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Decline of Mule Deer Population at Saguaro National Park (Rincon Mountain District)

by

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## ABSTRACT

Saguaro National Park has over 60 years of deer survey and vegetation cover data. The deer survey data demonstrated a shift in the deer population at Saguaro National Park leaving resource managers curious about what factors may have been responsible for the change. I investigated if there was a correlation between vegetation life form cover, housing density and the shift of deer populations from predominately mule deer (*Odocoileus hemionius*) in the lower elevations to Coues white-tailed deer (*Odocoileus virginianus couesi*). I found a 10% increase of vegetation cover generated by trees, shrubs, and succulents detected in the vegetation data sets. Increased vegetation cover in conjunction with the conversion 210km<sup>2</sup> of adjacent private lands towards relatively high housing densities is the likely cause of the observed shifts in the deer populations at Saguaro National Park.

## Introduction

The earliest accounts of mammal populations at Saguaro National Park (SNP) were summarized notes written by park employees and published in Annual Wildlife Reports (AWR) (Bucci 2007). As early as 1940, AWRs suggested a decline in the park's mule deer (*Odocoileus hemionus*) population. Some resource managers and biologists believed this decline was due to over-hunting of deer outside the park and an increase in small mammals, which were competing with deer for forage (Bucci 2007). In general, other researchers attributed the decline of mule deer to overgrazing by livestock (Anthony and Smith 1977; Avey et al. 2003; Brunjes et al. 2006) and fire suppression (Anthony and Smith 1977; Avey et al. 2003). Whereas grazing and fire suppression may be contributing factors, the recent land use and disturbance history of the park suggests that they are not the primary drivers of the observed mule deer declines. Livestock grazing was prohibited in 1976 (Swann et al. *unpublished*) and three wildfires have burned large section of the lower elevations of the park in 1989, 1994, and 1999 (Swann et al. *unpublished*).

In 1951 Lowell Sumner, a biologist with the Arizona Game and Fish Department (AZGFD), completed a comprehensive survey of deer and other mammals in the park's Rincon Mountain District (RMD) and created a map of locations where Coues white-tailed deer, (*Odocoileus virginianus couesi*) and mule deer, had been observed (Fig. 1). This map indicated differences in the ranges of each species, with a distinct shift from mule deer to white-tailed deer as the elevation increased to approximately 6,000 feet (1,829m) (Sumner 1951).

# Map from Sumner (1951)

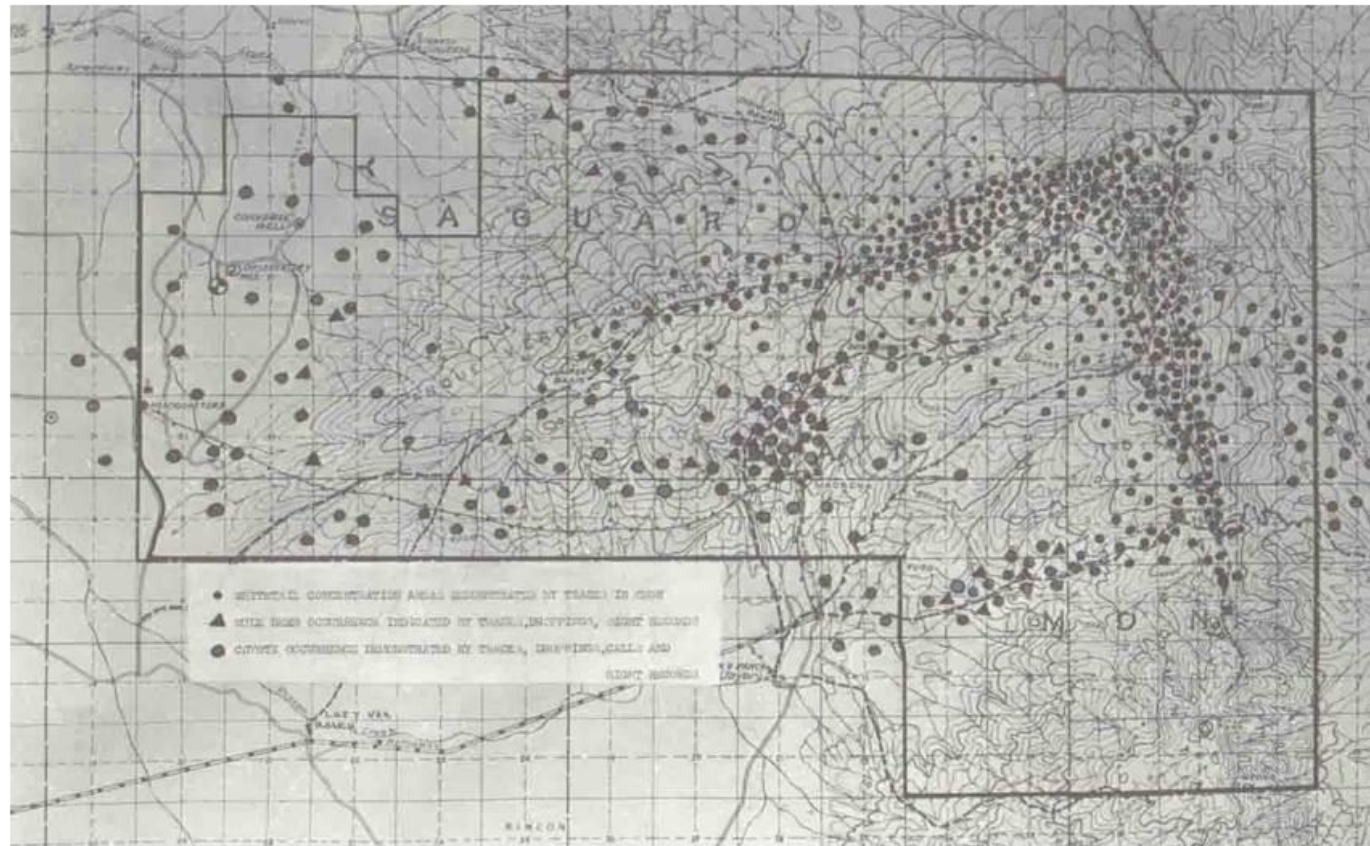


Figure 1. Observations or signs of deer, by species, at Saguaro National Park, Rincon Mountain District, 1951 (Sumner 1951). The smaller circles are observations of white-tailed deer, the large circles are mule deer, and the triangles are coyotes.

From 1960 to 1974 Gerald Day, a biologist with the AZGFD, counted javelina (*Pecari tajacu*) along a series of transects to determine if there was a correlation between climate and javelina populations (Day 1977). Day also counted deer by species along transects in the lower elevations of SNP, and his data supported Sumner's conclusions: mule deer were common in the park's lower elevations. In 1989 and from 2000 to 2006, AZGFD employees conducted helicopter surveys of large mammals under the guidance of SNP resource managers. Results from data collected in the 1989 survey (AZGFD *unpublished data*) reflected the conclusions of both Sumner and Day. However, survey results from 2000 documented no mule deer and eight white-tailed deer in the lower elevations (AZGFD *unpublished data*). This new pattern in distribution of the two species has persisted to the present (NPS *unpublished data*) and led to concerns by resource managers about the future of the mule deer population within SNP and the factors that may have been responsible for the changes.

### Research Question and Objectives

I contend that the population shift from mule to white-tailed deer is inadequately explained by grazing competition or fire suppression. I propose that the primary cause of the shift may be due to a change in the park's vegetation structure, coupled with changes in adjacent housing density. As such, my research assessed whether there is a correlation between the timing of the decline in mule deer with a change in vegetation on the park and an increase in housing density outside the park. My specific objectives were to:

1. Acquire and analyze historical vegetation composition at Saguaro National Park.
2. Assess how changes in vegetation cover on the park relate to the habitat preferences of mule and white-tailed deer.

