	1m	2m	5m
1	1.00	1.00	0.98
2	0.93	0.96	0.91
3	1.00	0.96	0.91
4	1.00	1.00	0.97
5	1.00	1.00	0.99
6	1.00	1.00	0.94
7	0.92	0.88	0.88
8	1.00	1.00	0.94
9	1.00	0.93	0.91
10	0.93	0.92	0.93
11	0.88	0.92	0.97
12	1.00	0.92	0.94
13	1.00	1.00	0.87
14	1.00	1.00	0.96
15	0.92	0.93	0.91
Kiva	0.986	0.984	0.952
GBI	0.965	0.950	0.925
Overall	0.972	0.961	0.934

Table 3 gives the average [absolute] difference between the expected and measured perpendicular distances from the model to the walked line. All measurements for all models during the 2-day trial were used for this estimate and capture two different sources of inaccuracies: 1) using a compass and measuring tape to record distances to the models, plus 2) inaccurately following the trajectory of the transect. The latter source of error does not occur on monitoring transects, because the walked transect is the true transect. On training lines, measurement error increased if crew path diverged from the measured line used to place the models. The "Available Models Detected by Leader" column reports the proportion of all models that were found first by the leader. During training, this number was used to identify crews in which 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 3. Diagnostics for individual crews after training in 2021.

Team	Proportion available models within 2m of centerline by leader	Proportion available models within 2m of centerline by team	Measured versus exact distance (m)	Estimated abundance	95% CI Lower limit	95% CI Upper limit
1	0.89	1.00	-0.12	487	406.2	583.7
2	0.89	0.96	-0.27	399	347.6	457.7
3	0.93	0.96	-0.16	432	320.9	582.3
4	1.00	1.00	-0.01	383	342.1	427.9
5	1.00	1.00	-0.07	492	422.5	572.0
6	0.96	1.00	-0.31	470	417.9	528.0
7	0.78	0.88	-0.26	388	337.9	446.5
8	0.85	1.00	0.02	415	373.9	460.7
9	0.93	0.93	0.00	370	293.5	465.8
10	0.88	0.92	-0.24	418	359.5	486.2
11	0.92	0.92	0.03	406	370.6	444.9
12	0.92	0.92	-0.32	379	285.4	502.4
13	0.89	1.00	0.02	379	291.0	492.8
14	0.89	1.00	-0.04	417	340.1	510.9
15	0.85	0.93	-0.49	345	303.2	392.1
Kiva	**0.942**	**0.984**	**-0.126**	**438.5**	**367.8**	**524.7**
GBI	**0.882**	**0.950**	**-0.159**	**398.6**	**337.3**	**473.0**
Overall	**0.902**	**0.961**	**-0.148**	**411.9**	**347.5**	**490.3**

Although some individual metrics were below-target (gray cells in Tables 2 and Table 3), 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 5 and 6 and were used to generate abundance estimates in Table 3. Crews were not evaluated on their ability to match curves of teammates; however, such overlays were used to focus field personnel on an additional level of conformity they could work toward. Distance sampling and development of a single detection curve from many observers is robust to the effects of pooling across observations from crews with variable search patterns, when observers contribute proportionally to the overall pattern (Marques et al., 2007).

In 2021, all 10 of the Kiva surveyors were returnees to the project. Two of the twenty GBI surveyors were returnees.

