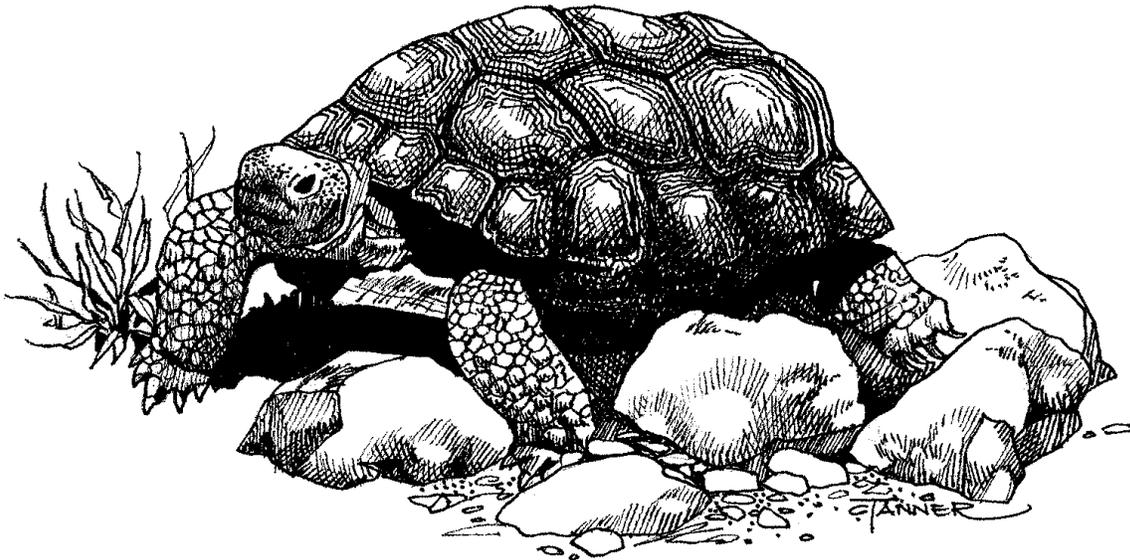


SURVEY PROTOCOL FOR SONORAN DESERT TORTOISE MONITORING PLOTS:

REVIEWED AND REVISED

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*ARIZONA INTERAGENCY DESERT TORTOISE TEAM*

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## PREFACE

The Arizona Interagency Desert Tortoise Team (AIDTT) consists of biologists and managers assigned to the Team by the following agencies (alphabetically): Arizona Game and Fish Department; Arizona State Land Department; U.S. Department of Agriculture Forest Service; U.S. Department of Defense Luke Air Force Base, Marine Corp Air Station, and Yuma Proving Ground; and U.S. Department of Interior Bureau of Land Management, Bureau of Reclamation, Bureau of Indian Affairs, Fish and Wildlife Service, Geological Survey, and National Park Service. In accordance with a Memorandum of Understanding, finalized in 1995 and signed by the above agencies, the Team serves as a forum to discuss desert tortoise issues, with a specific objective to conduct and coordinate research and management efforts. This interagency cooperation is intended to: (1) ensure the perpetuation of the species and (2) prevent loss and improve quality of habitat in Arizona. The AIDTT is also open to participation by other federal, state or tribal agencies interested in the conservation of the desert tortoise in Arizona and recognizes the participation of the Tohono O'odham Nation, in particular.

## ACKNOWLEDGEMENTS

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INTRODUCTION

A state-wide monitoring program is important for collecting data necessary for effective desert tortoise (*Gopherus agassizii*) management in Arizona (Arizona Interagency Desert Tortoise Team [AIDTT] 1996). Surveys of the Mojave Desert population in Arizona, as defined by the U.S. Fish and Wildlife Service (USFWS 1990), have been conducted since 1977, and surveys of plots within the Sonoran Desert population have been conducted since 1987. To date, 4 Mojave population plots have been surveyed (3 at least twice each), and 28 Sonoran population plots have been surveyed (17 at least twice each; Figure 1, Table 1). These surveys provide a solid baseline and a framework from which to continue efforts to accurately identify trends in Arizona's tortoise populations.

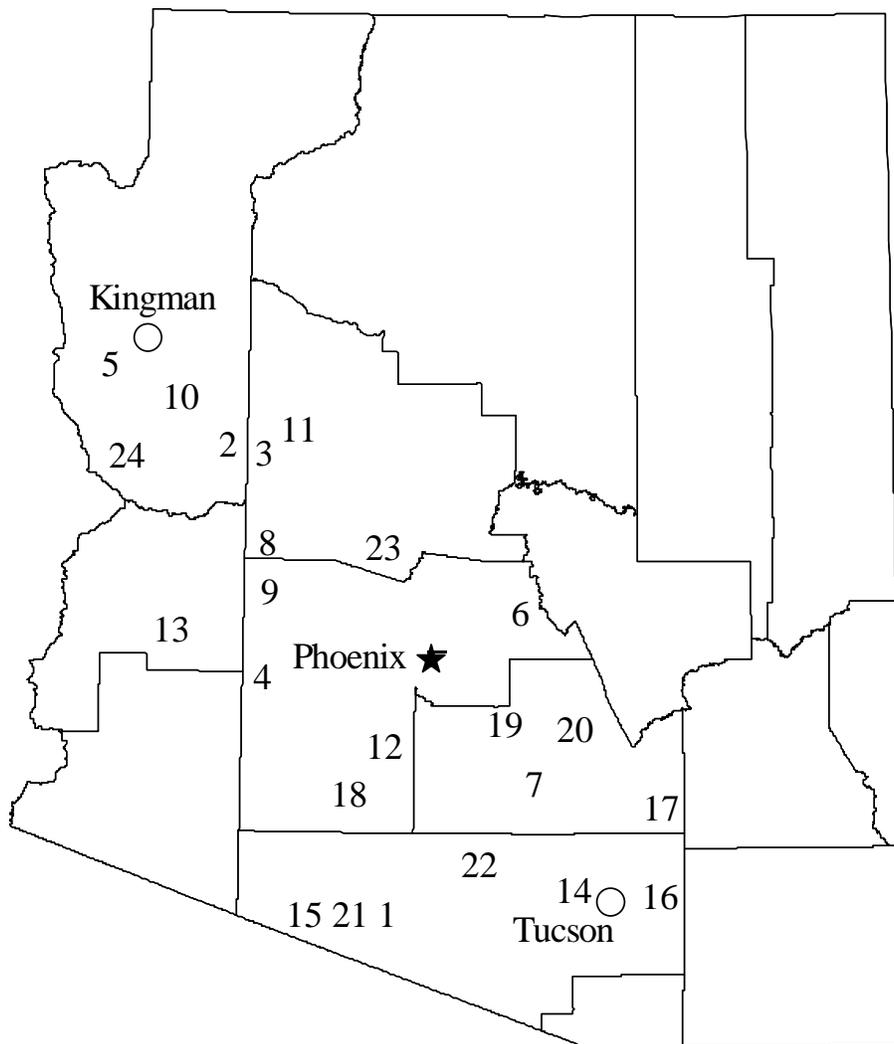


Figure 1. Sonoran Desert tortoise monitoring plots. Symbols refer to plots listed in Table 1.

Table 1. Sonoran Desert tortoise monitoring plots. Superscripts correspond to plot locations in Figure 2. Subscripts refer to land management agency: ASLD, Arizona State Land Department; BLM, Bureau of Land Management; LAFB, Luke Air Force Base; ORPI, Organ Pipe Cactus National Monument; SAGU, Saguaro National Park; TNF, Tonto National Forest.

| Plot  | 1987 | 1988 | 1989 | 1990                   | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|------|------|------|------------------------|------|------|------|------|------|------|------|------|------|
| <sup>1</sup> Ajo Mountain Dr. <sub>ORPI</sub>     |      |      |      |                        |      |      |      |      |      | X    |      |      |      |
| <sup>2</sup> Arrastra <sub>BLM</sub>              | X    |      |      |                        |      |      |      |      |      |      | X    |      |      |
| <sup>3</sup> Bonanza Wash <sub>BLM</sub>          |      |      |      |                        |      | X    |      |      |      |      | X    |      |      |
| <sup>4</sup> Eagletails <sub>BLM</sub>            | X    |      |      | X                      | X    | X    | X    | X    |      |      |      | X    |      |
| <sup>5</sup> East Bajada <sub>BLM</sub>           |      |      |      | X                      |      |      | X    |      |      |      | X    |      |      |
| <sup>6</sup> Four Peaks <sub>TNF</sub>            |      |      |      |                        |      | X    |      |      | X    |      |      |      |      |
| <sup>7</sup> Granite Hills <sub>ASLD</sub>        |      |      |      | X                      | X    | X    | X    | X    |      |      |      | X    |      |
| <sup>8</sup> Harcuvars <sub>BLM</sub>             |      | X    |      |                        |      |      | X    |      |      |      | X    |      |      |
| <sup>9</sup> Harquahalas <sub>BLM</sub>           |      | X    |      |                        |      |      |      | X    |      |      |      |      |      |
| <sup>10</sup> Hualapai Foothills <sub>BLM</sub>   |      |      |      |                        | X    |      |      |      |      | X    |      |      |      |
| <sup>11</sup> Little Shipp <sub>ASLD</sub>        |      |      |      | X                      | X    | X    | X    | X    |      |      |      | X    |      |
| <sup>12</sup> Maricopa <sub>BLM</sub>             | X    |      |      | X                      |      |      |      |      |      |      |      |      |      |
| <sup>13</sup> New Water <sub>BLM</sub>            |      | X    |      |                        |      |      |      |      |      |      |      |      | X    |
| <sup>14</sup> Panther Peak <sub>SAGU</sub>        |      |      |      |                        |      |      |      |      |      | X    | X    |      |      |
| <sup>15</sup> Quitobaquito Hills <sub>SORPI</sub> |      |      |      |                        |      |      |      |      |      |      | X    |      |      |
| <sup>16</sup> Rincones Burn <sub>SAGU</sub>       |      |      |      |                        |      |      |      |      |      | X    |      |      |      |
| <sup>16</sup> Rincones Javelinas <sub>SAGU</sub>  |      |      |      |                        |      |      |      |      |      | X    | X    |      |      |
| <sup>17</sup> San Pedro <sub>BLM</sub>            |      |      |      |                        | X    |      |      |      | X    |      |      |      |      |
| <sup>18</sup> Sand Tanks A&B <sub>LAFB</sub>      |      |      |      |                        |      | A    |      | B    |      |      |      |      |      |
| <sup>19</sup> Santans <sub>BLM</sub>              |      |      |      | X                      | X    |      |      |      |      |      |      |      |      |
| <sup>20</sup> Tortillas <sub>BLM</sub>            |      |      |      |                        |      | X    |      |      |      | X    |      |      |      |
| <sup>21</sup> Twin Peaks <sub>SORPI</sub>         |      |      |      |                        |      |      |      |      |      | X    |      |      |      |
| <sup>22</sup> West Silverbells <sub>BLM</sub>     |      |      |      |                        | X    |      |      |      | X    |      |      |      |      |
| <sup>23</sup> Wickenburg Mtns. <sub>BLM</sub>     |      |      |      |                        | X    |      |      |      |      |      |      |      |      |
| <sup>24</sup> Mohave Mtns. <sub>BLM</sub>         |      |      |      | X (no tortoises found) |      |      |      |      |      |      |      |      |      |

The general objectives of desert tortoise population monitoring have been to document abundance and density of tortoises on plots across the state and changes in these numbers; demographic characteristics of each population, including sex ratios and age/size structure; and individual health and signs of disease within each population. Traditionally, efforts to monitor tortoise abundance have centered on permanent plot techniques originally developed for use in the Mojave Desert (Berry 1984). Differences in habitat of Mojave and Sonoran tortoises required that the Mojave survey methods be modified for use in the Sonoran Desert (Shields and others 1990; Hart and others 1992). Adequate data are now available to evaluate the methods used in monitoring Sonoran populations. In fact, several independent studies have already investigated various aspects of these methods. The purpose of this report is to compile the results of these studies for a comprehensive review of current monitoring methods on Sonoran plots. This review forms the basis of a revised protocol for future surveys of Sonoran plots.

