An Eighteen Year Study of Population Dynamics, Diet and Health of the Sonoran Desert Tortoise (*Gopherus agassizii*) in the San Pedro Valley of Southern Arizona.

By

W. Walter Meyer, Phil R. Ogden, Katie E. Cline, E. Lamar Smith, George B. Ruyle, Frances K. Meyer and Jenny A. Cordrey

A privately funded research project.

Submitted to the U. S. Fish and Wildlife Service in Response to the 2009 Petition to List the Sonoran Desert Tortoise as an Endangered Species.

January 2010

An Eighteen Year Study of Population Dynamics, Diet and Health of the Sonoran Desert Tortoise (*Gopherus agassizii*) in the San Pedro Valley of Southern Arizona.

By
W. Walter Meyer[1], Phil R. Ogden[2], Katie E. Cline[3], E. Lamar Smith[4], George B. Ruyle[5], Frances K. Meyer[6] and Jenny A. Cordrey[7]

A privately funded research project.

Submitted to the U. S. Fish and Wildlife Service in Response to the 2009 Petition to List the Sonoran Desert Tortoise as an Endangered Species.

January 2010

[1]Dr. W. Walter Meyer, Principal Research Specialist, University of Arizona, Retired.
[2]Dr. Phil R. Ogden, Professor and Range Management Specialist, University of Arizona, Retired.
[3]Katie E. Cline, Former Extension Range Monitoring Specialist, University of Arizona and Range Management Specialist, Natural Resources Conservation Service.
[4]Dr. E. Lamar Smith, Associate Professor Emeritus, University of Arizona, Retired.
[5]Dr. George B. Ruyle, Professor and Extension Specialist of Range Management, University of Arizona.
[6]Frances K. Meyer, Participating Rancher.
[7]Jenny A. Cordrey, Former Research Technician, University of Arizona

ACKNOWLEDGMENTS

Special thanks to Collins Cochran Jr., Area Wildlife Biologist for the Arizona Game and Fish Department, and to Dr. Vanessa M. Dickinson, Research Biologist for the Arizona Game and Fish Department, for their encouragement in this research project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The objectives of the study were to: 1) find and identify as many tortoises as possible within a defined study area which encompassed several Land Resource Areas (vegetation types); 2) determine the distribution of tortoises within the study area; 3) calculate an estimate of the number of tortoises within the study area; 4) compare tortoise data within four different livestock grazing systems; 5) determine the ratio between the number of adult males, adult females and juveniles (sub-adults); 6) study the diets of desert tortoises using visual observations of foraging tortoises and microhistological analyses of tortoise fecal material; and 7) determine the health of the tortoise population within the study area.

Cruise transects were used to sample each quarter section block in the 14,905 acre rectangular study area which encompassed three different vegetative zones and four different grazing systems. The sampling method was specific on details but flexible enough in sampling dates to adjust to when there was a good probability to achieve a reasonable sample number of tortoises. Transects were monitored throughout the year. Each tortoise sampled was tagged, its physical characteristics were recorded, and its activities and location was documented.

A major problem for observers was learning how and when to locate tortoises within the three different vegetation types, different topographic regions and geologic units within the study area. To achieve precision and accuracy in collecting tortoise data, it is crucial that the field monitors have knowledge and experience in order to locate tortoises across different geologic and vegetation units.

Tortoises were observed throughout the year and their activities were dependent upon temperature, season and precipitation with the greatest activity occurring from July to October. Tortoises were inactive during drought and most active during and after summer rains. Tortoises were not randomly distributed across the study area; they were concentrated into well-defined population cells, although there were numerous individuals observed at other locations across the study area. Population cells were located on all three vegetation types and on different topographic units. Salt licks (calcium carbonate deposits) were an important factor in the distribution of tortoises.

The Lincoln Index method was used to estimate the tortoise population within the study area. The 1996 estimated population on the 23.3 square mile study area is near 800 ± 200 tortoises, an average of 34 ± 9 tortoises per square mile, but not randomly distributed. The sex ratio of the population was 39.9% males, 34.3% females and 25.7% sub-adults. Tortoise diets varied between the three different vegetational types. Generalities about the effects of livestock grazing on desert tortoises should be avoided unless they can be placed in the context of a grazing regime, effective precipitation, habitat type, topography, and tortoise behavior and requirements. The overall apparent health of tortoises on the study area was good.

INTRODUCTION

Desert tortoises (*Gopherus agassizii* Cooper) are widespread in arid and semiarid regions of the southwestern United States and western Mexico (Woodbury and Hardy 1948, Germano 1988, Lamb et al. 1989, Germano et al. 1994). Three sub-populations of desert tortoises are recognized based on habitat, behavioral and morphological differences, life history and population status variations (Bailey 1992, Boarman and Beaman 2002, Meyer 2008.) The Mojave population is found in the high Mojave Desert of southwestern Utah, southern Nevada and southeastern California. The Sonoran population occupies western and southwestern Arizona and is also found in western Sonora and extreme northern Sinaloa, Mexico. The Sinaloan population is in eastern Sonora and extends into northern Sinaloa (Germano et al. 1994, Grover, Lesley and De Falco 1995 and Berry et al. 2002).

In 1980 a Sonoran desert tortoise study was initiated in the San Pedro Valley in southern Arizona as a result of an unusual natural resource concern. Jojoba (*Simmondsia chinensis* (Link) C.K. Schneid) had become the object of major interest because the oil made from its seed was purported to be a substitute for “whale oil” and was used in the manufacture of skin care products, shampoos, cosmetics and lubricants (Daugherty, Sineath and Wastler 1958). The resulting increase in the value of jojoba seeds encouraged a large number of “nut pickers” who ravaged the natural resources within the valley without regard to the plant and animal life of the desert community. The pickers were often without adequate provisions and therefore began taking for food many of the small animals in the area, including desert tortoises. The number of charred tortoise shells in their abandoned camp sites initiated concern and curiosity about tortoise numbers in the area.

This study continued for eighteen years. It was suggested by Dr. Vanessa Dickinson of the Arizona Game and Fish Department that eighteen years was enough initial data. She suggested that, in order to gain better insight of the tortoise population in the study area, more studies should be reinitiated in ten to fifteen years after the end of this study.

OBJECTIVES

This study began in 1980 and continued through 1997, although data continued to be collected when tortoises were encountered in the study area after 1997. Limited data was collected as late as November 2009. The objectives of the study were to: 1) find and identify as many tortoises as possible within a defined study area which encompassed several Land Resource Areas (vegetation types); 2) determine the distribution of tortoises within the study area; 3) calculate an estimate of the number of tortoises within the study area; 4) compare tortoise data within four different livestock grazing systems; 5) determine the ratio between the number of adult males, adult females and juveniles (sub-adults); 6) study the diets of desert tortoises using visual observations of foraging tortoises and microhistological analyses of tortoise fecal material; and 7) determine the health of the tortoise population within the study area.

The Study Area and Its Grazing History

The study area encompasses 14,905 acres in eastern Pinal County, Arizona. The area is located 8 miles south of Winkelman and runs west from the San Pedro River into the Tortilla Mountains. It encompasses the area spanning from south of Swingle Wash to north of Dodson Wash (Figure 1). Elevations range from 2000 feet along the San Pedro River to 4100 feet on Cedar Mountain. The average precipitation at the lower elevations is 13.8 inches and increases to 16.5 inches at the higher elevations. Three Land Resource Areas are represented in the study. The lower elevations are within the Upper Sonoran Desert Shrub Land Resource Area. Typical soils are complexes of thermic Haplargids, typic Calciorthids, and typic Calcigypsids that have formed on alluvium of mixed origin. Dominant vegetation for this resource area is foothill palo verde (*Parkinsonia microphylla* Torr), jojoba, numerous species of cactus (*Opuntia*, spp. Mill), threeawns (*Aristida* L.), slender janusia (*Janusia gracilis* A. Gray) and annual grasses and forbs. The mid elevations of the study area are within the Southern Arizona Semi-desert Grassland Land Resource Area. Typical soils for this resource area are rocky shallow Torriorthents, lithic Torriorthents, lithic Haplustolls and skeletal Haplargids that are associated with mixed alluvium and Precambrian sedimentary rocks. Dominant vegetation is a mix of perennial grasses dominated by grama grasses (*Bouteloua spp*. Lag), threeawns, curly mesquite (*Hilaria belangeri* (Steud.) Nash), cane beardgrass (*Bothriochloa barbinodis* (Lag.) Herter), jojoba, mesquite (*Prosopis glandulosa* Torr), guajilla (*Calliandra eriophylla* Benth.), slender janusia and other perennial and annual grasses and forbs. The upper elevations of the study area are within the transition between the Arizona Interior Chaparral Land Resource Area and the Southern Arizona Semi-desert Grassland Land Resource Area. Typical soils in this resource unit are fairly deep ustic Torrifluvents and lithic Torriorthents that have formed on Precambrian Ruin granite and sedimentary rock. Predominant vegetation for this resource unit is turbinella oak (*Quercus turbinella*

Greene), one seeded juniper (*Juniperus monosperma* (Engelm.) Sarg.), wait-a-bit (*Mimosa aculeaticarpa* var. *biuncifera* (Benth.) Barneby), jojoba, guajilla, shrubby buckwheat (*Eriogonum wrightii* Torr), red and yellow deervetch (*Lotus rigidus* (Benth.) Greene), grama grasses, threeawns, curly mesquite and annual grasses and forbs.

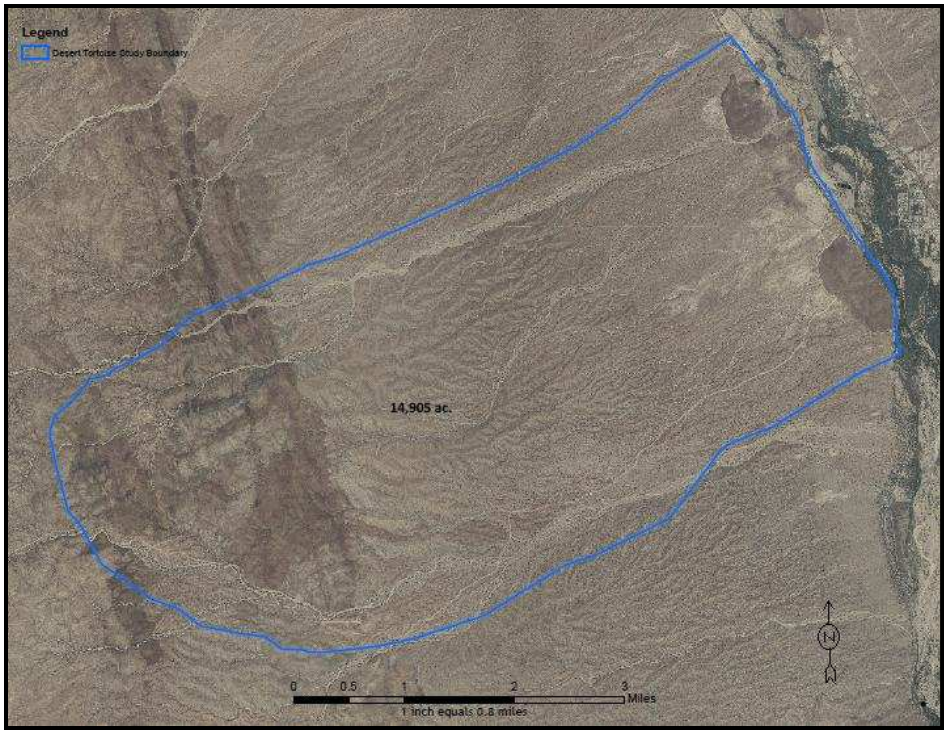

Figure 1. Aerial photo delineating the boundary of the 14,905 acre tortoise study area in the San Pedro River valley.

The study area, as well as all of southern Arizona and Pinal County, has a long history of livestock grazing. By 1694, 100,000 cattle grazed the headwaters of the San Pedro River in Southern Arizona and in 1697 Father Kino introduced more livestock into the San Pedro River valley at the Quiburi Mission (Hastings and Turner 1965, Allan 1989). The Pima revolt in 1751 brought about the abandonment of the missions and haciendas in southern Arizona. Subsequently livestock reverted to a feral state (Wagoner 1975). After the return of the Spaniards in 1752 livestock continued to run wild until the late 1800's (Allen 1989). In a letter to Griffiths (1901) Col. H. C Hooker wrote that in 1870 the San Pedro River area had an abundance of perennial grasses and undershrubs of many kinds and that "…the riverbed was shallow and grassy…with a luxuriant growth of vegetation." Hooker stated that by 1900 the forage production was reduced by 50% over the previous twenty-five year period and that cattle numbers were also reduced by 50% over the same period. Griffiths (1904) described "alfilerilla" (*Erodium cicutarium* (L.) L'Hér.) as an abundant and valuable forage and stated that jojoba was considered a valued browse species in the Dudleyville, Arizona, area. Figure 2 shows rangelands near Dudleyville in 1904 as fairly open grassland; in contrast this area would now be classed as Upper Sonoran Desert Shrub.

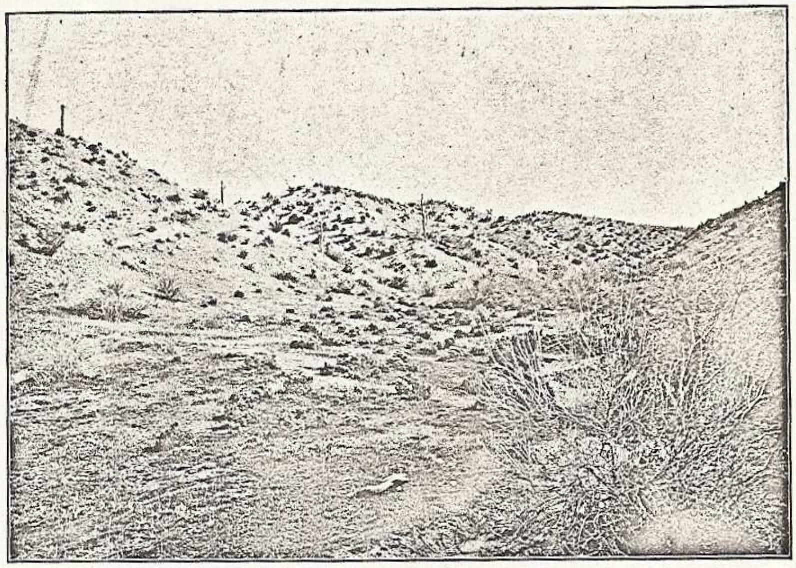

FIG. 1.—ALFILERILLA AND INDIAN WHEAT NEAR DUDLEYVILLE. IN THE CENTRAL FOREGROUND IS SHOWN CLOSELY GRAZED BUSHES OF "JOJOBA" (SIMONDSIA CALIFORNICA).

Figure 2. Photo and caption from Range Investigations in Arizona by David Griffiths (1904). This photo was taken within the study area.

Croxen (1926) states that the rangelands in central Arizona were fully stocked by 1880, that there was little selling of cattle, and those that were sold brought a low price resulting in an ever-increasing number of cattle on the rangelands. He further states that the drought of 1904 was so bad that "cattle died in bunches". Hastings and Turner (1965) state that there was an estimated one and a half million cattle in Arizona in 1891 and that the drought of 1892 and 1893 reduced the cattle numbers by 50 to 75%. They further state that there were only 250 head of calves branded between Florence and Tucson in 1893, and by June of that year there were over two hundred thousand cattle shipped from Arizona rangelands. Parr, et al. (1928) state that cattle numbers for Arizona and New Mexico peaked between 1890 and 1893, declined until 1900 and again increased until 1922. Sheep and goat numbers were lowest between 1890 and 1893 then increased to a maximum of 6,750,000 in Arizona and New Mexico in 1903; after 1903 there was a general decline in numbers of sheep and goats until 1927.

The aforementioned cattle numbers are in line with the approximate cattle numbers in eastern Pinal County during that time (Figure 3) (Meyer 1980). Livestock traversed the area unimpeded in their movements until the passage of the Taylor Grazing Act in 1934 and the transfer of lands to the Arizona State Land Department in the late 1930's and early 1940's. The remaining lands were withdrawn from entry (no further homesteads or free grazing allowed). The allocation of state and federal lands established existing ranch units. The fencing of these ranches in the late 1940's and early 1950's resulted in further reductions in livestock numbers on the rangelands.

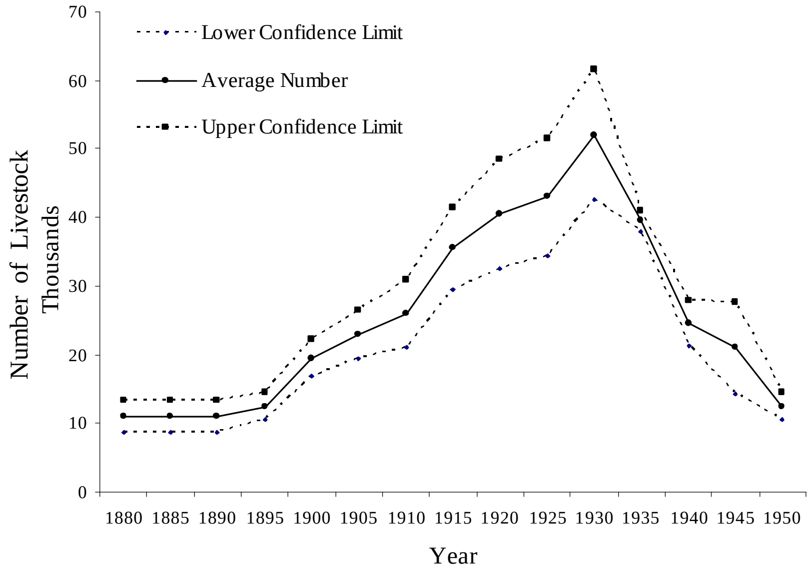

Figure 3. Livestock numbers in eastern Pinal County, Arizona, between 1880 and 1950. Confidence limits at the 0.95 level. (Meyer 1980).

