A History of Desert Tortoise Research at Saguaro National Park

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Desert tortoises (*Gopherus agassizii*) can be found in both the Rincon Mountain District (RMD) and Tucson Mountain District (TMD) of Saguaro National Park (SNP). These maps display locations of marked tortoises observed in and near the park between 1988 and 2008. Most of what we know about the distribution of tortoises in the park was determined during 3 studies (in 1988, 1995, and 2005-2006) that scattered visual encounter transects, distance-sampling transects, or occupancy sites throughout both districts.

Although most tortoises in the Sonoran Desert inhabit areas below 4000 ft (1220 m) in elevation, tortoises have been observed well above this elevation at SNP. A known population of tortoises occurs between 4600-4900 ft (1400-1500 m) along the Chimenea drainage on the south side of the Rincon Mountains (habitat pictured above left), and in 2000, a single tortoise was observed near the top of the Rincon Mountains in coniferous forest at 7808 ft (2380 m; pictured above right), an elevation record for the species!
Density of desert tortoises (number of adults per unit area) at RMD are among the highest observed in the Sonoran Desert. Mark-recapture studies were completed at 3 sites at RMD and 1 site at TMD in the 1980’s and 1990’s, and distance-sampling studies were completed at both RMD and TMD between 2000 and 2006. Density estimates at RMD ranged from 33-52 adult tortoises/km²; density estimates for the Panther Peak area at TMD were similar to those at RMD, but were slightly lower for the district as a whole (approximately 25 tortoises/ km²).

Numerous radio-telemetry studies at the park have helped us gain a better understanding of seasonal activity and movement patterns of desert tortoises. The map on the left depicts home ranges of 8 adult tortoises near the TMD visitor center between 2006 and 2008. Tortoises tend to be somewhat faithful to particular areas, often occupying the same shelter-site during consecutive winters. Occasionally however, tortoises will make long-distance movements. One tortoise (nicknamed “Thelma”), first located along the park boundary with the Rocking K Ranch, trekked over 30 km south to the Santa Rita Mountains in 2001. She was occasionally aided by people who carried her across human-constructed barriers like I-10 and railroad tracks.
Tortoises are long-lived animals, thought to reach ages of 80-100 years in the wild. Because of their longevity, females usually do not reproduce until they are at least 15 years old. Reproductive studies like that conducted by Eric Stitt at RMD between 2000 and 2002, demonstrated that in the Sonoran Desert, reproduction is closely tied to winter and spring rainfall. Using x-rays and ultrasound, researchers documented that females never lay more than 1 clutch of 2-8 eggs in a year, and often wait more than a year between reproductive events.

The diet of desert tortoises varies throughout the year depending on availability of particular plants and seasonal nutritional requirements. Diet studies completed by Thomas Van Devender and Olav Oftedal at SNP have used analyses of scat samples and observational bite counts of live tortoises to determine what plants are particularly important to tortoises in this region of the Sonoran Desert. In the spring, tortoises feed primarily on annual legumes, like desert lupine (above right), which contain high amounts of water and low amounts of potassium. When water is available during the summer monsoon season, a typical tortoise diet is composed primarily of annual and perennial grasses, supplemented by prickly pear fruit and desert vine (above center).
Blood samples gathered from tortoises in SNP were used as part of a regional genetic study completed by Taylor Edwards between 2000 and 2002. Edwards and his colleagues found that there were minimal genetic differences among desert tortoise populations in the Tucson area, suggesting that intermediate gene flow still occurs or occurred until recently among isolated populations, at the rate of $\geq 1$ migrant per generation. Given the proliferation of anthropogenic barriers that will likely prevent future movements between mountain ranges, small tortoise populations may now require occasional augmentation to remain viable.

Several studies in and around SNP have been initiated to assess the affects of human development along park boundaries on desert tortoise populations. Most of this work has been completed in the SNP expansion area bordering the Rocking K ranch, which has been slated for construction of a large-scale housing development for many years now. Although construction has not yet commenced, desert tortoise studies in the area have been completed to give the park a clear picture of the status of this population before construction drastically changes the landscape in this area. Studies by Audrey Goldsmith in 1990 and UA graduate students and park staff in 2000-2001 provided estimates of tortoise density in the area, and home range estimates were generated from radio-telemetry data collected between 1999 and 2005.
In areas bordering human development, tortoises may encounter another potential threat from released or abandoned domestic dogs. During desert tortoise surveys completed at TMD in 2006, researchers noted that an alarming number of tortoises had injuries consistent with attacks by dogs, particularly along park borders. A smaller proportion of tortoises at RMD presented these injuries, likely because much of RMD is bordered by protected lands without human development. Injuries sustained by adult tortoises are severe and can impact a tortoise’s chances for survival and for successful mating. Although adult tortoises can sometimes survive these brutal attacks, juvenile tortoises likely die as a result.