#### DESCRIPTION OF CURRENT METHODS

The following description of current monitoring plot methods is taken primarily from protocols established by the Bureau of Land Management (BLM) (for example, Appendix 1 of Assistance Agreement AZ950-A6-00004-T-1, 1996, between BLM and the Arizona Game and Fish Department [AGFD]) and a recent plot report (Woodman and others 1998), but also from other sources where indicated.

##### Plot Configuration and Coverage

The typical Sonoran Desert monitoring plot is a 1 mile square, with plot corners marked with green metal t-posts. A 0.1-mi<sup>2</sup> grid is overlaid on the topographic map for geographic reference. Grid cells are generally numbered according to their position within U. S. Geological Survey (USGS) sections, with the northwest cell of a USGS section numbered 00, the northeast cell numbered 09, the southwest cell numbered 90, and the southeast cell numbered 99 (Figure 2). Field effort during a typical plot survey consists of workers searching for tortoises for 60 person days on at least 45 calendar days during the summer monsoon season, coinciding with peak tortoise activity. A calendar day is an actual day spent in the field. A person day equals 6 or more hours of field effort during 1 calendar day; throughout the survey, field workers must average at least 8 hours per person day. Search routes vary according to the topography of the site, and field workers spend more time searching areas where tortoises have previously been found, either during the current survey or surveys in prior years. Burrows are flagged and rechecked periodically throughout a survey (Shields 1994). Search effort is generally split between morning and evening during the hottest part of the season but in the fall includes more time in mid-afternoon as temperatures begin to cool. During and following rain, emphasis is placed on finding smaller tortoises (juveniles and immatures) by concentrating on previously located shelters and what is perceived to be good tortoise habitat (Shields 1994). The effectiveness of such concentrated searches has not been documented, however.

|    |    |    |    |    |    |    |    |    |    |
|----|----|----|----|----|----|----|----|----|----|
| 55 | 56 | 57 | 58 | 59 | 50 | 51 | 52 | 53 | 54 |
| 65 | 66 | 67 | 68 | 69 | 60 | 61 | 62 | 63 | 64 |
| 75 | 76 | 77 | 78 | 79 | 70 | 71 | 72 | 73 | 74 |
| 85 | 86 | 87 | 88 | 89 | 80 | 81 | 82 | 83 | 84 |
| 95 | 96 | 97 | 98 | 99 | 90 | 91 | 92 | 93 | 94 |
| 05 | 06 | 07 | 08 | 09 | 00 | 01 | 02 | 03 | 04 |
| 15 | 16 | 17 | 18 | 19 | 10 | 11 | 12 | 13 | 14 |
| 25 | 26 | 27 | 28 | 29 | 20 | 21 | 22 | 23 | 24 |
| 35 | 36 | 37 | 38 | 39 | 30 | 31 | 32 | 33 | 34 |
| 45 | 46 | 47 | 48 | 49 | 40 | 41 | 42 | 43 | 44 |

Figure 2. Grid numbering system for monitoring plots. The diagram indicates a 1-mi square plot equally overlapping 4 USGS sections, the boundaries of which are denoted by bold grid lines. The shaded portion represents the northwest corner of the USGS section that falls within the southeast corner of the plot.

Several exceptions have been made to the standard survey duration and plot configuration. Shorter surveys (approximately 35 person days) have been conducted on the Eagletail Mountain (Hart and others 1992; Woodman and others 1993, 1994, 1995) and Bonanza Wash (Woodman and others 1998) 1-mi<sup>2</sup> plots. An additional rocky hill (approximately 0.06 square mi) was incorporated into the square-mile plot at the Arrastra Mountains (Wirt 1988), and surveys were reduced to 35 person days (Woodman and others 1998). The Granite Hills plot totals about 1 square mile of area but is configured as approximately 0.7 mi x 1.6 mi (Hart and others 1992; Woodman and others 1993, 1994, 1995). The Harquahala Mountain plot is 1.5 square miles in area (Holm 1989; Woodman and others 1995), and the Four Peaks (Murray 1993; Murray and Schwalbe 1997), Sand Tank Mountain (Geo-Marine, Inc. 1994), and Saucedo Mountain (Dames and Moore 1994; Geo-Marine, Inc. 1994) plots are all approximately 1 km<sup>2</sup> (0.6 mi<sup>2</sup>). Two 1-km<sup>2</sup> plots at Organ Pipe Cactus National Monument were divided into 9 grid cells (0.33 km<sup>2</sup>); a third plot was configured as 1.5 km x 0.67 km, with 9 grid cells (Wirt and others 1999). Several 1-km<sup>2</sup> plots on Saguaro National Park have also recently been surveyed (E. Wirt and N. Kline, pers. comm. 1999).

### Field Data

Standardized field notes for each field day include names of field personnel, search and processing times, summary of tortoise encounters and capture locations, carcasses collected and locations, weather data, and a map and general description of areas surveyed. Potential tortoise predators, human activity, and other wildlife observed are also recorded. Standard temperatures recorded include ground surface, 1 cm above ground, and 1.5 m above ground, taken with a shaded bulb at 0800h, 1200h, and 1600h each field day. Percent cloud cover, cloud type(s), and

wind speed and direction are also recorded at these times. Rainfall is measured with a rain gauge on site.

*Live Tortoises.*—Each tortoise encounter is categorized by capture type (CT): CT-1 is the first encounter of a tortoise; CT-2, a subsequent capture of a tortoise previously processed during the current year; and CT-3, the first encounter in the current year of a tortoise marked during a previous survey. Carcasses of marked individuals are classified as CT-5. The CT-4 category was originally created for captive releases but has not been used on Arizona plots (P. Woodman, pers. comm. 2000).

For every tortoise encounter, field workers record the following data on a standard form: capture type; location, referenced to position within grid cell; standard temperatures as described above and temperature 0.5 m deep inside the shelter, if applicable; shelter type, location, dimensions (length and opening width and height), orientation of slope and shelter entrance, and identification number (pre-stamped aluminum tag attached to shelter structure); activity and social interactions; foods eaten; whether new growth was visible on the shell; estimated volume, color, and viscosity of voided urine; and the beginning and end times for the process.

Field workers visually inspect each tortoise for injuries, morphological anomalies, ectoparasites, and symptoms of shell disease (cutaneous dyskeratosis) and upper respiratory tract disease. Field workers handle all tortoises with disposable latex gloves to minimize the spread of potential pathogens between individual tortoises. Any instruments coming into contact with the tortoise during handling are disinfected with bleach.

Physical data recorded for each tortoise depend on the capture type. For CT-1 tortoises, field workers typically record 8 shell measurements (straight midline carapace length [MCL], midline plastron length [between the gular and anal scute notches], greatest plastron length [the longest distance between tips of the gular and anal scutes on the left or right side], carapace width between the third marginal scutes, width between the fourth marginals, width between the seventh/eighth marginal seams, maximum width, and maximum height) and weight, corrected for the estimated mass of urine or feces voided prior to weighing. Lengths are measured to the nearest millimeter and weight to the nearest gram. The tortoise is assigned a number, and marginal scutes are notched accordingly with triangular files (Berry 1984). Bridge marginals are not notched on tortoises <120 mm MCL. The identification number is also written on a dot of correction fluid (or a small white label) on the right fourth costal scute and covered with clear, quick-drying epoxy. Gender is determined for tortoises  $\geq 180$  mm MCL. Close-up photographs are taken of the full carapace, full plastron, and left fourth costal; a label indicating study plot, date, and tortoise number is included in each photograph. Finally, a shell wear class is assigned based on the system of Berry and Woodman (1984a).

Usually, field workers do not record physical data for CT-2 tortoises, but weight (tortoises  $\geq 180$  mm MCL only) and MCL are recorded for tortoises if more than 14 days have elapsed or rain has fallen since it was last processed. Field workers identify CT-3 tortoises by their notches and epoxied numbers, if still present. File marks and epoxy numbers are redone, if necessary, and all other measurements are taken as for CT-1 tortoises.

*Carcasses.*—Field workers photograph each carcass *in situ* (including the general area the carcass was found, a mid-range photo of the carcass location, and a close-up of the carcass), with a label indicating study plot, date, carcass number, live tortoise number (if applicable), and investigator. They fill out a data sheet (2 copies) for each carcass. Data recorded include shell position and percent daylight hours exposed to sun; location, as with live tortoises; sex, MCL, and identifying marks (when possible); and notes on signs of cause of death. Carcasses are collected in Zip-loc<sup>®</sup> type plastic bags, with one of the data sheets, and usually deposited at AGFD. The other data sheet is filed separately. When MCL cannot be measured directly, it is estimated with a regression formula developed by Berry and Woodman (1984b) from tortoises in the Mojave Desert. Time since death is also classified as <1 year, 1-2 years, 2-4 years, or >4 years, based on a key developed by Berry and Woodman (1984b), also from tortoises in the Mojave Desert.

*Vegetation.*—Perennial vegetation is generally sampled with 5 100-m line-intercept transects. Species richness, cover (amount of transect covered by each species), relative cover (percent of all vegetation on a transect covered by each species), total cover (sum of cover of all species), and absolute cover (percent of transect covered by any perennial vegetation) are recorded for each transect. Summer annuals are sampled with 20 by 50 cm Daubenmire plots at 10-m intervals along each transect. Cover of live annuals is estimated by counting the number of square-cm grid cells each species occupies and dividing by the total number of grid cells on the transect (10,000 [1000 square cm x 10 plots per transect]). Dead spring annuals are noted but not quantified. Other nearby perennial and annual species are also noted but not quantified, and a general plant species list is updated with each survey.

### Data Analysis

*Size Distributions.*—Size distributions are summarized in 10-mm increment histograms and tabulated according to the classification of Turner and Berry (1984): Hatchling, no growth rings; Juvenile 1,  $\leq 59$  mm MCL; Juvenile 2, 60-99 mm; Immature 1, 100-139 mm; Immature 2, 140-179 mm; Subadult, 180-207 mm; Adult 1, 208-239 mm; and Adult 2,  $\geq 240$  mm.