METHODS AND PROCEDURES

Study Design

When designing the study, several assumptions were made. It was assumed that the same amount of field time would be spent monitoring each year and that the probability of observing tortoises would be the same across the different resource areas. For the study it was assumed that the distribution of tortoises would be random and that the ratio between adults and sub-adults, as well as the ratio between males and females, would remain constant from year to year and across the different resource areas. Seber (1965) states that all individuals in the population should have the same probability of capture and that, irrespective of the number of times the individual has been recaptured, the probability of capture remains the same. Recapture is defined as the collecting of a marked tortoise each year and does not include the collection of the same tortoise within the same year (Leslie and Chitty 1951 and Leslie 1952). Rupp (1966) states that when making population estimates, the mortality and recruitment between one monitoring time and another must be insignificant. He further states that if mortality and recruitment are not insignificant then the effects of mortality and recruitment must be nonselective with respect to the kinds of individuals into which the population is separated for the purpose of population estimate.

To achieve a representative sample of the population it is important to assure that the sampling area is large enough to characterize the natural variability that may occur within a population. Cook et al. (1962) state that elongated plots that are oriented with the long axis in the direction of greatest variability are more uniform than circular or square plots. They further state that block sampling (block type survey) within the larger area, by its very nature, insures that all parts of the area will be sampled fairly uniformly. Based on these and other principles the area for this study was established. The rectangular study area was designed to encompass three land resource units with an elevation gradient of 2100 feet and included several different topographies. Each quarter section, 160 acres, in the study area was considered a block that would be consistently monitored throughout the study period.

Transect Design

Tortoise observations began in August 1980 using the "cruising method" suggested by Erickson (1940). The cruising method is a census method used to monitor wildlife or other items of interest along a prescribed route. This method has several different names and variations, among these are line transect, strip transect and others. Erickson found that a cruising census has an optimum period of time during which it can be conducted. Krefting and Fletcher (1941) found that an effective way to run census lines was to travel along the line in a "hunting fashion" and that it was important to look around, stop, sit on a rock or stand perfectly still for a short time while taking sightings in order to maintain approximate direction and route of travel. Eberhardt (1968) stated that there is little information about the physical and psychological processes that lead to the sighting of an animal in the field. He suggests that detection depends primarily on searching by the observer and the visibility of the object being monitored. Robinette et al. (1974) agree with Eberhardt and state further that the biases in sampling arise from sampling conditions and the animal or object being monitored and that many other biases arise from the monitor himself. Hayne (1949) states that many of the biological considerations which determine a monitoring method's usefulness in conducting a census of any particular species are often based on erroneous assumptions. An example of these assumptions is that the capture distance observed by an investigator constitutes a good sample of all animals throughout the population. Other erroneous assumptions are that the animal has not moved out of the investigator's path or that the investigator has not failed to sight the animal. Giles (1971) recommends cruise transects in order to give even distribution across the sampling area. Based on the aforementioned review, the cruise transects for this study were designed to traverse each quarter section in a generalized course of travel that made covering rough topography easier than trying to maintain a strict straight line of travel. Every effort was made to consistently monitor each quarter section on a consistent basis. The location of every tortoise encountered was then recorded to the nearest ten acre plot.

Tortoise Sampling

Field monitoring was conducted throughout the year with the greatest amount of field work occurring from late June through early October. Transects were normally run in the mornings and afternoons; however, if the day was fairly cool or after a summer storm, monitoring was conducted at any time during daylight hours. When a tortoise was encountered, the legal description of the ten acre location was recorded along with a general description of the site. Tortoise dens and salt "licks" (calcium carbonate deposits) were documented and monitored as were pallets, scat and other tortoise sign. If a tortoise was observed in a den, that was noted, however no effort was made to remove it from the den. If fresh scat was observed in or near a den, it was noted that the den was occupied. If a tortoise was on a shallow pallet or resting under vegetation or in a white-throated wood rat (*Neotoma albigula* Hartley) midden the tortoise was measured. Tortoises that were actively foraging or utilizing salt licks were also measured. If any site was suspected of being a nesting site, any disturbance of the site was avoided; however, the site was documented and observed from a distance. If a tortoise was foraging, breeding or traveling, then extra time was spent observing its activity in order to gain a better understanding of tortoise habits. Throughout the study, all sites were continually revisited.

When a tortoise was collected, special care was taken in its handling in an effort to not overly stress the individual or cause it to urinate which could in effect cause dehydration. An observed characteristic of tortoises was that when a tortoise saw movement or heard any noise it stopped and remained still for a fairly long period of time before starting to move again. If the tortoise was approached fairly rapidly and picked up by clutching it on both sides, it typically urinated and struggled to be free. These observations helped to develop a monitoring procedure that was used throughout the study. Characteristically, a tortoise was approached carefully and slowly and an open hand was placed under its plastron with the other hand placed on its side or on the carapace to steady the animal while moving it to the area where it was to be measured. While measurements were taken, the tortoise was placed upon a flat surface or the investigator's leg with its head against the investigator's body or some stationary object. This procedure seemed to provide some security to the animal. When this procedure was followed, tortoises rarely urinated or struggled. After the prescribed data were collected, the tortoise was returned back to the site from which it was collected and placed in its previous position.

In addition to location and description of the location site, tortoise activities, such as resting, mating, foraging, etc., were also recorded. Associations between individuals were noted and any unusual marks, damage or unusual wear to an individual's carapace, plastron and scutes were documented. Calipers were utilized to measure length, width and height in centimeters. The length (L) was measured from the gular at the front of the plastron to the pygal in the back of the carapace. Width (W) was measured from the outside edge of the right inguinal to the outside edge of the left inguinal. Height (H) was measured from the longitudinal centerline of the plastron to the center vertebral plate on the carapace (Figure 4). The Chatillon Model IN-6 and Pesola 100g portable field scales were used to measure weight in grams. Care was taken to move slowly when lifting the tortoise for weighing. Weighing was the last physical measurement made of tortoises.

Apparent health of each tortoise was also evaluated. This evaluation consisted of observing nasal discharge, eye clarity, external parasites and any other physical problem that may be evident. If a tortoise had obvious damage to its carapace or plastron or body from attempted predation or other injury, this was also documented. Any diversion from the typical in the number of vertebrals or costals was also noted.

A basic age classification system for tortoises was developed for this study using characteristics described in Medica et al. (1975), Miller (1955), Woodbury and Hardy (1948) and Bogert (1937). This generalized system was based on observed differences in tortoise size, carapace shape and color, along with normal wear of the shell. The age classifications were: very old – large tortoises with nearly all of the scute annuli (growth rings) on the edge of the scute worn or damaged and the annuli on the concave costals and vertebrals not plainly apparent; old - large tortoises with some apparent wear on the scute, costals, and domed vertebrals; young - fairly small tortoises with the annuli showing little wear; very young - tortoises less than 10 centimeters in length; and, hatchling - tortoises approximately 4.5 centimeters or less in length with relatively soft shells and showing a distorted umbilical area. For this report, any tortoise too young to determine its sex was considered a juvenile or sub-adult.

Sex of the tortoises was recorded as male or female or as juvenile when the tortoise was too small to identify its sex. Based on the method set forth in Woodbury and Hardy (1948), each tortoise was then tagged by drilling a small dipple into the shell (not into the bone) on the appropriate scute and costal. For example, for Tortoise #212, scute 2 on the right side, scute 10 on the left side and the 200 costal were marked (Figures 4 and 5). In addition to this method, numbered metal tags were placed through a rear scute on tortoises whose shells were large enough to accommodate these tags. In later years of the research the metal tags were abandoned because the white-throated wood rats would gnaw them off and damage the scutes.

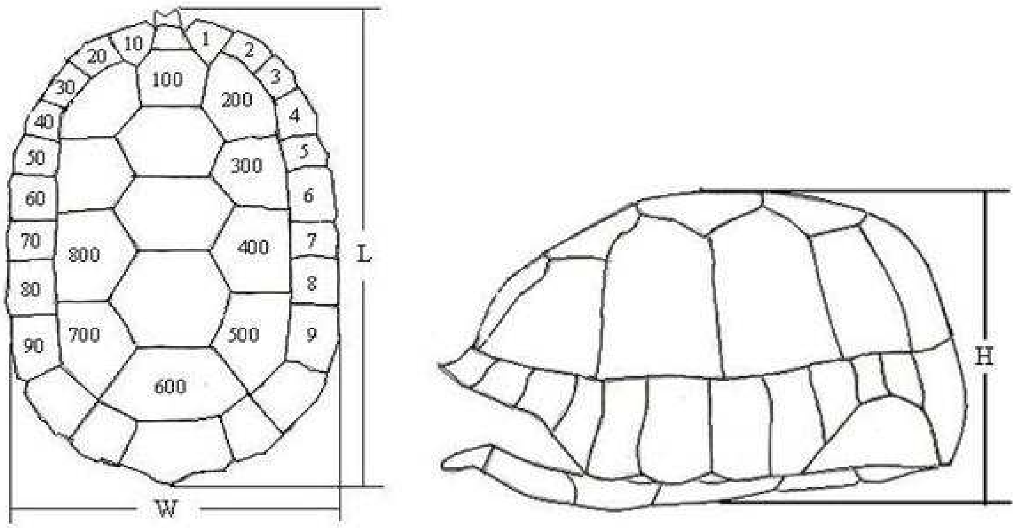

Figure 4. Tortoise tagging locations and length, width and height measurement sites.

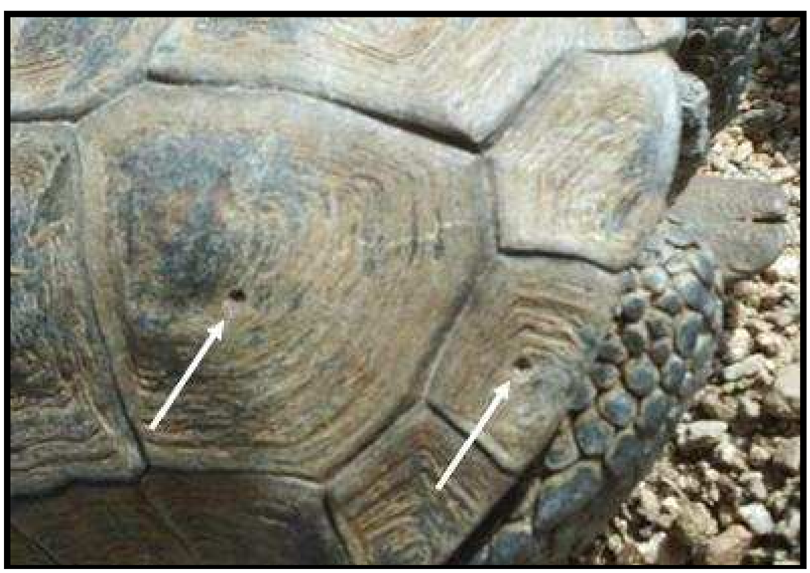

Figure 5. Tagging method used in the study; in this case Tortoise #212 tagged in 1981 and photographed in 2009. Note the wear on the annuli and the difficulty in using them to estimate age.

RESULTS

Finding and Identifying Tortoises

An average of 1,000 man hours per year was spent on the field surveys with approximately 25% of the field time occurring in the fall, winter and spring months and 75% occurring in summer months (Figure 6). All field survey days throughout the eighteen year study period were dependent on the amount of time the investigators had available to get in the field and the number of field investigators available on each survey day. The number of investigators needed was dependent on the terrain that was scheduled to be surveyed and the time of year. Fall winter and spring cruise transects were typically surveyed several times a month whenever temperatures were warm. Those surveys were made at different times of the day, usually from mid morning through late afternoon. In the summer, the greatest amount of field time occurred during cloudy days and on days after or during summer storms; these days often started early in the morning and lasted until late in the evening.

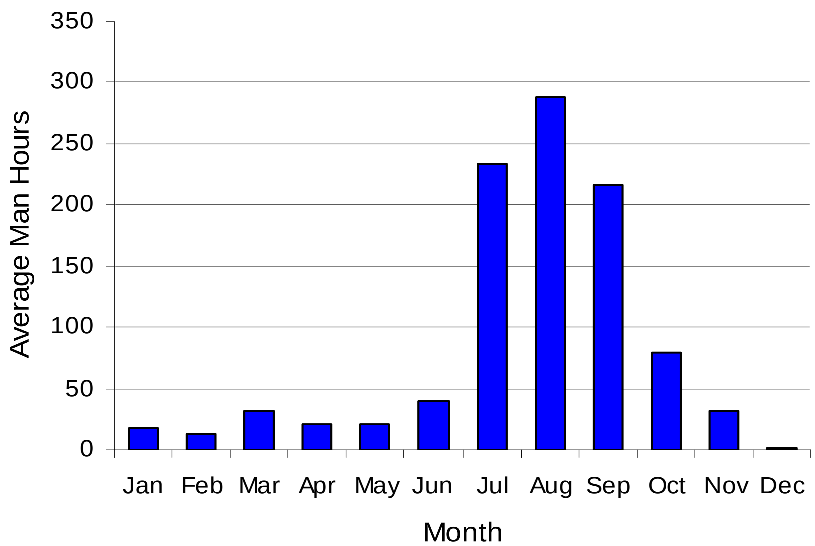

Figure 6. Average monthly man hours spent in the field each year of the study.

.

At the beginning of this study, the participating field investigators were completely inexperienced and naïve in tortoise sampling except for their intimate knowledge of the study area terrain and its vegetation. For this reason, initially the cruise transect surveys proved fairly unproductive with very few tortoises recorded. These cruises proved to be a learning experience of tortoise activity and behavior and how and where to locate tortoises. One of the key lessons learned during this training period was to pause occasionally and listen for the tap of the shell of the tortoise on rocks. This practice also helped in locating tortoises that normally stopped when they saw movement or heard any noise because these individuals would eventually begin to move again. It soon became evident that tortoises and tortoise sign were clustered in specific areas normally located in fairly dissected topography with limy soils and also in areas with fairly steep to very steep rocky slopes. It was also evident that there was little tortoise activity or tortoise sign found on flats, sand washes or areas with deep sandy soils. It also became apparent early on in the study that tortoise activity greatly increased during and after summer rain storms.

Tortoises were observed throughout the year and in every season during the eighteen year monitoring period. Their occurrences (activities) were highly dependent upon temperature and precipitation. Precipitation in the San Pedro Valley area is bimodal with summer and winter totals being relatively equal. Late fall, winter and spring precipitation produce numerous cool season annual grasses and forbs and often green up some perennial grasses and forbs. On warm fall, winter and spring days tortoises were sometimes observed foraging on annual forbs and grasses, particularly on south facing slopes near their dens. April, May and June are normally dry but tortoises were still using the remaining green spring foliage during this time and were occasionally found in their burrows near the front openings. Summer monsoons typically start in mid July and continue until the first of October. These are the months of greatest tortoise activity (Figure 7). It was observed that, during and just after summer storms, male, female and juvenile tortoises commonly congregated at areas that have fairly pure deposits of calcium carbonate. The major activity of the tortoises at these sites was eating limy soil. These salt licks were also areas where the greatest amount of aggression was displayed between males. Normally one or two different males were recorded and remained at each of these licks for a number of days throughout the summer months. These were the areas where male tortoises were occasionally found on their backs; but rarely were dead tortoises found at these sites. The licks were also the areas where much of the observed breeding activity was initiated and continued with the male following the female away from the site. Juveniles of all sizes were also commonly found at these licks. The eighteen years of data show that, if a tortoise was tagged at a particular lick, that individual tended to be recaptured at or near that same site in subsequent years.

Although the number of man hours of monitoring remained relatively constant from year to year, the number of new tortoises tagged increased each year through 1988 then greatly declined in 1989 (Figure 8). This decrease appeared to be associated with the decrease in July, August and September precipitation in 1989 (Figure 9). The 1983, 1984 and 1987 precipitation was greater than normal but there was a significant decrease in precipitation in 1988 and 1989. The total precipitation for the year 1989 for the study area was 4.9 inches, far below the 65 year average of 16.5 inches. The number of new tortoises tagged increased again in 1990 then became fairly stable with an average of 30 new tortoises tagged each year until the end of the study in 1997. The relationship between precipitation and tortoise observations was also obvious in the pattern in the number of tortoises recaptured (Figure10). After 1988 the number of recaptured tortoises usually outnumbered the new tortoises although on some days after 1988 all tortoises encountered were new ones. After the end of the study in 1997, the incidental tortoise sightings were about equally split between new and recaptured animals.

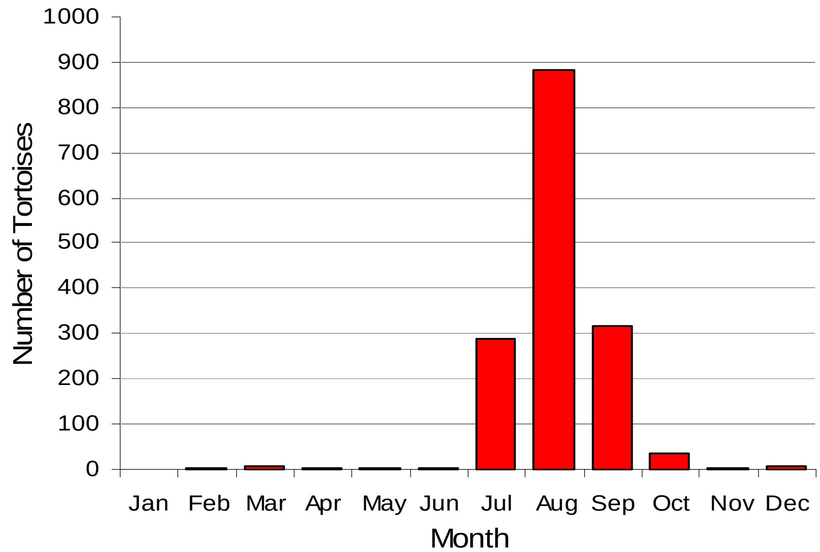

Figure 7. Total number of tortoise observations per month between 1980 and 2005.