Although historically fires were not common at lower elevations in the Sonoran Desert, they are increasing in frequency in recent years due to non-native plants like buffelgrass and red brome. In 1994, the Mother’s Day Fire was ignited along the east side of the Cactus Forest Loop Road, burning 340 hectares of Arizona Upland desertscrub that tortoises are known to inhabit. Within 2 months of the fire, Todd Esque and Cecil Schwalbe of the U.S. Geological Survey, initiated mortality surveys throughout burned areas. They found 7 tortoise carcasses and estimated that 11% of adult tortoises in the area died as a result of the fire. Additional surveys and radio-telemetry studies were conducted in the area for several years following the fire, but did not find significant long-term affects of the fire on the tortoise population.
Disease, particularly upper respiratory tract disease (URTD), is considered to be one of the primary causes of observed population declines of Mojave desert tortoises. Although present in the Sonoran Desert, URTD has not been implicated in significant population declines. Between 2003 and 2005, Cristina Jones collected samples from tortoises throughout SNP and the great Tucson area to assess URTD levels in wild and captive tortoise populations. Over 50% of wild tortoises sampled tested positive for previous exposure to the disease and over 30% exhibited signs of current infection, including wet nares and eyes like the tortoise pictured above. The good news, however, is that tortoises in the Sonoran Desert appear to be able to clear the infection, having clinical signs one year and not the next.

The question of how tortoise populations in the Sonoran Desert should be monitored has been debated by researchers throughout the state. In recent years, several different survey methods have been implemented in SNP and results have helped to answer this challenging question. Mark-recapture methods were used by Betsy Wirt and colleagues in 1996-1997 to estimate tortoise density on long-term monitoring plots, Erin Zylstra and park staff used distance sampling transects to estimate density in 2000-2001 and 2005-2006, and Zylstra also estimated occupancy of tortoises using repeated presence-absence surveys in 2005-2006. While a conclusive answer has not yet been reached, survey results from SNP have greatly contributed to the discussion.
During the past several years, Don Swann and the park’s interpretative staff, including Daina Dajevskis and Chip Littlefield, have developed a program to bring groups of school kids out to the park and track radio-marked desert tortoises. The program began at RMD in 2003 and continues today at TMD, with small groups of high school students taken out into the field to track tortoises and collect data on weather, tortoise activity, movements, and habitat use, among other things. It was expanded in 2007 to include younger children, who track desert tortoise shells. The program aims to give students an opportunity to learn about the desert and its wildlife and to get hands-on experience using current research techniques.
Introduction

Research on the desert tortoise (*Gopherus agassizii*) has taken place at Saguaro National Park (SNP) since the 1980s. Indeed, it is probably not an exaggeration to say that much of what we know about this species in the Sonoran Desert is the result of research that has taken place at the park, although other prominent tortoise study sites include the Four Peaks area near Phoenix and Ironwood National Monument northwest of Tucson.

Desert tortoises are found throughout the Mojave and Sonoran Deserts of the United States and Mexico (Germano et al. 1994, Van Devender 2002, Stebbins, 2003). In the Sonoran Desert, tortoises are typically found on rocky hillsides, mountain foothills, and incised washes, and only found in low densities in valley bottoms (Barrett 1990, Germano et al. 1994, Averill-Murray and Averill-Murray 2005). Desert tortoises are found in both districts of the park, and although most tortoises in the Sonoran Desert inhabit areas below 4000 ft (1220 m) in elevation, tortoises have been observed well above this elevation at SNP. A known population of tortoises occurs between 4600-4900 ft (1400-1500 m) along the Chimenea drainage on the south side of the Rincon Mountains (to be discussed later), and in 2000, a single tortoise was observed near the top of the Rincon Mountains in coniferous forest at 7808 ft (2380 m), an elevation record for the species (Aslan et al. 2003)!

Most of the prominent researchers of Sonoran desert tortoises have worked in some capacity at the park, including Roy Averill-Murray and Tom Van Devender; Charles Lowe and his students Elizabeth Wirt, Peter Holm, and Brent Martin; Cecil Schwalbe and his students Taylor Edwards, Eric Stitt, and Cristina Jones; Bob Steidl and his student Erin Zylstra; and prominent Mojave Desert tortoise researchers Todd Esque and Olav Oftedal. Quite a bit of this research is summarized in the book, *The Sonoran Desert Tortoise* (Van Devender 2002). There have also been a large number of published research papers and reports on tortoise research in SNP (see below).

Research at SNP has provided information on Sonoran Desert tortoise abundance, habitat, distribution, diet, reproduction, genetics, disease, and monitoring strategies. The goal of this short paper is to summarize these studies and their results, and to provide a bibliography of desert tortoise research in the park to date.