3. Assess whether an increase in housing density outside the park may have led to a loss of mule deer habitat.

## Background

### **Ecological Importance of Deer to Saguaro National Park**

The National Park Service (NPS) was created in 1916, under the NPS Organic Act. This legislation not only established the NPS but also identified its purpose and mission. One purpose of lands designated under this act is to conserve “natural objects,” including native wildlife (U.S. Congress 1916). Mule and white-tailed deer are the only two large ungulates currently known to inhabit SNP (Powell et al. 2006). Both species play a key role in park ecosystems as browsers of vegetation, with consequences for vegetation community structure, and as prey for large predators.

Despite overlapping habitat requirements, there is no physical or physiological explanation for why these two deer species prefer to feed on different vegetation species (Heffelfinger 2006). Mule deer diets consist primarily of browse (subshrubs and succulents) and forbs (Krausman et al. 1997). The importance of browse for mule deer increases in more arid climates (Heffelfinger 2006), such as southeastern Arizona. When precipitation is above average in such areas, mule deer will shift to eating a greater proportion of forbs (Heffelfinger 2006). Lactating mule deer will typically focus on mesquite beans (*Prosopis velutina*) to meet higher nutritional needs (Tull and Krausman 2007). White-tailed deer are also heavy browsers, but they tend to browse different species than mule deer, preferring seeds from pine and oak (Heffelfinger 2006), species typically found above 5,000ft (1,524m) in elevation in southeastern Arizona, and on new growth from most shrub species (Marshall et al. 2005). These differences in browsing

pressures have direct and indirect consequences on vegetation (Rooney and Waller 2003), and highlight the importance of large ungulates in regulating vegetation composition and diversity in SNP.

Tree mortality associated with browsing is generally limited to younger stands. Mature trees are capable of surviving even when browsing pressures are high (Gill and Beardall 2001). By browsing woody species, deer decrease stem density and increase openings in the subcanopy layer (Gill and Beardall 2001). These openings allow for light penetration, increasing species richness and abundance of the herbaceous and forb layer (Beguín et al. 2011). When deer populations are high, browsing pressure greatly reduces the abundance and distribution of browse-sensitive plant species (Rooney and Waller 2003). Deer also serve as a seed-dispersal mechanism for many plant species. The two most common methods of seed dispersal are endozoochory (seeds passing through the gut), and epizoochory (seeds being caught and carried either on the hooves or coats) (Gill and Beardall 2001).

The ecological consequences of deer are not limited to vegetation. The two deer species also allow large predators to persist in the park. Large predator species, such as mountain lions (*Puma concolor*), coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and, historically, gray wolves (*Canis lupus*) and jaguars (*Panthera onca*) (Swann 2011) prey on deer. Currently mountain lions account for approximately 60% of deer predation, whereas coyotes account for approximately 30% and bobcats for less than 5% (Pierce et al. 2004). There are no recent data on deer predation by gray wolves or jaguar, as both species were extirpated from SNP in the mid-1940s (Swann 2011).

## **Habitat Preferences of Mule Deer and White-tailed Deer**

Mule and white-tailed deer are highly studied animals because of their ecological and economic importance in the American Southwest. Their habitat, predator-evasion techniques, social behavior, and sympatric relationship with each other have all been well described.

Methods for defining and distinguishing mule deer habitat from white-tailed deer habitat are well articulated. A common approach focuses on slope and elevation. Mule deer prefer slopes of between 10 and 50%, but will use areas with slopes between 50 and 75%, whereas white-tailed deer prefer slopes of between zero and 10% (Orday and Krausman 1986; Avey et al. 2003). Mule deer are typically found at elevations from 2,000 to 4,500 feet (610m to 1,372m) (Anthony and Smith 1977; Orday and Krausman 1986; Heffelfinger 2006), whereas white-tailed deer prefer elevations from 6,000 to 8,000 feet (1,829m to 2,438m) (Sumner 1951; Anthony and Smith 1977; Heffelfinger 2006).

Although useful as general rules, slope and elevation are static factors that fail to explain the variation in habitat use that is observed over time, in nature. Biotic parameters, on the other hand, such as vegetation cover and composition, which change over time, could account for trends in deer populations and in their use of particular locations within the park. Mule deer prefer shrub cover of around 40%, whereas white-tailed deer prefer shrub cover of greater than 50% (Avey et al. 2003). The preferred mean of woody plant cover used by mule deer and white-tailed deer is about 40% and 60%, respectively (Wiggers and Beason 1986; Avey et al. 2003). Mule deer will generally leave an area when the woody plant cover exceeds 70% (Wiggers and Beason 1986; Koenen and Krausman 2002; Avey et al. 2003); white-tailed deer typically will not (Anthony and Smith 1977; Wiggers and Beason 1986; Brunjes et al. 2006).

The percent of preferred vegetation cover is related to the different predator-evasion strategies. The predator detection and avoidance tactics of mule deer are linked to the more open and rugged habitat in which they are typically found (Lingle and Wilson 2001). Mule deer generally detect predators at further distances than white-tailed deer (Lingle and Wilson 2001), and respond by grouping together, holding their ground, and use topography to maintain their distance from the predator. Mule deer tend to maintain visual contact with the predator, and may use their hooves and antlers to deter an attack (Lingle 2001). By contrast, white-tailed deer are more likely to alarm, with snorting or tail-flagging, and flee when a predator is detected (LaGory 1987). When other white-tailed deer are alerted by the sight of fleeing deer, they too will flee in different directions (Lingle 2001). Because white-tailed deer are typically found in woody habitats with gentle terrain, they take zigzag evasion routes and are able to outrun most predators (Lingle 2001). All of the parameters used to define habitats are a product of spatial segregation of the landscape by the two deer species. This is the reason why both species of deer have been able to coexist within the same landscapes (Kramer 1973; Anthony and Smith 1977).

### **Effects of Housing Density on Deer Habitat**

Urban development is an important cause of habitat loss and fragmentation (Markovchick-Nicholis et al. 2008). This change in land use is generally permanent, and is a threat to biodiversity worldwide (Markovchick-Nicholis et al. 2008). High human population densities and high water use compound the effects of urbanization (Dobson 1997). Response to the urbanization varies by species. Raccoons and woodrats are common in urbanized areas, and have adapted to survive within the new habitat; mule deer are very different (Markovchick-Nicholis et al. 2008). Species sensitive to urbanization, respond as they would to predators, as most will avoid the area or be highly cautious (Markovchick-Nicholis et al. 2008). Mule deer

reportedly have a negative response to high housing density (Markovchick-Nicholis et al. 2008), but can acclimate to low housing density (Tull and Krausman 2007).

## Methods

I choose to define and differentiate habitat of mule deer and white-tailed deer based on vegetation cover (%), because quantitative thresholds of vegetation cover have been defined for habitat preferred by mule deer and white-tailed deer. Vegetation cover correlates to predator-evasion tactics of the two species and vegetation cover can vary over time.

I analyzed a number of datasets including; surveys of deer population; long-term data on vegetation composition; Landsat data on the Normalized Difference Vegetation Index, which provides information on greenness by recording the dates of vegetation greenup and browndown (USGS 2012); and U.S. Census data on housing density changes in the Tucson area. This project focused on analyzing data collected from 1990 to 2000, the decade during which deer occupancy of RMD shifted from mule deer to white-tailed deer.

## Study Site

In 1933, President Herbert Hoover signed the executive order that created Saguaro National Monument, which became the first monument established to protect a species of plant: the giant saguaro cactus (*Carnegiea gigantea*). The Tucson Mountain District was added in 1961, with an additional 71,400 acres of wilderness designated as part of the monument in 1975. President William Jefferson Clinton signed the legislation that re-designated Saguaro National Monument as a national park in 1994. Saguaro National Park is divided into two districts: the Rincon Mountain District and Tucson Mountain District (TMD), which encompasses 91,327 acres. The RMD (Fig. 2) is located to the east of Tucson, Arizona, and the TMD is located to the west of the city (Powell et al. 2006).