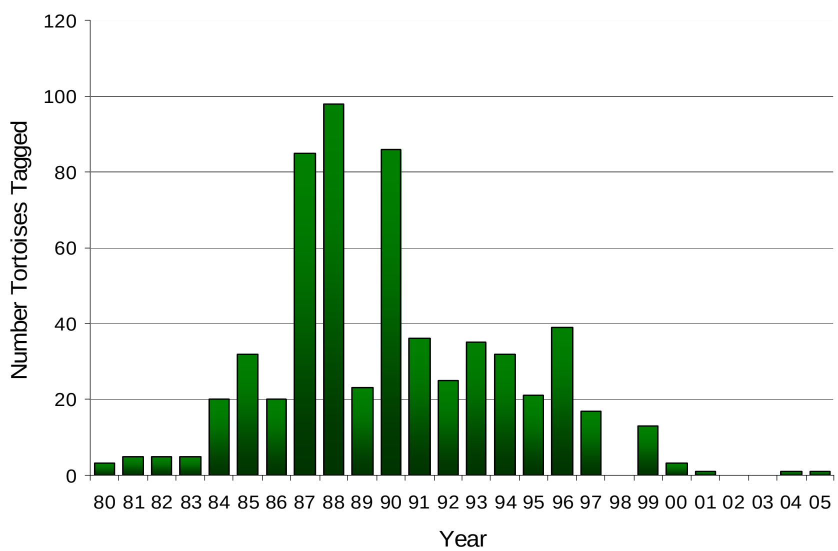

Figure 8. Number of new tortoises tagged each year between 1980 and 2005.

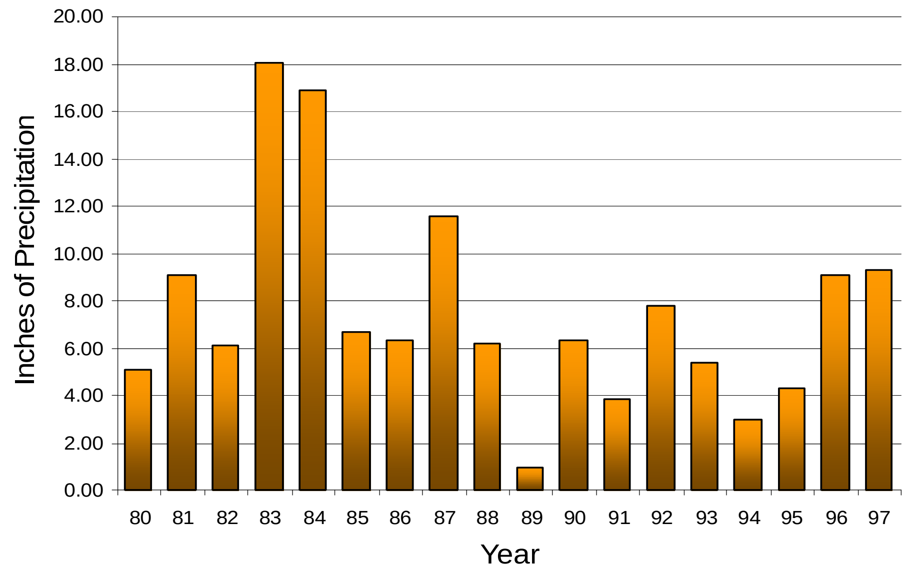

Figure 9. Total July, August and September precipitation recorded in the study area between 1980 and 1997. The average for these three months through the study period was 7.5 inches.

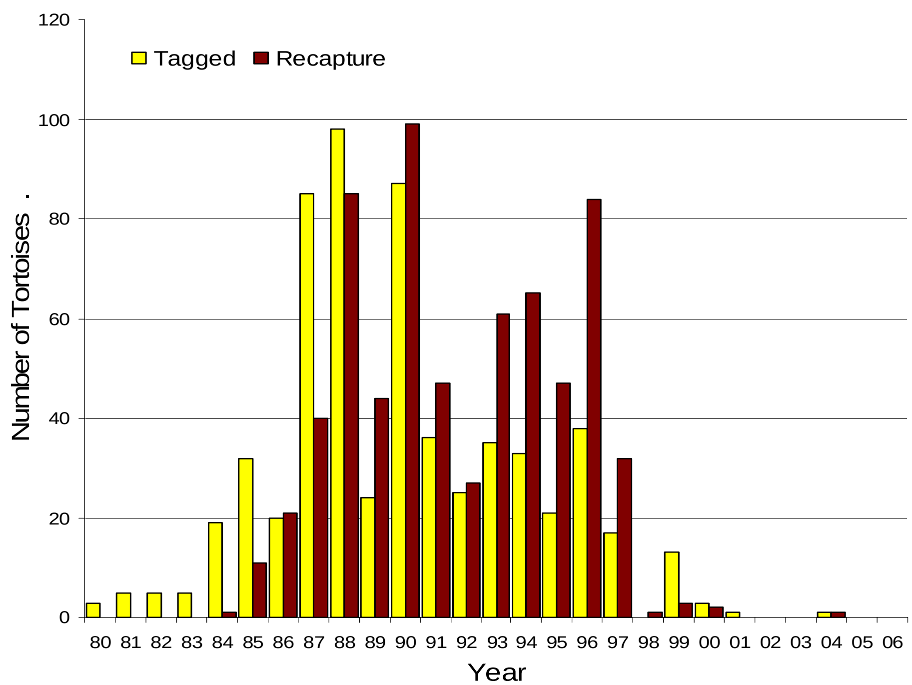

Figure 10. Number of newly tagged and recaptured tortoises observed each year between 1980 and 2005. Sample size (n) is the sum of newly tagged and recaptured tortoises.

Physical Distribution of Tortoises

Distribution of tortoises was not random across the study area; tortoises were clustered in well defined "population cells" (Figure 11). Tortoises in one cell normally remained within that cell area and were rarely observed in adjoining cells, although occasionally some males relocated into and remained in other cells.

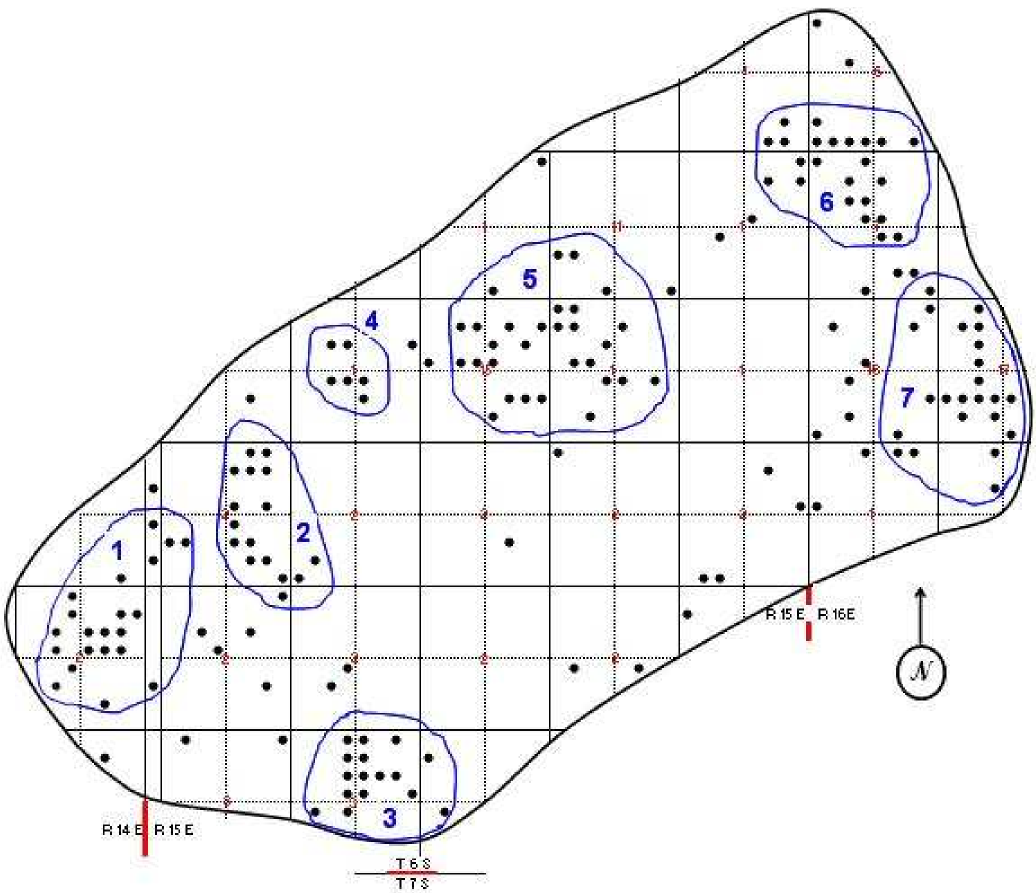

Figure 11. Distribution of tagged tortoises across the study area. Black dots indicate areas where tortoises were tagged and recaptured. The blue outlined areas indicate the population cells located in the study area.

Cells 1, 2, and 3 were located on sites that have shallow soils and similar topography with numerous rock outcrops. Cell 1 was within the mixed chaparral-grassland vegetation community. Soils on this site are shallow, cobbly to stony loams and clay loams with numerous rock outcrops. There are very few limy inclusions in these soils and those inclusions are widely distributed. Slopes on this site are fairly steep with the north facing slopes containing turbinella oak, one seeded juniper, desert ceanothus (*Ceanothus greggii* A. Gray), sacahuista (*Nolina microcarpa* S. Watson), sideoats grama (*Bouteloua curtipendula* (Michx.) Torr), cane beardgrass and other mid grasses. The vegetation on the south facing slopes is predominantly jojoba, guajilla, slender janusia, shrubby buckwheat, flattop buckwheat (*Eriogonum fasciculatum* Benth), slender grama (*Bouteloua repens* (Kunth) Scribn. and Merr.), curly mesquite, threeawns and annual grasses and forbs. Tortoise dens were mostly under large rocks and jojobas and in rat middens. Pallets were generally under shrubs, primarily jojoba. Licks were not common in this cell.

Cell 2 was within the Semi-desert Grassland vegetation community. Soils and slopes on this site are the same as those found on Cell 1. North facing slopes have scattered one seeded juniper, jojoba, spicebush (*Aloysia wrightii* (A. Gray) A. Heller), sotol (*Dasylirion wheeleri* S. Watson), sideoats grama, cane beardgrass, threeawns, curly mesquite and other mid grasses. South facing slopes have flattop buckwheat, jojoba, guajilla, slender janusia, shrubby buckwheat, slender grama, threeawns, curly mesquite and annual grasses and forbs. Tortoise dens and pallets were generally located under large boulders, in rock crevices, under shrubs or in colluvium along slopes. Licks usually appeared along canyon bottoms.

Cell 3 was on an east facing slope within a Semi-desert Grassland vegetation community. Soils on this site are cobbly to stony limy loams and clay loams with numerous scattered rock outcrops and caliche banks. Slopes are moderately level to steep with the north facing slopes containing jojoba, spicebush, sotol, sideoats grama, curly mesquite, other mid grasses and annual grasses and forbs. Vegetation on the eastern and southern slopes is predominantly jojoba, mesquite, guajilla, slender janusia, flattop buckwheat, numerous cactus species, slim tridens (*Tridens muticus* (Torr.) Nash), fluffgrass (*Dasyochloa pulchella* (Kunth) Willd. ex Rydb.), spike pappusgrass (*Enneapogon desvauxii* Desv. ex P. Beauv.), curly mesquite and annual grasses and forbs. Tortoise dens and pallets appeared on all slopes and under a number of different shrubs, in white-throated wood rat middens and under large boulders and were numerous in the hard caliche banks. Licks were primarily located along the caliche banks.

Population Cells 4 and 5 were located within the Upper Sonoran Desert Shrub and Semi-desert Grassland vegetation communities. These cells occurred on scattered clay loam uplands and on deep limy sandy loam soils. Slopes on these sites are moderately level to steep with the north facing slopes containing jojoba, spicebush, sotol, sideoats grama, curly mesquite, other mid grasses and annual grasses and forbs. The vegetation on the southern slopes is predominantly foothill palo verde, jojoba, chainfruit cholla (*Cylindropuntia fulgida* (Engelman.) F.M. Knuth), prickly pear (*Opuntia spp* Mill), spicebush, slender janusia, slim tridens, fluffgrass, spike pappusgrass, curly mesquite and annual grasses and forbs. Soils in the canyon bottoms are deep gravely sand and deep gravely sandy loams. Major vegetation on the bottoms is foothill palo verde, jojoba, chainfruit cholla, desert hackberry (*Celtis ehrenbergiana* (Klotzsch) Liebm.), littleleaf wolfberry (*Lycium exsertum* A. Gray), whitethorn (*Acacia constricta* Benth.) and numerous annual grasses and forbs. The lime licks on these cells were on caliche banks along ridgetops and in the bottoms of canyons that dissect the area. Tortoise dens and pallets were in rat middens, caliche banks and under trees and shrubs on all exposures.

Cells 6 and 7 were on the felsite (malpais) hills on the eastern side of the study area. Both sites have soils that are very shallow, cobbly to stony, gravely, limy clay loams with numerous rock outcrops and with deep calcigypsid clay soils on the adjoining gypsic badlands. Slopes are steep with vegetation typical of Upper Sonoran Desert Shrub which is dominated by foothill palo verde, jojoba, chainfruit cholla, saguaro (*Carnegiea gigantea* (Engelm.) Britton & Rose), slender janusia and annual grasses and forbs. Slopes on the calcigypsid soils are steep with scattered creosotebush (*Larrea tridentata* (DC.) Coville), jojoba and palo verde. Cell 6 was also located near abandoned level farmland that was invaded by mesquite and had large areas of bermuda grass (*Cynodon dactylon* (L.) Pers.), carelessweed (*Amaranthus palmeri* S. Watson) and other winter and summer annuals. Tortoise dens and licks were located in cemented colluvium at the base of hills.

Individual tortoises and small clusters of tortoises outside the population cells in the western portion of the study area were located on similar topography and vegetation found in Cells 1, 2 and 3. The outside individuals in the central and eastern portions of the study area were located within the Upper Sonoran Desert Shrub type vegetation. The outside tortoises in the south central part of the study area were on much flatter topography and on deep coarse sandier soils than those in the population cells. No well defined cells were found in this area.

Estimated Numbers of Tortoises

The Lincoln Index method was used to estimate the tortoise population within the study area. The Lincoln Index method provides the opportunity to formulate a population estimate based on the ratio of captured tagged to untagged animals (Giles 1971). This method has fairly simple computations which allows the field worker to see results while the field work is in progress, provides useful results over a wide range of conditions and the confidence intervals are fairly easy to calculate. The general goal for estimating the tortoise population in the study area was to make the best possible estimate of the numbers of tortoises across the three different land resource areas and also to be able to make a statement regarding the accuracy of this estimate. Tortoise numbers used in calculating estimates with the Lincoln Index did not include recaptures of the same tortoise observed, which were often multiple times in the same year.

There were four assumptions defined in the use of the Lincoln Index: 1) there is a well defined population of tortoises containing N animals; 2) there are a number of tagged tortoises in the population; 3) samples made of the population contain both tagged and untagged individuals; and 4) the probability of observing a tagged animal is equal to the probability of observing an untagged animal within each sample. Adams (1951) stresses the point in these assumptions that "The marked animals must become randomly mixed with the unmarked ones, or the distribution of sampling effort must be proportional to the number of animals in different parts of the habitat being studied." The population was estimated using the following formula: $N = nM/x$ where N is the estimated number of animals in the population, n is the sample size, M is the number of tagged animals and x is the number of tagged animals in the sample. Under the assumption of equal probability of capture, the number of tagged animals (x) approximates a Poisson distribution. Chapman and Overton (1966) present a table adapted from Chapman (1948) that can be used when setting confidence limits for a Lincoln Index experiment in which λ = nM. These values for calculating the upper and lower limits are best suited for x values less than fifty. Seber (1965) states that λ may be constant between samples but it may change from sample to sample as the sample size increases. Adams (1951) states that if the sample size was greater than or near 25, then the confidence limits for the Poisson distribution are better used. Giles (1971) recommends that for sample sizes greater than or near 25, then the confidence limits can be calculated using

$$N_L, N_U = \lambda \frac{(x+2) \pm 2\sqrt{x+1}}{x^2}$$

where N_L represents the lower confidence limit and N_U represents the upper confidence limit; and that using the Poisson approximation to calculate confidence intervals is much more conservative than using values from tables. This formula was used to calculate the 95% confidence limits.

The cumulative number of tagged tortoises increased between 1980 and 1997 (Figure 12) with an average of approximately 30 new tortoises tagged each year after 1990 (Figure 10). The number of tortoises observed between 1980 and 1984 was very low even though approximately the same number of hours was spent in the field each year. The estimated numbers of tortoises in the population between 1984 and 1987 was inconsistent (Figure 12); this variability reflects problems with trying to make predictions about the population dynamics with small sample size and number of tagged tortoises and with a fluctuating proportion of recaptured tortoises in the annual samples. For example, in 1984 there were 19 new tortoises tagged and only one recaptured tortoise that was tagged previous to 1984, although several of the tortoises tagged in 1984 were later observed that same year. These disproportionate ratios violated the basic requirement of the Lincoln Index which is that the proportion of the marked population to the total population estimate is the same proportion as the recapture to the sample number.

