Chelonian Conservation and Biology, 2002, 4(2):380–386

Regional Desert Tortoise Monitoring in the Upper Virgin River Recovery Unit, Washington County, Utah

Ann M. McLuckie[1], Deborah L. Harstad[1], Jesse W. Marr[1], and Rick A. Fridell[1]

[1]*Utah Division of Wildlife Resources, Washington County Field Office, 344 East Sunland Drive #8, St. George, Utah 84790 USA [E-mail: annmcluckie@utah.gov; Fax: 435-688-1427]*

Abstract. – Precise and accurate estimates of desert tortoise (*Gopherus agassizii*) density are recognized as a critical component of both the Desert Tortoise (Mojave Population) Recovery Plan and the Washington County Habitat Conservation Plan. Distance sampling was utilized within the Upper Virgin River Recovery Unit, managed as the Red Cliffs Desert Reserve, to assess current population densities of desert tortoises. Intensive full-scale monitoring was completed within Management Zones 2, 3, and 5 of the Red Cliffs Desert Reserve from 1998 to 2001. The baseline density estimate of adult tortoises was 0.32 tortoises per hectare (95% CI: 0.29-0.36; CV: 5.85%) within Management Zone 3 and 0.29 tortoises per hectare (95% CI: 0.26-0.33; CV: 5.87%) throughout the Reserve.

Key Words. – Reptilia; Testudines; Testudinidae; *Gopherus agassizii*; tortoise; density estimation; distance sampling; line transects; monitoring; Red Cliffs Desert Reserve; Utah; USA

The Mojave desert tortoise (*Gopherus agassizii*) population was listed as threatened under the Endangered Species Act in 1990 (USFWS, 1990). Rangewide declines of Mojave populations are associated with habitat degradation, disease, predation, and human-related mortality (USFWS, 1994). The Desert Tortoise (Mojave Population) Recovery Plan identifies the Upper Virgin River population as one of six Recovery Units, regions identified as critical for the recovery of the desert tortoise (USFWS, 1994). Due to its proximity to urban growth and considerably smaller size than other Recovery Units, it is considered a highly threatened population (USFWS, 1994).

The habitat conservation planning process was initiated in Washington County, Utah, in 1991, to resolve conflicts between urban development and desert tortoise conservation. Washington County completed a Habitat Conservation Plan (HCP) by February 1996, and received an incidental take permit for 1169 tortoises, 12,264 acres of desert tortoise habitat, and 31,282 acres of potential habitat (USFWS, 1996). The HCP identifies measures to minimize and mitigate incidental take by establishing the 61,022 acre Red Cliffs Desert Reserve (Reserve; Washington County Commission [WCC], 1995). The Reserve includes 38,787 acres of Mojave desert tortoise habitat and its goal is to maintain a stable or increasing tortoise population in perpetuity.

Accurate regional desert tortoise density estimates are a critical component of both the Recovery Plan and the Washington County HCP (USFWS, 1994; WCC, 1995). The Desert Tortoise (Mojave Population) Recovery Plan recommends long-term monitoring within Recovery Units for at least 25 years, the equivalent of one tortoise generation, to determine population trends (USFWS, 1994). The HCP requires the development and implementation of a long-term desert tortoise monitoring program to determine regional population trends within the Upper Virgin River Recovery Unit (WCC, 1995).

The identification of long-term trends within the Reserve requires a reliable method for estimating tortoise population densities. Estimates of tortoise densities traditionally included triangular strip transects and capture-recapture monitoring plots. Strip transects, calibrated with populations of known densities, estimated tortoise densities from observed sign. However, because the relationship between sign and animals varies with environment, habitat, and physiological factors, population estimation techniques that infer population size indirectly are not reliable for monitoring population trends (Lancia et al., 1994; Thompson et al., 1998; Anderson et al., 2001). Intensive surveys of capture-recapture monitoring plots provide information on desert tortoise demographics such as abundance estimates, age-size class structure, sex ratios, and mortality (White et al., 1982; Lancia et al., 1994). However, assumptions are difficult to uphold (i.e., all animals are equally likely to be captured) and estimates cannot be extrapolated beyond the boundaries of the monitoring plot (Thompson et al., 1998). Neither strip transects nor capture-recapture monitoring plots are appropriate methods to determine desert tortoise density estimates on a regional scale.