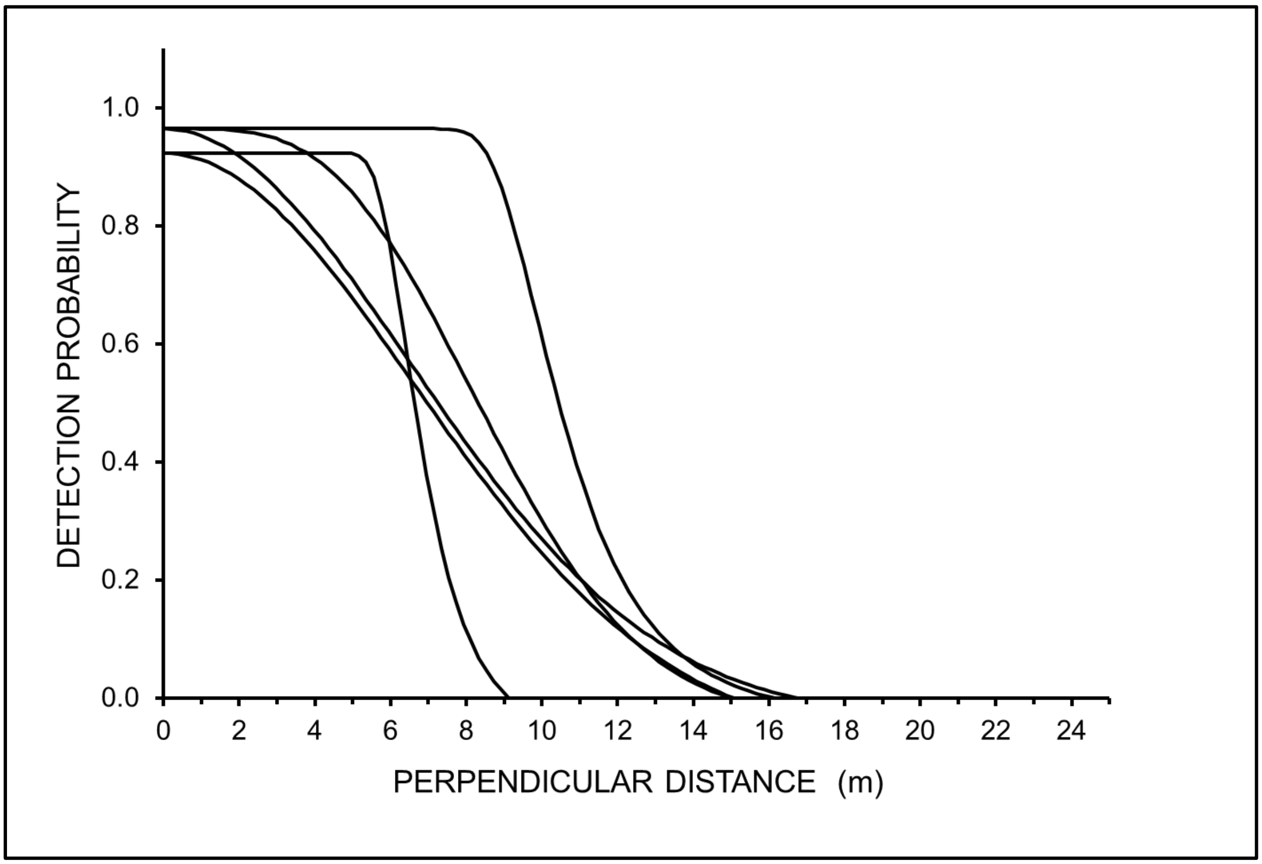


Figure 5. Detection curves for each of the 2021 Kiva crews during training. Each curve is based on a 16-km trial for one team with approximately 100 detections.

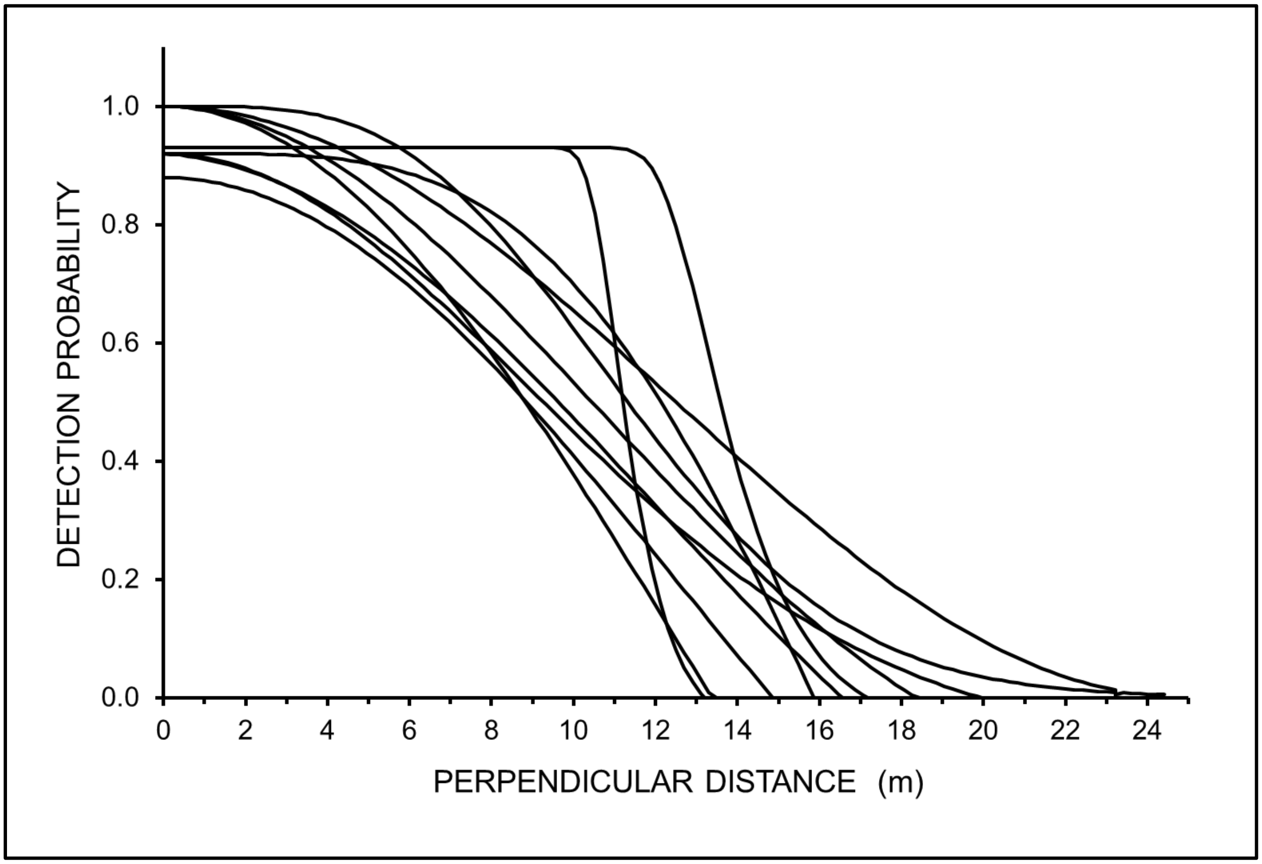


Figure 6. Detection curves for each of the 2021 GBI crews during training. Each curve is based on a 16-km trial for one team with approximately 100 detection.

Quality assurance and quality control

There were 21,789 transect records and 2232 G_0 records associated with the monitoring effort in 2019. The first data specialist worked with the field teams to resolve 701 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 193 issues remained or were discovered in the third (final) phase of QA/QC. Only 117 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 34 were corrected with recourse to paper datasheets. The remaining errors in 2019 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.

Data for this survey and previous years of surveys can be requested from the author at Linda_Allison@fws.gov.

Transect completion

Table 4 reports the number of assigned and completed transects in each stratum in 2021. Table 4 also indicates the number of assigned transects that could be completed as standard square 12-km transects or by reflecting around property boundaries and infrastructure (column 4). An additional number (column 5) were shortened and represent more rugged terrain. Finally, some transects were considered unwalkable (column 6). Figures 7 to 10 show locations of transects and observations of live and dead tortoises.

Table 4. Number and completion of transects in each stratum in 2021.