By 1988 the proportions of recaptured and new tortoises in the annual samples generally were less variable than prior to 1988 (Figure10). Figures 12 and 13 illustrate the difficulty in trying to make predictions about the size of the population. Figure 12 appears to show an upward trend in the estimated population but, in actuality, what is being shown is simply more tortoises were tagged on the study area over time, which in effect biases the population estimate upward. Figure 13, which shows the confidence limits for the estimated population, implies that the tortoise numbers on the study area are at least as great as 571 and no greater than 1200. Based on the 95% confidence limits calculated for the 1997 data, the density of the estimated tortoise population would be 38.0 tortoises per square mile with the lower confidence population at 24.5 tortoises per square mile and the upper confidence population at 51.4 tortoises per square mile (Table 1). Also note that the density of actually tagged tortoises is the same as the density of tortoises at the lower confidence limit. The 1989 drought also had an effect on the estimated population data with the estimated number of tortoises dropping from 586 in 1988 to 443 in 1989; this is very evident in Figure 13.

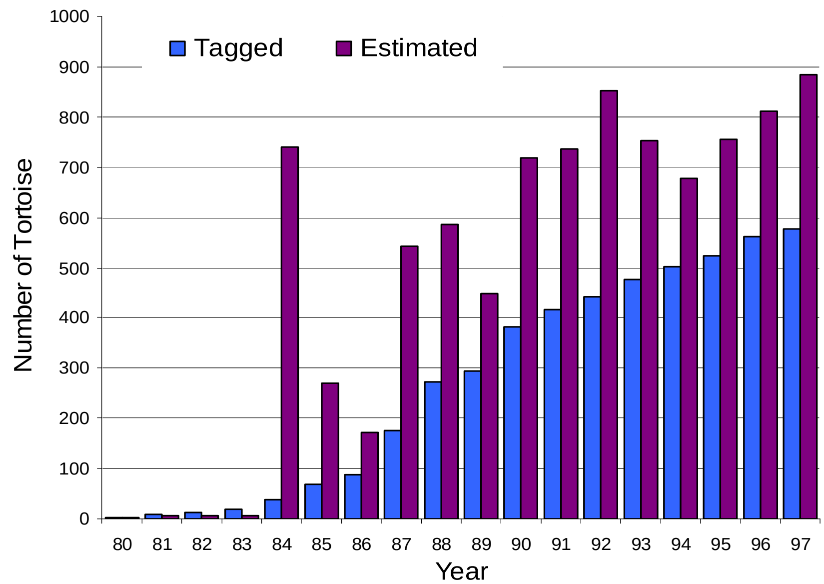

Figure 12. Cumulative number of tagged tortoises and population estimates each year between 1980 and 1997.

There were other factors that affected the estimation of population size. Even though tortoises that were tagged in a location were normally recaptured at or near the same location in subsequent years, there often were long periods of time, sometimes 10 or more years, before some tortoises were recaptured. Therefore it was difficult to know if those tortoises were dead or had left the area. For instance, a fairly young tortoise #J that was tagged in the western part of the study area in 1992 was found in 2005 by Jerry Perry of the Arizona Game and Fish Department approximately fourteen miles west of where it was originally tagged. Another factor affecting estimation is that the remains of only 15 dead tortoises were found in the study area which is too few to make an accurate assessment of tortoise death rate or to accurately estimate the death rates of tagged tortoises versus untagged tortoises. It was also impossible to estimate the time of death of tortoises. An additional factor is that the life of the study was not long enough to understand if the number of young tortoises coming into the population was proportional to the number of tortoises dying or leaving the population. Predation was always a concern; the shells of several young tortoises showed that they were killed by a mountain lion (*Felis concolor azteca* Merriam) and there was evidence that young tortoises near the licks were sometimes mauled, and probably eaten, by javelina (*Tayassu tajacu sonoriensis* Mearns).

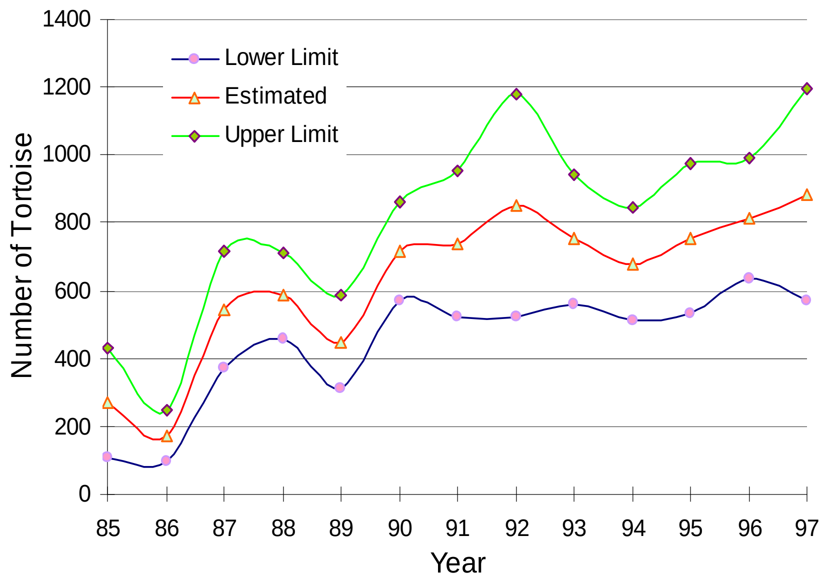

Figure 13. Upper and lower confidence limits at the 95% level on the total number of estimated tortoises in the study area between 1985 and 1997.

Table 1. Densities of tortoises in the 23.3 square mile study area.

Number Data	Number of Tortoise	Density Tortoise per sq. Mile[1]
Actual Tagged Population	577	24.7
Estimated Population[2]	884	38
Lower Confidence Population[3]	571	24.5
Upper Confidence Population[3]	1196	51.4

[1] Density based on the 23.29 square mile study area.

[2] Based on the1997 estimated data.

[3] Confidence interval at the 95% level.

Recapture Assessment

Eighteen years of recapture data were assessed using records from tortoises that were tagged between 1980 and 1989. The records indicated that it was not unusual for some tortoises to not be observed for many years after their initial tagging. Therefore, only tortoises tagged in the first ten years of the study were selected for this assessment. If data from tortoises tagged after the first ten years were used, the results would have been skewed because not enough time had elapsed to give valid results.

Seven classifications were developed for the recapture assessment. Those classifications reflect an average of how often and at what intervals particular tortoises were observed throughout the entire monitoring period. The classifications were: (1) every year (if the tortoise was seen every year); (2) every other year; (3) every 3 years; (4) every 4-5 years; (5) every 6-10 years; (6) every 11-18 years; and (7) never recaptured (Figure 14). Multiple recaptures of the same tortoise within the same year were excluded. Only one sighting of a tortoise within a particular year was counted in the assessment.

The results of the assessment were: 5% of tagged tortoises were seen every year; 5% every other year; 18% every 3 years; 13.6% every 4-5 years; 16.1% every 6-10 years; 11.8% every 11-18 years; and 30% never recaptured. Several possible reasons for never seeing a tortoise again exist. The tortoises may have left or been taken from the research area. Their tag enumerations (markings) may have been lost or modified. They may have died or they were simply undetected. It is doubtful that the entire 30% of the tortoises that were never seen again left of their own accord because most or all of them would have had to travel miles to get outside the research area. Only one tagged tortoise was ever found outside of the research area throughout the entire research period. Most of the tortoises had two different tagging methods to identify them therefore the loss or modification of an identification tag on an adult tortoise was unlikely. It is a possibility that markings on juveniles could have been lost or modified. However the numbers of juvenile tortoises in this category were limited and could not account for the total 30%. The likelihood of 30% of the tortoises being dead was also small since only 15 dead tortoises were observed across the study area during the entire eighteen years. It is highly probable that most of the tortoises that were not observed again were simply undetected because they were resting deep in dens or rat middens or under dense shrubbery or in a landscape where they were just too well camouflaged to spot. It is also possible that they had moved a short distance away from the monitoring transect. For example, a female Tortoise #286, an old tortoise when she was tagged in Population Cell 2 in August of 1991, was never seen again until November 2009, an eighteen year time span. When she was observed in 2009, she was within one third mile of where she was originally tagged, still within Cell 2. Another example is Tortoise #B, a 1984 hatchling. This tortoise was seen yearly at or near the same location until 1992, an eight year span. After 1992 its home range had increased enough that it was monitored along another transect line within the same cell. It is probable that many of the tortoises in the 30% category could be observed again in future research.

Livestock Grazing Systems

The tortoise study area encompassed four different grazing systems: a rest rotation system (Pastures A, C, D and E); a yearlong moderately grazed system (Pastures F and G); an occasionally very lightly grazed system (Pasture H); and a yearlong heavily grazed system sometimes with stocker calves added in the winter (Pasture B) (Figure 15). The rest rotation Pastures A and D and the moderately grazed Pastures F and G have primarily Southern Arizona Semi-desert Grassland vegetation with some Upper Sonoran Desert Shrub vegetation on the lower elevations. Pastures C and E are a mix of Arizona Interior

Chaparral vegetation on northern slopes and Southern Arizona Semi-desert Grassland vegetation on southern slopes. The vegetation in the yearlong heavily grazed Pasture B and the lightly grazed Pasture H is predominantly Upper Sonoran Desert Shrub where most of the forage is browse and annual grasses and forbs.

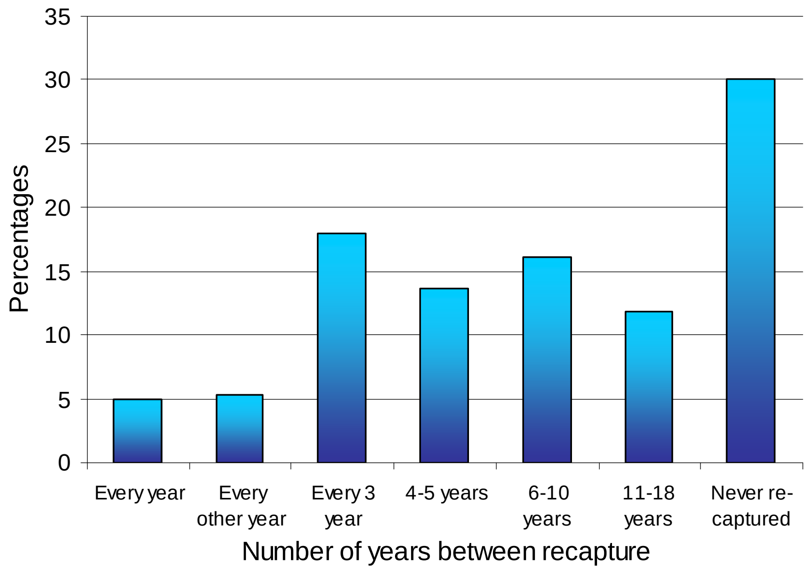

Figure 14. Percent frequencies of tortoise recaptures throughout the eighteen year monitoring period.

Error! Objects cannot be created from editing field codes.
Figure 15. Map showing the locations of the four different grazing systems in the study area.

Rest Rotation Pastures

Grazing in the rest rotation pastures was scheduled so that each of the pastures was deferred from grazing through a growing season every other year. Stocking rates in Pastures A, C and E were light to moderate throughout the grazing period with Pasture D receiving light to moderate short duration seasonal use in late spring. The desert tortoises in these pastures were in three fairly well defined "population cells" (Figure 16). Tortoise dens and pallets in Cells 1 and 2 (Figure 11) in these pastures were usually less than two feet deep and were normally found on the southern slopes, usually under jojoba bushes or sotols or in white-throated wood rat middens. Other dens were under large boulders or in crevices in rock outcrops; these deeper dens were found on all exposures and were also often occupied by wood rats. The deeper dens were used by more than one tortoise during the winter. During the summer, the tortoises occupied shallow pallets under low shrubs and rock overhangs and returned to these same pallets many times. It was not uncommon for some tortoises to remain at the same site for the duration of the summer. Due to the limited number of calcium carbonate licks in these two population cells, tortoises traversed the area quite widely with a typical home range (based on recapture data) exceeding 640 acres and they commonly interacted with tortoises from outside their population cell.

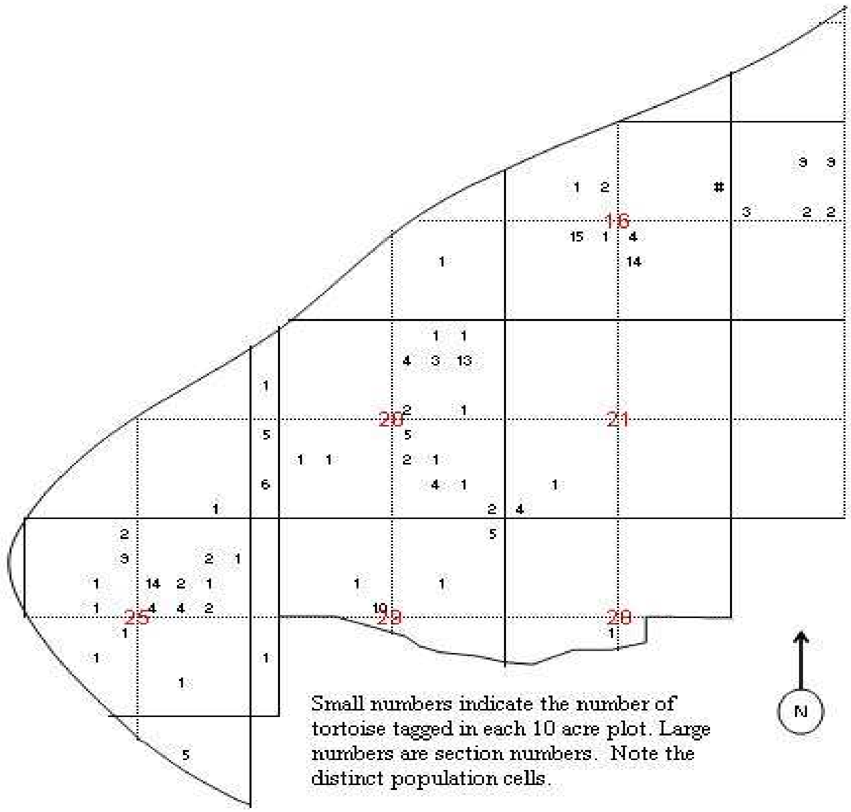

Figure 16. Distribution of desert tortoises in the rest rotation pastures in the study area.

Tortoise dens in Cell 4 (Figure 11) in Pasture A were found on all slopes and under a number of different shrubs, in white-throated wood rat middens, under large boulders and in fairly soft loamy soil banks. During summer, the tortoises occupied shallow dens and pallets under low shrubs and in wood rat middens. These dens and pallets were used throughout the summer season by different tortoises and some had more than one tortoise occupying the spot at the same time. Tortoises occupying this site had a home range of approximately 270 acres and they did not appear to interact with tortoises in the bordering population cells.

Within this 7.43 square mile grazing system, 215 tortoises were tagged in three different well-defined population cells (Table 2). Ninety-two of the tortoises were adult and 123 were juveniles and sub-adults of different ages. These cells had the highest number of observed juveniles. The calculated tortoise density on this 7.43 square mile site was 28.9 tortoises for every square mile. Figure 16 illustrates that there were nine quarter sections in which tortoises were not observed. This indicates that tortoises actually occupied approximately 4.8 square miles and that densities on this site were under calculated. In actuality densities within individual population cells may be high, but densities outside the boundaries of cells were low because tortoises were rarely found there. In other words, density is dependent on where the sample plot is located.

Table 2. The numbers and densities of tortoises in the different grazing systems in the study area.

Pasture	Square Miles	Adults No.	Adults Tortoise/sq.Mile	Juveniles No.	Juveniles Tortoise/sq.Mile	All Tortoise No.	All Tortoise Tortoise/sq.Mile
Light	3.56	48	13.48	4	1.12	52	14.61
Moderate	5.09	41	8.60	6	1.18	47	9.23
Heavy	7.21	212	29.40	54	7.49	266	36.89
Rotation	7.43	92	12.38	123	16.55	215	28.94
Total	23.29	393	16.87	187	8.03	580	24.9

Moderately Grazed Pastures

Pastures F and G were moderately stocked and grazed year round at a level that maintained a sustainable forage base. The tortoises in these pastures were found in the well defined population Cell 3 (Figure 11) and were also scattered in isolated locations across both pastures (Figure 17). Cell 3 was on soils that differed from other sites; the soils were more limy and had weathered stones and boulders of Escabrosa limestone. Fairly deep dens and overhangs were common along the caliche banks; these dens were commonly used in the winter. Summer dens and pallets across the landscape were under jojoba, palo verde and other shrubs. Based on recapture data, the home range of tortoises in Cell 3 was approximately 270 acres. The scattered tortoises in these pastures occupied fairly flat sandy sites in the eastern part of Pasture G and rocky terrain in the western part of Pasture F.

Within this 5.09 square mile grazing unit, 47 tortoises were tagged with 41 adults and 6 sub-adults and juveniles of different ages. The calculated tortoise density on this site was 9.2 tortoises for every square mile (Table 2). Tortoises were not found in approximately nine quarter sections in this unit. This indicates that tortoises only occupied approximately 2.8 square miles and that the density was again under calculated. Again, the densities in individual population cells may be high, but overall densities are diluted with lots of country where the tortoises were not found.