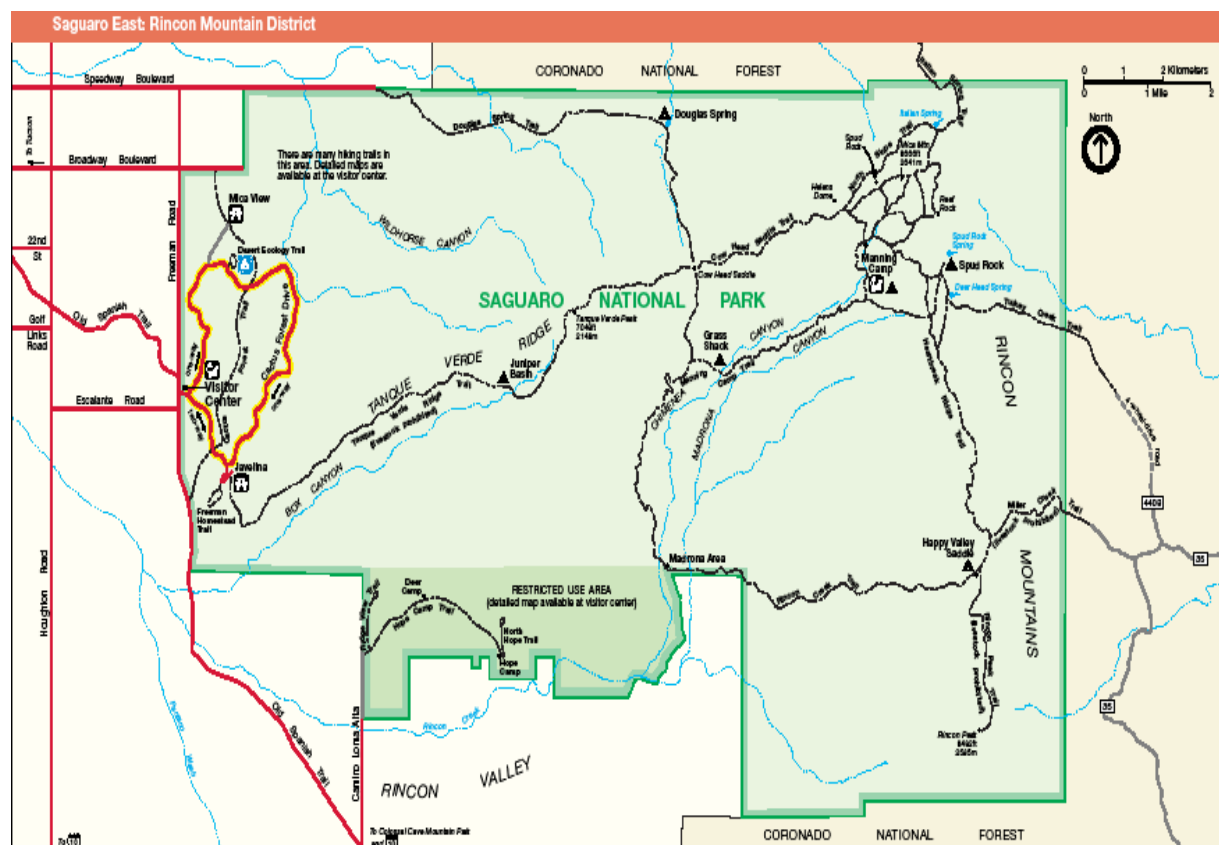


Figure 2. Visitor map of Saguaro National Park, Rincon Mountain District. The main roads around the park are in red, the main trail systems throughout the park are in black and main washes/drainages are in blue.

## Climate, Geology and Soils

The climate is indicative of the Sonoran Desert, with temperatures averaging 12°C (53.6°F) in the winter and 35.5°C (95.9°F) in the summer. Diurnal temperature swings of 15°C (59°F) are common during any season. Average rainfall of 28.6 cm (11.3 inches) is reported from data collected in Tucson, with much of the precipitation occurring during late-summer (July–September) monsoon storms (Powell et al. 2006).

The Rincon Mountain District lies at the foot of the Rincon Mountains, one of southern Arizona “sky islands.” Sky islands are defined as mountains surrounded by lowland area of a different environment. The Rincon Mountain District is primarily metamorphic in origin. Outcrops along Cactus Forest Drive have diagnostic features of many diverse types of

metamorphic core complexes (Davis 1987). Rock layers that once covered the crest of the Rincon Mountains have been eroded by water running along joints and faults. The movement of thin veneer rock debris allows for rain and snowmelt to move across the landscape. This effect, along with groundwater, creates annual water sources in the park's lower elevations, in the form of tinajas and springs (Bezy 2005).

### **Vegetation Communities**

Elevation ranges in RMD from 814m (2,670 feet) to 2,641m (8,665 feet). This large elevation change is one reason for the tremendous diversity of vegetation community types found in the park. Coniferous forest and mountain meadows are found at the highest elevations. Pine trees (*Pinus* sp.), firs (*Abies* sp.), aspens (*Populus* sp.), annual grasses, and forbs are typical in these areas. Oak savanna and grassland systems occur at mid-elevations within the park. Although many different perennial grass species and forbs are present in this community type, it also is defined by trees and shrubs, such as oaks (*Quercus* sp.) and manzanita (*Arctostaphylos* sp.). Desert shrub and desert plant community types are found at the park's lower elevations. Desert shrub is dominated by large mesquite (*Prosopis* sp.), palo verde trees (*Cercidium* sp.), and shrubs, such as creosote bush (*Larrea tridentata*). The saguaro cactus differentiates the Sonoran Desert, known for its large columnar cacti, from other deserts in the American Southwest (Powell et al. 2006).

### **Adjacent Land Development**

Both the RMD and TMD are adjacent by the metropolitan area of Tucson (Fig. 3), now home to approximately one-half million people, with the larger metropolitan area population at a slightly more than one million residents. Recent population growth (US Census 2012) has resulted in rapid residential development, including the areas immediately adjacent to the

western boundary of RMD (Figure 3.). This conversion of potential deer habitat to residential use represents a landscape-scale reduction in the carrying capacity of the land for ungulate use.

Coronado National Forest Service shares boundaries with the park to the north and east. The southern part of the park is predominately state owned land with land cover of desert shrub and xeroriparian vegetation.