Stratum	Assigned transects	Assigned and alternate transects completed	Assigned, completed 12k	Assigned, completed shortened	Assigned, judged unwalkable*
GB	90	90	37	29	24
MM	65	65	35	22	8
PV	60	60	42	7	11
GBI	215	215	114	58	43
AG	35	35	21	9	5
CK	100	100	48	32	20
FE	50	50	46	4	0
IV	83	83	67	16	0
OR	50	50	21	16	13
Kiva	318	318	203	77	38
Total	533	533	317	135	81

*Assigned transects that were not walked were to be replaced by alternates. In addition to transects that were unwalkable due to terrain and counted in the far right column above, 4 were replaced due to time constraints of accessing, and 5 were replaced due to wrong lock combination provided for a gate on NPS lands. One was replaced inadvertently.

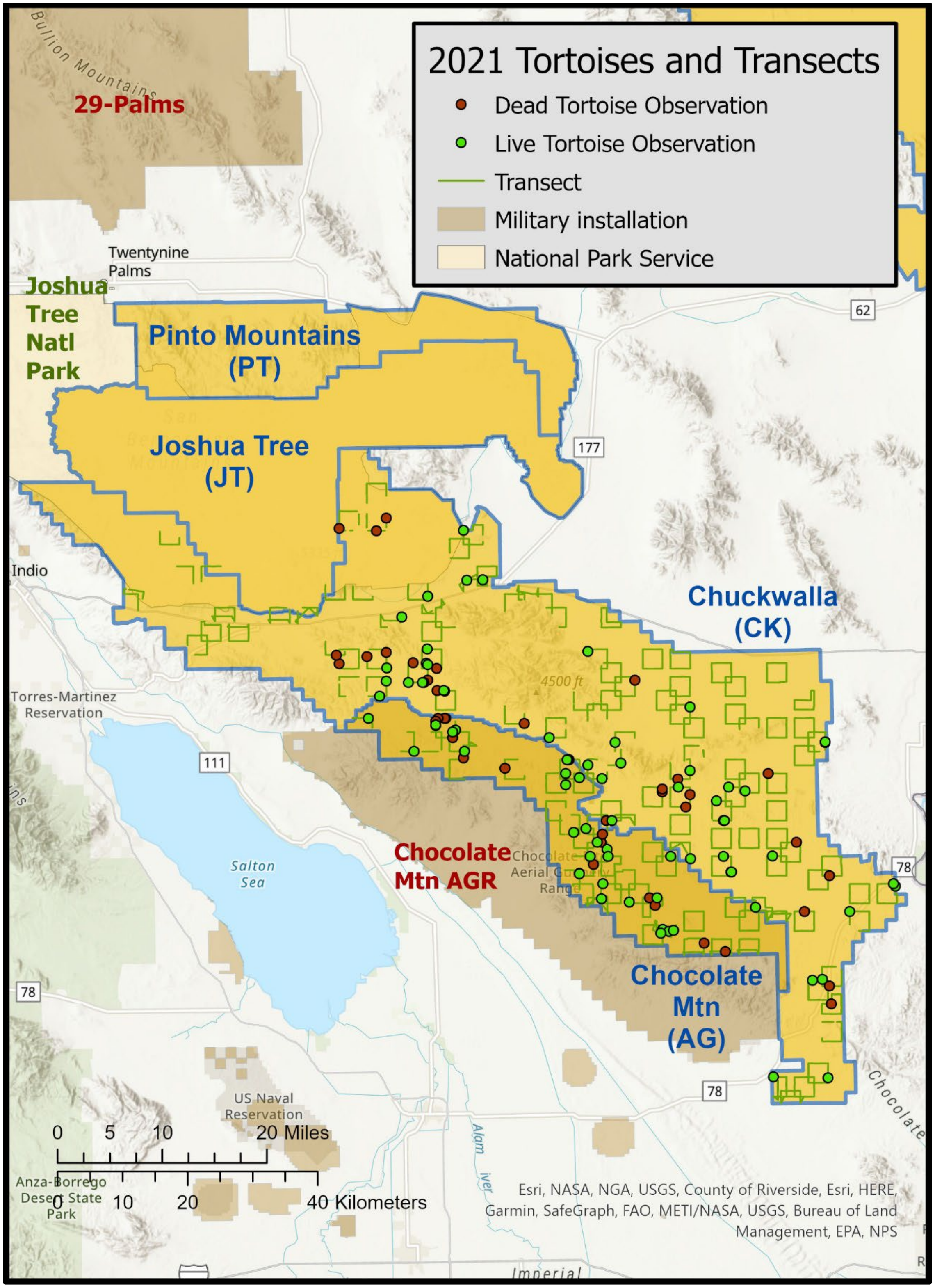


Figure 7. Distribution of distance sampling transects and tortoise observations in 2021 in Chocolate Mountain Aerial Gunnery Range and Chuckwalla in the southern part of the Colorado Desert Recovery Unit.