Distance sampling is a method used for estimating density of aggregated, random, or clustered biological populations over large areas (Buckland et al., 2001). Perpendicular distances from the transect line to observed objects allows estimation of the detection function, which models the decreasing detectability of objects at increasing distance from the transect line. Distance sampling allows estimates of density, even when a large proportion of the objects are undetected, as long as several critical assumptions are met (Buckland et al., 2001). The two main assumptions essential for reliable density estimates include: 1) objects on the transect line are always detected, and 2) perpendicular distances are measured accurately. All animals within 3 to 5 meters of the transect line should be detected and detections should gradually decrease with increasing distance (Buckland et al., 2001). Because tortoises spend a large percentage of time underground, the proportion of the population above ground must be estimated during monitoring in order to meet the first assumption and quantify the true probability of detection.

The Utah Division of Wildlife Resources has implemented distance sampling methodology within the Reserve to monitor desert tortoise densities. A pilot study was conducted in 1997 to standardize field techniques, to provide preliminary estimates of encounter rates, and to determine the field effort necessary to achieve regional density estimates (McLuckie et al., 1998). Total line length and sample size required to achieve the target precision level, as well as allocation of effort, were determined using methods described in Buckland et al. (2001). The monitoring objective for the Reserve is to: 1) obtain precise and accurate baseline abundance and density estimates, and 2) assess long-term density and abundance trends over a 20-year period.

METHODS

Study Area. — The Red Cliffs Desert Reserve is located in southwest Utah, Washington County, within the Upper Virgin River Valley. It is directly north of the City of St. George and extends from the Town of Ivins in the west to the City of Hurricane in the east. This Reserve represents the northeastern extent of the desert tortoise's geographic distribution.

The Reserve is divided into five management zones, Zones 1 through 5. Zone 3, approximately 38,541 acres, comprises the area between State Highway 18 and Interstate 15 in St. George, Utah. It contains the largest contiguous block of tortoise habitat within the Reserve, and includes some of the highest tortoise densities in the Reserve (Bury et al., 1994). Zone 2, approximately 10,372 acres, extends north of the Town of Ivins and east to State Highway 18, and includes Snow Canyon State Park and Paradise Canyon, areas with medium to high relative tortoise densities. Zone 5, approximately 766 acres, contains areas with moderate to high relative tortoise densities and is adjacent to the City of Hurricane. Zone 1 contains high elevation areas where tortoise are not expected to occur and a low density housing development (WCC, 1995). Zone 4 is a translocation site for displaced incidental take tortoises associated with the HCP.

Desert tortoises occupy a mosaic of Navajo sandstone outcrops, rugged rocky canyons, creosote-bursage flats and basalt-capped ridges interspersed with sandy valleys within the Reserve (Bury et al., 1994). A combination of these habitats are utilized for winter and summer dens, egg laying, and foraging (Esque, 1994). Overwintering tortoises are found in caves, deep fissures, rocky overhangs, and deep sandy burrows in Aeolian sand (Bury et al., 1994).

Vegetation within the Reserve is diverse and includes representative species from the Mojave and Great Basin desert scrub biomes (Turner, 1982a, 1982b). Major vegetation types consist of a transitional mix of creosote bush, blackbrush, and sagebrush scrub along with desert psammophyte (USFWS, 1994). Predominant vegetation within these groups includes creosote bush (*Larrea tridentata*), blackbrush (*Coleogyne ramosissima*), snakeweed (*Gutierrezia sarothrae*), ephedra (*Ephedra nevadensis*), sand sage (*Artemisia filifolia*), and big galleta (*Hilaria rigida*).

The Reserve is characterized by low humidity and precipitation, and a wide annual temperature range. Average annual precipitation, from 1893 to 2001, was 210.77 mm ± 6.71 (range = 90.17–425.45), with the majority of precipitation typically occurring from November to March (Western Regional Climate Center [WRCC], 2001). Winter storms are typically widespread, with low intensity storms bringing moisture from the north Pacific. Summer thunderstorms, which bring moist tropical air northward from the Gulf of California, are usually intense, local, and of fairly short duration (Pope and Brough, 1996).

Field Effort. — The sampling methodology used was consistent with the desert tortoise monitoring program described by Anderson and Burnham (1996). The monitoring program consisted of two independent teams of observers, one using distance sampling and the other using radiotelemetry. Monitoring efforts were concentrated in Management Zones 2, 3, and 5, while Zones 1 and 4 were not sampled. Transects were randomly located using a random number generator to establish UTM coordinates. These coordinates represented the northeast corner of a square 2 km transect, with 500 m sides. Due to the small size of Zone 5, linear transects were located systematically with a random starting point and placed laterally, from east to west, perpendicular to high concentrations of tortoises. Areas above 1400 m in elevation, as well as rocky segments with greater than 45° slopes, were excluded prior to sampling.