*Abundance Estimation and Other Analyses.*—The primary statistical analysis is the estimation of abundance. Abundance of tortoises  $\geq 180$  mm MCL is estimated with the Lincoln-Petersen estimator (Lincoln 1930; Petersen 1896), although other methods have been tested (see below). Typically, not enough tortoises  $< 180$  mm MCL are found to derive estimates for that size class, and differences in capturability between tortoises greater than or less than 180 mm preclude combining them into an overall abundance estimate for the entire population (Murray 1993; Schneider 1980). Abundance is usually only estimated for plots surveyed 2 or more times. The most recent survey serves as the “mark” sample, and the current survey serves as the “recapture” sample. Tortoise density has usually been estimated simply by dividing estimated abundance by plot area (for example, Schneider 1980; Turner and Berry 1984; Woodman and others 1995). Differences in population size between years have typically been evaluated simply by comparing point estimates and whether their 95% confidence intervals overlap, but Murray and Schwalbe (1997) used a proportional abundance estimator (Skalski and Robson 1992).

Other statistical procedures include comparison of sex ratios with the Chi-square or log-likelihood ratio tests, regression of mean annual growth against carapace length, and regression of carapace length against shell wear class.

## CRITIQUE OF CURRENT METHODS

### Plot Configuration and Coverage

Many of the unique configurations and survey durations of current plots were constructed or modified to account for the fact that tortoises often do not occur throughout an entire standard 1-mi<sup>2</sup> plot, at least in the Sonoran Desert. Murray (1993) demonstrated that tortoise distribution was significantly clumped within each of 3 1-square-mile plots. In fact, any configuration of an entire square mile will usually include a significant proportion of area unused by tortoises. An exception is the 1-square-mile Granite Hills plot, which is narrow and elongate to encompass a narrow, rocky ridge and to exclude as much of the surrounding creosotebush flats as possible (Hart and others 1992). Localized tortoise distributions within plots led to spatially and temporally reduced surveys at the Eagletail Mountains, Bonanza Wash, and the Arrastra Mountains (in works cited).

Specification of a 60 person-day field effort over 45 calendar days results in up to 30 days spent on the plot by a single person working alone. Although no major accident has occurred on a plot of this design, the rigorous terrain of most plots raises important safety issues (Murray and Schwalbe 1997). It may be desirable to allow surveys to occur over fewer calendar days with field personnel working in teams, as long as the surveys occur during high activity periods of tortoises.

### Field Data

*Live Tortoises.*—Special precautions should be taken to minimize the number of tortoises voiding their bladder during processing, as well as the amount of urine voided. Averill-Murray (1999a, in review) found that tortoises that void their bladders during handling were less likely to be recaptured in subsequent years, at least for some plots and years, suggesting that survival might be compromised by the fluid loss. Tortoises experience negative water balance even when eating succulent forage, if drinking water is unavailable (Nagy and Medica 1986). Metabolic rate increases after tortoises drink; after flushing their bladders, tortoises resume feeding and obtain energy for digestion and growth (Peterson 1996). Decreases in water stored in the bladder could affect the ability of tortoises to feed by limiting the amount of metabolic wastes that can also be stored in the bladder. In addition, water lost during handling could affect reproductive output in females. Reproductive females have higher total body water than non-reproductive females and forfeit this water to produce eggs; non-reproductive females conserve body water and maintain water balance, enabling them to return to a physiological condition capable of reproducing the following year (Henen 1997).

Re-evaluation of the types of data recorded on live tortoises presents opportunities to reduce handling and risk of tortoises voiding their bladders. A large database, compiled from monitoring plot surveys through the present, exists on tortoise shell morphology, so most shell measurements currently recorded could be eliminated. A measure of size (length) is needed to

characterize population demographics, so MCL should still be recorded. Variation in gular scute length causes plastron lengths to vary by individual and sex, making this measure undesirable for population-wide inferences. Tortoise weight is extremely variable within individuals and depends on each individual's hydration state, making it an unreliable indicator of tortoise health (Jacobson and others 1993); therefore, handling could be minimized by eliminating tortoise weights from the data recorded. Sharp files should always be used to minimize the time and physical effort required to notch the marginal scutes (Woodman and others 1998). Carapace and plastron photographs can be useful in documenting changes in the incidence of cutaneous dyskeratosis, but turning tortoises on their backs to photograph plastrons can cause them to void their bladders.

*Carcasses.*—The reliability of Berry and Woodman's (1984b) regression formulas for estimating MCL from Sonoran tortoise shell fragments is unknown, because Sonoran tortoises are morphologically different from tortoises in the Mojave Desert (Germano 1993; Weinstein and Berry 1987). Regression equations have not been developed specifically for Sonoran tortoises (Woodman and others 1998), and existing equations have not been tested on Sonoran carcasses of known size. Finally, while existing regressions were reported to be statistically significant ( $P < 0.0001$ ; Berry and Woodman 1984b), coefficients of determination ( $r^2$ ) have not been reported; therefore, the degree of variation explained by the regression is unknown.

The reliability of Berry and Woodman's (1984b) key for estimating time since death for tortoises in the Sonoran Desert is also unknown (Woodman and others 1998). This key places estimates of time since death into only 4 general categories of increasing length (<1, 1-2, 2-4, and >4 years). Differences in weathering and decomposition of carcasses between the 2 deserts probably only results in minor errors in the estimates, although this has not been tested.

*Vegetation.*—Vegetation measurements have been summarized descriptively, but no attempt to evaluate potential changes between surveys has been made. Transects have not been established randomly but have been chosen to include representative habitat types within the study plots, at least on a gross scale.

### Data Analysis

*Size Distributions.*—Turner and Berry's (1984) size categories have been used to describe tortoise population structure and to compare populations for almost 20 years (Woodman and others 1998). However, tortoise growth varies temporally (Medica and others 1975; Turner and others 1987) and geographically (Germano 1994; Murray and Klug 1996). Therefore, comparisons of artificial size categories between populations and years can confound accurate inferences. For example, tortoises at the Granite Hills grow to significantly smaller sizes than those at Little Shipp Wash (Murray and Klug 1996). The low numbers of "Adult 2" tortoises at the Granite Hills does not mean that population has lost its oldest individuals; likewise, smaller-size categories (for example, Immature 1, 2) may be compressed relative to other populations. Apparent differences in number within juvenile or immature classes between years or plots may reflect annual differences in growth rates rather than in age structures, as implied by the category labels.

*Abundance Estimation.*—Several studies have addressed the question of how to best estimate tortoise abundance. Schneider (1980) compared 3 methods of abundance estimation (the Lincoln-Petersen, Schnabel, and stratified Lincoln-Peterson methods) in the Chemehuevi Valley, California, and pointed out strengths and deficiencies in each. Unfortunately, he did not have a population of known size with which to evaluate his results, but he did recommend that estimates be limited to tortoises  $\geq 180$  mm MCL due to differences in capture probabilities between tortoises greater than and less than this size.

Dames and Moore (1994) had no success estimating tortoise abundance with Zippin's (1958) removal method on 7-day, 1-km<sup>2</sup> plots in the Sand Tank and Saucedo mountains, Arizona. The removal method is particularly ill-suited for estimating desert tortoise abundance, because it requires that capture numbers decrease during the survey period. Variation in capture probabilities between short-duration plot coverages (for example, responses of tortoise activity to rainfall) can result in increases in capture numbers and failure of the estimation procedure (Dames and Moore 1994; Zippin 1958).

Murray (1993) reviewed the general assumptions inherent to abundance estimation after noting that few tortoise studies have considered the effects of invalid assumptions on estimates, even though several have found failings in these assumptions (for example, Hart and others 1992; Holm 1989; Schneider 1980; Turner and Berry 1984). Generally, abundance estimators make 3 basic assumptions. First, the population under study must be "closed," both demographically (no births, deaths, immigration, or emigration) and geographically (no edge effect, movement of animals across the plot boundaries). Failure of this assumption leads to overestimates of the true population size due to an inflated ratio of unmarked to marked individuals. Some closed models, such as the Lincoln-Petersen method, may still be valid with either unknown additions to or deletions from the population, but are invalid if both effects occur during the study (Skalski and Robson 1992). Open models allow the relaxation of the demographic closure assumption but still require geographic boundary closure (White and others 1982). Minimizing the sampling period and maximizing the size of the study plot compared to the average movements of the target animals during each sample may satisfy, at least approximately, the geographic closure assumption (Thompson and others 1998). Edge effects result in abundance estimates associated with unknown sample areas or overestimates of density within the plot (Thompson and others 1998), but it is minimized on plots with unsuitable tortoise habitat outside the plot boundaries (for example, Granite Hills). Density estimates may be corrected for minor edge effects with the mean maximum distance moved method of Wilson and Anderson (1985; see below).

Tortoise longevity allows adult ( $\geq 180$  mm MCL) tortoise populations to be considered demographically closed within a given sampling season (Murray 1993). Mortality is low for mature tortoises in healthy populations, and slow growth rates prevent significant recruitment into this size class within a single season. Demographic closure will begin to break down as the number of seasons included in a given analysis increases, for example by using different years as "mark" and "recapture" samples. Most Sonoran Desert tortoise populations may be considered geographically closed due to small annual home ranges (Bailey 1992; Barrett 1990; Martin 1995).

The remaining assumptions are required by both open and closed abundance estimation models. The second and most important assumption requires each animal to have a constant and equal capture probability during each trapping occasion (Otis and others 1978). This assumption may fail due to 3 sources of variation: temporal differences in capturability between sample periods; behavioral responses to capture, such as trap-shyness and trap-happiness; and individual heterogeneity (that is innate differences in capturability between individuals). If heterogeneity is present in the population, individuals with higher capture probabilities will be marked earlier and caught more often than those with low capturability, resulting in an underestimate of the ratio of unmarked to marked individuals and, thus, the true population size (Pollock and others 1990). Similar results occur when animals are trap-happy, while trap-shy animals produce overestimates due to the opposite effect (Pollock and others 1990).

Larger tortoises are easier to find than smaller ones (Shields 1980), so it has been common practice to compute estimates separately for adult and juvenile tortoises. Schneider (1980) provided evidence for unequal capturability for tortoises within size classes, possibly due to differences in home range and activity patterns, but this problem has since received very little attention. Hart (1993) presented preliminary data suggesting differences in capturability between sexes. Individual tortoises may also be differentially subject to capture depending on the complexity of the habitat in their home ranges, especially in topographically diverse areas with varying concentrations of boulders (Murray 1993).

The third primary assumption in estimating animal abundance requires permanent marks which are recorded correctly at each trapping occasion (Otis and others 1978). Failure of this assumption leads to overestimates because of the loss of marks. Notching the marginal scutes results in permanent marks in large tortoises (unless the tortoise is chewed by a predator), but growth of young individuals between recaptures may obscure the notches. Correctly recording identification numbers is simply a matter of working carefully.