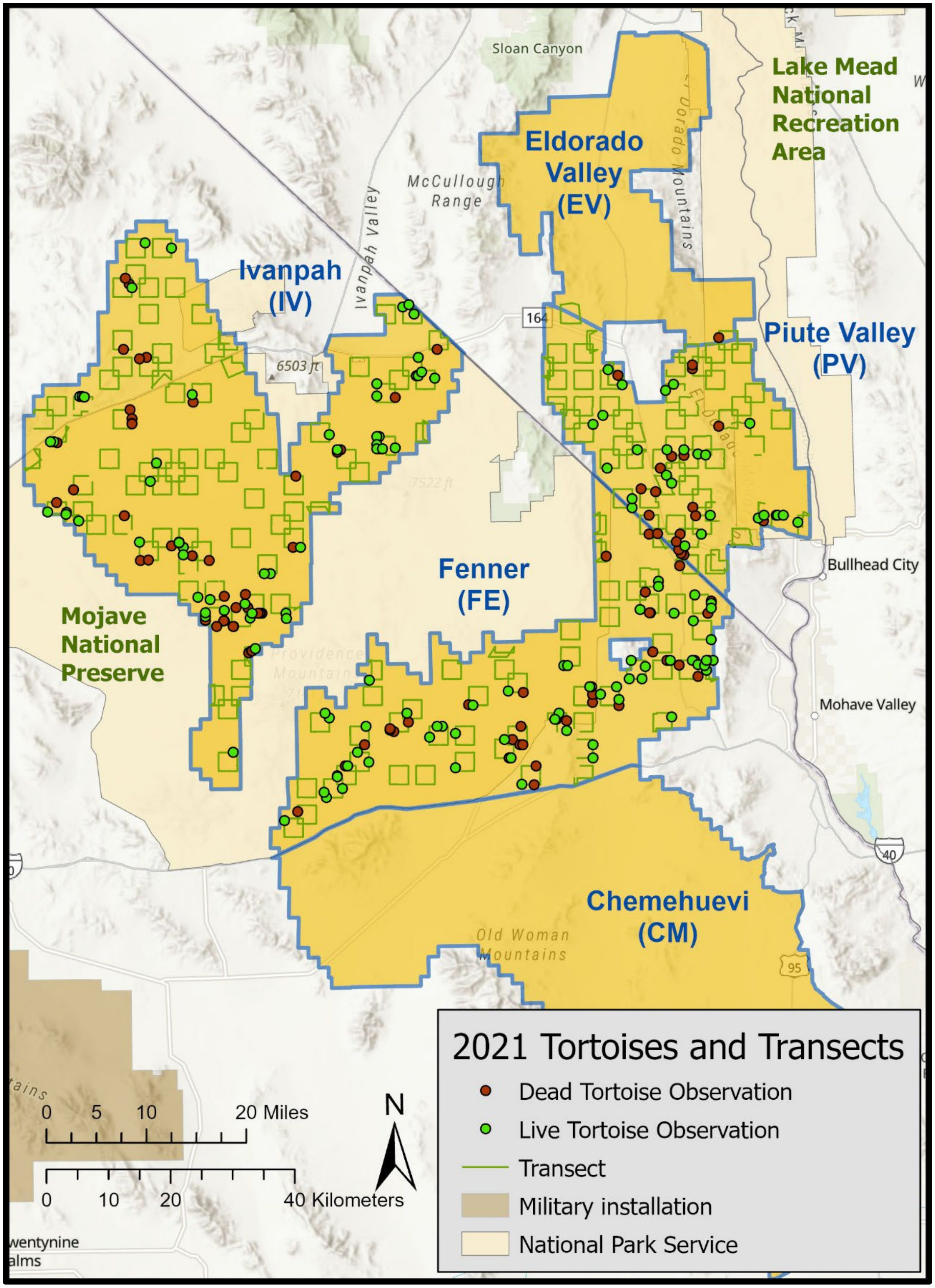


Figure 8. Distribution of distance sampling transects and tortoise observations in 2021 in the Ivanpah Valley stratum of the Eastern Mojave Recovery Unit and in the Fenner and Piute Valley strata of the Colorado Desert Recovery Unit.