Original Data

The large amount of research on tortoises at SNP led to an effort by park biologists, beginning in the late 1990s, to summarize the data from all of these studies. We made an effort to locate copies of all data sheets, particularly processing data sheets, and records for all marked tortoises at SNP. These sheets were copied and – thanks to many students and volunteers – entered into a database that has also been checked and updated regularly. We were not able to get copies of data from every study conducted since the early 1980s but we were able to obtain a great deal of information. All available copies of processing data sheets are filed, by project and by tortoise number, in the Resource Management office at the Rincon Mountain District (RMD) and at the Western Archaeological and Conservation Center (WACC) in Tucson. A database containing
information on all documented observations of marked tortoises at SNP is located on the park server: N:\GPS\GIS_Work\Tortoise\Marked_Tortoises\Master_GOAG.xls.

Study Locations

There have been 3 park-wide studies that have sampled tortoises throughout both RMD and the Tucson Mountain District (TMD). The first study was completed by Audrey Goldsmith in 1988, the second by Betsy Wirt in 1995, and the third by Erin Zylstra in 2005-2006. Other desert tortoise studies have taken place in several established study areas. These include, at RMD, the Javelina Picnic area, Mother’s Day Fire area, the Rocking K Ranch-SNP expansion area, and a site along the Manning Camp trail near Mesquite Flats (Fig. 1). At TMD, established study sites include the Panther Peak area and Visitor Center area (Fig. 2).

Desert Tortoise Studies in SNP (listed in chronological order)

Goldsmith-Shaw population studies, 1988-1990

The earliest known studies of desert tortoises in SNP were initiated in the 1980s as part of a comprehensive effort to study the effects of urban development on wildlife (Shaw et al. 1987). Professor William Shaw in the School of Natural Resources at the University of Arizona (UA) collaborated on parts of the project related to desert tortoises with a graduate student, Audrey Goldsmith. As part of the “Relationships between adjacent land uses and the wildlife resources of Saguaro National Monument” project, Goldsmith and Shaw surveyed transects throughout desert tortoise habitat in both districts of the park, completed population surveys at 2 long-term monitoring plots at RMD, and tracked radio-marked tortoises at both RMD and TMD (Shaw and Goldsmith 1988, Goldsmith and Shaw 1990, Wirt and Robichaux 2001). Although results of many of these studies were never provided to the park due to the serious illness of Audrey Goldsmith, much of the original data was supplied to the park many years later.

In 1988, 14 transects at RMD and 18 transects at TMD were surveyed for live tortoises and tortoise sign (scat or carcasses) by Brent Martin, Audrey Goldsmith, and others. Transects at RMD were primarily located in the western portion of the district, with a couple located near the Chimenea, Madrona, and Rincon Creek drainages (Fig. 3). Transects at TMD were located throughout the district (Fig. 4). A report detailing the results of the surveys was never completed by Goldsmith and Shaw, but a summary of their findings was provided several years later in a report submitted to the park by Wirt and Robichaux (2001). During the 1988 surveys, live tortoises or tortoise sign were found on 13 transects (93%) at RMD and 11 transects (61%) at TMD. They found 18 live tortoises on 11 transects (79%) at RMD and 19 tortoises on 9 transects (50%) at TMD, and concluded that most areas below 4,000 ft in SNP could be considered desert tortoise habitat.

Goldsmith and Shaw completed intensive population surveys of 2 1-mi² plots at RMD. In 1989 they hired Brent Martin to survey an area on the northwest side of Tanque Verde Ridge in the Javelina Picnic Area (referred to as the Javelina Picnic Area plot), and in 1990 they hired Ric Bieser, Nancy Fergusen, and others to survey an area along the southern park boundary adjacent
to the Rocking K ranch (Rocking K plot or Goldsmith plot; Fig. 1). They captured 45 unique tortoises at the Javelina Picnic Area plot and 32 tortoises at the Rocking K plot (Wirt and Robichaux 2001). Population estimates were not provided to the park, but datasheets associated with each tortoise observation were obtained at a later date.

Finally, in an attempt to estimate home range size and describe movements and seasonal activity patterns of desert tortoises, Goldsmith and Shaw fit 9 tortoises in the Javelina Picnic Area and 4 tortoises in the Red Hills area at TMD with radio-transmitters in 1988 and 1989. They found that home range sizes, measured by maximum length of the polygons, averaged over 400 m long, but ranged from 135 to almost 1 km, similar to home range sizes documented for tortoises in the Picacho Peak area (Vaughan 1984, Goldsmith and Shaw 1990).

Van Devender diet study 1991-1992

In 1991 and 1992, Thomas Van Devender, scientist at the Arizona-Sonora Desert Museum, and colleagues collected desert tortoise fecal samples from the Tucson Mountains to assess tortoise diet in Arizona Upland habitat. Samples were collected near Contzen Pass and Signal Hill at TMD (Fig. 2), and Brown Mountain in Tucson Mountain Park, just south of TMD. Fecal pellets were sorted by hand, identifiable plant fragments separated, and relative abundances of plant taxa estimated. After being sorted by hand, samples from the Brown Mountain area were ground up and microhistological analyses were used to identify epidermal characters of particular plant taxa found in the samples.