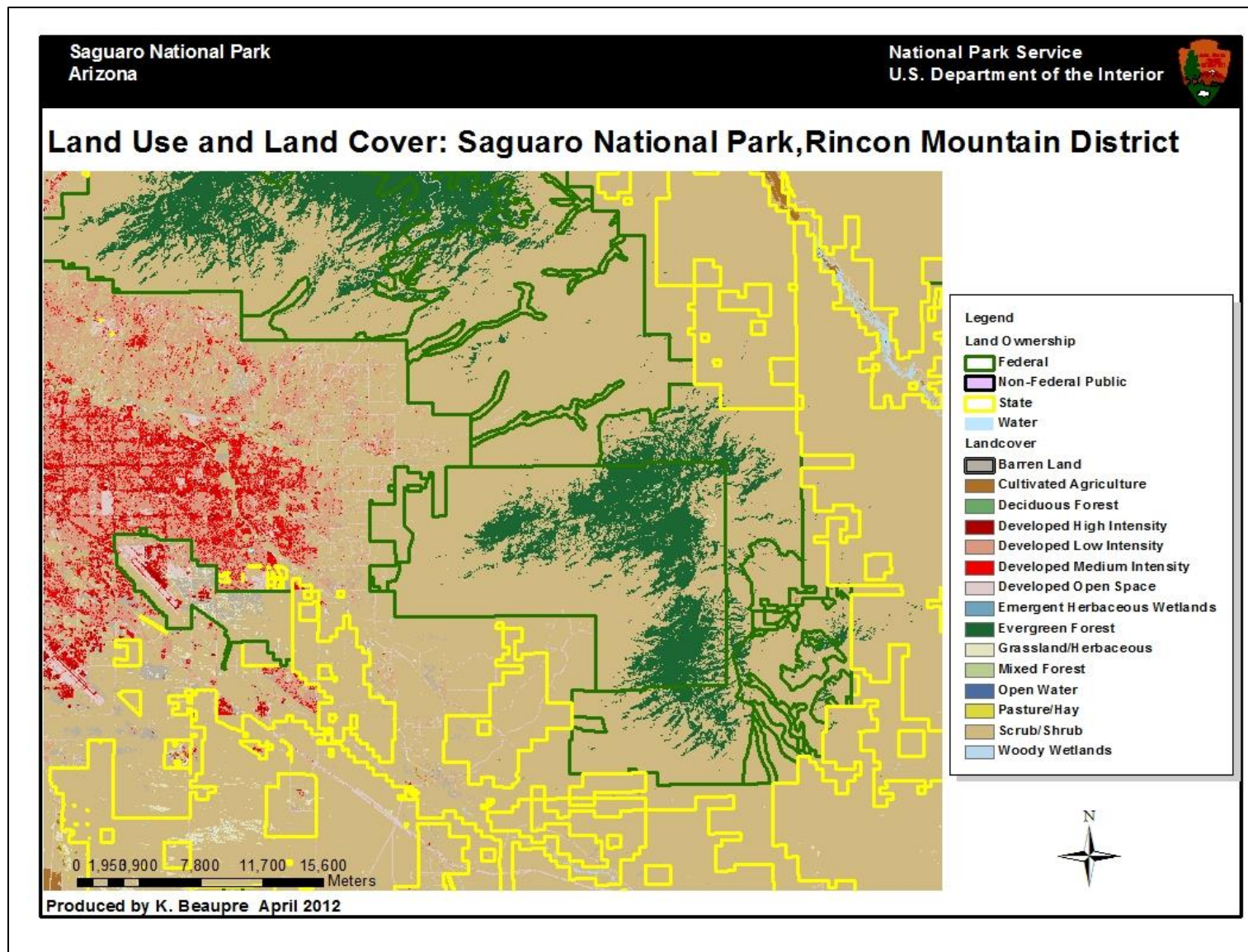


Figure 3. Land Use and Land Cover in and around Saguaro National Park, Rincon Mountain District; 2001 (NPS 2010a).

## Deer Survey Data

Observational data on deer at SNP have been collected for more than 70 years. Although the observers and methods have varied over time, I used only used these data to establish the presence or absence of mule deer at the park's lower elevations. I analyzed the datasets from four different surveys: the 1951 Sumner inventory project, deer data from Gerald Day's transect surveys of 1960–1974, data collected by the Arizona Game and Fish Department in 1989 and 2000–2006, and data collected by SNP employees in 2007–2011.

### Description

In 1951, Lowell Sumner completed a comprehensive survey of deer and other mammals in the RMD. During the winter months, Sumner rode horseback on the trails and documented where and what kind of tracks he observed in the snow or otherwise imprinted on the ground. His maps (Fig. 1) and photos represented the first inventory of mammals in the upper elevations of SNP (Sumner 1951).

From 1960 to 1974, Gerald Day completed a study to determine if there was a correlation between climate and javelina populations (Day 1977). Day's original datasheets indicate that while surveying for javelina, he systematically counted both white-tailed deer and mule deer along 10–15 transects of approximately one mile each in the RMD (Fig. 4). These transects were sampled annually from November to February. For each transect, the landscape feature providing the best vantage points were identified. From these vantage points, the surveyor used binoculars or a spotting scope to look in all directions for approximately 15 minutes. Any signs or observations of deer were recorded. Sampling began at daybreak and concluded at around 10 a.m., when deer would generally bed down (Bucci 2007). Since 2007, SNP employees have re-sampled Gerald Day's transects at the same time and used the same method as Day.

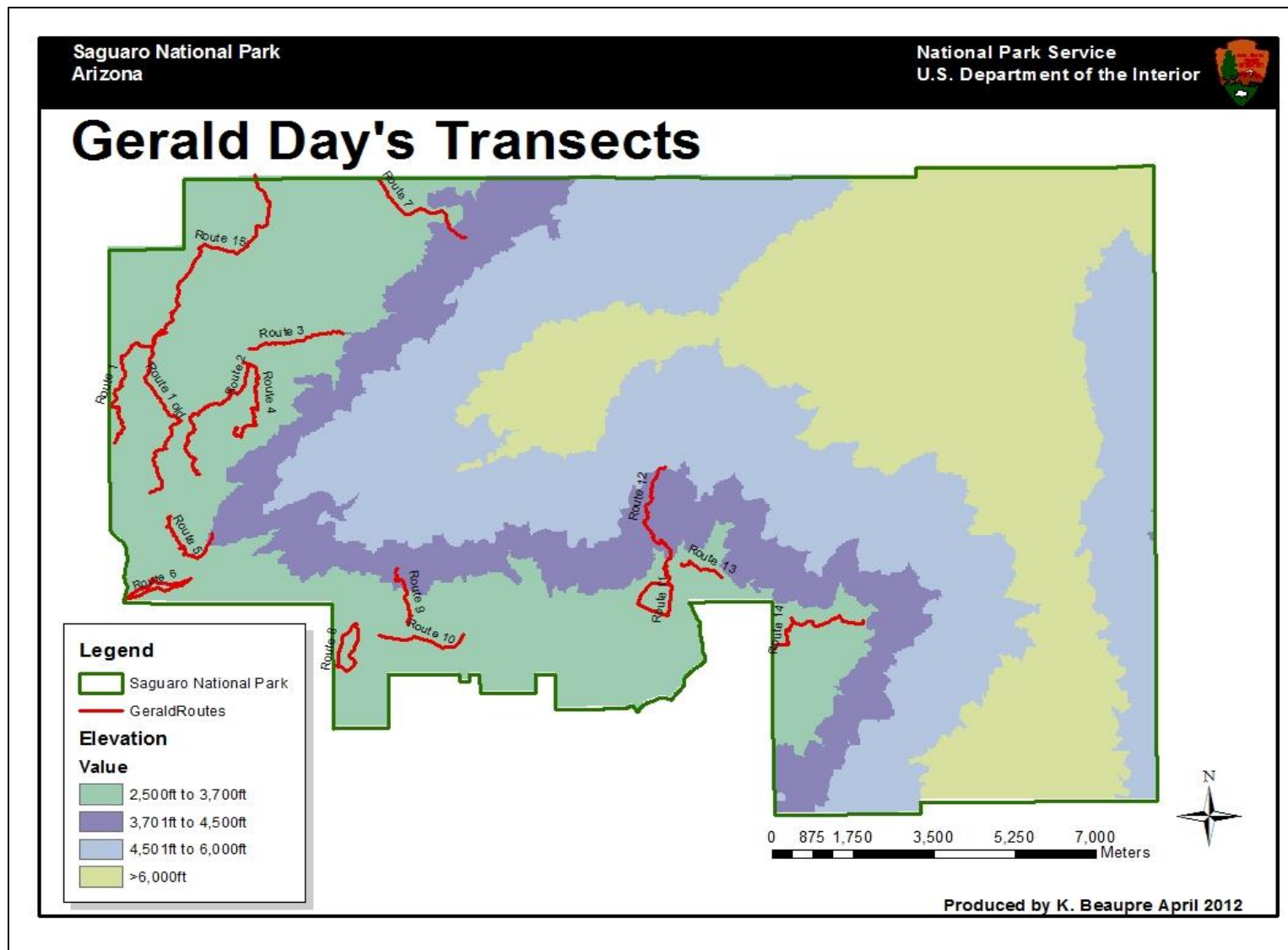


Figure 4. The locations of Gerald Day's sampling transects at Saguaro National Park, Rincon Mountain District (NPS unpublished data). Gerald recorded observations of javelina and deer species from 1960 to 1974. Saguaro National Park resamples these transect annually (since 2007).