Based on this review of assumptions and on computer simulations, Murray (1993) recommended that tortoise abundance on Sonoran Desert plots be calculated by 1 of 2 particular estimators contained in the software package, CAPTURE (Otis and others 1978; White and others 1982). Advantages of CAPTURE estimators include the allowance of temporal or (moderate) individual variation in capture probabilities. Murray and Schwalbe (1997) subsequently tested these recommendations against a population of known size (given certain assumptions) and concluded that the Lincoln-Petersen estimator provided more accurate results. Their application of the Lincoln-Petersen estimator differed from that generally used on tortoise plots in that they systematically searched a 1-km<sup>2</sup> plot 5 times within an overall survey duration similar to that of a standard 1-mi<sup>2</sup> plot. They pooled plot coverages into independent “mark” (first 3 coverages) and “recapture” (last 2 coverages) samples, which minimizes variation in individual capture probabilities. That is, even tortoises that are less likely to be captured during 1 plot coverage may be captured in 2 or more coverages (but still 1 sample), giving tortoises the same weight whether they were captured after 1, 2, or more opportunities (Murray and Schwalbe 1997). This provides a similar benefit to the current method of pooling tortoises within an entire season into either a mark or recapture sample and has the advantage of producing an abundance estimate within a single season. Therefore, violations of the Lincoln-Petersen method’s assumption that the

population is closed are minimized compared to between-year estimates, especially when plot surveys occur in non-consecutive years.

Howland and Klug (1995) investigated the utility of an open population abundance estimator, Program JOLLY (Pollock and others 1990), specifically because of concerns of violating the closure assumption. They found that JOLLY produced estimates similar to standard Lincoln-Petersen estimates but tended to have relatively wide confidence intervals. Abundance estimates from Program JOLLY are less precise, because open models make fewer assumptions about the data (that is population closure). Since more information about animal survival and movement must be gleaned from the data, larger variances result (Thompson and others 1998). Also, JOLLY cannot estimate abundance for the first and last years in a series of surveys. However, JOLLY can be used to estimate survivorship and recruitment (Pollock and others 1990).

*Trends in Abundance.*—A primary objective in a population monitoring program is to detect trends in abundance or density over time. Trend estimation requires multiple surveys, and for a long-lived animal like the desert tortoise, this requires many years to be meaningful. So far, individual tortoise populations in Arizona have been monitored for a relatively short time. However, managers still need to know if any short-term changes in population size have occurred while the long-term data are accumulating. This has typically been done in the past by comparing 95% confidence intervals of point estimates for the first and second surveys of a given tortoise plot. Statistically, this type of comparison does not test whether the population sizes at each time are equal (that is  $N_1 = N_2$ ) or whether they have even changed significantly. This comparison is based on an incorrect assumption that each confidence interval has a 95% chance of including the true population size and that overlapping intervals are thus not significantly different at the 95% confidence level. In fact, each interval indicates only that, on average, 95 out of 100 confidence intervals obtained from similar samples would include the true population size (Sokal and Rohlf 1995). Whether or not two intervals overlap indicates nothing about actual differences in population size.

Testing whether abundance is higher (or lower) between 2 surveys can be tested with proportional abundance estimation. This method estimates the proportion by which population size during the second survey differs from size during the first survey; a confidence interval for this proportion that includes zero indicates that there has been no detectable change in population size (Skalski and Robson 1992). Precision of the proportional abundance estimate, however, is a function of the precision of abundance estimates, which may limit the ability to detect changes between 2 surveys (Murray and Schwalbe 1997).

Current monitoring methods also have little power (ability) to detect trends in tortoise abundance over 3 or more years (Averill-Murray 1999b). Since current abundance estimation uses 1 year as the “mark” sample and the subsequent year as the “recapture” sample, annual estimates are not independent of each other, and temporal variation is underestimated (Averill-Murray 1999b; Murray and Schwalbe 1997). In addition to invalidating the use of proportional abundance estimation, the lack of independent abundance estimates makes trend estimates less reliable (Harris 1986). An important step to improve the power to detect trends is to minimize temporal variation in estimates within plots. By reducing plot size and excluding areas with few to no tortoises, multiple systematic (complete) coverages of the plot may be conducted within a single

survey. This will increase recaptures in the sampled population and produce precise abundance estimates within a single year by providing multiple sample periods within each year (Averill-Murray 1999b; Murray and Schwalbe 1997). This modification would necessarily result in some individual tortoises outside the population “core” (but within the original 1-mi<sup>2</sup> area) not being captured, but it would be offset by increased captures within the “core.” Focused survey efforts such as this can improve the power to detect trends by reducing variation in abundance estimates (Averill-Murray 1999b). The importance of minimizing sampling variation cannot be overstated, because poor precision from an inadequate survey means there will be no power to reject the null hypothesis of no trend, resulting in a default decision of no action (Thompson and others 1998).

A long-term commitment to monitoring tortoise populations is also necessary to detect anything other than a catastrophic population decline (Averill-Murray 1999b). Power to detect trends is negligible if populations are only surveyed 2 or 3 times. With the exception of 1990-94 when 3 plots were surveyed annually, monitoring efforts have been haphazard (Table 1). Several plots have been surveyed across long time intervals or have yet to be resurveyed at all. Inconsistent funding will result in an increased period of time before trend estimation is possible for each plot. Long survey intervals could result in gradual declines over several years not being detected until a significant absolute decline in abundance has already occurred. Catastrophic declines (such as that at the Maricopa Mountains; Shields and others 1990) might not be recognized as such, reducing the ability to identify and correct the cause of the decline (Averill-Murray 1999b).

*Density Estimation.*—Dividing estimated abundance by study plot area to calculate density overestimates true density by as much as 99% by not accounting for “edge effects” of plot boundaries (Wilson and Anderson 1985). Wilson and Anderson (1985) provided an unbiased method of estimating animal density based on mark-recapture methods, and this has been applied to 1 tortoise plot in Arizona (Murray 1993; Murray and Schwalbe 1997).

*Rangewide Inferences.*—It is important to note that the current set of plots (Table 1, Figure 2) does not represent a random sample from the entire range in Arizona, or even within individual land management agencies. Most plots were selected largely on relatively high evidence of tortoise sign and a likelihood of finding tortoises; other criteria included public land ownership, which was not likely to get traded or mined; distribution across the tortoise’s range in Arizona; and relative “representativeness” of an area or habitat type (T. Cordery, pers. comm. 1999). The advantage of this approach was the minimization of effort spent on plots randomly selected with few to no tortoises. A serious disadvantage is the inability to extrapolate results to the entire Sonoran population in Arizona; inferences are limited to the selected plots themselves (Thompson and others 1998).

Four possible scenarios could occur if patterns in population trends on the plots are extrapolated regionally or rangewide. 1) Plot results may indicate a stable or increasing trend in tortoise numbers or survival, and regional populations are also stable to increasing. 2) A negative trend on plots occurs concurrently with a negative regional trend. 3) A negative trend on plots may occur while regional tortoise populations are actual stable or increasing. 4) Tortoise numbers on plots appear to be stable or increasing but are actually declining outside the plots. Scenarios 1 and 2 would generally provide correct information to managers regarding regional tortoise status, but the degree of change may differ within and outside plots. Scenario 3 would indicate that

regional tortoise populations are in worse shape than they really were, possibly leading to more conservative management policies than necessary, rather than site-specific actions appropriate to particular areas containing declining populations. Under scenario 4, regional tortoise populations could suffer large-scale, catastrophic declines before they were observed on the plots.

The wide distribution of plots across the tortoise's distribution could possibly buffer against incorrect inferences as in scenarios 3 and 4, but since the plots were selected based on a perceived chance of finding many tortoises in an area, they may not be representative of tortoise populations at a larger scale. Scenario 3 could result because tortoise populations on the plots are at or near carrying capacity; a negative trend on a plot may be a short-term demographic effect resulting from an inability to pack more tortoises into the population, while surrounding populations may actually be increasing (possibly even partly via emigration from the plot). On the other hand, scenario 4 would result if a plot was placed in the best tortoise habitat in the area and was buffered more strongly against negative impacts occurring to populations elsewhere. Regional populations may be in decline long before recognized. With the current plot set, it is important to at least be alert for potential population impacts or declines in tortoise habitat between individual plots.

## REVISED SONORAN DESERT TORTOISE MONITORING PLOT PROTOCOL

Continued statewide monitoring of desert tortoise populations is important to assess the status of populations within Arizona. Population surveys are necessarily intensive efforts due to the difficulty of finding tortoises, especially within the complex habitats in which they occur in the Sonoran Desert. In many cases, the following protocol closely follows the current methods, but it does address deficiencies identified in those methods in order to maximize the scientific and management value of survey efforts.

Objectives

This protocol has several objectives. Primary objectives deal directly with desert tortoise populations. Secondary objectives capitalize on the time and intensity required to meet the primary objectives. They focus on collecting information that is relatively inexpensive to gather and which has foreseeable application to tortoise research, as well as other biological and environmental research.

*Primary Objectives.*—Primary objectives of the Sonoran Desert Tortoise Monitoring Protocol include the following:

- 1) Estimate trends in population numbers (abundance and density) and survival for individual plots. Ideally, negative annual trends of about 5% would be detectable. Use these trend data in conjunction with observations between plots (for example, through AGFD's scientific collecting permit process) to assess tortoise status throughout the Sonoran Desert in Arizona.
- 2) Estimate plot-specific life history and demographic parameters, including annual growth rates, sex ratio, and size distribution.
- 3) Collect data necessary to investigate relationships between tortoise abundance/density with number and density of burrows. Determine spatial and temporal patterns of burrow use, within and between individual tortoises.
- 4) Collect other natural history data, including diet, frequency of morphological anomalies, aspects of health and trauma, and factors contributing to mortality (human or natural).

*Secondary Objectives.*—*Secondary objectives of this protocol are to:*

- 1) Quantify changes in vegetation structure and composition.
- 2) Collect data and monitor long-term trends on other diurnal species, including richness, diversity, and relative abundance.

### Plot Configuration and Coverage

*Plot Configuration.*—New study plots should be configured and surveyed similarly to current standard methods on 1-square-mile areas. Surveys of square-mile plots will allow researchers to determine and map tortoise distribution in the general area. This information can then be used to modify plot configuration for more efficient future surveys. Boundaries for subsequent surveys of a plot should be drawn to include as many tortoises as possible within approximately 1 square km. However, the actual area of the plot is less important than a configuration that contains tortoises distributed throughout the plot and that can be completely surveyed 4 to 6 times (see *Plot coverage*, below).