Transect corners were located using Global Positioning System units and permanently marked with 16" rebar. The rebar was painted red with enamel exterior spray paint to facilitate relocation of transect corners. Transect corners were labeled using double-faced aluminum tags identifying the transect number and directional orientation of each corner (e.g., NE, SE, SW, NW).

Each 2 km transect was surveyed by a two person crew. Using a compass to check directional alignment, a 50 m surveyor tape was placed along the transect line. Crew members walked in a sinuous pattern on opposite sides of the surveyor tape, observing tortoises on both sides of the transect line. Search efforts were concentrated within 10–12 m of the line, with one member of the team confirming that all tortoises along the line were detected. This procedure was repeated in 50 m increments until the entire transect was completed. Search time and observer speed varied with vegetation and topography.

For each tortoise located, the perpendicular distance from the line was accurately measured using a 50 meter open reel fiberglass tape. In addition, distance along the transect line, UTM coordinates, and time detected were also recorded. Standard tortoise carapace measurements were taken including straight midline carapace length (CL). Additional data collected included sex, determined for all tortoises with a CL ≥ 180 mm, health observations, injuries, and shell anomalies. Environmental variables including dominant vegetation, soil type, wind speed, cloud cover, and ambient/surface temperatures were also taken. Each tortoise was assigned a unique set of carapace notches for future identification (Cagle, 1939).

The proportion of tortoises above ground (g_0) was estimated by simultaneously tracking a subset of radioed tortoises. Adult tortoises (CL ≥ 180 mm) were fitted with radiotransmitters (Telonics Model 125, Mesa, AZ) affixed to the anterior of the carapace using quick-drying gel epoxy. Transmitters were attached below the highest point of the carapace to reduce interference in shelters. Antennas were attached to marginal scutes and masking tape was placed directly onto scute seams, to prevent epoxy from soaking into seams.

Once radioed, tortoises were located using a Telonics receiver (Model TR-2E) and directional antenna. Radiotelemetered adult tortoises were monitored weekly at representative sites located in the central portion of Management Zone 3. Tortoises were monitored at a single site within Zone 3, after the spring of 1999. Activity and UTM coordinates were noted for all radioed tortoises located. Above ground was defined as tortoises seen on the surface or in burrows with only the aid of mirrors (Anderson and Burnham, 1996). Tortoises deep in burrows and not visible were considered below ground. Associated vegetation, time found, wind, and ambient/surface temperatures were also recorded to eventually develop a model of g_0.

Field crews were intensively trained on distance sampling theory, field protocols, and search patterns. Data were checked daily for quality and analyzed weekly to assess the detection histogram and improve search efforts. Field crews were regularly rotated between distance sampling and radiotelemetry to allow training in the overall survey method as well as improve tortoise search image.

Statistical Analysis. — Detailed distance sampling analysis is described in Buckland et al. (2001). Density estimates were made for all adult tortoises (CL ≥ 180 mm). Density and abundance estimates are presented within Management Zone 3 as well as across the Reserve (Zones 2, 3, and 5). Zone 3 was intensively sampled because it contains the most significant portion of tortoise habitat within the core of the Reserve. The total area sampled was determined using heads-up digitizing from Arc View (v. 3.2). Means are presented ± one standard error (SE).

A weighted mean for g_0, the proportion of tortoises above ground, was computed annually by using the following formula:

$$\bar{g}_0 = \Sigma(N_J \cdot \hat{g}_J) / \Sigma N_J$$

where N_J equals the total number of tortoise observations and g_J equals the number of locations above ground. Sampling variance for g_0 was calculated annually using the following formula:

$$\hat{\text{var}}(\hat{g}_0) = \Sigma N_J (\hat{g}_J - \hat{g}_0)^2 / [(\Sigma N_J)(n_T - 1)]$$

where n_T equals the number of radioed tortoises. The delta method was used to determine the variance of g_0 (e.g., 1999–2001, 1998–2001) during the study. Standard error is merely the square root of the variance.

Four detection models were examined (uniform + cosine, uniform + simple polynomial, half-normal + cosine, half-normal + hermite polynomial) to determine the detection model that best fit the perpendicular distance data based on the minimum Akaike Information Criterion (AIC) value (Buckland et al., 2001). Data were truncated when $g(x)$, probability of detection at perpendicular distance x, was 0.15. Outliers provide little information for estimating the detection function at $x = 0$, are difficult to model, and may increase the sampling variance of the density estimate (Buckland et al., 2001).

Encounter rates, density, and abundance estimates, and 95% confidence intervals were calculated using program DISTANCE (Thomas et al., 1998). The precision of density and abundance estimates were computed by program DISTANCE as coefficients of variation (Thomas et al., 1998). The precision level of estimates (i.e., $\hat{P}_A$, $\hat{g}_0$, $\hat{D}$, $\hat{N}$) will be refined as additional years of monitoring data are collected.