Results from the fragment analysis suggested that grasses were most frequently consumed, although there was a high diversity of annual plants found in the fecal samples. Limited microhistological analyses found high densities of herbaceous perennials, such as *Abutilon* sp. and *Herissantia* sp. (both in the Mallow family) in the fecal samples. Details of the study provided to the park were limited, but can be found in Van Devender and Lawler (1995).

Esque-Schwalbe fire ecology study 1994-1999

In May 1994, a fire burned approximately 340 acres of Arizona Upland desertscrub east of the Cactus Forest Loop Road at RMD (Esque et al. 2004; Fig. 1). Within 2 months of the fire, Todd Esque and Cecil Schwalbe, U.S. Geological Survey scientists with extensive experience studying tortoises in both the Sonoran and Mojave Deserts, initiated a study evaluating the effects of fire on saguaros and desert tortoises (Esque et al. 1994). Esque and Schwalbe worked with a number of collaborators and students at the University of Arizona on the Mother’s Day Fire project between 1994 and 1999.

In June 1994, Esque and Schwalbe used 10-m wide belt transects to survey the entire area burned within Arizona Upland habitat for desert tortoises. They found 6 live tortoises and 7 carcasses, 5 of which could be directly attributed to fire, and estimated that approximately 11% of the adult tortoises in the area died (Esque et al. 2003). In 1996, Esque and Schwalbe also attached radio-transmitters to 12 tortoises, 6 in burned areas and 6 in unburned areas to assess tortoise use of burned and unburned areas. Tortoises were tracked throughout the year, but no differences in
movement or activity patterns between tortoises in burned and unburned areas nor long-term effects of the fire on surviving tortoises were observed (C. Schwalbe, personal communication). While not all of the data from this study were provided to the park, a summary of the mortality surveys can be found in Esque et al. (2003) and an overview of fire in Arizona Upland habitat, using the Mother’s Day Fire as a case study can be found in Esque et al. (2002).

In 1999, Esque and Schwalbe turned over the Mother’s Day Fire radio-telemetry study to park biologist Don Swann, who continued monitoring tortoises in the Mother’s Day area with the help of Dr. Schwalbe’s graduate students and lab technicians at the University of Arizona. Beginning in 1999, Erin Zylstra, Cristina Jones, and several SNP volunteers and interns regularly tracked radio-marked tortoises, as often as twice a week during the active season. Radio-telemetry data from the Mother’s Day area was incorporated into a number of subsequent desert tortoise studies in the park, including work done by Taylor Edwards, Eric Stitt, Cristina Jones, and Erin Zylstra. Radio-telemetry was discontinued at this site in the spring of 2006, when construction on the Cactus Forest Loop Road prevented access to the site during the upcoming monsoon season.

Wirt-Lowe population studies 1995-1998

Elizabeth Wirt, a student of Professor Charles Lowe in the Department of Ecology and Evolutionary Biology at UA, began desert tortoise studies at the park in 1995. She was assisted by Peter Holm, Steve Hale, and Brett Martin, another Lowe student who studied desert tortoises in the Tortilita Mountains as part of his master’s project.

Wirt was involved in many desert tortoise projects at SNP. She helped to survey for tortoise sign on transects scattered throughout both districts of the park, complete population surveys of several long-term monitoring plots, and track movements of radio-marked tortoises at the Mother’s Day site and a high elevation site near the Chimenea drainage along the Manning Camp trail. Wirt summarized these studies in an unpublished report (Wirt and Robichaux 2001) and provided copies of her original data sheets to the park.

In 1995, Wirt and colleagues surveyed 13 transects at RMD and 18 transects at TMD for live tortoises and tortoise sign (Figs. 3 and 4). Many transects overlapped considerably with transects surveyed by Goldsmith and Shaw in 1988. Live tortoises or tortoise sign were found on all transects at RMD and 9 transects (50%) at TMD. They found 16 tortoises on 8 transects (62%) at RMD and 9 tortoises on 4 transects (22%) at TMD. Although fewer adult tortoises were found in 1995 despite increased efforts (person hours), differences in encounter rates between the two years were not significant.

Four tortoises, 2 males and 2 females, were found during a transect survey in 1995 along Chimenea canyon between 4600-4900 ft (1400-1500 m) and were subsequently fitted with radio-transmitters (Fig. 1). These tortoises were radioed because they were some of the highest elevation tortoises known from this region of the Sonoran Desert. The area is can be described primarily as semi-desert grassland, with patches of madrean evergreen woodland along riparian areas. Tortoises were tracked between October 1995 and April 1998. Movement patterns of
these high-elevation tortoises did not appear to differ considerably from lower-elevation tortoises.