In 1989, and annually from 2000 to 2006, Arizona Game and Fish Department staff conducted helicopter surveys of large mammals under the guidance of SNP resource managers. Although the precise route of the 1989 flight is unknown, an official memo to the park indicated that its duration was approximately two hours and all elevations of the RMD were sampled. The AZGFD did not survey SNP again until 2000. In that year, location data were obtained by the helicopter's GPS unit and maps of the full flight path was created (Fig. 5). Observation data were recorded in a pre-formatted Excel spread sheet. For each observation, AZGFD recorded a GPS point, the species, the number of individuals spotted, and the age class of the group. In 2000–2005, AZGFD flew over the lower elevations of the park for approximately two hours on each survey. They flew over the entire RMD in 2006, mule deer observation counts were still very low, while white tailed deer were observed throughout the park.

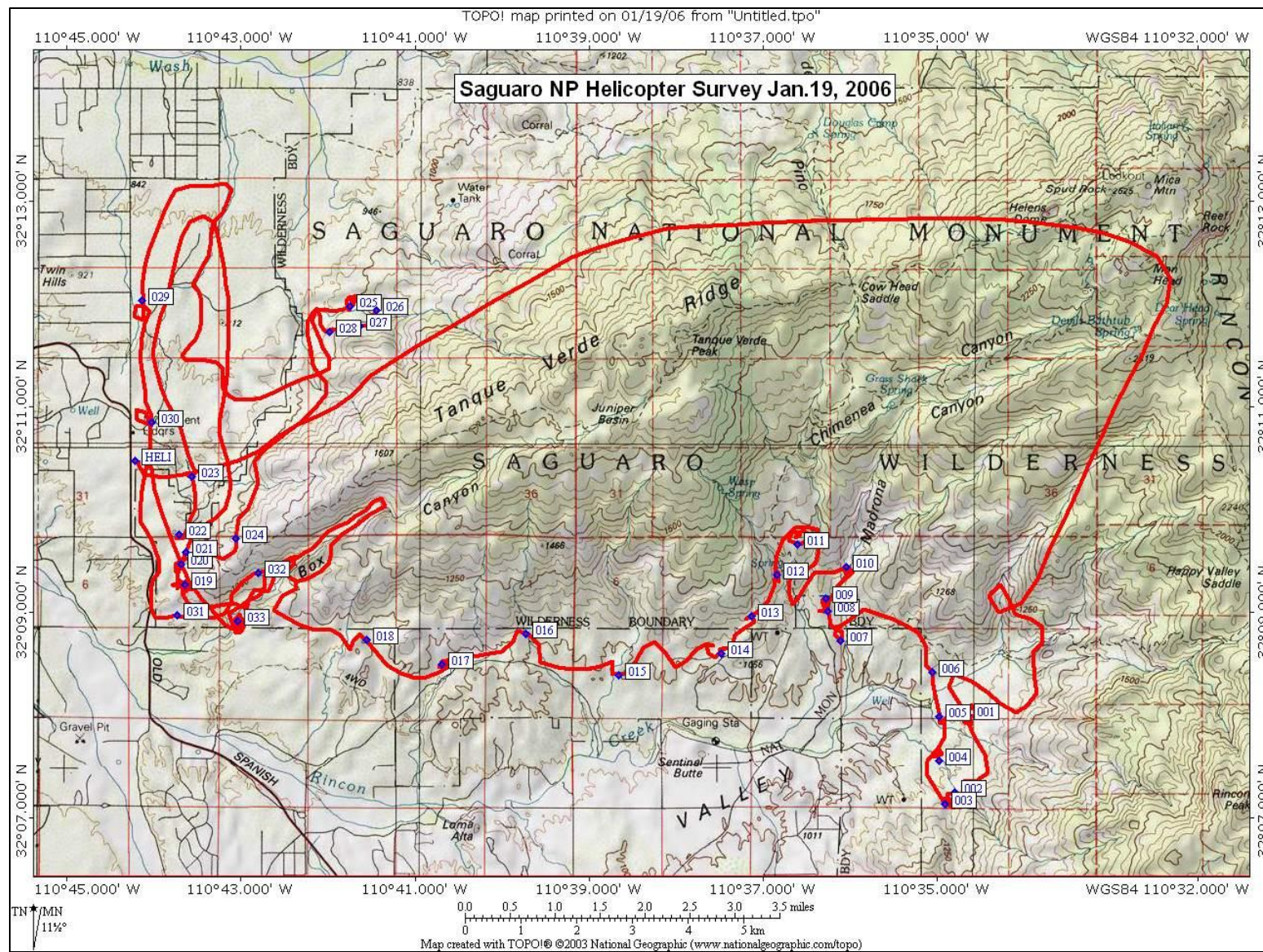


Figure 5. AZGFD Flight Report of flight path to Saguaro National Park, Rincon Mountain District; 2006 (AZGFD unpublished data). The red line is the flight path of the helicopter and the numbered boxes correspond to either deer or javelina observation.

## **Analysis**

I used the deer survey data to demonstrate the shift in the deer population in the lower elevations of SNP. The data collected from each survey were entered into an Excel spreadsheet and graphed to show trend of the mule deer and white-tailed deer population at the lower elevations of SNP.

### **Long-term Vegetation Data**

Saguaro National Park has a rich array of long-term vegetation studies. Although the projects have had different goals, data collectors, and methods, the data were used in this project only to detect broad changes in vegetation cover. This project evaluated the saguaro census plots dataset established by D. Turner in 1990 (Springer et al *in press*).

## **Description**

Saguaro census monitoring is ongoing at SNP, in an effort to better understand the effects of climate change on saguaro cacti and vegetation community composition. In 1990, forty-five permanent plots were established in the RMD and TMD. This project used data collected from the smaller vegetation plots established at the RMD and excluded data from the larger census plots, where only saguaros were counted (Fig. 6). The 25 plots used were 100m<sup>2</sup> and were sampled using a plane table and alidade in 1990 and 2000. In 2010, the data were collected using a total station. Each time the plots were sampled, observers recorded (1) the species and (2) area of cover of each individual plant (Springer et al *in press*).