RESULTS

Distance Sampling Field Effort. — A total of 201.4 km (103 transects) were completed in Zone 3 of the Red Cliffs Desert Reserve from 18 April to 4 June 1998 (Table 1). Over

Table 1. Sample size of truncated data (n), total line length (L), number of transects (k), density ($\hat{D}$, tortoises per ha) and abundance ($\hat{N}$, total animals per area sampled) estimates with associated 95% confidence interval (CI), and % coefficient of variation (CV) for adult (CL ≥ 180 mm) tortoises encountered within Zone 3 as well as across the Reserve (Zones 2, 3, and 5), Red Cliffs Desert Reserve, Washington County, Utah, 1998 to 2001.

Analysis	Year	n	L	k	$\hat{D}$ (95%CI)	$\hat{N}$ (95%CI)	CV(%)
Zone 3	1998	121	201.4	103	0.32 (0.23-0.43)	3226 (2363-4404)	15.83
	1999	132	225.9	116	0.31 (0.22-0.43)	3138 (2220-4435)	17.62
	2000	136	221.3	112	0.32 (0.23-0.45)	3301 (2356-4624)	17.17
	2001	146	230.9	117	0.33 (0.25-0.45)	3396 (2517-4582)	15.24
	Pooled$_{98\text{-}01}$				0.32 (0.29-0.36)	3267 (2911-3666)	5.85
Zones 2, 3, and 5	1999	150	306.5	158	0.27 (0.21-0.37)	3154 (2372-4194)	14.52
	2000	162	302.0	153	0.30 (0.23-0.40)	3457 (2599-4598)	14.54
	2001	168	313.8	159	0.30 (0.23-0.39)	3450 (2629-4527)	13.83
	Pooled$_{99\text{-}01}$				0.29 (0.26-0.33)	3354 (2962-3789)	5.87

Table 2. Size structure of live desert tortoises encountered during distance sampling monitoring, Red Cliffs Desert Reserve, Washington County, Utah, 1998 to 2001.

Size Class	CL Range (mm)	Number of tortoises 1998	1999	2000	2001	Total Tortoises
Juvenile	< 99	22	17	9	12	60
Immature	100-179	25	19	20	24	88
Subadult	180-207	11	14	12	14	51
Adult	> 208	124	168	156	146	594
Adult/Subadult[1]	> 180	3	10	22	22	57
Total		185	228	219	218	850

[1]Tortoises were not measured because they could not be removed from deep burrows.

300 km of distance sampling were completed annually from 1999 to 2001 in Zones 2, 3, and 5 (30 March to 10 June 1999, 5 April to 9 June 2000, 2 April to 11 June 2001; Table 1). Transect lengths ranged from 1.28 to 2.0 km depending upon elevation and topography.

During the four years of monitoring, 850 live tortoises were encountered (Table 2). Of those tortoises, 57 adults and subadults were not marked or measured because they could not be removed from deep soil burrows. Median CL of tortoises ranged from 41 to 316 mm.

Above Ground Estimate. — Radiotelemetered tortoises used to estimate g_0 were located up to 24 times annually during the sampling period. Average CL of radiotelemetered tortoises in all years of the study was 247.2 mm ± 3.12 (range: 200–295). The proportion of time spent above ground varied from 0.65 ± 0.05 to 0.85 ± 0.03 (Table 3). The mean g_0 from 1998 to 2001 was 0.79 ± 0.02. Above ground activity was roughly consistent in all years of the study excluding the spring of 1999, when g_0 was below the 95% CI of g_0 in 1998, 2000, and 2001 monitoring years.

Detection Histogram and Probability Plots. — Examination of the detection histogram revealed the existence of extreme observations or outliers up to 45 m from the line. Data were truncated at the perpendicular distance of 22 meters for analysis of Zone 3 and 18 meters for Reserve wide analysis. The uniform + cosine model was selected when data were analyzed within Management Zone 3 (AIC = 3191.3). The effective strip width, ESW, was 11.99 m ± 0.60 (95% CI: 10.87-13.22; CV: 4.99) and the proportion of tortoises detected within transect width w, $\hat{P}_A$, was 0.54 ± 0.03 (95% CI: 0.49-0.60; CV: 4.99). When data were analyzed across the Reserve, the half-normal + hermite polynomial model was selected (AIC = 2683.0). The ESW was 11.43 m ± 0.46 (95% CI: 10.56-12.36; CV: 4.01) and P_A was 0.63 ± 0.02 (95% CI: 0.59-0.69; CV: 4.01). The detection histograms revealed field data which followed the shape criterion outlined, including detectability certain near the line and the presence of a "shoulder" of detection 2 to 3 m from the line (Buckland et al., 2001; Figs. 1 and 2).