Wirt and colleagues also completed intensive mark-recapture surveys at 3 1-km² monitoring plots in the park. In 1996, the Javelina Picnic Area plot and Mother’s Day Fire plot at RMD (Fig. 1) and the Panther Peak plot at TMD (Fig. 2) were surveyed. In 1997, the Javelina and Panther Peak plots were resurveyed. Density estimates ranged from 39-49 adult tortoises/km² at the Javelina and Panther Peak plots during the 2 years of surveys, some of the highest tortoise densities reported in the Sonoran Desert (Averill-Murray et al. 2002). Estimated tortoise density at the Mother’s Day site, 33 adults/km², was lower than the other 2 sites, but encouraging given that the area burned only 2 years before.

Urban impact study, 1999-2001

In 1999, several studies were initiated in the Rocking K-SNP Expansion area to evaluate the long-term effects of land use change along the park’s southern boundary (Fig. 1). These studies were done in collaboration with scientists from UA (Cecil Schwalbe, Taylor Edwards, and others), Arizona Game and Fish Department (Roy Averill-Murray), Saguaro National Park (Don Swann), and the Rincon Institute, with support from the park and the Rocking K Ranch. The studies initiated in 1999 were an expansion of an earlier collaboration in 1994-1995 that among other things, inventoried the reptile and amphibian species found in the Rincon Valley and bordering SNP Expansion area (Murray 1995, Murray 1996).

Beginning in July 1999, radio-transmitters were attached to tortoises on both sides of the park boundary with the Rocking K Ranch. The study was designed to investigate changes in desert tortoise habitat use, activity, and movements as a result of development in the Rincon Valley. MCP home range estimates for tortoises along the park border averaged 10.2 ha (95% CI = 5.8-18.0), and did not differ significantly from home range estimates of tortoises in the Mother’s Day area between 1999 and 2001 (Schwalbe et al. 2002). Project collaborators continued to track radio-marked tortoises through the spring of 2005, and the data were used in several studies carried out by Cecil Schwalbe’s graduate students, described below. Although the study was originally designed to look at differences in tortoise populations before and after development, as of this writing in 2008, the ranch has still not been developed.

During the course of the radio-telemetry project, researchers documented an extraordinary long-distance movement by an adult female tortoise originally marked and radioed just south of the park border. Over the course of one year, the tortoise, nicknamed “Thelma,” moved more than a 30-km straight-line distance from the Rincon Mountains to the Santa Rita Mountains (occasionally aided across human-made barriers; Edwards et al. 2004b). After the tortoise was found between the 2 mountain ranges, near I-10, the next year, researchers moved the tortoise back to its original capture location south of SNP. Although tortoise biologists have previously noted that tortoises are likely to make long-distance movements, documentation of such an extreme movement is very rare.
As part of this study in 2000 and 2001, project collaborators used distance sampling to estimate the number of tortoises on the Rocking K Ranch and the SNP expansion area. Around this time, researchers were investigating how to implement distance-sampling methods as part of a long-term monitoring strategy for tortoises in the Mojave Desert (Anderson et al. 2001, U.S. Fish and Wildlife Service 2006). This 2000-2001 study in SNP represents the first attempt to use distance-sampling methods to estimate density of tortoises in the Sonoran Desert. With the help of many student interns and volunteers, 34 1-km transects on the Rocking K Ranch were each surveyed twice in 2000 and 34 1-km transects in the SNP expansion area were each surveyed twice in 2001 (Fig. 5). Swann and collaborators estimated density of adult tortoises in the Rocking K Ranch was 0.52/ha (Swann et al. 2001, Swann et al. 2002), and density in the SNP expansion area was 0.41/ha (Averill-Murray and Swann 2002). Density estimates from the distance-sampling study were similar to those generated using mark-recapture methods on long-term monitoring plots in 1996 and 1997 (Wirt and Robichaux 2001). Data sheets and results from these studies were provided to the park in Swann et al. (2001) and Averill-Murray and Swann (2002). Results from 2000 were also published in the Journal of Wildlife Management (Swann et al. 2002).

Edwards-Schwalbe genetic study, 2000-2002

Taylor Edwards, a graduate student of Cecil Schwalbe and SNP volunteer, initiated the first study of desert tortoise genetics at the park in 2000. The goal of the study was to determine if historical movements occurred between what are now isolated populations of desert tortoises in the mountain ranges surrounding Tucson. Edwards studied populations of tortoises at RMD, TMD, Desert Peak, Florence, Picacho Mountains, Ragged Top, Sugarloaf, Tumamoc Hill, and the West Silver Bell Mountains. In addition, an evaluation of genetic relatedness among individuals was completed for tortoises at RMD, because supplementary information regarding movement and home range sizes was available through radio-telemetry studies.