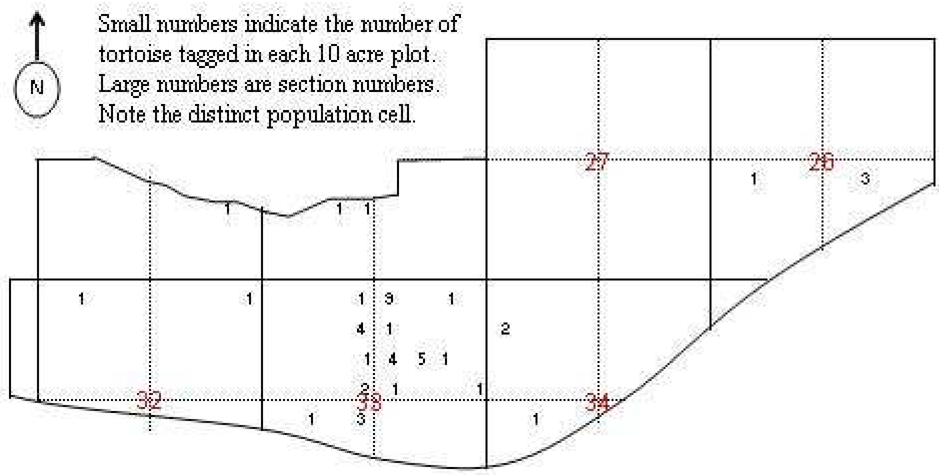

Figure 17. Distribution of desert tortoises in the moderately grazed pasture.

Lightly Grazed Pasture

Pasture H was lightly stocked for short periods of time and was deferred from grazing through most of the eighteen year monitoring period. Population Cell 7 (Figure 11) in the eastern part of the pasture was on Malpais Hill and on calcigypsid soils (gypsic clays) adjoining Malpais Hill (Figure 18). Other tortoises were scattered in isolated locations across the rest of the pasture. Soils on the steep slopes of Malpais Hill are very shallow, cobbly to stony, gravelly, limy clay loams with numerous rock outcrops. Dens were fairly deep, were located under cemented colluvium around the base of Malpais Hill and were commonly used in winter. Dens on the calcigypsid soils were shallow or in wood rat middens that were dug into the clayey soils. Pallets on the Malpais Hill area were under palo verde or jojoba while those on the clayey soils were under jojoba. Individual tortoises in the western and central portion of this pasture were scattered. Soils in these areas are gravely sandy loams, sandy clay loams to limy sandy loams. Slopes range from fairly flat to steep. Dens and pallets in this area were more difficult to locate but the majority of those found were shallow dens located under jojoba or in wood rat middens. Most of the tortoises monitored in this area were located because they were active.

Within this 3.56 square mile pasture 52 tortoises were tagged and consisted of 48 adults and 4 sub-adults and juveniles of different ages. The calculated tortoise density on this site was 14.6 tortoises for every square mile (Table 2). Tortoises were typically found in all quarter sections in this pasture, indicating that the tortoises were more randomly distributed than those in the other pastures.

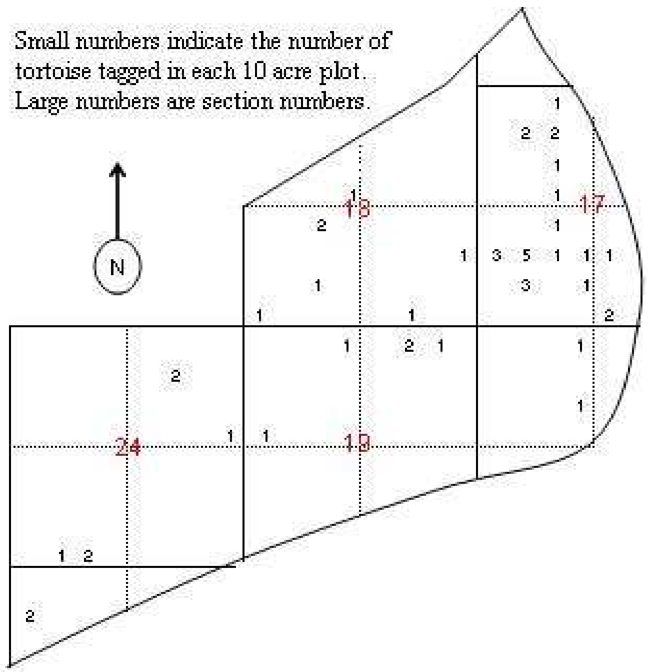

Figure 18. Distribution of desert tortoises in the lightly grazed pasture.

<u>Heavily Grazed Pasture</u>

Pasture B was grazed year long with the permitted number of livestock. In addition, every fall through spring, except years 1987 through 1989, varying numbers of excess stocker cattle were permitted by the land agencies; this was the typical procedure throughout the study. Population Cells 5 and 6 (Figure 11) in this pasture were well defined (Figure 19). Cell 5 in the western portion of the pasture was in the Upper Sonoran Desert Shrub vegetation community. Soils on this site are deep limy sandy loams with scattered clay loam uplands. Slopes range from moderately level to steep and are dissected by numerous small canyons. Tortoise dens were found on all slopes and under a number of different shrubs, in white-throated wood rat middens, under large boulders and in fairly soft loamy soil banks. During the summer months, the tortoises occupied shallow dens and pallets under low shrubs and were most commonly seen in wood rat middens. These dens and pallets were used throughout the summer season by different tortoises and some, at times, had more than one occupying the spot at the same time. Based on the range of recaptured tagged tortoises the home range of tortoises on this site is approximately 960 acres.

Cell 6, in the eastern portion of the pasture, was located on and around the felsite hills north of Swingle Wash and has the same ecological characteristics found on Malpais Hill in the lightly grazed pasture. Soils on the steep slopes of these hills are very shallow, cobbly to stony, gravely, limy clay loams with numerous rock outcrops. Tortoise dens were fairly deep and located under cemented colluvium and in bedrock crevices around the base of the hills; they were commonly used in winter. Cell 6 also encompassed abandoned farmland on the east side. Dens in the calcigypsid soils around the hills were in pipings (erosional tubes that occur in the clayey soils); other dens were located in shallow cavities under scattered shrubs.

Within this 7.21 square mile grazing unit, 266 tortoises were tagged in two different well defined population cells (Table 2). Two hundred twelve of the tortoises were adult and 54 were sub-adults or juveniles of different ages. The calculated tortoise density on this site was 36.9 tortoises for every square mile. Figure 19 shows that there are thirteen quarter section plots in which tortoises were not observed; these plots were comparatively flat to slightly sloping and were dissected by numerous small dry stream channels.

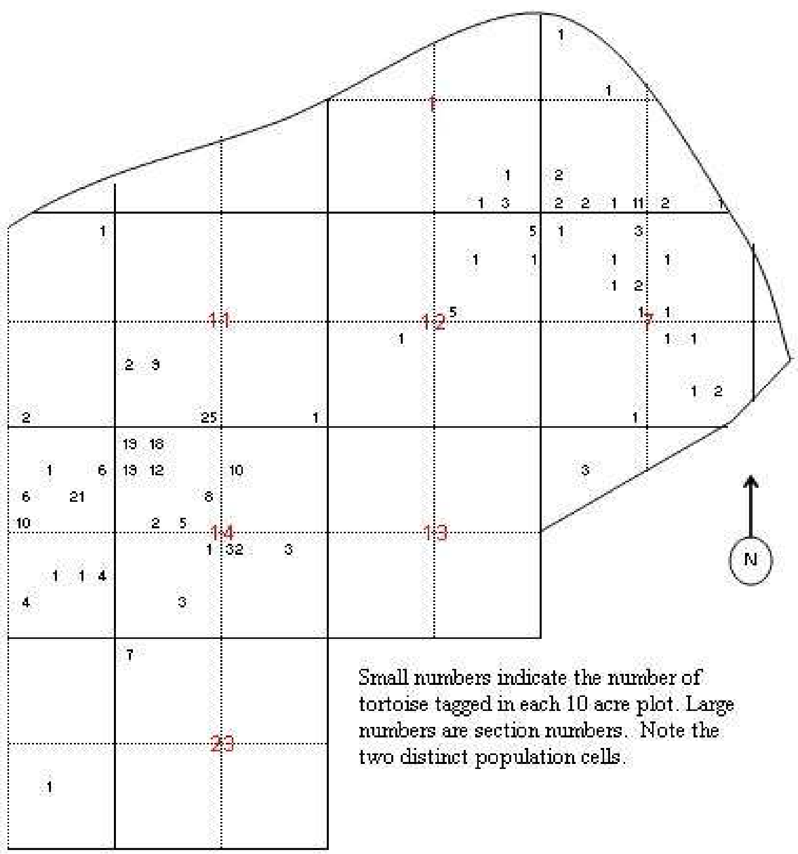

Figure 19. Distribution of desert tortoises in the heavily grazed pasture.

Age and Sex Ratios of Tortoises

Based on eighteen years of data, determining the age distribution and sex ratios of tortoises in the study area was very subjective. Aging tortoises using the number of scute annuli was impractical because of the amount of wear on the scutes (Figure 5); therefore age was defined in the monitoring protocol as very old, old, young, very young, and hatchling. Another problem became evident in determining the sex of individual tortoises through time. When tortoises classed as juvenile at the time they were first tagged grew older, their sex became evident so the very young and hatchling data changed. Consequently, the age class and sex ratios of tortoises observed in any one year were always changing. Therefore, the age and sex ratios data presented in this section were based on age class and sex of the individuals when they were first tagged.

There were 242 males, 208 females and 156 juvenile tortoises tagged in the study area between 1980 and 2006 (Figure 20). The number of dead tortoises observed was very low and only reflected dead tortoises actually observed. It was difficult to determine how many tortoises were taken by predators (especially juveniles taken by javelina), how many had moved out of the area or how many were just unseen by the surveyors. Based on the aging protocol, the age class distribution for the study area was approximately 11% very old, 39% old, 35% young, 13% very young and 3% hatchlings (Table 3).

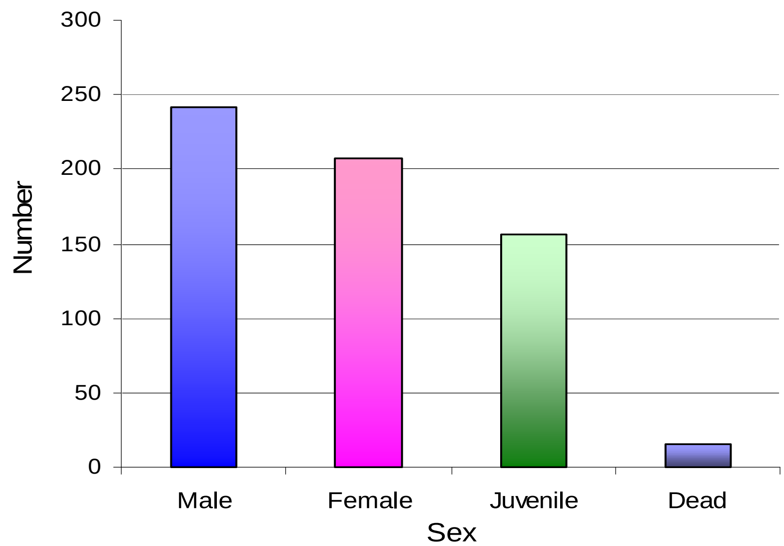

Figure 20. Number of male, female, juvenile and dead tortoises observed in the study area between 1980 and 2006.

Table 3. Distribution of tortoises by age and sex class in the study area.

Sex	Very old	Old	Young	Very young	Hatchling
Male	7.3%	20.9%	12.0%	1.1%	0.0%
Female	3.6%	17.8%	15.5%	0.8%	0.0%
Juvenile	0.0%	0.0%	7.1%	11.2%	2.8%
Total	10.8%	38.7%	34.6%	13.1%	2.8%

Tortoise Diets

A diet study of desert tortoises was conducted using visual observations of foraging tortoises and microhistological analyses of tortoise fecal material. Data from visual observations of tortoises was collected from 1980 through 1990. Since the majority of these observations occurred during the summer and fall months, the diets from visual observations represent the summer and fall season. Composition was calculated as the number of observations of tortoises foraging on a given species divided by the total number of foraging observations (n = 141).

Tortoise fecal samples were collected to represent low, medium and high elevations of the study area. The summarized fecal sample data only represents summer and fall diets. Information used to determine tortoise diet composition was gained from fecal sample analysis conducted by the Range Analysis Lab at the University of Arizona.

Coupled with the diet study, forage production was collected on the study area. Permanent production transects and directions of sampling were randomly selected. Cool season annual production was sampled in the spring and perennial plant production was clipped following the summer rainy season. Each location data set was obtained by clipping current year production from ten 9.6 square foot plots placed fifteen steps apart. Production on shrubs was clipped up to five feet above ground level.

For this report the 1981 spring and fall vegetation data set was selected for comparisons because the annual and seasonal precipitation was near average for the area in that year. Production on the lower elevation Upper Sonoran Desert Shrub Resource Area was 1,481 pounds per acre with 45% of the production cool season annual grasses and forbs and 49% shrubs. Composition on this site was 49% shrubs, 37% grasses and 14% forbs (Appendix A Table 2). Production on the mid elevation Semi-desert Grassland Loamy Upland site was 993 pounds per acre with approximately 39% cool season annual grasses and forbs. Vegetative composition on this site was 25% shrubs, 43% grasses and 31% forbs (Appendix A Table 3). Production on the mid elevation Semi-desert Grassland Limy Slope site was 975 pounds per acre with approximately 61% cool season annual grasses and forbs. Composition on this site was 11% shrubs, 36% grasses and 53% forbs (Appendix A Table 4). Production on the upper elevation Semi-desert Grassland Granitic Hills site was 595 pounds per acre with approximately 50% cool season annual grasses and forbs. Composition on this site was 25% shrubs, 32% grasses and 43% forbs (Appendix A Table 5).

The desert tortoises in the study area ate a great diversity of plant species. Both observations and fecal samples indicated that tortoises ate prickly pear fruit, catclaw acacia, curly mesquite, annual and perennial threeawns, lotus, globe mallow and a variety of other shrubs, forbs and grasses. At the lowest elevations, slender janusia was a preferred species. At the higher elevations where grasses were abundant, grass was dominant in the diets. A variety of forbs were consumed but none appeared to be highly selected. Tortoises were also often observed eating Bermuda grass and annual grasses and forbs on the abandoned farm sites.

The general tortoise diet determined from visual observations showed a high preference for grasses; 61.6% of the diet was grasses with approximately 31.2% sixweeks threeawn (*Aristida adscensionis* L.), 6.4% needle grama, (*Bouteloua aristidoides* (Kunth) Griseb), followed by Arizona panicgrass (*Urochloa arizonica* (Scribn. & Merr.) O. Morrone & F. Zuloaga) at 3.6% (Appendix A, Table 1). The major forage shrubs were the fruits of Engelman's prickly pear (*Opuntia engelmannii* Salm-Dyck ex Engelm) 15.6%, flattop buckwheat 2.8% and guajilla 2.1%. The major forage forb was filaree (*Erodium cicutarium* (L.) L'Hér. ex Aiton) at 2.8%.

The tortoise diets calculated from fecal samples for the Upper Sonoran Desert Shrub study area, population Cell 5, showed a strong preference for slender janusia, a small woody vine, and constituted 65% of the diet (Appendix A, Table 2). Grasses were 21% of the tortoises' diets with threeawns making up 13.6% and grama grasses making up 2.3% of the diet. Approximately 14% of diets were forbs with globe mallow (*Sphaeralcea ambigua* A. Gray) making up 11.6%. Slender janusia also was the preferred diet item on the Loamy Upland and Limy Slope sites on the Semi-desert Grassland Areas. On the Loamy Upland site in Cell 2, slender janusia made up 42.1% of the diet with other shrubs making up 5% (Appendix A, Table 3). Grasses were 45.2% of their diets with threeawns, curly mesquite and grama grasses making up 11.8%, 10.5%, and 8.2% of the grasses respectively. Numerous forbs made up 7.8% of the diet. Again slender janusia was the major shrub at 12.6% on the Limy Slope sites in Cells 3 and 4 (Appendix A, Table 4). Grasses made up 46.8% of the diets with grama grass 19%, threeawns 17.2% and other grasses 10.6%. Forbs made up 38.3% of the diets with foothill lotus (*Lotus humistratus* Greene) 15.5% and globe mallow at 13.9%. Shrubs only made up 2.8% of the tortoise diets on the Granitic Hills site on the Semi-desert Grasslands in Cell 1 (Appendix A, Table 5). Grasses made up 82.7% of the tortoise diets on this site with grama grasses at 54.1%, curly mesquite 14.7% and other grasses 13.9%. Forbs made up 14.4% of the diets on this site; half of those forbs were globe mallow. Vaughan (1984) and Van Devender et al. (1993) found similar diets for Sonoran desert tortoises in the Upper Sonoran Desert Shrub vegetation community in the Tucson Mountains and on Picacho Peak. The results of the microhistological (fecal) study of Mojave desert tortoises by Hansen et al. (1976) in western Arizona and southern Utah also had similar results to those on the Semi-desert Grassland areas of this study.