Density and Abundance Estimates. — Annual density and abundance estimates within Management Zone 3, as well as across the Reserve, are consistent in all years of the study with minimal variation (Table 1). The pooled density estimate of Zone 3 was 0.32 tortoises per hectare (95% CI: 0.29-0.36; CV: 5.85%) while the pooled density in Zones 2, 3, and 5 was estimated at 0.29 tortoises per hectare (95% CI: 0.26-0.33; CV: 5.87%). The largest variance component in all years of the study was the spatial variation in the encounter rate (Table 3). The abundance of adult tortoises in Zone 3, pooled across years, was 3267 tortoises per area sampled (10,176 ha; 95% CI: 2911-3666; Table 1). Pooled abundance estimates within Zone 2, 3, and 5 of the Reserve was estimated at 3354 tortoises per area sampled (11,457 ha; 95% CI: 2962- 3798). The variance associated with estimates $\hat{P}_A$ and $\hat{g}_0$ decreased by pooling multiple years of data, resulting in increased precision of density and abundance estimates.

DISCUSSION

Density and abundance estimates, from 1998 to 2001, were calculated for adult tortoises within Management Zone 3 as well as within Management Zones 2, 3,

Table 3. Encounter rate (n/L), proportion of tortoises detected within transect width w ($\hat{P}_A$), number of radiotelemetered tortoises (n), proportion of tortoises above ground ($\hat{g}_0$), the standard error (SE), and the contribution of each component to the density variance for adult tortoises (CL ≥ 180 mm) encountered within Zone 3 as well as across the Reserve (Zones 2, 3, and 5), Red Cliffs Desert Reserve, Washington County, Utah, 1998 to 2001.

Analysis	Year	n/L ± SE	$\hat{P}_A$ ± SE	n ($\hat{g}_0$)	$\hat{g}_o$ ± SE	Variance Component (%) n/L	$\hat{P}_A$	$\hat{g}_o$
Zone 3	1998	0.60 ± 0.09	0.54 ± 0.03	30	0.83 ± 0.03	87.5	9.9	2.6
	1999	0.58 ± 0.10	0.54 ± 0.03	30	0.65 ± 0.03	89.9	8.0	2.1
	2000	0.61 ± 0.10	0.54 ± 0.03	15	0.83 ± 0.03	89.4	8.4	2.2
	2001	0.63 ± 0.09	0.54 ± 0.03	12	0.85 ± 0.03	86.5	10.7	2.8
Zones 2, 3, and 5	1999	0.49 ± 0.07	0.63 ± 0.02	30	0.65 ± 0.03	87.9	7.6	4.5
	2000	0.54 ± 0.07	0.63 ± 0.02	15	0.83 ± 0.03	87.9	7.6	4.5
	2001	0.53 ± 0.07	0.63 ± 0.02	12	0.85 ± 0.03	86.5	8.4	5.0