After developing PCR primers for 6 microsatellite loci, Edwards and his colleagues found that there were minimal genetic differences among desert tortoise populations in the Tucson area (Edwards et al. 2003, Edwards et al. 2004a). This suggested that intermediate gene flow still occurs or occurred until recently among isolated populations, at the rate of ≥ 1 migrant per generation. Given the proliferation of anthropogenic barriers that will likely prevent future movements between mountain ranges, small tortoise populations may now require occasional augmentation to remain viable. After the project was completed, all original data sheets were provided to the park and results from the study were provided in a report (Edwards et al. 2002) and published in the journal, Conservation Genetics (Edwards et al. 2004a).

Genetic data gathered by Edwards in SNP in 2000-2001 are also contributing to long-term research evaluating relationships among desert tortoises throughout their range. Recent work suggests that tortoises in the Mojave and Sonoran Deserts have not exchanged genetic material in more than 4 million years, strengthening the case being made by some that Sonoran and Mojave tortoises represent separate species (Murphy et al. 2007). Additionally, comparisons between samples collected in the Mojave and northern Sonoran Deserts, including RMD, and samples
recently gathered in southern Sonora, Mexico indicate that tortoises at the southern extent of the range differ considerably from those in and near the U.S (T. Edwards, personal communication).

**Stitt-Schwalbe desert tortoise ecology and reproduction study, 2000-2002**

Eric Stitt, another graduate student of Cecil Schwalbe and SNP volunteer, initiated a number of desert tortoise studies at both the Mother’s Day Fire site and Rocking K Ranch-SNP expansion area between 2000 and 2002. Radio-telemetry data gathered at the Rocking K site were used to characterize home range size and movements of tortoises prior to development at the Rocking K Ranch. Stitt worked closely with Roy Averill-Murray from the Arizona Game and Fish Department, using x-ray and ultrasound to describe patterns of reproduction in tortoises at both study sites. Additionally, an undergraduate biology student at UA, Amber Blythe, worked with Stitt to complete field experiments evaluating the effects of small-scale translocation on desert tortoises.

Mean yearly home range size (MCP) for tortoises at both study sites was 15.7 ha (Stitt et al. 2003c), somewhat larger than the estimate provided by Schwalbe et al. (2002). This difference may be due to several tortoises that made long-distance movements in the Rocking K area in 2002. Home range sizes did not differ between the two sites or between males and females, although males did tend to have slightly larger home ranges. Stitt’s data on tortoise reproduction corroborated results from one of Roy Averill-Murray’s earlier studies (Averill-Murray 2002), which indicated that unlike tortoises in the Mojave Desert, Sonoran desert tortoises never lay more than 1 clutch in a year. Additionally, both the number of eggs laid and the number of females laying eggs in a given year were correlated with the amount of winter and spring rainfall (Stitt et al. 2003c). Finally, distance tortoises were translocated affected movement patterns. Many individuals returned to their original locations within 2 or 3 days after they were translocated 800 m, suggesting that while small-scale translocation efforts may not affect the health of the tortoise, they also may not prevent tortoises from returning to areas where they were translocated from. Original data sheets from all tortoises handled during the project were not available, but a detailed summary of results was provided in a report to the park (Stitt et al. 2003). Additionally, as part of these research projects, short reports were produced documenting the use of infrared cameras to monitor nest survival and burrow associates of tortoises (Stitt et al. 2003a), gila monster predation of tortoise nests (Stitt et al. 2003b), tortoise association with africanized bees (Stitt et al. 2005), and tortoise caliche mining (Stitt and Davis 2003).

**Oftedal nutritional ecology study, 2003-2004**

Olav Oftedal, a biologist with the Smithsonian Institution, incorporated data collected in the Mother’s Day area in 2003-2004 into part of a larger study evaluating spring and summer foraging behavior of tortoises in the Sonoran Desert. In August 2003, Oftedal, along with Smithsonian staff and park volunteers, observed 11 tortoises foraging for a total of 118 hours and catalogued the number of bites taken of each plant species eaten. They completed similar work in April 2004, observing 5 tortoises for a total of 55 hours. Similar spring and summer observations were completed at Ragged Top, in the Ironwood Forest National Monument and Sugarloaf Mountain in the Tonto National Forest between 2002 and 2004.
In the spring, tortoises selected plants with high water and protein contents and low potassium contents. In the Mother’s Day area, more than half of tortoises’ diets in the spring consisted of annual legumes, including *Lotus humistratus* (spreading lotus), *Lupinus sparsiflorus* (desert lupine), and *Astragalus nuttallianus* (Nuttal’s milkvetch). Tortoises were less selective during the summer, eating mostly annual and perennial grasses, including *Bouteloua aristidoides* (needle grama) and *Panicum* sp. (panic grass). Additionally, tortoises favored *Janusia gracilis* (desert vine) in both the spring and summer and *Opuntia engelmannii* (prickly pear) fruit when ripe in the summer. For additional results from this nutritional ecology study, see Oftedal (2008).