Tortoise Health

The general health of tortoises on the study area was observed and recorded throughout the monitoring period. The overall apparent health of tortoises was good. After major storm events tortoises tended to visit the licks more often and consumed more calcium carbonate than during dry periods. This characteristic is not fully understood but may have some nutritional implications. Marlow and Tollestrup (1982) found similar behavior in their study of the Mojave desert tortoise and suggest that female tortoises use these sites to replenish their depleted calcium reserves after development of egg shell. The eighteen year study revealed that all sexes and all age groups commonly utilized the licks. An unidentified species of tick was a fairly common external parasite found on tortoises across the study area but appeared to be isolated to locations along their necks. The occurrence of cactus spines was very common on the legs and necks of tortoises but no abscesses were observed from these spines. Several other maladies were observed. Some tortoises, especially young ones, had part of a leg damaged or missing. For example, Tortoise #B, a 1984 hatchling, was first tagged in 1984 and recaptured in 1985; at some time between the two sample dates the lower portion of its left front forelimb had been severed and was scarred over. This tortoise continued to be monitored at several different locations through the end of the study in 1997. Despite what appeared to be a devastating injury that occurred at a very young age, this tortoise continued to be quite mobile and to live and grow large enough for the observer to feel fairly confident in determining its sex as a female in 1994. Several tortoises' eyes were opaque and appeared to be blind. Both eyes of Tortoise #173 on the western side of the study area were opaque and that tortoise was commonly associated with another tortoise that used the same den. A common observation on many of the older tortoises was damage to the posterior marginal scutes. The damage consisted of gnawed areas that in some cases removed more than half of the scute. A number of older tortoises had large portions of the shell on their costals missing and some had bone showing on both the scutes and costals. This damage was also consistent with rat gnawing.

In August 1996 a cooperative health study was conducted in cooperation with Dr. Vanessa Dickinson from the non-game branch of the Arizona Game and Fish Department. The intent of the study was to gain physiological information about the free ranging tortoises on the study area. Eight male and seven female tortoises were collected from across the study area on August 27, 1996. These tortoises were examined with the intent to collect samples for analysis for upper respiratory tract disease (URTD) (*Mycoplasma agassizii* sp. nov.) (Brown et al. 2001), bacteria and blood chemistry.

Each tortoise was immobilized when the samples were taken by placing it upside down atop a three pound coffee can. Blood samples were taken from the jugular vein and nasal aspirates were taken by swabbing the nares after flushing them with saline solution. Cloacal bacteria were collected from fecal material and by swabbing the cloaca (Figure 21). For a more detailed description of these methods see Dickinson et al. (1995). After the samples were taken, each tortoise was rehydrated by injecting a mix of normosol and dextrose into the body cavity between the neck and front leg (Figure 22). The amount of rehydrating solution given each tortoise was based on 1-2% of its body weight. After the samples were taken and it was rehydrated, the tortoise was observed for a period of time to make sure there were no ill effects caused by the handling and sampling. On August 28 each tortoise was taken back and released at the site from which it was collected.

Figure 21. Collecting the cloacal bacteria sample from a desert tortoise with a swab.

Figure 22. Rehydrating the tortoise by injecting fluid into its body cavity.

Blood and fecal samples and nasal and cloacal swabs were sent to the Animal Diagnostic Laboratory Inc. at the University of Arizona. in Tucson to evaluate blood chemistry and the presence of URTD and cloacal bacteria. Additional blood samples were sent to ANTECH Diagnostics in Irvine, California, to evaluate the blood hematology and look for blood parasites. Additional blood samples were sent to the University of Arizona Department of Veterinary Science to evaluate the blood plasma levels of vitamins A and E.

Immunological analyses indicated three tortoises suspect for upper respiratory tract disease (Table 4) although none of the three showed any physical signs of URTD as defined in Jacobson (1991) and Brown (1994). Those suspects were male #311 and female #340 from population Cell 6 and male #394 from population Cell 7. These cells are located in the lower elevations of the eastern portion of the study area. Tortoises sampled from the other population cells were all negative for URTD. All tortoises sampled had two of three different cloacal bacteria. Five tortoises were found to have several Pseudomonas species; one of those tortoises was from Cell 3, two tortoises were from Cell 6, and two were from Cell 7. No tortoises were found to have Salmonella or blood parasites. It appeared that all "normal" parameters were based upon analyses of Mojave desert tortoise data.

Table 4. Results of analyses of nasal swabs for URTD and cloacal exams of desert tortoises from the study area.

		Cloacal Analysis		
Tortoise	URTD	Enteric Flora	Pseudomonas spp	Salmonella spp
295 F[1]	neg	2 + Mixed flora	None	None
311 M[2]	Suspect	3 + Mixed flora	None	None
318 M	neg	3 + Mixed flora	None	None
319 F	neg	3 + Mixed flora	None	None
332 M	neg	2 + Mixed flora	2 species	None
340 F	Suspect	3 + Mixed flora	None	None
350 F	neg	3 + Mixed flora	2 species	None
351 F	neg	3 + Mixed flora	None	None
373 M	neg	3 + Mixed flora	None	None
394 M	Suspect	3 + Mixed flora	None	None
400 F	neg	3 + Mixed flora	2 species	None
441 F	neg	3 + Mixed flora	None	None
442 M	neg	3 + Mixed flora	3 species	None
443 M	neg	3 + Mixed flora	2 species	None
444 M	neg	3 + Mixed flora	None	None

[1] Female
[2] Male

The blood chemistry analyses show some differences between the male and female tortoises sampled (Table 5). On average female tortoises had higher triglycerides, cholesterol, calcium and albumin levels than males. Data presented in Rostal et al. (1994), Dickinson et al. (1995) and Henen (1997) show that these elevated levels are consistent with females that are probably in vitellogenesis, the process of yolk formation, via nutrients being deposited in the oocyte. The average levels of uric acid, total protein, phosphorus, potassium and vitamins A and B did not greatly differ between male and female tortoises. The hematological data show some differences in monitored parameters between male and female tortoises (Table 6). Both male and female tortoises had higher lymphocyte and eosinophil levels than normal. Lymphocytes ranged between 9% and 62% for the males and between 22% and 57% for the females. Eosinophil levels varied from 4% to 10% in the males and from 5% to 16% in the females. Data in Dickinson et al. (1995) and Jacobson et al. (1991) indicate that these high levels may be in response to infections by pseudomonas organisms and other infections. Blood platelets were estimated to be adequate in all tortoises sampled.

Table 5. Blood chemistry analyses for the tortoises sampled on the study area.

		Sample Data		Normal[3]	
Parameter		Male	Female	Male	Female
Uric acid	mg/dl	7.55	6.03	0-8	
Total protein	g/dl	3.7	4.1	2.4-4.5	2.5-4.5
Albumin	g/dl	1.46	1.71	1.3-2.2	1.0-2.5
Cholesterol	mg/dl	53.7	147.6	20-171	109-361
Triglycerides	mg/dl	28.1	243.3	4-160	18.2-816
Calcium	mg/dl	9.3	14.7	8.1-12	8.2-15
Phosphorus	mg/dl	2.6	3.3	1-3.7	2.2-9
Potassium	meq/l	4.0	3.8	2.7-4.8	2.6-5
Vitamin A	µg/ml	0.54	0.42	0.05-.8	0.05-0.9
Vitamin E	µg/ml	2.38	3.3	0.5-10.1	0.5-13.7

[3] Normal limits from data in Dickinson et al. 1995.

Table 6. Hematological data of the tortoises sampled on the study area.

		Sample Data		Normal	
Parameter	Unit	Male	Female	Male	Female
Hemoglobin	g/dl	11.3	11.4	8.3-14.2	7.6-12
White blood cell estimate (k/µl)	k/µl	8.5	6.1	1.5-10.2	1.7-8.5
Heterophils	%	38.4	32.1	46-81	
Lymphocytes	%	34.6	36.9	3-23	
Monocytes	%	0.02	1.14	0-2	
Azurophils	%	6.1	9.4	0-30	0-24
Eosinophils	%	6.1	9.4	0-36	0-88
Basophils	%	7.3	5.6	0-39	
Platelet estimate		Adequate			

DISCUSSION

The experiences and results from this study of the Sonoran desert tortoise in the San Pedro Valley of southern Arizona identified tortoise population characteristics in the study area and sampling problems during the study. In addition, the study identified numerous factors which influence the accuracy, precision and interpretation of desert tortoise population estimates.

Sampling Protocol

The sampling protocol for the eighteen year study period was developed early in the sampling process and remained consistent throughout the study. It was specific on details of sampling but flexible enough in sampling dates to adjust to when there was a good probability to achieve a reasonable sample number of tortoises. The primary author of this paper and field crew members live within the study area and could make the decision of when to sample in order to maximize sample size. Even though the same field crew collected the data throughout the study period, a written protocol was periodically reviewed to keep sampling consistent between sample periods. Appropriate sampling protocol is a major factor in determining estimated tortoise populations.

Sampling protocols for determining population estimates and trends must differ from protocols developed for the purpose of inventory (to determine the presence of tortoises). Inventory protocols require covering a large area quickly and only one time. Protocols for monitoring to determine population dynamics must require a more thorough, deliberate and consistent search along sample lines from one year to the next. For example, inventory plots were established in 1988 by Bureau of Land Management personnel in the San Pedro Valley area (Schnell and Drobka 1988). Three of these plots, in part, included areas within two of the population cells identified in this report. Only 2 tortoises were found for 30 hours of field time on these three plots plus a fourth plot. The eighteen year study recorded 91 tortoises on the same area. Data collected to determine if tortoises are present in an area should not be compared with well planned monitoring plot data.

Finding Tortoises

A major problem for observers during the early stages of this eighteen year study was just learning how to locate tortoises within the three different vegetation types, different topographic regions and geologic units within the study area. Tortoise resting locations and movement patterns were different among the three different vegetation and terrain units. A key lesson learned to find tortoises when walking the cruise transects was to occasionally stop and take sightings down the transect line, listen, and watch for movement.

In addition to having to learn how to spot tortoises when walking a monitoring transect route, the field crew needed to time samplings to when tortoises were active. The greatest tortoise activity was generally observed after storm events. An exception was in July, August, and September of 1983 and 1984 when rainfall was much greater than average for the study area. Very few tortoises were observed during this time frame. Sample numbers were also low during the 1989 drought. Duda et al. (1999) report similar observations in their drought study on the Mojave tortoise. When precipitation was adequate to produce excess forage, tortoises were less active because they did not need to travel very far from the burrow to forage, and they were also less active during drought.

Seasonal activities of tortoises during the eighteen years of this study were greatest in July through September with highest activity in August. A few tortoises could be found during every month of the year, but not in great enough numbers to obtain an adequate sample to determine population estimates. These observations of the Sonoran desert tortoise are consistent with Averill-Murray and Klug (2000) who state that "…spring and winter activity increases with increasing rainfall during those seasons. Spring foraging appears to be important, especially for females, since ovarian follicles mature during spring." This period of activity is different from that of the Mojave desert tortoise population. Nagy and Medica (1986) found that in Nevada the aboveground activity of Mojave desert tortoises extended through the March and November warm seasons but during the droughty period between June and early July the aboveground activity was reduced. O'Conner et al. (1994) and Boarman and Beaman (2002) state that the Mojave desert tortoises are primarily active between May and June and have a secondary period of activity from September through October.

Spatial Distribution of Tortoises

The eighteen year study revealed that tortoises were not randomly dispersed across the study area. They were concentrated into seven well-defined "population cells", although there were numerous individuals observed at other sites across the study area. These cells were located on all three vegetation and topographic units. They were located on deep limy and clayey soils with fairly level to steep slopes and on very stony and cobbly, shallow soils on hillsides at both lower elevations and upper elevations. These population cells and interspaces between them revealed a problem with using small sample areas (i.e. one square mile) for estimating population dynamics. If a small plot falls within a cell containing many tortoises, the sample provides a high tortoise population estimate. If the plot falls in an area outside a cell that contains few or no tortoises, there will be a bias downward in the population estimate. To achieve accuracy in estimating tortoise populations, sample areas must be large enough to encompass both areas of low density and areas of high density.

Estimating Tortoise Populations

The sample data over the eighteen years illustrate sample characteristics over a large range of sample sizes, numbers of tagged tortoises and proportions of newly tagged to recaptured tagged tortoises in the sample. Annual tortoise population estimates can be compared and biases in tortoise sampling can be identified.

Between 1980 and 1984 there were 37 tortoises tagged on the study area. In 1984, 20 tortoises were sampled; nineteen of these tortoises were newly tagged and 1 tortoise was a recapture. A population estimate was calculated using these numbers and the estimated population was 740 tortoises. This is an obvious outlier data point, as it was not until 1990, with approximately 400 tortoises tagged, that the population estimate again exceeded 700.

The answer to why such a high estimate occurred in 1984 can be found by examining the primary assumption of the Lincoln Index used to calculate estimated numbers for this study. This assumption is that the proportion $M/N = x/n$. This proportion is equal when the cross products of the proportion are equal, $Mn = Nx$ or $N = nM/x$. M is the number of tortoises tagged, N is the population estimate, x is the recaptured tagged tortoises, and n represents sample size. Sample size (n) is the sum of the newly tagged tortoises and recaptured tagged tortoises. Random samples fit a binomial distribution except when a very small portion of the tortoise population is tagged.

When the number of total tagged tortoises is a small portion of the total population, finding a tagged tortoise is a rare event. The probability of finding a rare, tagged tortoise does not fit a binomial distribution curve. The probability curve is skewed to a higher probability of finding a low estimate of the tagged tortoises (Poisson distribution). The ratio of x/n in the 1984 sample is 1 to 20. This low estimate of x biases the population estimate upward. Low precision with small sample numbers intensifies the problem.

From the beginning of the study in 1980 until 1988, the newly tagged tortoises were more abundant in the sample data than recaptured tagged tortoises, except for in 1986. In the 1986 sample of 41 tortoises, x/n was near 1 to 2. The sample ratio of x/n in 1987 is about 1 to 3. With a sample number near 125, this 1987 ratio is a more precise estimate of an expected ratio of x/n at this time in the study. The 1 to 2 x/n ratio in the 1986 sample resulted in a relatively low tortoise population estimate, apparently due to low sample precision associated with the low sample size.

The summer of 1989 was very dry and the sample number dropped from 183 in 1988 to 67 in 1989. The x/n ratio shifted to 2 to 3, with recaptured tagged tortoises representing more than half of the sample population. During this period of the study, the expectation for the ratio should have been about 1 to 2, based on 1987 and 1988 data with higher sample numbers and better sample precision. The shift to a 2 to 3 x/n ratio was extreme and resulted in a lowered estimated tortoise population. This low estimate appears to be the result of low precision with a relatively low sample size. The sample size of 67 is less than 10% of the estimated population determined in 1990.

A sample protocol which is biased to improve the probability of finding recaptured tagged tortoises (x) results in low population estimates. Also, observations during this study found that newly tagged tortoises were recaptured frequently the same year as tagged, often multiple times. This was assumed to cause a downward bias in population estimates, so population estimates were computed without the newly tagged tortoise numbers for the year in which they were tagged. Data collected with a sample protocol to mark and recapture during the same sample season likely will over estimate x and have a bias to underestimate tortoise populations.

Sample numbers in both 1988 and 1990 were the highest for the study period (about 180). This is a 25% sample of the 1990 population estimate. The x/n ratio in 1988 was slightly less than 1 to 2 and in 1990 slightly greater than 1 to 2. The summer precipitation was near average. Between 1988 and 1990, the high portion of newly tagged tortoises in the sample during the first years of the study shifted to being the lower portion of the sample for the rest of the study. The number of tagged tortoises at the beginning of 1988 was near 300 and near 400 at the beginning of 1990. The interpretation is that the tagged portion of the population is near 50 percent at this time period of the study, and the population mean can be estimated to be between 600 and 800. This estimate of confidence intervals closely matches the calculated confidence intervals for the tortoise population in 1990 which is near 700 ± 100 tortoises.

The 1992 data represent another year with a low (near 40) sample number. The x/n ratio for this sample is about 1 to 2 and is an under estimate of the recaptured tagged tortoises, compared to 1992 data with a 2 to 3 x/n ratio and greater sample number. The low estimate of the recaptured tagged tortoises (x) increased the estimated tortoise population. This result reinforces the observation that an over estimate of x provides a low population estimate, and an under estimate of x results is a high estimate of the population.

The declining rate of increase in the cumulative total tagged tortoises after 1990 is expected, as there are fewer and fewer untagged tortoises remaining in the population. In fact, with a continuation of the study until all tortoises are tagged, the ratio is expected to approach x/n = 1 and N = M. The x/n ratio, however, remains near 2 to 3 for the 1993 to 1997 period. This lower than expected x/n ratio increases the tortoise population estimate. The implication is that the approximately 30 newly tagged tortoises each year represent recruitment to the population.

The tortoise population at the end of the study is best estimated by the 1996 data, as it is based on a greater sample number and is a more precise estimate than the 1997 sample data. The 1996 estimated tortoise population on the 23.3 square mile study area is near 800 ± 200 tortoises, an average of 34 ± 9 tortoises per square mile, but not randomly distributed. This estimate is an increase of 100 tortoises since the 1990 estimate of 700 ± 100 tortoises (30 ± 4 tortoises per square mile). This increase in estimated tortoise numbers from 1990 to 1996 cannot totally be attributed to recruitment in the population. The cumulative number of tagged tortoises (M) also contributes a bias toward higher population estimates, as the assumption is that all the tagged tortoises are still alive. The sample of dead tagged tortoises is too small to provide an estimate of tagged tortoise death loss, so information is not available to determine if the recruitment may represent an increasing or stable tortoise population.

Two brief experimental samples were made on two different population cell locations in September of 2009 by field crew members involved in the eighteen year study. Precipitation in the summer of 2009 was well below average. The first sample day involved two observers who spent nine man hours and observed 13 tortoises, 3 of which were already tagged and 10 were not tagged. On the second day, approximately 5 hours were spent by one observer who located 4 tortoises, two of which were tagged and two were not. Thus, 14 man hours of survey found 17 tortoises, 5 tagged (during the 1980 to 1997 study) and 12 untagged. Sample size was small but does show that tortoises are still present in 2009, and the population includes both tagged and untagged tortoises. New recruitment to the population over the twelve years since the end of the eighteen year study could account for the relatively higher portion of untagged tortoises in this small sample.