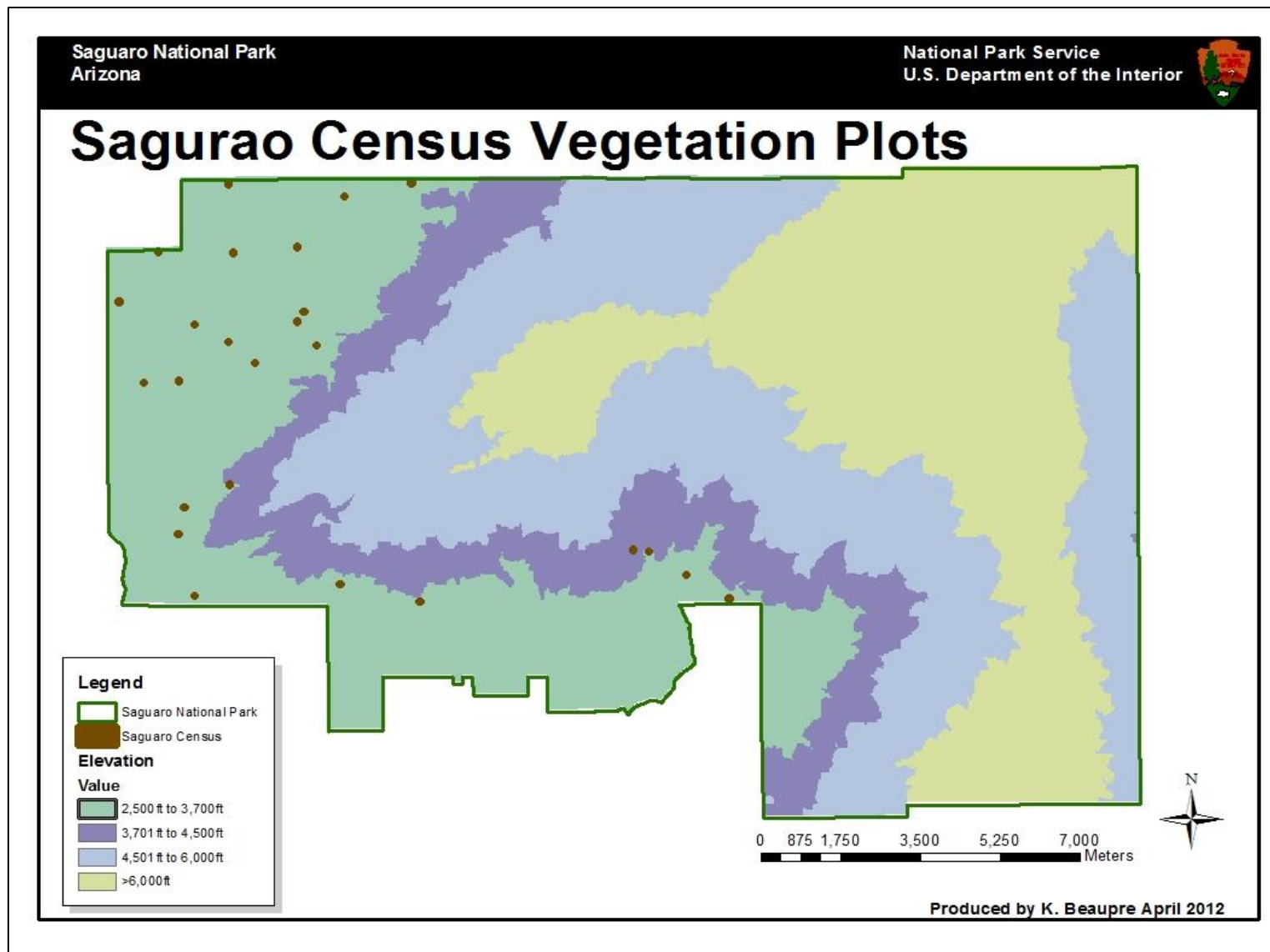


Figure 6. Locations of saguaro census vegetation plots at Saguaro National Park, Rincon Mountain District; 2010 (Springer et al *in press*).

## Analysis

A Cooperative Ecosystems Study Unit (CESU) agreement between the University of Arizona and SNP provided funding to have these historical vegetation datasets analyzed and published. The purpose for the CESU agreement was to analyze data to determine if the research question proposed by the originator of the dataset was true or null. I analyzed these same datasets to determine if vegetation cover by life form (i.e. tree, shrub, grass etc.) changed over time.

I verified that the life form attributed to each species was accurate. Next I imported the data into Microsoft Excel to calculate total cover from every species by life form. The sample size for this vegetation dataset was 25, and I could not automatically assume a normal distribution. I used XLStat (Addinsoft 2012), an add-on in Microsoft Excel, to test if the data was normally distributed. I chose the Shapiro-Wilk test because the sample size was small. Next I imported the datasets into JMP (SAS 2010) for analysis. Since I could not assume a normal distribution for all of the life forms categories with the saguaro census data, I used the matched paired t-test and the Wilcoxon Signed Rank test to determine if there was a change of vegetation cover by life form. For each life form category; I compared the mean cover from all 25 plots between the years of 1990 and 2000. The outputs were the mean difference, standard error, t-ratio, t-probability, and S-probability. I choose to use the standard P value  $\leq .05$  to determine if the change detected in the dataset was significant or not.

### Normalized Difference Vegetation Index

I used spatial data analysis of satellite imagery to answer vegetation cover questions at the landscape scale. This dataset was used to assess if there was an increase in vegetation cover.

The Normalized Difference Vegetation Index (NDVI) is a value of greenness; which I used as a proxy of vegetation cover (Xian and Moody 2005). This type of imagery analysis is comparable to other common vegetation estimate methods; Tasseled Cap Greenness, spectral mixture analysis, and soil adjusted vegetation index. Spectral mixture analysis (SMA) is the best estimator of vegetation cover, however there is only a 5% variation in results when compared to NDVI (Sonnenschein et al. 2011). Also I did not have enough vegetation plots to train the imagery for the SMA analysis. NDVI values were calculated and extracted in both historical mule deer habitat and white-tailed deer habitat to analyze how these values compare between the two habitats and over the years. Landsat was chosen because (1) data acquisition occurred in the timeframe of the deer population shift and (2) the spatial resolution is smaller than the scale at which deer make habitat decisions;  $1\text{km}^2$  (Brunjes et al. 2009) .

### **Description**

I acquired near-annual Landsat 4-5 TM (thematic mapper) images from the U.S. Geological Survey (<http://glovis.usgs.gov/>) for the years 1983–2011. Each scene covers the park and the city of Tucson (Path 36, 38). Only images from mid-November to late January (the period when only large trees, shrubs, and succulents are green, and with low cloud cover), were used for analysis. To generate the NDVI, I used the ArcMap 10 (ESRI 2011) Raster Calculator function located in the Spatial Analyst Tools. The NDVI equation is  $\text{NDVI} = (\text{NIR band} - \text{red band}) / (\text{NIR band} + \text{red band})$ . For Landsat imagery, NIR is the fourth band and red is the third band; hence, the equation I entered was  $\text{NDVI} = \text{float}(\text{band } 4 - \text{band } 3) / \text{float}(\text{band } 4 + \text{band } 3)$ . The output consisted of raster files in which each 30-m pixel stored the NDVI value.

I next attached the NDVI values to the sampling locations of Gerald Day's deer surveys, historically considered to be mule deer habitat, and purposefully created sampling locations in

what is considered to be historical white-tailed deer habitat. For Gerald Day's routes, I used the converted lines to points tool within the Hawth's Tools ArcGIS add-on (Beyer 2004) with a distance of 30 meters. This tool produced a point feature every 30 meters along the line. Because these routes primarily occurred along the washes and trails, I moved those sampling points to the adjacent pixel to get the NDVI of the vegetation, not the bare soil. To ensure that one 30-m cell was not oversampled, I scanned through all of the sampling points and deleted any duplicate points along Gerald Day's routes (more than one within a 30-m cell). The sampling locations I created, in the upper elevation, was done so systemically, hence no oversampling of a pixel would occur.

To create the sampling locations in upper elevations of the park, I used the randomly-located, spatially-balanced points created for the Sonoran Desert Network Terrestrial Vegetation and Soils Monitoring Protocol (Hubbard et al. 2012). The 402 and 502 strata, defined as greater than 4,500 feet (1,372m) in elevation with a rock-fragment content percent of >35. To match the number of Day's routes, I used the first 15 points. I created routes in ArcMap by creating a new line feature. For each route, I used a random number generated in Excel (0–359) for bearing for each route direction. The route length was the average from Gerald Day's sampling transects. Next I merged both the Gerald Day sampling points and sampling points for the upper elevation together. Then I used the Extract Multi Value to Points tool to append the NDVI values from each year's raster to the sampling point location shapefile.

## **Analysis**

I used NDVI values to determine if greenness increase in the lower elevations of SNP and how those NDVI values compared to the higher elevations of the park. I exported the data from ArcMap into the statistical software JMP (SAS 2010). I separated the lower-elevation

sampling points from the higher-elevation sampling points and analyzed each dataset using the matched paired t-test. I focused my analysis on the years 1989, 1990, 2000, and 2010 as the sample periods. The outputs were the mean difference, standard error, t-ratio, t-probability, and S-probability. I choose to use the standard P value of  $\leq .05$  to determine if the change detected in the dataset was significant or not.

### Housing Density

Saguaro National Park resource managers are concerned with the impacts of the urban-wildlife interface now adjacent to its boundaries. I used housing density as a measure of severity when land use is converted from private undeveloped to urban. This will determine if this specific land use change had a potential effect on the mule deer population at SNP.

#### **Description**

Data on housing density were obtained from U.S. Census Bureau and processed by the NPS NPScape program. All data processed by this program is clipped to a 30-km buffer of the park boundary, creating the area of analysis (AoA). The AoA for SNP includes the city of Tucson. A python script was used to process and categorize housing-density data. There are 13 pre-defined categories for housing density. Each census block was coded to attribute it to the corresponding housing density category. The output is a shapefile for each decade that has 13 classes and a count of how many cells are in each category (NPS 2010b).