*Jones-Schwalbe disease study, 2003-2005*

Another Schwalbe graduate student, Cristina Jones, studied desert tortoises in SNP and the greater Tucson area to evaluate patterns of disease occurrence. Disease, particularly upper respiratory tract disease (URTD), is considered to be one of the primary causes of observed population declines of Mojave desert tortoises (Knowles 1989, Jacobson et al. 1991, USFWS 1994). Although present in the Sonoran Desert, URTD has not been implicated in significant population declines. An alarming number of tortoises in RMD, however, tested positive for this disease in 2001-2002 (Riedle and Averill-Murray 2003).

Jones tested the theory that URTD rates would be highest near urban areas, as a result of disease transmission from released domestic tortoises (desert tortoises and exotic species). She tested four groups of tortoises along an urban gradient: captive tortoises; tortoises in high-visitor impact areas, including the Mother’s Day Fire area; tortoises in suburban areas, including the Rocking K Ranch-SNP expansion area and Panther Peak area; and tortoises in remote sites. Jones examined each tortoise for clinical signs of URTD, collected blood to run an ELISA test for antibodies indicating previous exposure to *Mycoplasma agassizii*, and collected nasal lavage samples for a PCR analysis to determine if the tortoise was currently infected with the disease.

As expected, Jones found that the proportion of tortoises testing positive for previous exposure to the disease differed along the urban gradient (Jones et al. 2005). However, the pattern was not exactly as predicted. A greater proportion of tortoises in suburban areas tested positive for previous exposure to the disease than all other areas, including captive tortoises. In fact, while a smaller proportion of tortoises in remote areas tested positive for previous exposure, the difference between remote and captive populations was remarkably small. All original datasheets from this study were provided to the park, and a summary of results can be found in Jones et al. (2005).

Results from the Jones-Schwalbe study were also used as part of a larger study initiated by the Arizona Game and Fish Department, examining patterns of disease occurrence on a state-wide scale. For this larger study, Jones collected samples throughout parks in the Phoenix area and protected land surrounding Kingman, Arizona. A report detailing results from this study has not yet been completed, but a summary will be provided in Jones’ thesis, which she expects to complete by December 2008.
Erin Zylstra, a graduate student of Bob Steidl at UA and park volunteer, performed surveys for the desert tortoise in 2005-2006 in an attempt to compare the efficacy of different methods to be used as part of a long-term monitoring program. Monitoring species that are rare, cryptic, and have limited activity periods, like the desert tortoise, can be challenging. Current monitoring approaches use mark-recapture methods to estimate tortoise density on 1-km$^2$ or 1-mi$^2$ plots, but are typically inefficient and limited in scope. Zylstra initiated the study to compare the efficiency and statistical power of distance-sampling and site-occupancy approaches as part of a long-term monitoring approach for tortoises in the Sonoran Desert. Site-occupancy estimation is a relatively new approach for species with low rates of detection that uses repeated presence-absence surveys to estimate the proportion of area occupied.

In 2005, surveys were completed in the western portion of RMD below 3800 ft (1150 m; Fig. 5), and in 2006, surveys were completed throughout TMD (Fig. 6). To complete the distance-sampling portion of the project, 60 1-km randomly-located transects were surveyed each year, and to complete the occupancy portion of the project, 20 3-ha randomly-located sites were each surveyed 5 times. Radio-transmitters were also attached to tortoises at RMD (in the Mother’s Day Fire area) and tortoises at TMD (in the Panther Peak area and near the visitor center) to estimate the proportion of animals available to be detected on distance-sampling surveys.

When combining results from the 2 districts, tortoise density was 0.31 adult tortoises/ha (95% CI = 0.21-0.44) and tortoise occupancy was 0.71 (95% CI = 0.59-0.83). Occupancy surveys were more efficient than distance-sampling surveys, and also had greater statistical power to detect annual declines in occupancy than distance sampling did to detect annual declines in density. These findings suggest that occupancy estimation may be a viable alternative to current desert tortoise monitoring strategies. All original data sheets from this study were provided to the park, and additional results from the study can be found in Zylstra et al. (2006) and Zylstra (2008b).

Results from this study will also be used in an upcoming project that Zylstra will be working on with the Arizona Game and Fish Department, restructuring the state-wide monitoring plan for Sonoran desert tortoises.