Livestock Grazing Effects

The following photos, taken near population Cell 5, reveal that the vegetation throughout the study area has undergone a very striking change between 1904 and 2009 (Figure 23). The upper photo, taken in 1904, shows an open rangeland with scattered shrubs, mostly jojoba. The lower photo, taken in 2009, shows a similar area with numerous palo verde, cactus, jojoba and other shrubs. No documentation exists on the numbers of tortoises in this area in 1904 or how tortoise numbers were affected with the increase in livestock numbers between the early 1900's and the mid 1930's. Regardless of past grazing history, there appears to exist a reasonably large population of tortoises across this area. At no time during or after this study have the samplers ever observed any interaction between livestock and tortoise. No tortoise den was found collapsed or otherwise impacted by livestock nor was any tortoise ever found crushed by a livestock hoof.

The data show that estimating the densities of desert tortoise on the four different livestock grazing systems gave mixed results. The heavily grazed pasture and the pastures that were managed under a rest rotation system had the highest tortoise densities. The lightly grazed pasture had a lower tortoise density than either the rest rotation system or the heavily grazed pasture. The moderately grazed pastures had the lowest tortoise density of all the pastures. Tortoise densities on the different grazing systems were confounded by differences in vegetation, topography, soils, and the distribution of tortoise population cells on specific favored habitat within the different vegetation and terrain units within these pastures. The heavily grazed pasture had two cells; one cell had steeply dissected terrain on deep limy soils and the second cell had very shallow stony soils. There were very few flat to gently sloping areas in this pasture. The rest rotation pastures, pastures in which livestock are seasonally grazed at different times of the year, were very similar to the heavily grazed pasture in that they contained more than one tortoise population cell. One cell was on the same steeply dissected terrain with deep limy soils similar to that found on the heavily grazed area. Two of the cells appeared on very shallow stony to cobbly loam soils that have numerous rock outcrops. The moderate and lightly grazed pastures had one cell each that were on very shallow stony soils. Each of these last two pastures had a large amount of terrain that is relatively flat with deep sandy soils.

Age and Sex Ratios of Tortoises

There were 242 male tortoises observed throughout the study, with approximately 7% of the males very old, 21% old, 12% young and 1% very young (Table 3). Two hundred and eight female tortoises were observed with approximately 4% of them very old, 18% old, 16% young and less than 1% very young. Approximately 14% of the population was sub-adults which were too young to have their sex determined. Population Cell 1 had the highest number of sub-adult tortoise observations than any of the other cells. There appeared to be sufficient recruitment of young to replace death loss.

Tortoise Diets

The tortoise diets on the lower elevation showed a strong preference for slender janusia (65%), a small woody vine, followed by grasses (21%) and forbs (14%). Tortoises on the mid elevation sites also showed a preference for slender janusia. At mid elevations, 47% of the diet was shrubs (42% was slender janusia), grasses were 45% and forbs were 8%. The diets of tortoises at the higher elevations were 3% shrubs, 83% grasses and 14% forbs. The diet data from the New Water Mountains near Yuma, the Grand Canyon in Mojave County and the Beaver Dam Wash in Washington County, Utah, are very similar to the diets of tortoises in the higher elevations of this study area (Hansen, et. al. 1976). Slender janusia was also a preferred species in those three studies. Tortoises were observed eating tortoise dung in both the Hansen study and in this eighteen year study. Overall tortoises had a varied diet.

Tortoise Health

No tortoises were observed with swollen eyes or runny noses or other symptoms of upper respiratory disease. No report of concern was received from the Arizona Game and Fish Department regarding their testing of 15 tortoises from the study area in 1996. No tortoise was ever observed with lesions or disease of its carapace. Several tortoises appeared to be blind or partially blind. Some had portions of their legs missing but appeared to be able to recover from the injuries. Many had gnawed areas on their posterior marginal scutes, which were probably caused by wood rats. Many tortoises were observed with cholla spines stuck in their legs and necks but no abscesses were observed. An unidentified tick specie was observed on a number of tortoises' necks. Few dead tortoises were observed throughout the eighteen year study. Overall, the apparent health of tortoises on the study area was good.

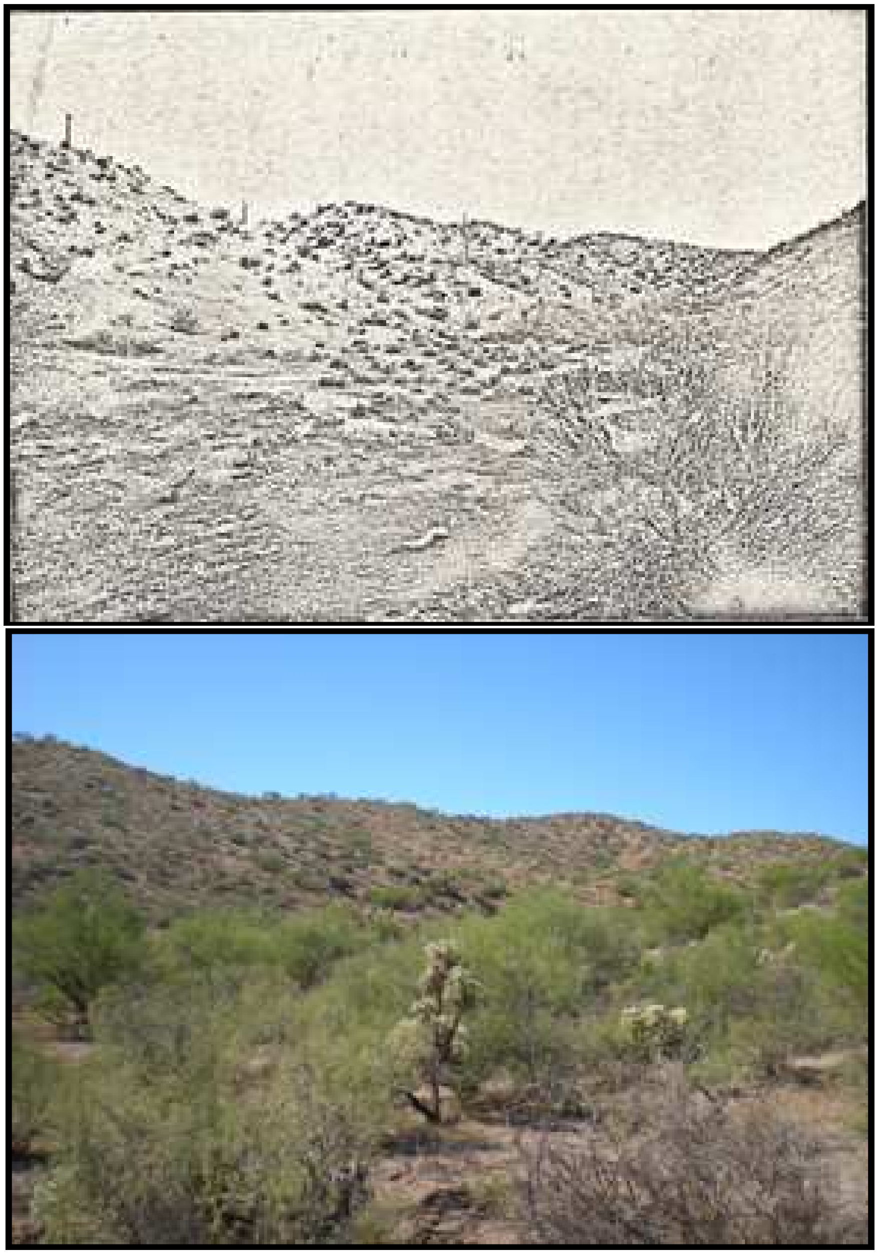

Figure 23. Photos illustrating change in vegetation in the Dudleyville, Arizona, area between 1904 and 2009. The lower photo was taken near the upper photo location.

CONCLUSIONS

The monitoring study reported in this paper is unique in that the spatial area monitored was large at 23.3 square miles, it was long duration (eighteen years), a large number of tortoises were tagged (577) and the sampling crew was the same throughout the study period.

To achieve precision and accuracy in collecting tortoise data, it is essential to develop a written sampling protocol that is specific on sampling details but flexible enough in dates for sampling to adjust for achieving a reasonable sampling of tortoises. It is also imperative that the written protocol be periodically reviewed by the monitoring team to maintain consistency in the monitoring data between sampling periods. Knowledge and experience of samplers is crucial in order to locate tortoises across different geologic and vegetation units.

Tortoise activity was dependent upon temperature, season and precipitation. Greatest activity was observed after summer storm events when male, female and juvenile tortoises commonly congregated in areas with deposits of calcium carbonate (licks) where they ate the limy soils and mated and where the most aggression was displayed by the males. Licks appeared to play a crucial role in tortoise distribution. Tortoise activity was greatly reduced by drought.

Tortoises on the study area were mainly in seven well defined population cells that were located either on steeply-sloped rocky topography with cobbly to stony shallow soils or on fairly dissected topography with limy soils. The population cells were present in the three different vegetation types and at the different topographies at different elevations. No population cell was located on flat topography with sandy to coarse sandy soils although widely dispersed individual tortoises were observed on these areas. These population cells and interspaces between cells illustrate the necessity for appropriate experimental design. If small study areas are placed within the population cells there would be a high tortoise population estimate; conversely, if small study areas are placed between population cells there would be bias downward in the population estimate

When the total number of tagged tortoises is a small portion of the total tortoise population, the tendency is to over estimate the total population. When the number of tagged tortoises nears or is greater than 50% of the population, then the population can be estimated with greater accuracy. The lack of knowledge of death rate and recruitment further complicates making further population estimates. It cannot be assumed that tortoises that were unobserved for ten or more years were dead. The estimated population of tortoises on this 23.3 square mile study area was near 800 ± 200 tortoises which equates to an average density of 34 ± 9 tortoises per square mile.

Generalities about the effects of livestock grazing on desert tortoises should be avoided unless they can be placed in the context of a grazing regime, effective precipitation, habitat type, topography, and tortoise behavior and requirements. Tortoise densities between heavily grazed and rest rotation systems were similar. The lightly grazed system had the lowest tortoise density. This does not imply by any means that heavy livestock grazing is beneficial to tortoise densities. It appeared that tortoise densities were affected by soil, topography and vegetation and had little or no relationship to livestock grazing or grazing systems.

There appeared to be appropriate ratios of male to female and young to old tortoises in the study area. Recruitment of young tortoises appeared to be adequate to replace death loss, however actual death loss was unknown since few dead tortoises were observed. Tortoises had a varied diet that consisted of a mix of shrubs, grasses and forbs. No tortoise health concerns were illuminated in this study. All tortoises appeared to be healthy. Many endured common maladies stemming from everyday activities but they were healthy enough to recover.

It is concluded that poor performance and bias of sampling procedures is driven by insufficient study length and plot sample size, inconsistent methodologies, inconsistent technician expertise and an overall lack of knowledge of desert tortoise behavior and life needs. It is essential that all efforts must be directed to increasing numbers of tortoises found in order to produce reliable results. Our results suggest that presently utilized methods may not be capable of accurately estimating desert tortoise populations.

APPENDIX A

Table 1. Composition of tortoise diets calculated as a percentage of visual observations of tortoises foraging, 1980-1990.

Table 2. Annual vegetative production, species composition, and tortoise diet composition on a Loamy Upland range site within the Central Arizona Basin and Range Upper Sonoran Desert Shrub Major Land Resource Area (Sample location #2 Population Cell 5).

Table 3. Annual vegetative production, species composition, and tortoise diet composition on a Loamy Upland range site within the Southern Arizona Semi-desert Grassland Major Land ResourceArea (Sample location #7 Population Cell 4).

Table 4. Annual vegetative production, species composition, and tortoise diet composition on a Limy Slope range site within the Southern Arizona Semi-desert Grassland Major Land Resource Area (Sample location #12 Population Cell 4).

Table 5. Annual vegetative production, species composition, and tortoise diet composition on a GraniticHills range site within the Southern Arizona Semi-desert Grassland Major Land ResourceArea (Sample location #12 Population Cells 1 and 2).

Table 1. Composition of tortoise diets calculated as a percentage of visual observations of tortoises foraging, 1980-1990.
(n = 141)

Species	Perennial (P) Annual (A)	% Comp.
Shrubs		
Calliandra eriophylla	P	2.1
Eriogonum fasciculatum	P	2.8
Janusia gracilis	P	1.4
Opuntia engelmannii	P	15.6
Simmondsia chinensis	P	1.4
Total		23.3
Grass		
Aristida adscensionis	A	31.2
Aristida arizonica	P	0.7
Aristida glauca	P	1.4
Bouteloua aristidoides	A	6.4
Bouteloua curtipendula	P	0.7
Bouteloua filiformus	P	0.7
Bouteloua rothrockii	P	0.7
Cynodon dactylon	P	2.1
Bouteloua barbata	A	0.7
Bromus rubens	A	0.7
Festuca octoflora	A	0.7
Hilaria belangeri	P	2.8
Muhlenbergia microsperma	A	1.4
Panicum arizonicum	A	3.6
Setaria macrostacha	P	0.7
Tridens muticus	P	2.1
Tridens pilchellus	P	0.5
Total		61.6
Forbs		
Amaranthus palmeri	A	1.4
Ayenia pusilla	P	0.7
Boerhaavia coulteri	A	2.1
Cassis bauhinioides	P	0.7
Erodium cicutarium	A	2.8
Eriogonum deflexum	A	0.7
Euphorbia spp	A/P	1.4
Perezia nana	P	0.7
Perezia wrightii	P	0.7
Porophyllum gracile	P	0.7
Sida neomexicana.	P	0.7
Total		12.6
Other		
Tortoise dung		0.7
Total		98.2

Table 2. Annual vegetative production, species composition, and tortoise diet composition on a Loamy Upland site within the Central Arizona Basin and Range Upper Sonoran Desert Shrub Major Land Resource Area (Sample location # 2 Population Cell 5).

Species	Perennial (P) Annual (A)	Production lb/A	% Comp.	Tortoise Diet % Conp. *
Shrubs				
Calliandra eriophylla	P	166	11.2	
Cercidium microphyllum	P	18	1.2	
Eriogonum fasciculatum	P	48	3.2	
Haplopappus laricifolius	P	10	0.7	
Janusia gracilis	P	48	3.2	65.0
Menodora scabra	P	44	3.0	
Simmondsia chinensis	P	392	26.5	
Total		726	49.0	65.0
Grass				
Aristida spp.	A/P	90	6.1	13.6
Bouteloua spp	P	---	---	2.3
Bromus rubens	A	432	29.2	
Festuca octoflora	A	1	0.1	
Hilaria belangeri	P	---	---	1.3
Hordeum pusillum	A	---	---	1.9
Schixmus barbata	A	28	1.9	0.4
Unknown		---	----	1.9
Total		551	37.3	21.4
Forbs				
Astragalus sp.	A	1	0.1	
Ayenia pusilla	P	---	---	1.7
Erodium cicutarium	A	164	11.1	
Eriastrum diffusum	A	2	0.1	
Eriophylum pringlei	A	4	0.3	
Lotus humistratus	A	1	0.1	
Pectocarya setosa	A	8	0.5	
Plagiobothrys arizonicus	A	4	0.3	
Plantago purshii	A	20	1.4	
Sphaeralcea ambigua	P	---	---	11.6
Unknown		---	---	0.4
Total		204	13.9	13.7
Total		1,481	100.2	100.1

* n = 2

Table 3. Annual vegetative production, species composition, and tortoise diet composition on a Loamy Upland site within the Southern Arizona Semi-desert Grassland Major Land Resource Area (Samplelocation #7 Population Cell 2).

Species	Perennial (P) Annual (A)	Production lb/A	% Comp.	Tortoise Diet % Conp*
Shrubs				
Acacia constricta	P	---	---	0.3
Acacia greggii	P	12	1.2	1.5
Calliandra eriophylla	P	154	15.4	
Eriogonum wrightii	P	26	2.6	
Haplopappus tenuisectus	P	4	0.4	
Hymenoculea monogyra	P	---	---	1.1
Janusia gracilis	P	---	---	42.1
Opuntia violacea	P	38	3.8	
Prosopis juliflora	P	18	1.8	
Simmondsia chinensis	P	---	---	0.3
Total		252	25.2	47.1
Grass				
Aristida spp.	A/P	46	4.6	11.8
Bouteloua spp	P	140	14.0	8.2
Bromus rubens	A	106	10.6	0.5
Cynodon dactylon	P	---	---	1.1
Eragrostis spp.	A/P	---	---	0.5
Festuca octoflora	A	2	0.2	
Hilaria belangeri	P	140	14.0	10.5
Hordeum pusillum	A	---	---	0.3
Lycurus phleoides	P	---	---	0.3
Muhlenbergia spp	A/P	---	---	0.5
Panicum arizonicum	A	---	---	5.0
Trachypogon sp.	P	---	---	2.2
Tridens pilchellus	P	---	---	0.3
Unknown		---	---	4.0
Total		434	43.4	45.2
Forbs				
Ayenia pusilla	P	----	----	0.5
Erodium cicutarium	A	84	8.4	
Franseria confertiflora	P	2	0.2	
Lotus humistratus	A	2	0.2	0.3
Lupinus sp	P	1	0.1	1.5
Pectocarya setosa.	A	6	0.6	
Plagiobothrys arizonicus	A	12	1.2	
Plantago purshii	A	174	17.4	
Sida sp.	A	----	----	0.3
Sphaeralcea ambigua	P	26	2.6	1.8
Sida sp.	A	----	----	7.1
Stephanomeria pauciflora	A	----	----	0.3
Unknown		----	----	3.4
Total		307	30.7	7.8
Total		993	99.3	100.1

* n = 6

Table 4. Annual vegetative production, species composition, and tortoise diet composition on a Limy Slope site within the Southern Arizona Semi-desert Grassland Major Land Resource Area (Sample location #12 Population Cells 3 and 4).