Plot configuration need not be square but should be shaped to best fit presumed tortoise habitat (for new plots) or observed tortoise distribution (for existing plots) in the chosen area (for example, the Granite Hills). A low perimeter/area ratio is best for plots susceptible to edge effect (that is plots with contiguous habitat outside plot boundaries; Thompson and others 1998). A 0.1-mi<sup>2</sup> grid will be overlaid on the topographic map for geographic reference. Grid cells will be numbered according to their position within USGS sections, with the northwest cell of a section numbered 00, the northeast cell numbered 09, the southwest cell numbered 90, and the southeast cell numbered 99. The English measurement system is recommended for ease of adaptation to most USGS maps. A 0.1-km<sup>2</sup> grid may be used in areas mapped with kilometer intervals, such as some Department of Defense lands. Plot area for irregularly shaped plots can be determined by counting the number of cells within their defined boundaries (Figure 3). Grid numbering systems different than this standard on existing plots should generally be retained on those plots to eliminate confusion when comparing location information between surveys (if specific within-cell location information was previously recorded). Plot corners and prominent landmarks should be recorded with a global positioning system (GPS) and post-processed (corrected) for accuracy, if necessary.

|    |    |    |    |    |    |    |
|----|----|----|----|----|----|----|
|    |    |    | 69 | 60 | 61 | 62 |
|    |    | 78 | 79 | 70 | 71 | 72 |
|    | 87 | 88 | 89 | 80 | 81 | 82 |
| 96 | 97 | 98 | 99 | 90 | 91 | 92 |
| 06 | 07 | 08 | 09 | 00 | 01 | 02 |
| 16 | 17 | 18 | 19 | 10 | 11 | 12 |

Figure 3. Grid numbering system for a hypothetical, irregularly-shaped monitoring plot. The diagram shows a 1-square-km plot (solid outline, 36 grid cells \* 0.01 square mi = 0.36 square mi ≈ 1 sq. km) overlapping 4 USGS sections, the boundaries of which are denoted by bold lines. Inclusion of the areas inside the dashed line (1/2 each of grid cells 68, 77, and 86) would make the total plot area 0.375 square mi.

*Plot Coverage.*—To the maximum extent practicable, new (1-square-mi) plots should be surveyed during the summer monsoon season with 2 complete and independent coverages to allow population size estimation (see below) and an unbiased evaluation of tortoise distribution within the plot. Existing plots (reconfigured to approximately 1-square-km) will be surveyed

during the monsoon season with a minimum of 4 and maximum of 6 complete, independent coverages; the actual number of coverages will be determined by plot size, topography, and complexity (Table 2). In general, total field effort on both new and existing plots will consist of 60 person days during no fewer than 30 calendar days per survey, with field personnel working in teams of 2. However, 4 coverages of plots with relatively simple (not necessarily flat) topography with highly localized populations, such as the Eagletails plot, may be performed in 40 person days (4 separate plot coverages of 10 days each) but including no fewer than 20 calendar days (Table 2). A calendar day is an actual day spent in the field (>4 hours); a person day equals 8 hours of field effort. A 60-person-day survey over 44-45 calendar days is also acceptable (Table 2), but extra caution must be exercised when working alone.

Table 2. Numbers of plot coverages possible with varying amounts of search effort per coverage. Person day/calendar day ratios > 2:1 (indicated with italics) require at least some days on the plot by a single field worker.

| Plot size | No. coverages | Coverage duration |               | Total survey duration |               |
|-----------|---------------|-------------------|---------------|-----------------------|---------------|
|           |               | Person days       | Calendar days | Person days           | Calendar days |
| 1 sq. mi  | 2             | 30                | 15            | 60                    | 30            |
|           |               | <i>30</i>         | <i>22.5</i>   | <i>60</i>             | <i>45</i>     |
| ~1 sq. km | 4             | 15                | 7.5           | 60                    | 30            |
|           |               | <i>15</i>         | <i>11</i>     | <i>60</i>             | <i>44</i>     |
| ~1 sq. km | 5             | 12                | 6             | 60                    | 30            |
|           |               | <i>12</i>         | <i>9</i>      | <i>60</i>             | <i>45</i>     |
| ~1 sq. km | 6             | 10                | 5             | 60                    | 30            |
|           |               | <i>10</i>         | <i>7.5</i>    | <i>60</i>             | <i>45</i>     |
| <1 sq. km | 4             | 10                | 5             | 40                    | 20            |

Initiation of surveys should coincide with the beginning of the monsoon season, if possible, but should occur by no later than mid-August and should conclude by the end of September to early October. All accessible areas of the plot should be searched with non-linear transects determined by topography and vegetation. Areas searched each day should be mapped to ensure even, thorough plot coverages. Burrows may be flagged and rechecked during subsequent coverages. However, search effort should be distributed evenly across the plot, approaching 100% as nearly as possible; “high grading” is not acceptable. Daily search effort should be concentrated during times of the day when temperatures are <40 C. During the heat of summer this will result in split effort between morning and evening hours, but as temperatures cool during the fall, search effort may occur throughout the day.

#### Field Data

Field notes (Appendix 1) should include field personnel; search and processing times; tortoise encounters; carcasses found; weather data, including temperatures 1 cm and 1.5 m above ground at 0800h, 1200h, and 1600h and daily rainfall; and a map and general description of areas searched each day. Potential tortoise predators, human activity and impacts, other disturbances and impacts, and other wildlife should also be recorded. Locations of tortoises, carcasses, vegetation transects, impacts, and other significant observations should be indicated on the map.

Wildlife notes should include a simple list of amphibian, reptile, and mammal species seen each day; a bird list for the entire season's survey is also desirable. The number of days each species is observed during the plot survey provides an index of relative abundance. Recording these additional wildlife data increases the value of the survey effort beyond desert tortoises, by providing important status information on "common" species, with little to no additional time or expense. Dodd and Franz (1993) point out the need for such information due to general emphasis only on commercially important or threatened species, inconsistent definitions of commonness, and a lack of historical population data leading to subjective evaluations of abundance. Even though index information will only provide a rough guess at population trends (Thompson and others 1998), as each plot is repeatedly surveyed over time, it may be possible to detect gross changes in relative abundance for some species that normally would not have received any attention and provide an opportunity to further investigate the magnitude and cause of the change. These data provide "free" species inventories, at least for diurnal species, and baseline data for vertebrate communities. However, emphasis should remain on searching for tortoises, with other wildlife noted opportunistically; for example, excess time spent "birding" could seriously compromise tortoise capture results because of differences in search strategies.

*Live Tortoises.*—Field workers should handle all tortoises with a clean pair of disposable latex gloves, and any instruments coming into contact with a tortoise should be disinfected with bleach or a veterinary disinfectant, such as Nolvasan<sup>®</sup>. Nolvasan<sup>®</sup> is less corrosive to equipment than bleach and does not irritate human skin. Each tortoise will be categorized by capture type (CT): CT-1 includes the first encounter of a tortoise (that is when the tortoise was first marked); CT-2, a subsequent capture of a tortoise previously found during the current survey; and CT-3, the first encounter during the current survey of a tortoise marked during any previous survey. The sum of CT-1 and CT-3 equals the total number of individual tortoises found during a survey, less any unidentified tortoises (for example, could not be extracted from burrow). The sum of CT-1, CT-2, and CT-3 equals the total number of tortoise encounters during a survey, less any unidentified tortoises.

Field workers will complete a data sheet (Appendix 2) for every tortoise encounter. The specific data sheet included in Appendix 2 (or other copy available from AGFD) should be used in order to facilitate data entry into the statewide desert tortoise database maintained by AGFD. This data sheet includes the following information: capture type; location (grid cell); shaded-bulb temperatures 1 cm and 1.5 m above ground and 0.5 m inside the burrow, if applicable; activity and social interactions; foods eaten; estimated volume, color, and viscosity of voided urine; and the beginning and end times for the process. When a tortoise is found inside a shelter, sheltersite type (for example, soil burrow, rock burrow, rock overhang, boulder pile, pallet, etc.), cover type (for example, soil, boulder, shrub, etc.), depth (rear of shelter to edge of roof, as closely as possible), orientation of slope and burrow entrance (facing away from the slope or burrow), and identification number (pre-stamped aluminum tag attached to sheltersite structure) should be recorded. These data should only be recorded for burrows with tortoises actually inside, exiting, or entering; they need not be repeated on subsequent observations of the same burrow during the same survey. If possible, the location of each tortoise (and burrow) should also be recorded with a GPS receiver. The rover file name should be written on the data sheet for cross reference when the location data are corrected for accuracy. At that time, UTM coordinates should be entered on

the data sheet; if a real-time corrected GPS receiver is used, record UTM coordinates directly on the data sheet in the field.

Each tortoise should be visually inspected for injuries, morphological anomalies, ectoparasites, and symptoms of cutaneous dyskeratosis and upper respiratory tract disease (URTD). Symptoms of cutaneous dyskeratosis include gray-white, dry, roughened, and flaky scutes (Jacobson and others 1994). Cutaneous dyskeratosis usually affects the plastron but may also occur on the carapace or limb scales. On the shell, the lesions usually begin at the seams and spread toward the middle of the scutes as the condition progresses. Clinical symptoms of URTD include serous discharge flowing or bubbling from the nares and may also be found on the forelimbs when infected tortoises wipe their faces; swollen eyes, eyelids, and conjunctiva; and listless behavior (Jacobson and others 1991; University of Florida, undated pamphlet).

Morphometric data recorded for each tortoise should generally be limited to MCL (nearest mm); even this is unnecessary for CT-2 tortoises. Each tortoise should be assigned a unique identification number and its marginal scutes notched accordingly (Appendix 3). Bridge marginals should not be notched on tortoises <120 mm MCL. The identification number should also be written with black ink on a small dot of correction fluid on the right fourth costal scute and covered with clear epoxy. Notches and epoxied numbers may require touching up for CT-3 tortoises. Gender should be recorded for tortoises  $\geq$ 180 mm MCL. Close-up photographs (slides) should be taken of the full carapace, full plastron, and left fourth costal; a label indicating study plot, date, and tortoise number, should be included in each photograph.

Several procedures should be implemented to minimize risk of tortoises voiding their bladders. Recording morphometric data, including weights, other than MCL is discouraged (unless for a specific research objective) in order to minimize the handling and processing time of each tortoise. Files should be replaced after marking no more than 10 tortoises (or 10 uses/edge of triangular files) to ensure that only sharp files are used; a system of tracking file use should be implemented, such as making tick marks on the file with a marker after each use. Plastron photographs should be taken as quickly as possible, and tortoises should be handled carefully at all times. To further minimize the risk of tortoises voiding their bladders, CT-2 tortoises should not be handled at all except to verify their identification number, if necessary, especially if the tortoise is in a burrow and its epoxied number is visible. If a tortoise does void its bladder, the processing activity at the time of voiding should be recorded on the data sheet.

*Carcasses.*—Carcasses of marked tortoises will be classified as CT-5. Field workers should photograph all carcasses *in situ* (2-3 photos showing general location and a close-up of the carcass, each with a label indicating study plot, date, carcass number, and live tortoise number [if applicable]) and fill out a data sheet (Appendix 4). Data recorded should include shell position and percent daylight hours exposed to sun; location, as with live tortoises, including GPS location, if possible; sex, MCL, and identifying marks, when possible; and notes on signs of cause of death. Time since death should be estimated based on Berry and Woodman's (1984b) key (Appendix 5).