During the 2005-2006 surveys, Zylstra noted that an alarming number of tortoises at TMD had injuries consistent with canine attacks. As a result, a study was undertaken to evaluate whether these injuries were likely caused by free-roaming dogs and whether injury rates varied over space or time. After conferring with veterinarians in the area, Zylstra determined that severe injuries to the gular and marginal scutes were likely caused by free-roaming dogs. Further, injuries rates were higher at TMD than RMD and have increased between 1996 and 2007. Given the high rate of development surrounding TMD in recent years, it is likely that these injuries to tortoises were caused by released or abandoned pets. Zylstra (2008a) details results of this study evaluating the effects of free-roaming dogs on desert tortoise populations.
Desert tortoise educational research, 2005-present

Park biologist Don Swann began working with high school and college interns on desert tortoise research projects in 1999, and found that high school students learned considerably from and enjoyed radio telemetry. He began informally bringing small groups of students into the field to track tortoises. In 2005, based on a small grant from the Friends of Saguaro National Park, Don and the park’s interpretive division began formalizing this program, first at RMD and then at TMD. The RMD program was discontinued in 2006 after all the radios were removed from tortoises at the Mother’s Day Fire site when the Cactus Forest Loop Road was closed for renovation.

Radio telemetry began at TMD in July 2006 as part of the Zylstra-Steidl monitoring study. Telemetry was discontinued at Panther Peak in 2007, but was expanded in the visitor center area for the educational project. Small groups of high school students are taken out into the field to track tortoises and collect data on weather, tortoise activity, movements, and habitat use, among other things. Daina Dajevskis and Chip Littlefield, SNP employees at TMD, are currently working on the desert tortoise education program, which is funded by the Friends and a Heritage grant from the Arizona Game and Fish Department. In 2007-2008, the program was expanded to include younger children (middle and elementary schools) who tracked tortoise shells, rather than live tortoises, in Red Hills wash near the Visitor Center. In July 2008, radio-transmitters were removed from all but 2 of the TMD tortoises that inhabited areas in close proximity to the visitor center.

Conclusions

Our current understanding of Sonoran desert tortoise ecology is largely based on research conducted at SNP since the 1980’s. Because of this work, we have a clearer picture of tortoise reproduction, diet, genetics, and diseases. In addition, we’ve gained information that can directly impact management efforts, including estimates of tortoise abundance, distribution, habitat use, and appropriate monitoring techniques. Although a great deal of research has been done, there are still many questions left to answer. Hopefully, future tortoise research at SNP will benefit from and build upon the results and resources provided by previous studies outlined in this paper.

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Figure 1. Locations of long-term study areas for desert tortoises in the Rincon Mountain District of Saguaro National Park, Tucson, Arizona, USA, 1988-2007.
Figure 2. Locations of long-term study areas for desert tortoises in the Tucson Mountain District of Saguaro National Park, Tucson, Arizona, USA, 1988-2007.
Figure 3. Transects surveyed for desert tortoises in the Rincon Mountain District of Saguaro National Park, Tucson, Arizona, USA, 1988-1995.
Figure 4. Transects surveyed for desert tortoises in the Tucson Mountain District of Saguaro National Park, Tucson, Arizona, USA, 1988-1995.
Figure 5. Distance-sampling transects and occupancy sites surveyed for desert tortoises in the Rincon Mountain District of Saguaro National Park, Tucson, Arizona, USA, 2000-2005.
Figure 6. Distance-sampling transects and occupancy sites surveyed for desert tortoises in the Rincon Mountain District of Saguaro National Park, Tucson, Arizona, USA, 2006.
Appendix A. Name or numbers and locations of visual encounter transects, distance-sampling transects, mark-recapture plots, and occupancy sites surveyed for desert tortoises in Saguaro National Park, Tucson, Arizona, USA, 1988-2006.

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Type: DS = distance-sampling transect, MR = mark-recapture plot, OCC = occupancy site, VET = visual encounter transect.


District: RMD = Rincon Mountain District, TMD = Tucson Mountain District.

UTMs: Approx. = Approximated UTMs from plot boundaries drawn on topographic maps, Provided = UTMs provided in a report or electronic file associated with the study, Unavailable = UTMs unavailable.

Easting and Northing: all locations provided in NAD83 datum.

Corner: Specifies which of the 4 corner locations the provided UTMs describe for distance-sampling transects, mark-recapture plots, and occupancy sites that were laid out as rectangles or squares along the cardinal directions. All distance-sampling transects were laid out as 250 m x 250 m squares; all occupancy sites were laid out as 170 m x 170 m squares. Locations of the NW, NE, and SE corners of distance-sampling transects and occupancy sites were not provided as locations could be extrapolated from locations of the SW corners.

Source of location info.: Source of transect or plot location information. Wirt maps = set of topographic maps with hand-drawn transect locations provided to SNP by Betsy Wirt and stored at the SNP resource office, Misc. project materials = miscellaneous project information and data sheets provided by Audrey Goldsmith to SNP and stored at WACC, SNP Server = electronic files with survey locations provided by principal investigator to the park and stored on the N: drive of the SNP server.