Species	Perennial (P) Annual (A)	Production lb/A	% Comp.	Tortoise Diet % Conp*
Shrubs				
Acacia greggii	P	----	----	0.3
Calliandra eriophylla	P	18	1.8	
Encelia farinosa	P	22	2.2	
Eriogonum wrightii	P	20	2.0	
Haplopappus laricifolius	P	2	0.2	
Janusia gracilis	P	----	----	12.6
Hymenoclea monogyra	P	----	----	1.5
Krameria parvifolia	P	----	----	0.3
Simmondsia chinensis	P	46	4.7	----
Total		108	10.9	14.7
Grass				
Aristida spp.	A/P	2	0.2	17.2
Bouteloua spp	P	46	4.7	19.0
Bromus rubens	A	232	23.7	
Festuca octoflora	A	1	0.1	
Hilaria belangeri	P	42	4.3	2.1
Hordeum pusillum	A	----	----	0.5
Muhlenbergia spp	A/P	----	----	1.1
Panicum arizonicum	A	----	----	
Tridens pilchellus	P	26	2.7	
Trachypogon sp.	P	----	----	0.5
Unknown		----	----	2.5
Total		349	35.7	46.8
Forbs				
Ayenia pusilla	P	----	----	0.5
Descurainia Sophia	A	6	0.6	
Erodium cicutarium	A	346	35.4	
Euphorbia sp.	A/P	14	1.4	
Franseria confertiflora	P	10	1.0	
Lotus humistratus	A	----	----	15.5
Pectocarya setosa.	A	4	0.4	
Perezia wrightii	P	----	----	0.3
Plagiobothrys arizonicus	A	10	1.0	
Plantago purshii	A	120	12.3	
Sida sp.	A	----	----	7.1
Sphaeralcea ambigua	P	2	0.2	13.9
Stephanomeria pauciflora	A	----	----	0.5
Tragia sp	P	6	0.6	
Unknown		----	----	0.5
Total		518	52.9	38.3
Total		975	99.5	99.8

* n = 6

Table 5. Annual vegetative production, species composition, and tortoise diet composition on a Granitic Hills site within the Southern Arizona Semi-desert Grassland Major Land Resource Area (Sample location #12 Population Cell 1).

Species	Perennial (P) Annual (A)	Production lb/A	% Comp.	Tortoise Diet % Conp. *
Shrubs				
Calliandra eriophylla	P	118	19.8	
Clematis drummondii	P	----	----	1.8
Dasylirion wheeleri	P	6	1.0	
Eriogonum wrightii	P	2	0.3	
Krameria parvifolia	P	24	4.0	1.0
Total		150	25.1	2.8
Grass				
Aristida spp.	A/P	6	1.0	5.0
Bouteloua spp	P	78	13.2	54.1
Bromus rubens	A	104	17.5	
Festuca octoflora	A	2	0.3	
Hilaria belangeri	P	----	----	5.0
Trachypogon sp.	P	----	----	14.7
Unknown		----	----	3.9
Total		190	32.0	82.7
Forbs				
Anemone tuberose	P	----	----	1.8
Amsinckia intermedia	A	1	0.2	
Cassia covessii	P	----	----	1.8
Erodium cicutarium	A	100	16.8	
Euphorbia sp.	A/P	58	9.7	
Evolvolus sp	P	2	0.3	
Lotus humistratus	A	1	0.3	
Pectocarya setosa	A	2	14.5	
Plantago purshii	A	86	----	2.9
Sphaeralcea ambigua	P	----	----	7.9
Unknown		255	42.9	14.4
Total				
Total		595	100.0	99.9

* n = 2

SELECTED REFERENCES

Adams, Lowell. 1951. Confidence Limits for the Petersen or Lincoln Index used in Animal Population Studies. Jour. Wildlife Manage. 15: 13-19.

Allan, Larry S. 1989. Roots of the Arizona Livestock Industry. Rangelands 11: 9-13.

Anderson, D. R. and R. S. Pospahala (1970) Correction of Bias in Belt Transect Studies of Immotile Objects. Jour. Wildlife Manage. 34: 141-146.

Averill-Murray, R. C., and C. M. Klug 2000. Monitoring and Ecology of Sonoran Desert Tortoise in Arizona. Technical Report 161, Non-game and Endangered Wildlife Program Arizona Game and Fish Department. Phoenix, Arizona

Bailey, Scott Jay.1992. Hibernacula use and Home Range of the Desert Tortoise (*Gopherus agassizii*) in the San Pedro Valley. M. S. Thesis. Univ. Ariz. 82 p.

Barrett, Sheryl L. 1990. Home Range and Habitat Of the Desert Tortoise (*Xerobates agassizi*) in the Picacho Mountains of Arizona Herpetologica, 46 : 202-206

Berry, Kristin H., David J. Morafka, and Robert W. Murphy 2002. Defining the Desert Tortoise(s): Our First Priority for a Coherent Conservation Strategy. Chelonian Conservation and Biology, 4: 249-262

Boarman, W. I. and K. Beaman. (Ed) 2002. The Sensitive Plant and Animal Species of the Western Mojave Desert. U.S. Geological Survey, Western Ecological Research Center, Sacramento, Ca.

Bogert, Charles. M. 1937. Notes on the Growth Rate of Desert Tortoise, *Gopherus agassizi* Copeia 3:191-192

Boguslavsky, G. W. 1956. Statistical Estimation of the Size of a Small Population Science, 124 : 317-318

Bostick , V. 1990. The Desert Tortoise in Relation to Cattle Grazing. Rangelands 12 :149 - 151

Brown, M. B., D. R. Brown, I. M. Schumacher, P. A. Klein, K. Harris, Terrie Correll, and E. R. Jacobson 1994. *Mycoplasma agassizii* Causes Upper Respiratory Tract Disease in the Desert Tortoise. Infection and Immunity 62:4580-4586

Brown, M. B., D. R. Brown, P. A. Klein, G. S. McLaughlin, I. M. Schumacher, E. R. Jacobson, H. P. Adams and J. G. Tully. 2001. *Mycoplasma agassizii* sp. nov., Isolated from the Upper Respiratory Tract of the desert tortoise (*Gopherus agassizii*) and the Gopher Tortoise (*Gopherus polyphemus*). Int, Jour. of Systematic and Evolutionary Microbiology. 51:413-418

Bulova, Susan J. 1994. Patterns of Burrow use by Desert Tortoises: Gender Differences and Seasonal Trends. Herpetological Monographs, 8 : 133-143

Bury, Bruce R., Paul S. Corn 1995. Have Desert Tortoise Undergone a Long-term Decline in abundance? Wildlife Society Bull, 23 : 41-47

Chapman, D. G. 1948. A Mathematical Study of Confidence Limits of Salmon Populations Calculated from Sample Tag Ratios. International Pacific Salmon Fish Comm. Bull. 2:69-85.

Chapman, D. G. and W. S. Overton, 1966. Estimating and Testing Differences Between Population Levels by the Schnabel Estimation Method. Jour. Wildlife Manage. 30: 173-180.

Cook, C. Wayne, Harold H. Biswell, R. T. Clark, E. H. Reid, L. A. Stoddart, M. L. Upchurch 1962. Range Research Basic Problems and Techniques. Pub. 890 National Academy of Science-National Research Concil. Washing, D. C.

Conner, Michael J. 1989. Molecular Biology and the Turtle: The Desert Tortoise and its Relatives. Tortuga Gazett 25(8): 10-11

Cordery, T. E., T. A. Duck, T. C. Esque and J. J. Slack 1993. Vegetation needs of the Desert Tortoise (*Gopherus agassiziii*) in the Sonoran and Mojave Deserts. Symposium on Vegetation Management of Hot Desert Rangeland ecosystems Phoenix Arizona 61 – 80 p.

Croxen, Fred W.1926. History of Grazing on Tonto. Paper given at the Tonto Grazing Conference in Phoenix, Arizona 7 p.

Daugherty, P. M., H. H. Sineath and T. A. Wastler 1958. Industrial Raw Materials of Plant Origin. IV A Survey of *Simmondsi Chinensis* (Jojoba). Economic Botany. 3: 296-306.

Dickinson, Vanessa. M., Timothy Duck, Cecil Schwalbe and James L. Jarchow, DVM. 1995. Health Studies of Free-Ranging Mojave Desert Tortoise in Utah and Arizona. Arizona Game and Fish Department Research Branch. Technical Report No. 21 70 p.

Duda, JJ, Krzysik AJ and Freilich JE. 1999. Effects of Drought on Desert Tortoise Movement and Activity. Jour.Wildlife Manage 63 : 1181-1192

Duda, J. J., Anthony J. Krzysik and Joel M. Meloche 2002. Spatial Organization of Desert Tortoises and their Burrows at a Landscape Scale. Chelonian Conservation and Biology 4 : 387–397

Duncan, D. K. 1989, Desert Tortoise Inventory Safford Districe BLM. U.S.D.I. Bur. Of Land Manage. Safford District

Eberhardt, L. L. 1968. A Preliminary Appraisal of Liner Transects. Jour. Wildlife Manage. 5: 412-415.

Erickson, Arnold B.1940. Notes on a Method for Cruising White-tail Deer in the Spring And Summer. Jour. Wildlife Manage. 4: 15-18.

Feldman, Sanford H., Jeffrey Wimsatt, Rachel E. Marchang, April J. Johnson, William Brown, Joseph C. Mitchell, and Jonathan M. Sleeman. 2006. A Novel Mycoplasma Detected in Association with Upper Respiratory Disease Syndrome in Free-ranging Eastern Box Turtles (Terrapene Carolina Carolina) in Virginia Journal of Wildlife Diseases, 42 : 279–289

Freilich, J. E., R. J. Camp, J. J. Duda and A. E. Karl 2005. Problems with Sampling Desert Tortoise: a Simulation Analysis Based on Field Data. Jour.Wildlife Manage 69 :45- 56

Germano, David J.1988. Age and Growth Histories of Desert Tortoises Using Scute Annuli. Copeia 4: 914-920

Germano, David J., R. Bruce Bury, Todd C. Esque, Thomas H. Fritts, and Philip A. Medica 1994. Range and Habitats of the Desert Tortoise. In: David J. Germano, R. Bruce Bury, eds. Biology of North American tortoises. Washington, D.C. U.S. Dept. of the Int., Nat. Bio. Survey, Fish and Wildlife Research. 73-84.

Giles, Robert H. ed.1971. Wildlife Management Techniques. 3rd. ed. The Wildlife Society. Washington, D. C. 633 p.

Griffiths, David 1901. Range Improvements in Arizona. U.S.D.A. Bur.of Plant Industry. Bull. No. 4 31 p.

Griffiths, David 1904. Range Investigations in Arizona. U.S.D.A. Bur.of Plant Industry. Bull. No. 67 68 p.

Grover, Mark C., Lesley A. De Falco 1995. Desert Tortoise (*Xerobates agassizii*) Status-of-Knowledge Outline With References. U.S.D.A. Forest Serv. Intermountain Research Station. Gen Tech Report INT-GTR-316. 140 p.

Hansen, Richard H. Mark K. Johnson and Thomas R. Van Devender 1976. Foods of the Desert Tortoise, *Gopherus agassizii*, in Arizona and Utah. Herpetologica 32: 247 -251

Hastings, James R., and Raymond M. Turner. 1965. The Changing Mile: An Ecological Study of Vegetation Change with Time in the Lower Mile of an Arid and Semiarid Region. University of Arizona Press. Tucson 317 p.

Hayne, Don W., 1965. An Examination of the Strip Census Method for Estimating Animal Populations. Jour. Wildlife Manage 13:145-157.

Henen, Brian T., 1997. Seasonal and Annual Energy Budgets of Female Desert Tortoises (Gopherus agassizii). Ecology 78:283-296.

Jacobson, E. R., J. M. Gaskin,M. B. Brown, R. K.Harris, C.H. Gardner, J. L. LaPointe, H. P. Adams, and C. Reggiardo. 1991. Chronic Upper Respiratory Tract Disease of Free-ranging Desert Tortoises (Xerobates agassizii). Journal of Wildlife Diseases 27: 296–316.

Kazmaier, Richard T. Eric C. Hellgren, Donald C. Ruthven III and David R. Synatzske 2001. Effects of Grazing on the Demography and Growth of the Texas Tortoise. Conservation Biology 15 : 1091-1101

Kazmaier, Richard T. Eric C. Hellgren, and Donald C. Ruthven 2001. Habitat Selection by Texas Tortoise in a Managed Thornschrub Ecosystem. Jour. Wildlife Manage. 63: 739-747.

Krefting, Laurits W. and Jack B. Fletcher. 1941. Notes on the Cruising Method of Censusing White-tail Deer in Oklahoma. Jour. Wildlife Manage. 5: 412-415.

Lamb, Trip, John C. Avise, and J. Whitfield Gibbons 1989. Phylogeographic Patterns In Mitochondrial DNA of the Desert Tortoise ((Xerobates agassizii), and Evolutionary Relationships among the North American Gopher Tortoises. Evolution. 43:76-87.

Leslie, P. H. 1952. The Estimation of Population Parameters from Data Obtained by Means of the Capture-Recapture Method: II The Estimation of Total Numbers. Biometrika. 39:363-388.

Leslie, P. H. and D. Chitty. 1951. The Estimation of Population Parameters from Data Obtained by Means of the Capture-Recapture Method: I The Maximum Likelyhood Equations for Estimating the Death-Rate. Biometrika. 38:269-292.

Marlow, Ronald William, and Kristine Tollestrup. 1982. Mining and Exploitation of Natural Mineral Deposits by the Desert Tortoise, *Gopherus agassizii*. Animal Behavior 30:475-478.

Medica, P. A., R. B. Bury and F. B. Turner. 1975. Growth of the Desert Tortoise *Gopherus Agassizi* in Nevada. Copeia 4:639-643.

Meyer, Rachelle, 2008. *Gopherus agassizii*. Fire effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Services Laboratory. 19 p.

Meyer, W. W., 1980. Winkelman Natural Resource Conservation District, Field Report 1980. 60 p.

Miller, Loye, 1955. Further Observations on the Desert Tortoise, *Gopherus agassizi*, of California. Copeia 2:113-118.

Nagy, Kenneth A. and Philip A. Medica, 1986. Physiological Ecology of Desert Tortoise In Southern Nevada. Herpetologica 42: 73-92

Ogden, Phil R., 1993. Diets of Desert Tortoise (*Xerobates agassizii*) Along the San Pedro River Watershed of Arizona. Symposium on Vegetation Management of Hot Desert Rangeland ecosystems Phoenix Arizona 107 – 113 p.

Parr, Virgil V., G. W. Collier, and G. S. Klemmedson. 1928. Ranch Organization and Methods of Livestock Production in the Southwest. U.S.D.A. Tech. Bull 68 103 p.

Robinette, W. L., C. M. Loveless, and D. A. Jones. 1974. Field Test of Strip Census Methods Jour. Wildlife Manage. 38: 81-96.

Rostal, David. C., V. A. Lance, J. S. Grumbles, and A. C. Alberts. 1994. Seasonal Reproductive Cycle of the Desert Tortoise (Gopherus agassizii) in the Eastern Mojave Herpetological Monographs. 8: 72-82.

Rupp, Robert S. 1966. Generalized Equation for the Ratio Method of Estimating Population Abundance. Jour. Wildlife Manage. 30: 523-526.

Schnell, Jay and Diane Drobka. 1988. The 1988 Desert Tortoise Survey San Pedro Population. U.S.D.I. Bur. Of Land Manage. Safford District. Field Work and Initial Report. 21 p.

Seaman, D. Erran, J. J. Millspaugh, B. J. Kernohan, G. C.Brundige, K. J. Raedeke and R. A. Gitzen. 1999. Effects of Sample Size on Kernal Home Range Estimates Jour. Wildlife Manage. 63: 739-747.

Seber, G. A. F. 1956. A Note on the Multiple-Recapture Census. Biometrika. 52:249-259

Swann, Don E, R. C. Averill-Murray, C. R Schwalbe 2002. Distance Sampling for Sonoran Desert Tortoise. Jour. Wildlife Manage. 66: 969-975.

U.S.D.I. National Oceanic and Atmospheric Administration 2006, Winkelman 6S, Arizona Climatological Data.

Van Devender, T. R., H. E. Lawler, and E. B. Wirt 1993. Preliminary Study of Desert Tortoise (*Xerobates agassizii*) diet in the Northeastern Sonoran Desert. Proceedings of the 18th Symposium of the Desert Tortoise Council.

Vaughn, S. L. 1984. Home Range and Habitat use of the Desert Tortoise (*Gopherus Agassizii*) in the Picacho Mountains, Pinal County, Arizona. M. S. Thesis Arizona State University, Tempe. 111 p.

Wagoner, Jay J. 1975. Early Arizona : prehistory to Civil War. The University of Arizona Press, Tucson. 547 p.

Woodbury, Angus M, and Ross Hardy 1948. Studies of the Desert Tortoise, *Gopherus agassizii*. Ecological Mongraphs. 18: 145-200

Woodman, P., P. Frank, E. Green, C. Keaton, B. Reiley, and J. Smith. 2005. Desert Tortoise Population Survey at Four Plots in Arizona, Fall, 2004. Report to Arizona Game and Fish Dept., Phoenix, AZ.