A large collection of tortoise carcasses has been accumulated from tortoise surveys through the present. However, no specific use has been identified for these carcasses, and storage space is in

short supply. Therefore, until a specific need is identified, only a representative sample of carcasses from each survey will be stored, unless there is a particular interest in analyzing all carcasses from a survey. Excess carcasses could potentially be given to Native American tribes for cultural uses, donated to educational displays, or discarded.

*Vegetation.*—Vegetation should be sampled on each plot along 5 100-m line transects, stratified among different vegetation associations (determined by visual estimation). Previous transects should be used as much as possible on existing plots, depending on potential plot reconfiguration. Endpoints of each transect should be marked with re-bar and their locations recorded and mapped with a GPS. All perennial vegetation crossing the line should be identified to species and lengths of any part of each plant overlapping the line measured to the nearest cm. Totals for each species will be summed to determine cover and divided by the sum of all species to determine relative cover. Summer annual vegetation should be sampled with 20 x 50 cm Daubenmire plots at 10-m intervals along the transect. Cover of live annuals will be estimated by counting the number of square-cm grid cells each species (or lowest taxonomic category possible) occupies and dividing by the total number of grid cells on the transect (10,000 [1000 square cm x 10 plots per transect]). Dead spring annuals should be noted but need not be quantified.

#### Data Analysis and Reporting

Original or photocopied data sheets and field notes will be archived by AGFD, depending on whether the specific funding agency requests the originals. All data will be incorporated into AGFD's statewide desert tortoise data base. Preferably, field workers would enter the data into computerized Microsoft Access<sup>®</sup> forms based on the data sheet in Appendix 1; each database could then be appended to the statewide database. A skeleton copy of the database, including data entry forms, is available from AGFD for ease of standardization. Slides will be archived by AGFD, unless the specific funding agency prefers otherwise.

Annual survey reports should contain, at a minimum, the following sections: table of contents, list of tables, list of figures, summary, introduction, methods, separate results from each plot surveyed, and appendices. Separate conclusions and recommendations may also be added, and comparison with previous surveys of the same plot is also desirable. The plot results sections and appendices should contain at least the following information, with data analyzed as indicated.

*Plot Description.*—Include descriptions of the plot topography, geology, vegetation (in general, as well as sampling results), and any human impacts. These topics may be reduced for previously-surveyed plots. Also discuss weather during the survey, including rainfall measured. Describe the coverage history, including previous plot configurations.

*Population Parameters.*—Abundance/density, sex ratios, and size distributions should be reported as follows.

*Abundance and Density.*—Numbers of each capture type should be tabulated separately for tortoises <180 mm and  $\geq$ 180 mm MCL; for comparison, include data from all previous surveys in separate columns. Numbers of each capture type for the current survey should also be graphically presented in a histogram or bar graph by sample period (that is plot coverage).

Abundance of tortoises  $\geq 180$  mm MCL should be estimated with the Lincoln-Petersen estimator (see Pollock and others 1990), using capture data pooled from the first 3 plot coverages (2, for plots with localized populations and on which only 4 coverages are completed) as the “mark” sample. Data pooled from the remaining coverages will comprise the “recapture” sample. For example, for a plot surveyed with 5 complete coverages, all tortoises captured 1 or more time during the first 3 coverages will make up the “mark” sample. All tortoises captured 1 or more times during the last 2 coverages will make up the “recapture” sample, with those tortoises captured at least once during the first 3 coverages *and* at least once during the last 2 coverages representing the recaptures. Individuals will only be counted once in each sample, regardless of the actual number of times found.

Density, if estimated, should be calculated with the following modification of Wilson and Anderson’s (1985) mean maximum distance moved (MMDM) method. With this method, the estimated maximum (straight-line) distance moved between successive recaptures for each individual is estimated from the mapped capture locations. For example, a tortoise that was captured twice will have 1 estimated distance moved, the simple straight-line distance between its 2 capture points, and this would be its maximum distance moved. A tortoise captured 3 times will have 2 estimated distances moved; the largest of these 2 would be its maximum distance moved. Individual movement data should be tabulated in the report. The mean of all the maximum distances moved is calculated (=MMDM), and a boundary strip area equal to  $\frac{1}{2}$  the MMDM is added to the mapped study plot boundaries across which tortoise habitat continues (that is boundary strips are not added alongside unsuitable habitat, such as creosotebush flats). The boundary strip corrects for edge effects of tortoise home ranges overlapping artificial plot boundaries. The area of the study plot plus added boundary strips estimates the effective area sampled. Density is then calculated by dividing the abundance (estimated with the Lincoln-Peterson method) by the effective sample area. Variance of the density and confidence intervals can be calculated for plots with a complete boundary strip with Wilson and Anderson’s equations.

*Sex Ratio and Size Distributions.*—Report the sex ratio of tortoises  $\geq 180$  mm MCL and compare to 1:1 with a Chi-square or log-likelihood ratio test. Size distributions should be tabulated in 10-mm increments and graphically presented in a size histogram (for example, Appendix 6). Size distributions should indicate the number of sample periods ( $>1$ ) in which each tortoise was captured, tortoises captured off-plot (for example, with circles), and mortalities of marked tortoises during the survey (for example, with triangles).

*Other Sections.*—Notes on mortality, reproduction, individual growth between surveys, morphological anomalies, health and trauma, potential predators and other vertebrates observed on the plot, behavior (especially foraging observations and social interactions), and problems encountered during the survey (for example, numbering problems, missing slides, missing vegetation transect markers, etc.) should also be included in the report. Carcasses found on the plot should be tabulated according to estimated time since death (Berry and Woodman 1984b; Appendix 5). Other data should be tabulated or presented graphically, as appropriate. Patterns of tortoise distribution within the plot should be described, especially for initial surveys of square-mile plots.

*Appendices.*— Separate appendices in plot reports should contain sample data sheets, including live tortoise, carcass, and field notes forms; abundance and density calculations; the marking system used on the plot; maps, including live tortoise distribution (separated by sex for high-density populations), carcass locations, numbered burrows, vegetation transects and notable landmarks, and human impacts; a plant list and vegetation sampling raw data; tabulated burrow data, including identification numbers of the burrow and tortoise, tortoise sex, and date of each tortoise observation in a burrow, plus the cover type and burrow depth (measured in cm); a complete master list of all tortoise encounters on all surveys of the plot, also minimally including sex, capture dates, capture types, plot grid cells, and MCL; tabulated work effort, including date, field worker, grid cells searched, time, and tortoises and carcasses found; and a daily vertebrate inventory.

#### Monitoring Trends in Abundance and Survival

A consistent schedule is needed to obtain the most useful trend estimates for each tortoise population monitored. The monitoring program should include plots from populations across the tortoise's distribution in Arizona. Most plots should be surveyed on a consistent 4-year rotation. For example, a set of 16 plots could be surveyed with a 4 plot/year rotation. Additional plots should be surveyed opportunistically as funding allows, serving as “check-ups” within the intervening tortoise distribution between regularly surveyed plots.

Trends in population size should be estimated for plots with 3 or more independent abundance estimates with linear regression after  $\log_e$ -transforming the data. Significant trends will be determined as those regression slopes whose 95% confidence interval do not include zero. If the regression assumption of normally distributed random errors is not met, randomization or nonparametric methods may be used (Thompson and others 1998). The fact that little power exists to detect a trend based on a small number of samples should not be overlooked (Averill-Murray 1999b). Survival can be estimated with Program MARK (White 1999) with which models can be developed and tested to detect differences between groups or survey intervals and trends over time.

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Appendix 1. Sample Field Notes Form (adapted from Woodman and others 1997)

Date: \_\_\_\_\_

Desert Tortoise Monitoring Plot Field Notes

\_\_\_\_\_ Plot; Township \_\_\_\_\_, Range \_\_\_\_\_, Section(s) \_\_\_\_\_  
 \_\_\_\_\_ County, Arizona; Agency: \_\_\_\_\_

|                     |  |
|---------------------|--|
| Start/Finish times: |  |
| CT-1:               |  |
| CT-2:               |  |
| CT-3:               |  |
| CT-5/other shells:  |  |

|                   |  |  |  |        |
|-------------------|--|--|--|--------|
| Fieldworker:      |  |  |  | TOTALS |
| Total field time: |  |  |  |        |
| Processing time:  |  |  |  |        |

| Time  | T <sub>1.5m</sub> (deg. C) | T <sub>1cm</sub> (deg. C) | Cloud cover (%) | Rainfall (mm) <sup>a</sup> |
|-------|----------------------------|---------------------------|-----------------|----------------------------|
| 0800h |                            |                           |                 |                            |
| 1200h |                            |                           |                 |                            |
| 1600h |                            |                           |                 |                            |

Scanned topographic map of plot with grid overlay.

<sup>a</sup>Record rainfall in morning and evening. Report when last checked, if not on previous day.



Appendix 2. Desert Tortoise Data Sheet (adapted from Woodman and others 1997)

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# Data Sheet and Health Form for Desert Tortoises

Township \_\_\_\_\_, Range \_\_\_\_\_; \_\_\_\_\_ County, Arizona

Site \_\_\_\_\_  
 Section \_\_\_\_\_  
 Grid # \_\_\_\_\_  Off plot  
 Rover file \_\_\_\_\_  
 UTM (northing) \_\_\_\_\_  
 UTM (easting) \_\_\_\_\_  
 Coverage # \_\_\_\_\_  
 Fieldworker(s) \_\_\_\_\_

Date (mm/dd/yy) \_\_\_\_\_  
 Start time (MST) \_\_\_\_\_  
 End time (MST) \_\_\_\_\_  
 Last precip. \_\_\_\_\_  
 Temps (°C):  
 1.5 m \_\_\_\_\_ 1 cm \_\_\_\_\_  
 Aspect \_\_\_\_\_

ID# \_\_\_\_\_  
 Sex \_\_\_\_\_  
 CT  1  2  3  5  
 MCL (mm) \_\_\_\_\_  
 Epoxy number present  
 New growth present  
 Photo: Roll \_\_\_ Frames \_\_\_\_\_

**Behavior:**

- |  |                                   |                                   |
|--|-----------------------------------|-----------------------------------|
| <input type="checkbox"/> Inside shelter      | <input type="checkbox"/> Basking  | <input type="checkbox"/> Drinking |
| <input type="checkbox"/> At shelter entrance | <input type="checkbox"/> Combat   | <input type="checkbox"/> Foraging |
| <input type="checkbox"/> In open             | <input type="checkbox"/> Courting | <input type="checkbox"/> Walking  |
| Other tortoises _____                        | <input type="checkbox"/> Other    |                                   |
- Describe \_\_\_\_\_

**Coversite type:**

- Burrow  
 Pallet  
 Caliche cave  
 Rock shelter  
 Unmod. shrub

**Burrow data:**

Number \_\_\_\_\_  
 Depth \_\_\_\_\_  
 Orientation \_\_\_\_\_  
 Temp. at 0.5 m \_\_\_\_\_  
 Notes \_\_\_\_\_