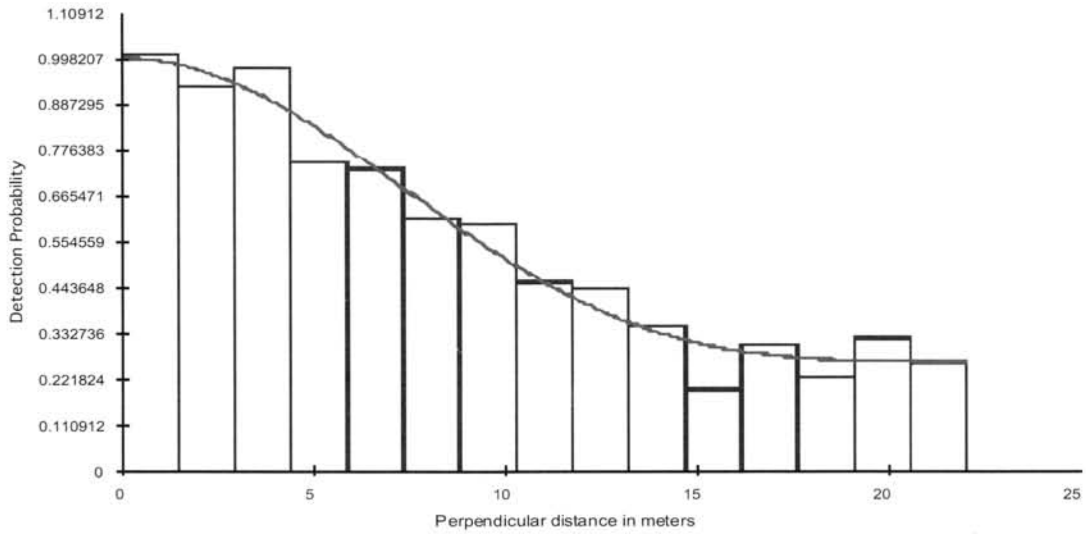

Figure 1. Detection histogram of truncated perpendicular distances ($n = 535$) and the detection probability plot (uniform + cosine model) for reproductive tortoises (CL ≥ 180 mm) encountered within Management Zone 3 of the Red Cliffs Desert Reserve, Washington County, Utah, 1998 to 2001.

and 5 of the Reserve. These regional density estimates are some of the most precise reported for any desert tortoise Recovery Unit (USFWS, 1994; Corn et al., unpubl. data). Because tortoises are not reproductive until approximately 15 to 20 years of age, long-term population trends cannot be assessed until additional years of data are collected.

Density estimates have been previously reported for the Reserve and include some of the highest recorded densities in the Mojave Desert (Bury et al., 1994; Fridell et al., 1995; WCC, 1995). However, these density estimates cannot be compared to estimates from distance sampling due primarily to unrepresentative, nonrandom areas sampled (Fridell et al., 1995) and limitations with the monitoring technique (WCC, 1995). McLuckie et al. (1998) reported density estimates for both the spring and fall of 1997. Although a small, unrepresentative area within Zone 3 of the Reserve was sampled, 1997 pilot study estimates (spring: $\hat{D} = 0.18$ *n*/ha, 95% CI: 0.10–0.33, CV = 28.28%; fall: $\hat{D} = 0.25$ *n*/ha; 95% CI: 0.10–0.61; CV = 44.38%) were roughly consistent with pooled density estimates from this study (McLuckie et al., 1998).

The majority of tortoises encountered during Reserve monitoring were subadult and adults (83%); only 17% of the tortoises observed had a CL of < 180 mm. Juvenile and immature tortoises exhibit low capture rates because they are more difficult to observe due to their small size, secretive nature, and limited time spent above ground (Diemer, 1992; Wilson et al., 1994). Anderson et al. (2001) recommended excluding juveniles and immatures (CL < 140 or < 180 mm) from analyses because they are more likely to be undetected along the

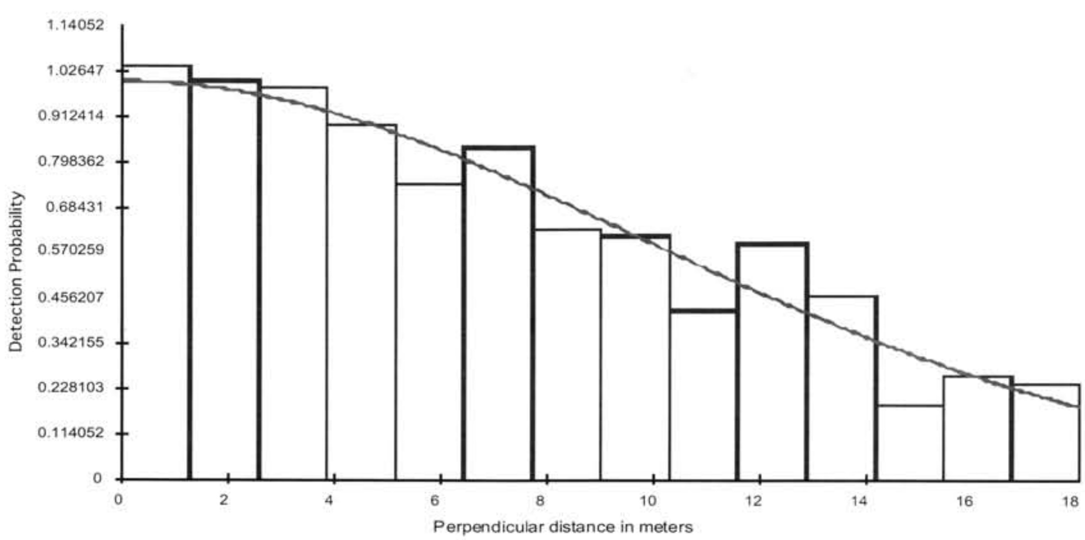

Figure 2. Detection histogram of truncated perpendicular distances ($n = 480$) and the detection probability plot (half-normal + hermite polynomial model) for reproductive tortoises (CL ≥ 180 mm) encountered within Zones 2, 3, and 5 of the Red Cliffs Desert Reserve, Washington County, Utah, 1999 to 2001.

transect line. Including these undetected objects may cause density estimates to be biased low (Thompson et al., 1998; Buckland et al., 2001). Tortoise population estimates should not include juveniles and immatures, unless methods incorporate specific search protocols for these individuals (e.g., use of trained search dogs on centerline, quantify above ground activity of juveniles and immatures).