I used the housing density rasters for the decades 1950 to 2010. For each housing density raster, I reclassified datasets into two categories: housing density greater than 24 units/km<sup>2</sup> or commercial (not mule deer habitat) and housing density less than 24 units/km<sup>2</sup> or private undeveloped (potential mule deer habitat). The housing density threshold is the midrange of the

pre-defined housing density categories generated by the NPScape program. I was unable to locate within the literature this specific threshold associated with mule deer habitat. Next, I reclassified the “federal lands” attribute into two elevation categories: <4,500 feet (potential mule deer habitat) and > 4,501 feet (not mule deer habitat). I then merged the federal lands rasters to their comparable housing density rasters (mule-deer habitat and non-mule-deer habitat), converted each raster to shapefiles, then calculated the area of the two categories in meters squared. The output was a shapefile for each decade from 1950 to 2010 that showed the calculated area of what is and what is not potential not mule deer habitat.

### **Analysis**

I used these datasets to quantify how much land was converted to private un-developed to high housing density land use. The data collected from each year were entered into an Excel spreadsheet and graphed to show trend in the amount of potential mule deer habitat lost.

## Results and Discussion

Results of the data analysis described in the Methods chapter confirmed the observed shifts in mule and Coues white-tail deer populations at lower elevations of the RMD at SNP. There was a dramatic decrease in the park's mule deer population, and an increase in white-tailed deer. The saguaro census vegetation dataset indicated an overall increase in vegetation cover from 37% to 48% in the lower elevations of the park, and the housing density data revealed a 210-km<sup>2</sup> loss in potential mule-deer habitat in close proximity to the park. This combination of change is a possible explanation for why mule deer are now nearly absent in SNP and why white-tailed deer are currently observed throughout the park.

### Deer Surveys

The shift from mule deer to white-tailed deer, in the lower elevations of SNP, occurred sometime between 1990 and 2000 (Fig. 7). Prior to 1990, the annual count of mule averaged  $85 \pm 5.26$  (Average  $\pm$  SE) individuals (Table 1). After 2000, the average annual count of mule deer was  $4 \pm 1.15$ . The change was first detected via the helicopter surveys in 2000. Helicopter surveys conducted over the next six years confirmed the trend. After Gerald Day's transect surveys were resumed in 2007, they also indicated a similar decrease. Over larger spatial scales, the downward trend in mule deer populations has been observed by: Kramer (1973), Wiggers and Beason (1986), Koenen and Krausman (2002), Avey and others (2003), and Brunjes and others (2006).

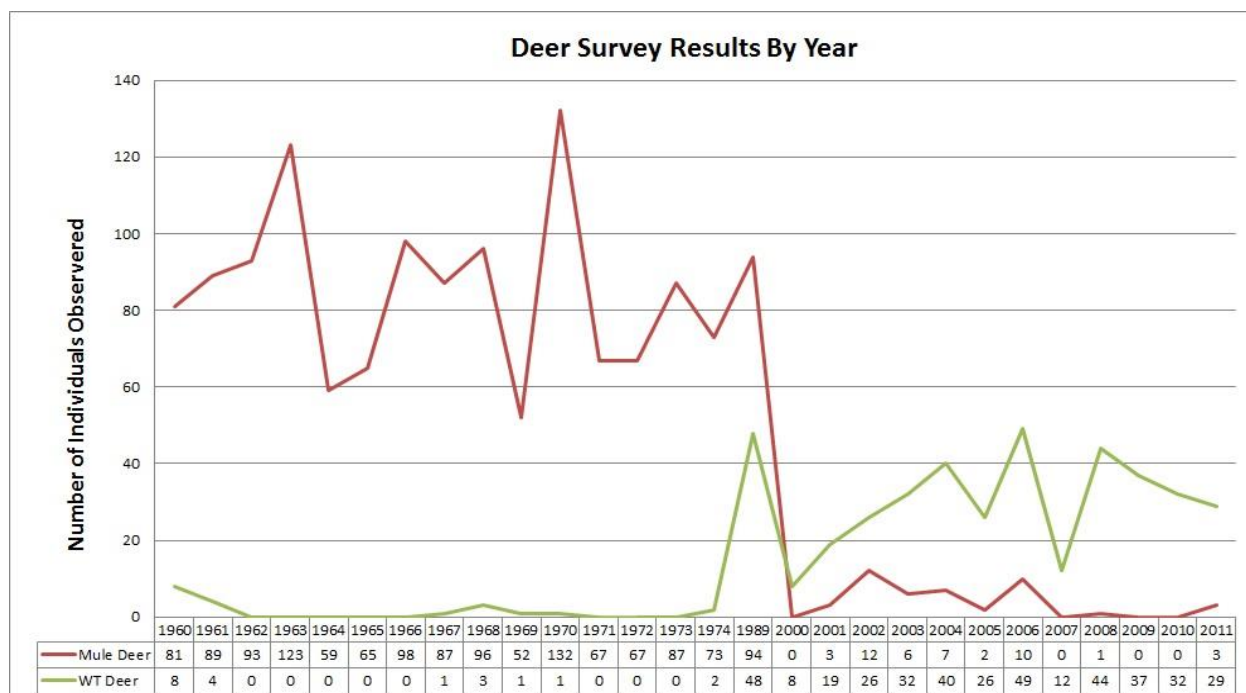


Figure 7. Deer observation counts at Saguaro National Park, Rincon Mountain District; 1960 to 2011 (NPS unpublished data). The shift in deer population occurred sometime between 1990 and 2000, there is a decade where no deer observation data was collected. WT = White-tailed deer.

Table 1. Deer Survey Data at Saguaro National Park, Rincon Mountain District (NPS unpublished data).

| Year | Mule Deer | WT Deer | Total Deer | Survey Type    | Collector | Elevation         |
|------|-----------|---------|------------|----------------|-----------|-------------------|
| 1960 | 81        | 8       | 89         | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1961 | 89        | 4       | 93         | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1962 | 93        | 0       | 93         | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1963 | 123       | 0       | 123        | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1964 | 59        | 0       | 59         | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1965 | 65        | 0       | 65         | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1966 | 98        | 0       | 98         | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1967 | 87        | 1       | 88         | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1968 | 96        | 3       | 100        | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1969 | 52        | 1       | 53         | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1970 | 132       | 1       | 133        | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1971 | 67        | 0       | 67         | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1972 | 67        | 0       | 67         | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1973 | 87        | 0       | 87         | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1974 | 73        | 2       | 75         | Ground Surveys | G. Day    | 2,500ft - 4,500ft |
| 1989 | 94        | 48      | 142        | Aerial Surveys | AGFD      | 2,500ft - 8,000ft |
| 2000 | 0         | 8       | 8          | Aerial Surveys | AGFD      | 3,000ft - 5,000ft |
| 2001 | 3         | 19      | 22         | Aerial Surveys | AGFD      | 2,500ft - 4,500ft |
| 2002 | 12        | 26      | 38         | Aerial Surveys | AGFD      | 2,500ft - 4,500ft |
| 2003 | 6         | 32      | 38         | Aerial Surveys | AGFD      | 2,500ft - 4,500ft |
| 2004 | 7         | 40      | 47         | Aerial Surveys | AGFD      | 2,500ft - 4,500ft |
| 2005 | 2         | 26      | 28         | Aerial Surveys | AGFD      | 2,500ft - 4,500ft |
| 2006 | 10        | 49      | 59         | Aerial Surveys | AGFD      | 2,500ft - 8,000ft |
| 2007 | 0         | 12      | 12         | Ground Surveys | NPS       | 2,500ft - 4,500ft |
| 2008 | 1         | 44      | 45         | Ground Surveys | NPS       | 2,500ft - 4,500ft |
| 2009 | 0         | 37      | 37         | Ground Surveys | NPS       | 2,500ft - 4,500ft |
| 2010 | 0         | 32      | 32         | Ground Surveys | NPS       | 2,500ft - 4,500ft |
| 2011 | 3         | 29      | 32         | Ground Surveys | NPS       | 2,500ft - 4,500ft |

### Long-term Vegetation Data

The results from the standard paired T-test on the saguaro census data showed a significant increase ( $P \leq .002$ ) in vegetation cover between 1990 and 2000 for all life forms except trees, which showed a no change ( $P = .4$ ) in cover (Appendix 2). Subshrubs had the largest magnitude of change, when 1990 was compared to 2000, with an increase ( $P \leq .0001$ ) of  $7.7 \text{ m}^2$  in mean cover, across all plots. Shrubs ( $P \leq .0001$ ) and succulents ( $P \leq .0001$ ) increased by approximately  $6 \text{ m}^2$  and  $4 \text{ m}^2$  in mean cover respectively (Fig. 8). Grass, forbs, and vines ( $P \leq .002$ ) together increase by approximately  $3 \text{ m}^2$  in cover. The percent vegetation cover from tree, shrub, and succulents increased from 37.1% to 47.7% ( $P \leq .0014$ ).