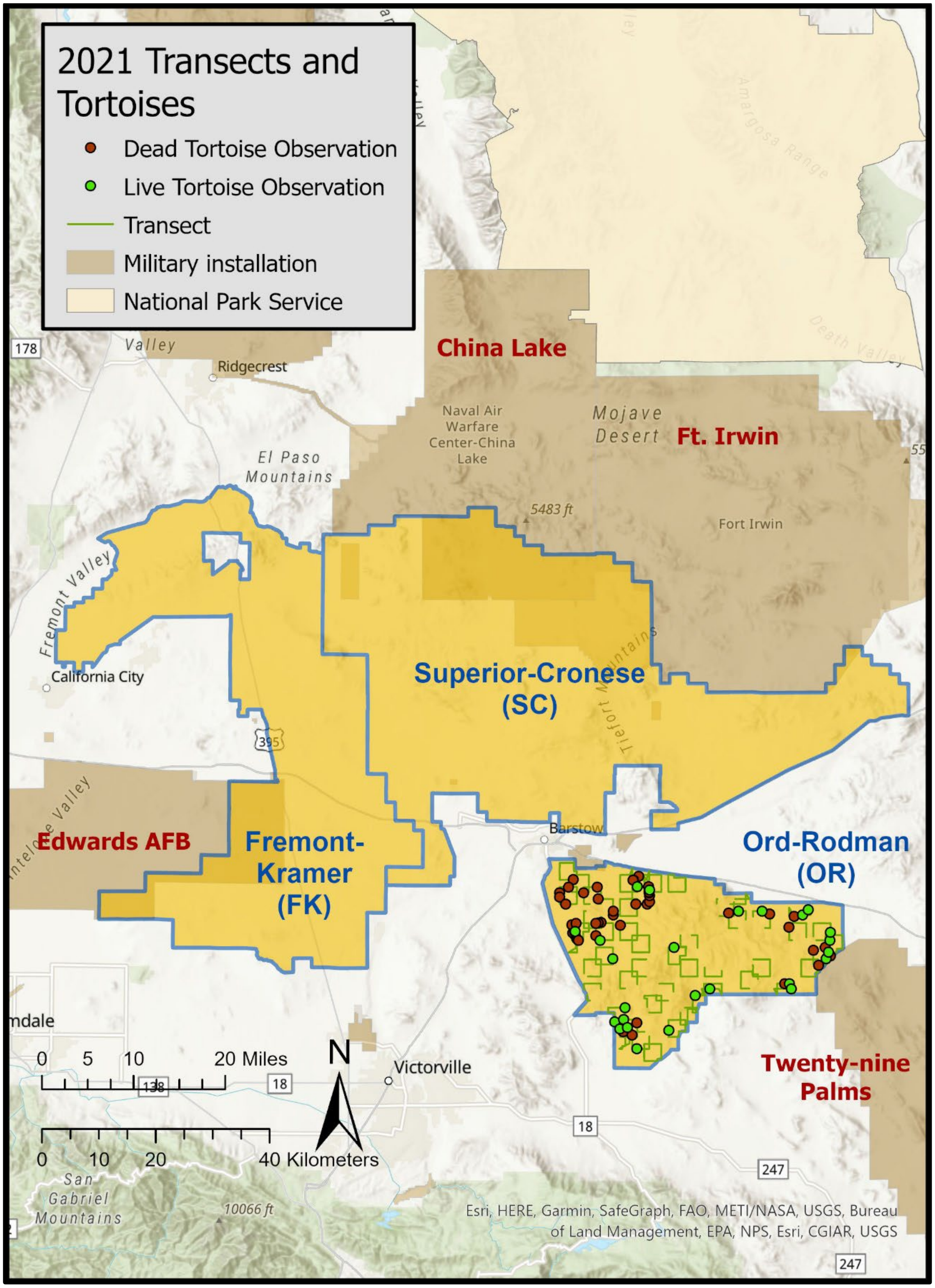


Figure 9. Distribution of transects and tortoise observations in 2021 in the Ord-Rodman stratum of the Western Mojave Recovery Unit.

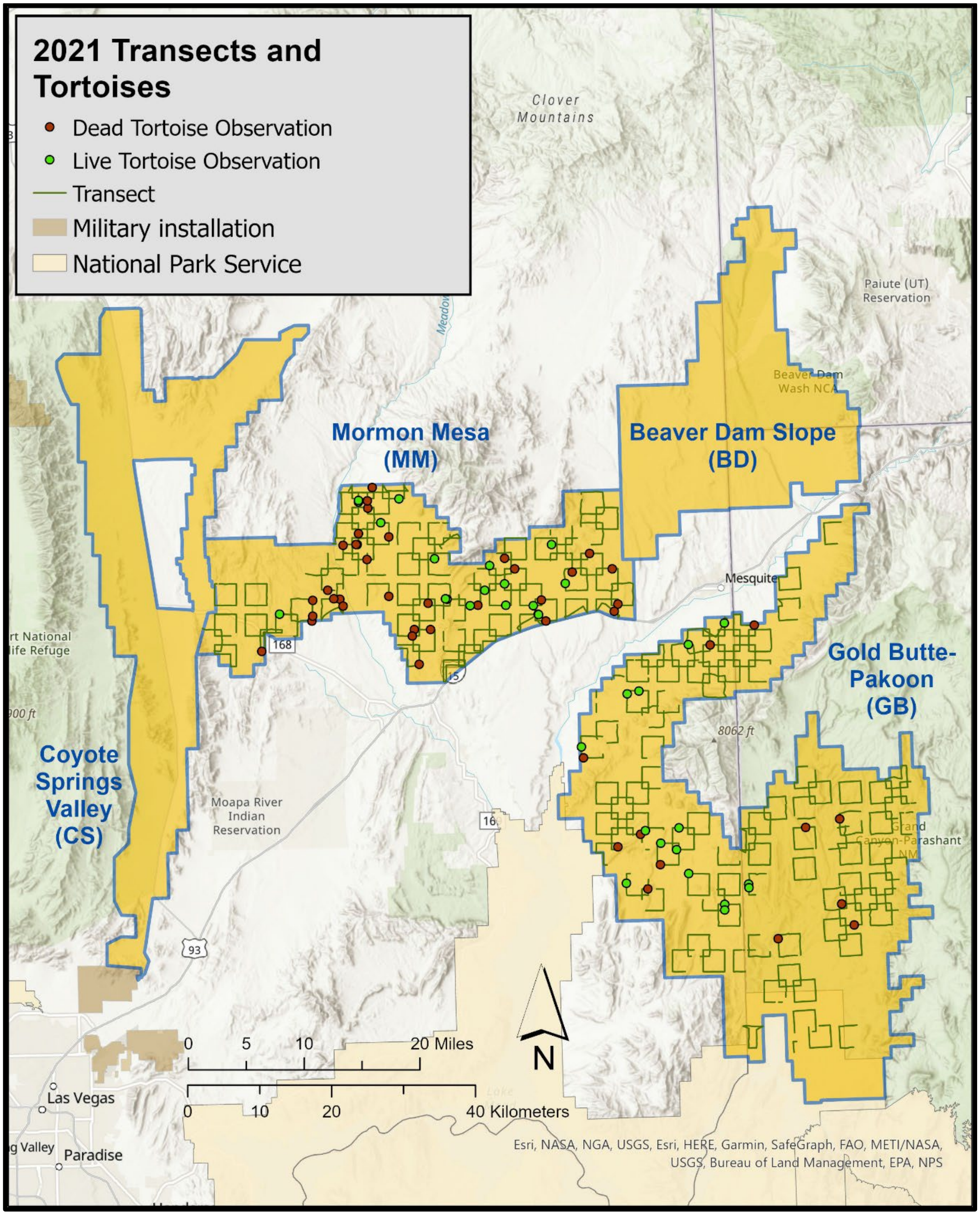


Figure 10. Distribution of transects and tortoise observations in 2021 in the Mormon Mesa and Gold Butte-Pakoon strata of the Northeastern Mojave Recovery Unit.

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

In general, telemetry sites and associated strata were completed sequentially, from south to north. This pattern corresponds to the expected timing of tortoise activity; peaking first in the south, later in the north. Visibility was higher in the western part of the range than in the east during surveys in the spring of 2021 (Table 5). Given the ongoing drought throughout the Mojave, it is not surprising that tortoises in some areas were sheltering deep in burrows, so not available for detection.

Table 5. Availability of tortoises (G_0) when transects were walked in 2021 in the same or in neighboring strata.