**Beak & Nares:**

- |  |  |
|--|--|
| <input type="checkbox"/> Not seen            | <input type="checkbox"/> *Naris(es) occluded |
| <input type="checkbox"/> *Beak/nose wet      | <input type="checkbox"/> *Dirt on nose/beak  |
| <input type="checkbox"/> *Nasal exudate      | <input type="checkbox"/> *Other              |
| <input type="checkbox"/> *Bubbles from nares |  |

**Breathing:**

- |                                    |  |
|------------------------------------|--|
| <input type="checkbox"/> Not heard | <input type="checkbox"/> *Rasping/clicking |
| <input type="checkbox"/> *Wheezing | <input type="checkbox"/> *Other            |

**Eyes:**

- |   |                                  |
|---|----------------------------------|
| <input type="checkbox"/> Not seen       | <input type="checkbox"/> *Sunken |
| <input type="checkbox"/> *Swollen/puffy | <input type="checkbox"/> *Other  |

**Behavior:**

- Alert, responsive  
 \*Lethargic  
 \*Other

**Posture:**

- Can withdraw tightly into shell  
 \*Limbs, head hanging loose  
 \*Other

**Urine:**

Volume \_\_\_\_\_  
 Color \_\_\_\_\_  
 Particulates \_\_\_\_\_  
 Process \_\_\_\_\_

**Shell disease:**

- \*Lesions  
 \*Other

**Anomalies:**

- \*Scute numbering anomalies  
 \*Extra flakes  
 \*Other

**Legend for diagram**

)))

Shell lesions

Draw epoxied #, notches, oulars, anomalies, injuries, parasites, shell

**Evidence of trauma:** \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**Notes:** \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Live Tortoise Data Sheet Instructions

**Site:** site name  
**Section:** USGS Section  
**Grid:** plot grid cell number number  
(specify NW, NE, SW, or SE ¼ of grid cell)  
**Off plot:** check, if found off plot  
**Rover file:** GPS filename  
**UTMs:** corrected UTM coordinates  
**Coverage #:** plot coverage no. (1-6)  
**Fieldworker(s):** list

**Date:** mm/dd/yy  
**Start time:** found tortoise  
**End time:** left tortoise  
**Last precip.:** day of last rain  
**Temps, 1.5 m & 1 cm:**  
shaded-bulb temps above ground  
**Aspect:** compass orientation of slope

**ID#:** tortoise ID  
**Sex:** male, female, unknown (<180 mm)  
**CT:** capture type, check (1=new tortoise, 2=recapture during current year, 3=recapture from previous year, 5=marked carcass)  
**MCL:** straight midline carapace length  
**Epoxy number:** check, if present  
**New growth:** check, if detected  
**Photo:** reference roll and frame nos.

---

**Behavior:** check all boxes that apply and describe  
-Tortoises "At shelter entrance" may be inside or outside.  
-"Courting" includes mating.  
-Be sure to check the "Other" box and note behaviors not listed.  
**Other tortoises:** list sex and ID of other tortoises

**Coversite type:** check most appropriate box (\*\*requires numbered burrow tag)  
**\*\*Burrow:** at least partial soil excavation, ≥ tortoise length  
**Pallet:** partial excavation or scrape, < tortoise length  
**\*\*Caliche cave:** eroded cave in wash bank  
**\*\*Rock shelter:** not modified by tortoise, e.g., crevice, boulder pile  
**Unmod. shrub:** plant cover without excavation or scraping

**Burrow data:** record, if tagged  
**Number:** ID number attached to coversite  
**Depth:** depth of coversite (cm)  
**Orientation:** compass direction of entrance  
**Temp.:** temperature 0.5 m inside coversite  
**Notes:** other pertinent information

---

**IMPORTANT:** Any entry in a field marked with an asterisk\* requires description under notes and, if applicable, should be indicated on the shell diagram

**Beak & Nares:** check appropriate box(es)

**Breathing:** check most appropriate box

**Eyes:** check most appropriate box

**Behavior:** check most appropriate box

**Posture:** check most appropriate box

**Urine:**

**Volume:** estimate volume voided (ml)

**Color:** describe

**Particulates:** describe

**Process:** processing activity when voiding occurred

**Shell disease:**

**Lesions:** check, if present

**Other:** describe, if present

**Anomalies:**

**Scute numbering anomalies:** check, if fewer than normal number of scutes present or if extra scutes (with identifiable growth rings) present; see shell diagram

**Extra flakes:** check, if extra keratinaceous growths (lacking identifiable growth rings) present

**Other:** describe, if present

**Shell diagram:** draw epoxied number, shell notches, gular scutes, anomalies, injuries, parasites, shell lesions, etc. Use symbols indicated in legend to illustrate shell lesions and trauma.

The normal number carapace scutes is:

5 vertebrals down the back;

4 costals on each side, adjacent to the vertebrals;

11 marginals on each side;

1 nuchal above the head; and

1 pygal above the tail.

The plastron normally has the following series of paired scutes, from front to back: gulars, humerals, pectorals, abdominals, femorals, and anals.

**Evidence of trauma:** describe

**Notes:** Specifically, record descriptions of any health abnormalities checked (fields marked with an asterisk). Record any behavioral, feeding, or burrow notes that do not fit in the spaces provided and any other notes of interest.

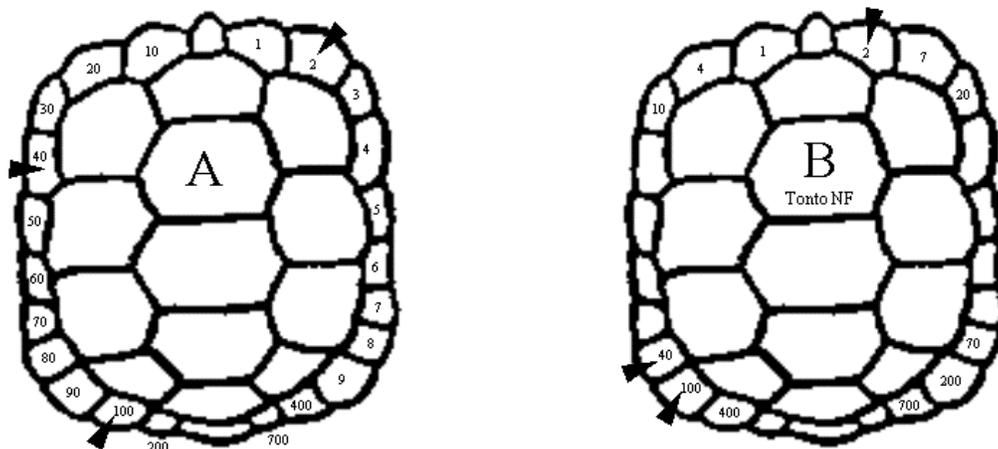
## Appendix 3. Marking Desert Tortoises (adapted from Woodman and others 1997)

Tortoises can be given long-term identification numbers by marking the marginal scutes of the carapace. Notches are made with triangular files of various sizes on all sizes of tortoises. Larger tortoises require larger files. Fingernail or toenail clippers or small scissors can be used on hatchlings and very small juveniles.

Before notching a tortoise, field workers should carefully examine the tortoise to make sure it has not already been notched. Old notches may be very shallow, almost like chips. Some notches may have been destroyed by chewing of predators. *If necessary, renotch and deepen existing notches using the method described below.* Remember that these tortoises may not be recaptured for 3 to 10 or more years!

As described below, notch depth should vary with the size of the tortoise and location on the carapace. Depth may vary from three to four mm on a hatchling to 15-20 mm on a large tortoise with flared marginals. If the tortoise is very small, the field worker should select an identification number (out of sequence, if necessary) that allows notching of anterior and posterior marginals only, not the bridge (the shell connecting carapace and plastron). Notches should be deeper on the anterior and posterior marginals than on the bridge, because these scutes are more vulnerable to wear and chewing by predators, and because the bone is farther from the marginal edge – especially in younger tortoises. Notches on the bridge may touch the bone, and in many cases the bone should be exposed to make an adequate mark, but the bone itself should not be notched. Generally, there will be no bleeding, unless the notches pass through bony tissue. If notches are cut too deep on the bridge and bone is damaged, the tortoise may eventually shed the scute. Notches on the bridge can be 12-20 mm in length on larger tortoises.

Notching System A should be used for most plots in Arizona's Sonoran Desert. Notching System B has been established on the Tonto National Forest and should be used there. Both numbering systems begin at the anterior end of the tortoise to avoid confusion with individuals having more than 11 marginals on either side. Both diagrams indicate tortoises marked #142. REMEMBER: MAKE NOTCHES AS CLEARLY AS POSSIBLE. DON'T MAKE SHALLOW NOTCHES.



Appendix 4. Desert Tortoise Carcass Data Sheet

## Desert Tortoise Shell and Skeletal Remains

Township \_\_\_\_\_, Range \_\_\_\_\_; \_\_\_\_\_ County, Arizona

Site \_\_\_\_\_  
 Section \_\_\_\_\_ Grid # \_\_\_\_\_  Off plot  
 Roverfile/UTMs \_\_\_\_\_  
 Date (mm/dd/yy) \_\_\_\_\_  
 Fieldworker(s) \_\_\_\_\_

Carcass # \_\_\_\_\_ Live tortoise # \_\_\_\_\_  
 MCL (mm) \_\_\_\_\_  Measured  Estimated  
 Time since death (TSD):  
 <1 yr  1-2 yrs  2-4 yrs  >4 yrs  
 TSD key progression: \_\_\_\_\_

### Location of remains (describe in notes):

- Open
- Under shrub
- In wash
- Partially buried
- Buried
- At tortoise coversite
- At predator site

### Position of remains:

- Upright
- Overturned
- Disarticulated

Exposure to Sun (%) \_\_\_\_\_

### Evidence of disease or causes of death:

- |  |          |
|--|----------|
|  | Describe |
| <input type="checkbox"/> Puncture wounds – teeth   | _____    |
| <input type="checkbox"/> Puncture wounds – beak    | _____    |
| <input type="checkbox"/> Chew/gnaw marks           | _____    |
| <input type="checkbox"/> Remains scattered*        | _____    |
| <input type="checkbox"/> Predator site             | _____    |
| <input type="checkbox"/> Predator tracks/sign      | _____    |
| <input type="checkbox"/> Livestock tracks/sign     | _____    |
| <input type="checkbox"/> Vehicle tracks/trail/road | _____    |
| <input type="checkbox"/> Gunshot (targets/shells)  | _____    |
| <input type="checkbox"/> Other                     | _____    |