Precipitation, temperatures, and annual productivity are important factors influencing tortoise activity levels, movement, burrow use, and annual home range size. Duda et al. (1999) found that desert tortoise activity and movement declined during drought years, with activity levels proportional to forage biomass. Density estimates from capture-recapture monitoring plots are suspect in dry years due to low recapture rates (Freilich et al., 2000). However, distance sampling estimates are robust to annual and seasonal variations in tortoise activity patterns due, in part, to quantifying g_0. The proportion of tortoises above ground in the Reserve was less in 1999 than other years of the study. Annual precipitation in the St. George area in 1999 (140.21 mm ± 3.81) was 70.56 mm below the 100 year mean (210.77 mm ± 6.71; WRCC, 2001). Contrary to the capture-recapture technique (Freilich et al., 2000), estimates obtained from distance sampling during a drought year were consistent with years of abundant rainfall (e.g., 1998: 354.84 mm ± 6.05). Quantifying the proportion of tortoises above ground concurrent with distance sampling is critical. This allows accurate estimation of desert tortoise densities even with seasonal and annual variation in g_0.

Distance sampling was an effective method to estimate regional density and abundance of adult tortoises within the Reserve. Although sampling was conducted in both dry and wet years, annual density estimates were consistent in all years of the study. The precision level of density and abundance estimates increased by pooling multiple years of data. These baseline density and abundance estimates will be compared to future estimates to reveal regional trends. Ultimately, modeling g_0 as a function of environmental and physical covariates (i.e., temperature, precipitation, size, sex) will quantify above ground activity patterns in a cost-effective and comprehensive way (Anderson and Burnham, 1996; Buckland et al., 2001).

Due to the number of potential threats within the Reserve and its proximity to rapidly growing communities, long-term monitoring is critical to assess density and abundances of the desert tortoise population (USFWS, 1994). Life history strategies associated with desert tortoises include a low reproductive rate, high juvenile mortality, and low adult mortality (Congdon and Gibbons, 1990). These attributes make tortoise populations highly sensitive to human induced perturbations (USFWS, 1994). As pressures from human populations increase, active management will be essential to ensure the continued existence of tortoises within the Reserve.

Acknowledgments

We are grateful to C. Balcombe, M. Baumflek, J. Bostic, D. Donato, S. Gibson, W. Heyborne, T. Hyde, K. Kietzer, B. McCleery, J. Nichols, D. Rabosky, A. Sacerdote, K. Sams, C. Schade, K. Schroeder, M. Stidham, M. Swan, H. Tangerman, K. Wheeler, M. Wolfgram, and B. Zettle for their field efforts. T. Esque, D. Haines, and S. Eckert from the U.S. Geological Survey, Biological Resources Division, Western Ecological Research Center provided assistance in many stages of the project. We thank D. Anderson, K. Burnham, and P. Lukacs, Colorado State University, for providing study design, analysis, and technical review. Finally, we thank A. Krzysik and one anonymous reviewer for providing manuscript comments. This project was funded by the Utah Division of Wildlife Resources and the Washington County Habitat Conservation Plan.

LITERATURE CITED

Anderson, D.R. and Burnham, K.P. 1996. A monitoring program for the desert tortoise. Fort Collins: Colorado Cooperative Fish and Wildlife Research Unit, 13 pp.

Anderson, D.R., Burnham, K.P., Lubow, B.C., Thomas, L., Corn, P.S., Medica, P.A., and Marlow, R.W. 2001. Field trials of line transect methods applied to estimation of desert tortoise abundance. J. Wildl. Mgmt. 65(3):583-597.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., and Thomas, L. 2001. Introduction to Distance Sampling: Estimating abundance of biological populations. UK: Oxford University Press, 432 pp.

Bury, R.B., Esque, T.C., DeFalco, L.A., and Medica, P.A. 1994. Distribution, habitat use, and protection of the desert tortoise in the eastern Mojave Desert. In: Bury, R.B. and Germano, D.J. (Eds.). Biology of North American Tortoises. Fish and Wildlife Research 13:57-72.

Cagle, F.R. 1939. A system for marking turtles for future identification. Copeia 1939:170-173.

Congdon, J.D. and Gibbons, J.W. 1990. The evolution of turtle life histories. In: Gibbons, J.W. (Ed.). Life History and Ecology of the Slider Turtle. Washington, DC: Smithsonian Institution Press, pp. 45-54.