G_0 site	Stratum	Dates	Days	G_0 (Std Error)
Chuckwalla	Chocolate Mtn south	7 Mar – 10 Mar	4	0.81 (0.123)
Chuckwalla	Chocolate Mtn north	12 Mar – 14 Mar	3	0.74 (0.138)
Chuckwalla	Chuckwalla	6 Mar – 7 Apr	20	0.83 (0.097)
Piute-Mid	Piute Valley	5 Apr – 13 Apr	6	0.59 (0.116)
Ivanpah	Fenner	9 Apr – 20 Apr	12	0.93 (0.094)
Gold Butte	Gold Butte	15 Apr – 29 Apr	10	0.40 (0.112)
Ivanpah	Ivanpah	20 Apr – 8 May	19	0.90 (0.094)
Halfway Wash	Mormon Mesa	29 Apr – 18 May	10	0.34 (0.116)
Ord-Rodman	Ord-Rodman	9 May – 19 May	11	0.97 (0.088)

Tortoise encounter rates and detection functions

All survey pairs worked together from the beginning to the end of the season. All Kiva crews surveyed either 63 or 64 transects and overall they detected 195 tortoises larger than 180 mm MCL ("adults"). GBI surveyors walked a median 23 transects with one team that ended surveys after 11 transects due to injury. GBI teams reported 47 adult tortoises. Because GBI did not have a large number of observations on which to base their detection curve, a single detection curve was tested against separate curves for each group, but at several truncation distances, separate curves for each team were most strongly supported. Kiva's detection pattern best fit a hazard rate curve with first-order cosine adjustment and using all observations up to 20 m from the centerline. GBI best fit a hazard rate curve using observations as far as 26 m from the centerline. Figure 11 and 12 are histograms of the observed number of tortoises seen at increasing distance from the transect centerline. Truncation distance for Kiva removed 6% of the most distant observations resulted in good fit overall and near the centerline. All but one stratum surveyed by Kiva had at least 20 observations (n=19 for Ord-Rodman). Truncation distance for GBI removed only 2 of the observations, and had a simple shape (no adjustments). None of the three strata surveyed by GBI had 20 observations before truncation, but all had at least 11 after truncation (Table 6). The detection rate for Kiva crews within 20 m of the transect centerline was 46.7% (Kiva; CV=0.085) and for GBI crews it was 24.1% (CV=0.230).

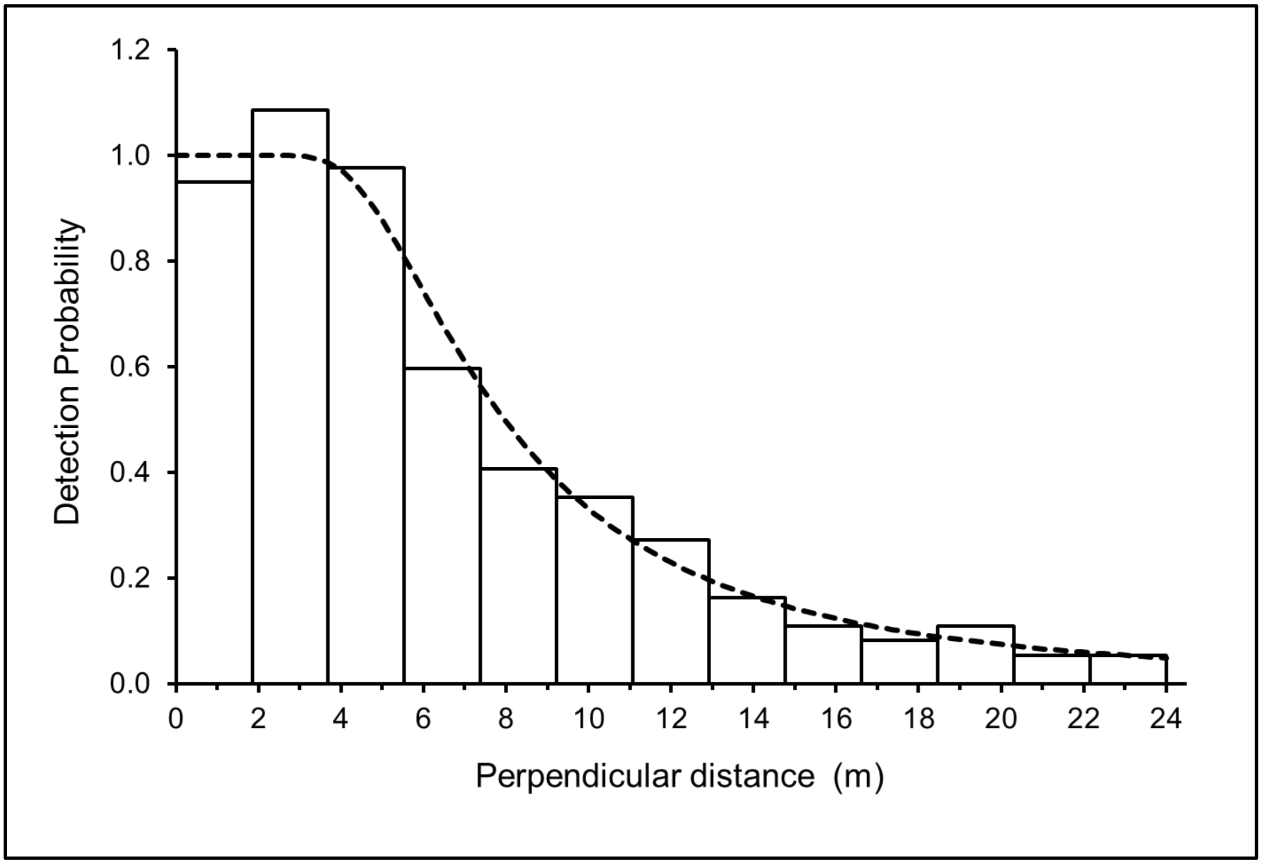


Figure 11. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by Kiva in 2021.
This curve uses only the n=188 observations found within 20 m of the line.