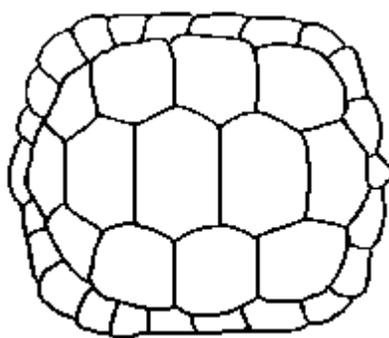
\*State distances and location

Evidence of scavenging: \_\_\_\_\_

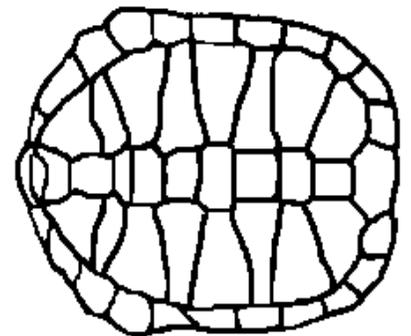
Notes: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

| Parts present:         | partial                  | entire                   | none                     |
|------------------------|--------------------------|--------------------------|--------------------------|
| Head                   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Left foreleg           | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Right foreleg          | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Left hindleg           | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Right hindleg          | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Pectoral girdle        | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Pelvic girdle          | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| % scutes present _____ |                          |                          |                          |
| % bones present _____  |                          |                          |                          |

### Diagram of existing shell and bones

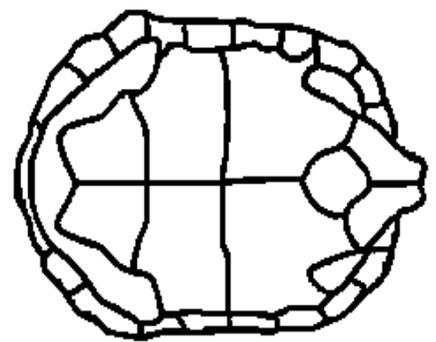
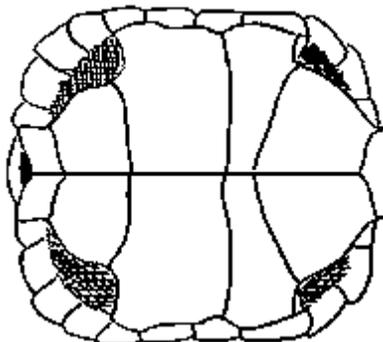


Scutes



Bones

- Legend**
- Pieces present & intact
  - Pieces present but not intact
  - Predator chew marks
  - Not present



### Tortoise Carcass Data Sheet Instructions

**Site:** site name

**Section:** USGS Section

**Grid:** plot grid cell number (specify NW, NE, SW, or SE ¼ of grid cell)

**Off plot:** check, if found off plot

**Rover file/UTMs:** GPS filename or corrected UTM coordinates

**Date**

**Fieldworker(s):** list

**Carcass #:** Carcass ID (year-sequential #; e.g., 2000-01)

**Live tortoise #:** ID of live tortoise, if applicable

**MCL:** straight midline carapace length; check if measured directly or estimated (to nearest 50 mm)

**Time since death:** check appropriate box based on key

**TSD key progression:** list key pathway leading to estimate recorded for time since death

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**Location of remains:** check all appropriate boxes; describe in Notes

**Position of remains:** check most appropriate box

**Exposure to sun (%):** estimate maximum daily exposure to sun

**Evidence of disease or causes of death:** check all appropriate boxes and describe

**Evidence of scavenging:** describe

**Notes:** Specifically, record description of the carcass location. Record any notes that do not fit in the spaces provided and any other notes of interest.

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**Parts present:** check most appropriate box for each line; estimate percentage of scutes and bones present to nearest 10%

**Shell diagrams:** use symbols indicated in legend to indicate individual scutes and bones present and predator chew marks; also note other identifying features

Appendix 5. Key for Estimating Time Since Death for Shell-Skeletal Remains (adapted from Berry and Woodman 1984a, 1984b, and Woodman and Berry 1984)

|   |           |
|---|-----------|
| A) Shell $\leq$ 50 mm MCL .....   | B         |
| B) Scutes may be fading slightly, and/or bone may be slightly porous with <75% bone surface pitted .....          | <1 year   |
| BB) Scutes more weathered than above; bone, if still present, extremely porous with >75% bone surface pitted..... | C         |
| C) Scutes faded, curling, may be breaking.....  | 1-2 years |
| CC) Scutes breaking apart, very faded, curled; growth rings peeling and cracking .....                            | >2 years  |
| AA) Shell >50 mm MCL .....  | D         |
| D) Shell 51-120 mm MCL .....  | E         |
| E) Scutes not fading, and/or bone solid.....  | <1 year   |
| EE) Scutes and/or bone more weathered than above .....  | F         |
| F) Scutes fading, growth rings beginning to peel, and/or bone solid or slightly porous.....                       | 1-2 years |
| FF) Scutes faded; growth rings peeling, cracking, and brittle; and/or bone slightly to extremely porous.....      | G         |
| G) Scutes faded, usually curling; growth rings peeling and cracking; <75% bone porous.....                        | 2-4 years |
| GG) Scutes very faded, curling, usually breaking, and/or bone extremely porous ( $\geq$ 75%).....                 | >4 years  |
| DD) Shell >120 mm MCL .....   | H         |
| H) Scutes not faded, and/or bone solid .....  | <1 year   |
| HH) Scutes and/or bone more weathered than above .....  | I         |
| I) Scutes of both the plastron and carapace faded.....  | J         |
| J) Shell worn with depressed scutes.....  | K         |

- K) Very slight peeling or cracking of growth rings,  
and/or bone solid ..... 1-2 years
- KK) Scutes and bone more weathered than above.....L
- L) Some peeling and cracking of growth  
rings on scutes, and/or bone solid ..... 2-4 years
- LL) Growth rings peeling and cracking,  
and/or bone peeling, cracking, or showing  
mosaic cracking.....>4 years
- JJ) Scutes on shell not depressed.....M
- M) Growth rings not peeling or cracking, and/or  
bone solid ..... 1-2 years
- MM) Scutes and/or bones more weathered than  
above ..... N
- N) Growth rings beginning to crack and peel  
on scutes, and/or bone solid ..... 2-4 years
- NN) Growth rings peeling and cracking on  
scutes, and /or bone peeling, cracking, or  
showing mosaic cracking  
.....>4 years
- II) Scutes of either the plastron or the carapace faded, but not both..... O
- O) Shell worn with depressed scutes .....P
- P) Some peeling and cracking of growth rings,  
usually on the vertebrales, and/or bone solid  
..... 1-2 years
- PP) Scutes and/or bone more weathered than above..... Q
- Q) Growth rings on scutes peeling and  
cracking, usually not curled, and/or bone  
solid or beginning to crack and peel  
..... 2-4 years
- QQ) Growth rings on scutes peeling,  
cracking, and usually curled; and/or bone

solid if scutes still cover it, or peeling and  
cracking if exposed.....>4 years

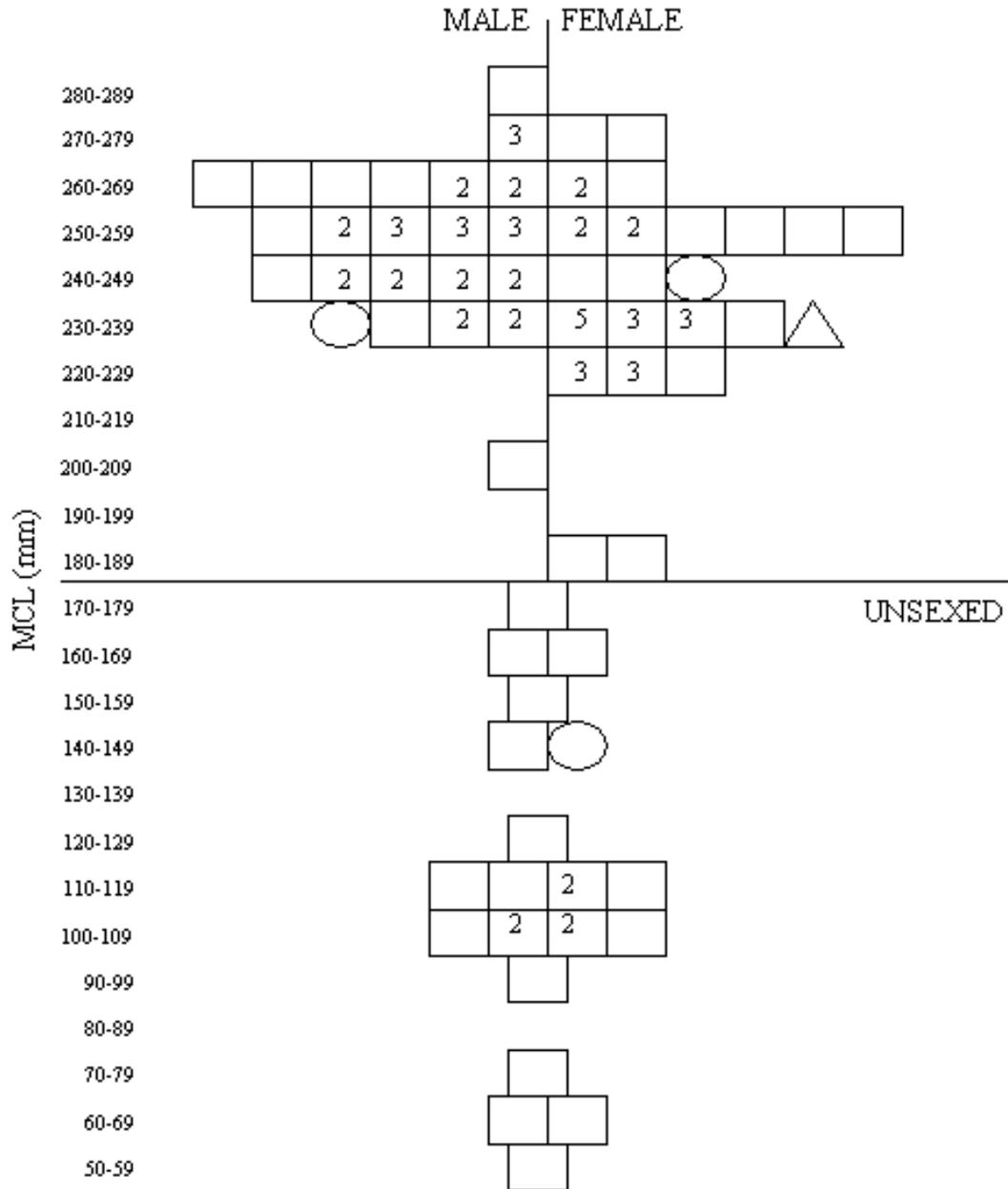
OO) Scutes on shell not depressed.....R

R) Growth rings may be beginning to crack and  
peel, and/or bone solid ..... 1-2 years

RR) Scutes and/or bone more weathered than above.....S

S) Scutes may be curling at edges; growth  
rings cracking and peeling; and/or bone  
solid if still covered by scutes, or may show  
some cracking and peeling if exposed..... 2-4 years

SS) Scutes may be curling and/or breaking,  
growth rings cracking and peeling, and/or  
bone solid if still covered by scutes .....>4 years



Appendix 6. Sample Tortoise Size Distribution (from the Four Peaks monitoring plot, 1995; adapted from Murray and Schwalbe 1997). Numbers reflect the number of sample periods in which a given tortoise was captured (single captures not numbered). Circles represent captures off plot, and triangles represent individuals initially found alive, but later found dead, during the survey.