Diemer, J.E. 1992. Home range and movements of the tortoise *Gopherus polyphemus* in northern Florida. J. of Herpetol. 42:125-133.

Duda, J.J., Krzysik, A.J., and Freilich, J.E. 1999. Effects of drought on desert tortoise movement and activity. J. Wildl. Manage. 63:1181-1192.

Esque, T.C. 1994. Diet and diet selection of the desert tortoise (*Gopherus agassizii*) in the northeast Mojave Desert. M.S. Thesis, Colorado State University, Fort Collins.

Freilich, J.E., Burnham, K.P., Collins, C.M., and Garry, C.A. 2000. Factors affecting population assessments of desert tortoises. Conservation Biology 14:1479-1489.

Fridell, R.A., Snider, J.R., Comella, K.M., and Lentsch, L.D. 1995. Status of the desert tortoise population on the City Creek monitoring plot, Upper Virgin River Valley, 1994. Salt Lake City: Utah Div. of Wildlife Resour., Publ. Number 95-05, 40 pp.

Lancia, R.A., Nichols, J.D., and Pollock, K.P. 1994. Estimating the number of animals in wildlife populations. In: Bookout, T.A. (Ed.). Research and Management Techniques for Wildlife and Habitats. Bethesda, MD: The Wildlife Society, pp. 215-253.

McLuckie, A.M., Fridell, R.A., Smith, T.K., and Zettle, B.A. 1998.

UDWR 1997 Annual Report: Distance sampling in the Red Cliffs Desert Reserve, Washington County, Utah. Salt Lake City: Utah Div. of Wildl. Resour, Publ. Number 98-04, 27 pp.

POPE, D. AND BROUGH, C. 1996. Utah's Weather and Climate. Salt Lake City: Publishers Press, Utah, 245 pp.

THOMAS, L., LAAKE, J.L., DERRY, J.F., BUCKLAND, S.T., BORCHERS, D.L., ANDERSON, D.R., BURNHAM, K.P., STRINDBERG, S., HEDLEY, S.L., BURT, M.L., MARQUES, F., POLLARD, J.H., AND FEWSTER, R.M. 1998. DISTANCE 3.5. UK: University of St. Andrews, Research Unit for Wildlife Population Assessment.

THOMPSON, W.L., WHITE, G.C., AND GOWAN, C. 1998. Monitoring Vertebrate Populations. San Diego: Academic Press, Inc., 365 pp.

TURNER, R.M. 1982a. Mojave Desert scrub. In: Brown, D.E. (Ed.). Biotic communities: southwestern United States and northwestern Mexico. Salt Lake City: University of Utah Press, pp. 157-168.

TURNER, R.M. 1982b. Great Basin Desert scrub. In: Brown, D.E. (Ed.). Biotic communities: southwestern United States and northwestern Mexico. Salt Lake City: University of Utah Press, pp. 145-155.

U.S. FISH AND WILDLIFE SERVICE. 1990. Endangered and threatened wildlife and plants: determination of threatened status for the Mojave population of the desert tortoise. Fed. Register 55:12178-12191.

U.S. FISH AND WILDLIFE SERVICE. 1994. Desert tortoise (Mojave population) Recovery Plan. Portland, OR: U.S. Fish and Wildl. Serv., 73 pp.

U.S. FISH AND WILDLIFE SERVICE. 1996. Issuance of permit for incidental take of threatened species. Fed. Register 61:26529.

WASHINGTON COUNTY COMMISSION. 1995. Habitat Conservation Plan, Washington County, Utah. Flagstaff, AZ: SWCA, Inc. Environmental Consultants, 192 pp.

WESTERN REGIONAL CLIMATE CENTER. 2001. URL *www.wrcc.dri.edu*. Reno: University of Nevada, Desert Research Institute.

WHITE, G.C., ANDERSON, D.R., BURNHAM, K.P., AND OTIS, D.L. 1982. Capture-recapture and removal methods for sampling closed populations. New Mexico: Los Alamos Natl. Lab., LA-8787-NERP, 235 pp.

WILSON, D.S., MUSHINSKY, H.R., AND MCCOY, E.D. 1994. Home range, activity, and use of burrows of juvenile gopher tortoises in central Florida. In: Bury, R.B., and Germano, D.J. (Eds.). Biology of North American Tortoises, Fish and Wildlife Research 13. Washington, DC: U.S. Dep. Interior, National Biological Survey, pp. 147-160.

Received: 3 June 2000
Reviewed: 4 August 2002
Revised and Accepted: 7 November 2002