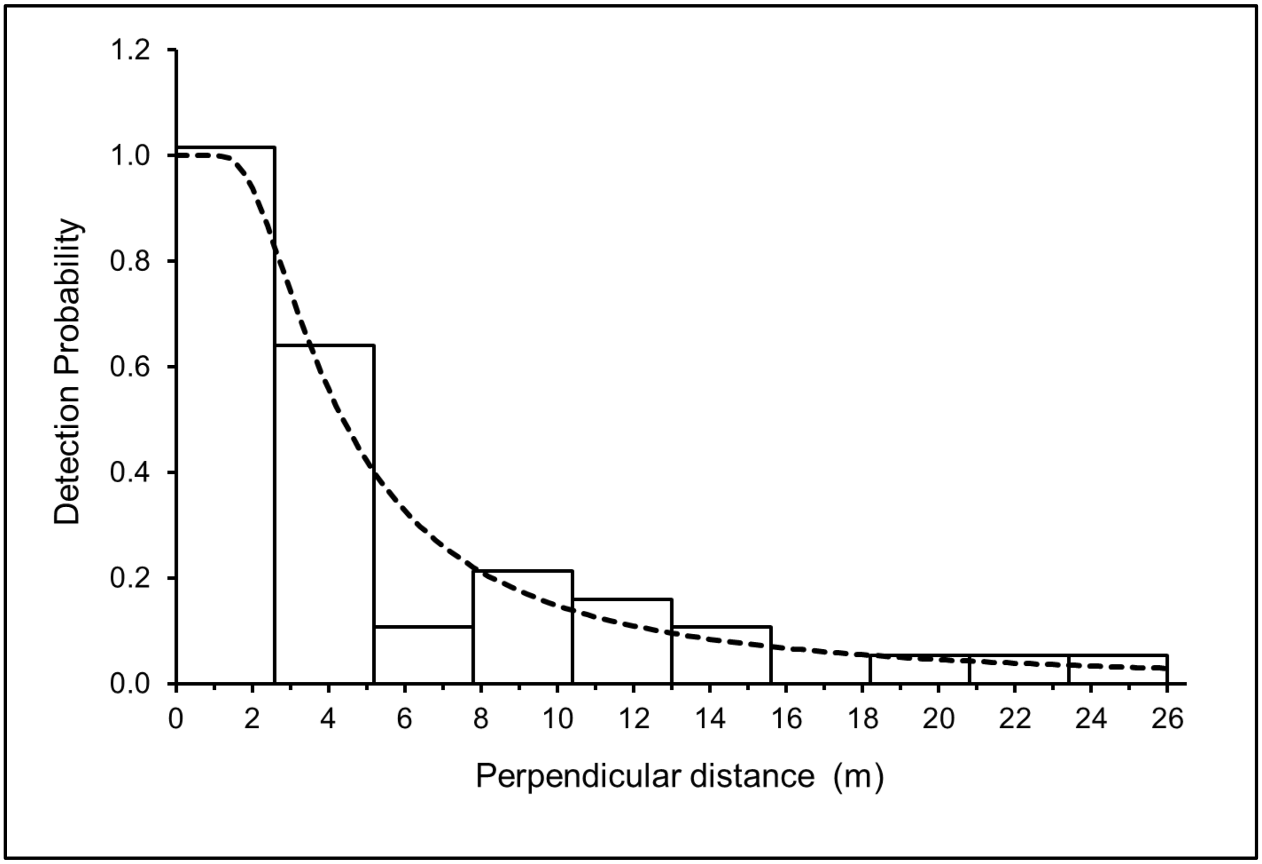


Figure 12. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by GBI in 2021.
This curve uses only the n=45 observations found within 26 m of the line.

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 2021, for 129 detections of tortoises within 5 m of the transect centerline, 116 were found by the observer in the lead position and 13 by the follower, so that the probability of detection by single observer, $p = 0.896$, and the proportion detected using the dual observer method, *g(0 to 5 m)* = 0.989 (SE = 0.049). Figure 13 shows that *g(0)* was converging on 1.0 in 2021. 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, 2012b, 2012c, 2013, 2014, 2015, 2016, 2018, 2019b, 2022a, 2022b). Previous years of data and the pattern in Fig. 13 indicate the assumption of perfect detection on the centerline was met; consequently, no adjustment was made to the final density estimate.

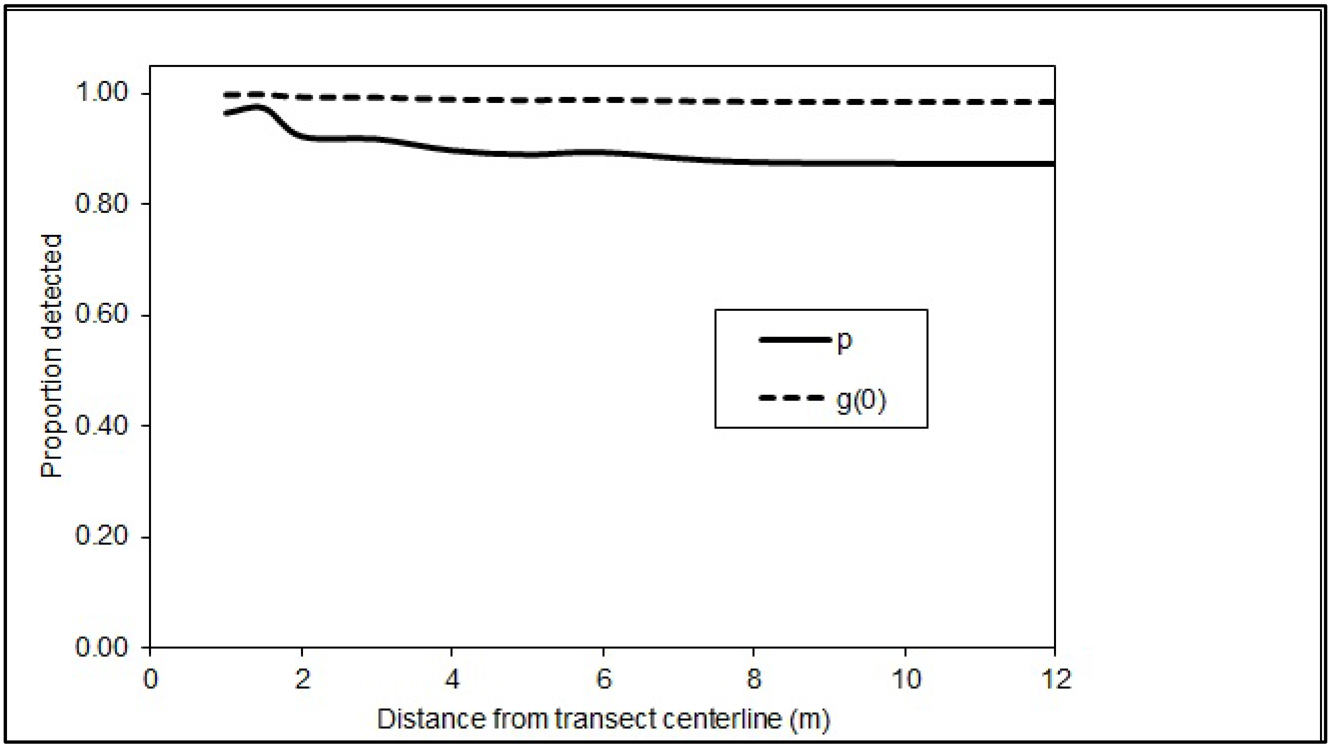


Figure 13. Detection pattern for the leader (*p*) and by the team (*g(0)*) based on all observations out to a given distance (*x*) from the centerline in 2021. Note convergence of *g(0)* on 1.0 as *x* goes to 0.

Estimates of tortoise density

Density estimates were generated separately for each monitoring stratum (Table 6). 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. The density of tortoises in Ord-Rodman was estimated with and without including tortoises translocated in 2017 from MCAGCC Twentynine Palms.

Table 6. Stratum-level encounters and densities in 2021 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 ($/km^2$) D	Lower limit, 95% CI	Upper limit, 95% CI	%CV
Western Mojave			**24**	**50**	**525**	**9-May**	**19-May**				
Ord-Rodman	OR	1124	24	50	525	16-Mar	16-Mar	2.5	1.6	4.0	24.3
Ord-Rodman (residents only)	ORr	1124	18	50	525	16-Mar	16-Mar	1.9	1.1	3.2	27.1
Colorado Desert			**132**	**245**	**2654**	**6-Mar**	**20-Apr**				
Chocolate Mtn north	AGN	351	13	14	130	12-Mar	14-Mar	7.2	3.5	14.7	37.8
Chocolate Mtn south	AGS	403	8	21	237	7-Mar	10-Mar	2.2	1.0	5.1	43.8
Chocolate Mtn	AG	755	21	35	367	7-Mar	14-Mar	3.9	2.1	7.2	31.8
Chuckwalla	CK	3509	41	100	1034	6-Mar	7-Apr	2.6	1.6	4.1	24.0
Fenner	FE	1841	54	50	590	9-Apr	20-Apr	5.3	3.6	7.8	19.8
Piute Valley	PV	1070	19	60	663	5-Apr	13-Apr	3.9	1.9	8.1	38.6
Northeastern Mojave			**26**	**155**	**1600**	**15-Apr**	**18-May**				
Gold Butte-Pakoon	GB	1977	11	90	918	15-Apr	29-Apr	2.4	1.0	5.9	48.1
Mormon Mesa	MM	968	15	65	682	29-Apr	18-May	5.2	2.1	13.0	49.7
Eastern Mojave			**48**	**83**	**963**	**20-Apr**	**8-May**				
Ivanpah	IV	2567	48	83	963	20-Apr	8-May	3.0	1.8	4.8	24.5

DISCUSSION

The year 2021 was the second consecutive year in which drought conditions were coupled with extreme temperatures, so that wildlife simultaneously expended more water for cooling and metabolism but less water was available. At our telemetry sites, a percentage of the transmittered tortoises did not emerge at all during the regular spring activity period. We saw relatively fewer tortoises even than last year, which was also dry and hot, and our correction factors estimated that a significant proportion of the population was below ground at any one time.

Tortoises are found through large areas of the Mojave and Colorado desert, and so are our transects. In addition to sanctioned land use activities, crews encountered people involved with illegal drug operations, which they avoided. We have noticed increasing numbers of unpermitted marijuana production plots over the years. Some of these are on private inholdings, others are on public lands. These usually small operations nonetheless often involve land movers that create berms, cinder block or plywood surrounding structures, guard dogs, security personnel, and illegal water pumping. These operations have become so widespread in the southern part of Ord-Rodman that we will defer surveys in this TCA until these operations are curtailed to the extent that crews are not regularly endangered. Apparently, a similar density of operations have been built out in Fremont-Kramer since our visit in 2020, so we will also defer future surveys in that TCA.

Base expansion of MCAGCC Twentynine Palms affected many tortoises, and starting in 2017, 727 adult tortoises were translocated to two areas either inside (n=426) or at the boundary of the Ord-Rodman critical habitat unit (n=301) before the surveys reported here. Although this expansion negatively impacts tortoises and their habitat elsewhere (USFWS 2017b), augmenting the resident population in OR with reproductive adults may result in local population growth by increasing the number of juveniles produced each year. In conjunction with fencing, law enforcement, and other mitigation implemented in OR, population augmentation is a strategy that may accelerate the process of stabilizing this population (USFWS 2011). Other monitoring is in place to assess the success of the translocations measured by survivorship, for instance, but the ongoing range-wide monitoring program reported here will provide a composite view of the success of the suite of recovery activities that are now occurring in OR. This year, the program estimated an increase of 534 adult tortoises due to translocations (Table 6). While this estimate is lower than the 727 that were actually translocated in and nearby, we do not have a specific prediction for the number of translocatees that would settle inside or outside the boundaries of the surveyed critical habitat unit. Instead, these surveys will document whether there is an overall increase in the number of tortoises over time. The northwestern part of Ord-Rodman did not receive translocatees. In Figure 9, the relatively high number of dead tortoises found there this year is striking, as it was last year.

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