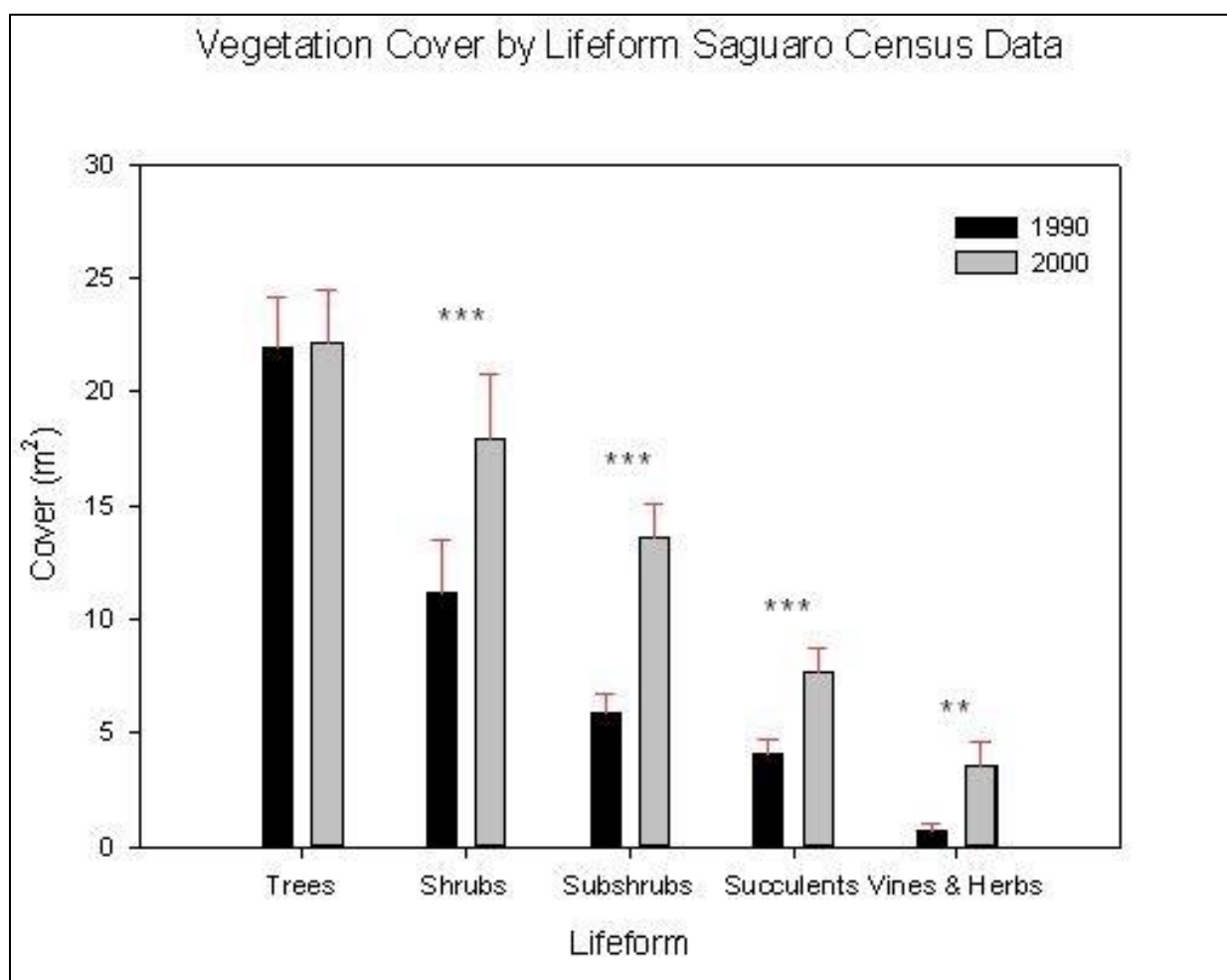


Figure 8. Change in vegetation cover by life form at Saguaro National Park, Rincon Mountain District; 1990 compared to 2000 (Springer et al *in press*). \* =  $P \leq 0.05$ , \*\* =  $P \leq 0.01$ , and \*\*\* =  $P \leq .001$ .

### Normalized Difference Vegetation Index

The results from the paired T-test on the NDVI data from lower-elevation sampling points showed a significant increase in greenness when the years of 1982 was compared to 1990, 2000, and 2010 ( $P \leq .0001$ ) (Table 2). When 1990 was compared to 2000 and 2010, there was a significant increase ( $P \leq .0001$ ) detected than a significant decrease ( $P \leq .0001$ ), respectively (Table 2). Again a significant decrease ( $P \leq .0001$ ) was detected when 2000 was compared to 2010. The results between the decades of 1990, 2000, and 2010 are consistent with climatic events in Southern Arizona. The increase between the years of 1990 and 2000, when Southern Arizona had slightly above average precipitation, was probably dwarfed by the drought that began in the late 1990's and ended in the late 2000s. Results from high-elevation sampling points showed a significant decrease ( $P \leq .0001$ ) in greenness when the years of 1982 was compared to 1990, 2000, and 2010. Only when the 2000 data was compared to 2010 was a significant increase detected (Table 2).

Table 2. Results from NDVI data for Saguaro National Park, Rincon Mountain District, both lower and higher elevation. The green-up arrow is a significant increase in greenness and the brown-down arrow is a significant decrease in greenness.

| NDVI Lower Elevation |      |      |      |      |
|----------------------|------|------|------|------|
|                      | 1982 | 1990 | 2000 | 2010 |
| 1982                 |      | ↑    | ↑    | ↑    |
| 1990                 | ↑    |      | ↑    | ↓    |
| 2000                 | ↑    | ↑    |      | ↓    |
| 2010                 | ↑    | ↓    | ↓    |      |
| NDVI High Elevation  |      |      |      |      |
|                      | 1982 | 1990 | 2000 | 2010 |
| 1982                 |      | ↓    | ↓    | ↓    |
| 1990                 | ↓    |      | ↓    | ↓    |
| 2000                 | ↓    |      |      | ↑    |
| 2010                 | ↓    | ↓    | ↑    |      |

### Housing Density

From 1950 to 2010, approximately 210km<sup>2</sup> (Fig. 10) of potential mule deer habitat was lost in proximity to SNP. From 1950 to 1960, the change from private undeveloped to a housing density of <1.5 units/km<sup>2</sup> still permitted those lands to support mule deer. From 1960 to 1970 most of the land use changed from lower density housing - still suitable mule deer habitat - to higher density housing that was no longer suitable mule deer habitat. This trend continues until the present. The largest decrease of potential mule deer habitat related to housing density increase occurred between 1970 and 1980, when a little over 77km<sup>2</sup> of potential mule deer habitat was lost (Fig. 10). Between the years of 1980 to 1990 an additional 22km<sup>2</sup> of the landscape was converted to high density housing and another 16km<sup>2</sup> from 1990 to 2000. Even though the least amount of land was converted during the years of 1990 to 2000, this was the first decade where the high density housing completely surrounded the west side of the park (Fig. 9). Most of the land converted from 2000 to 2010 was to the southwest of the park boundary (Fig. 9).

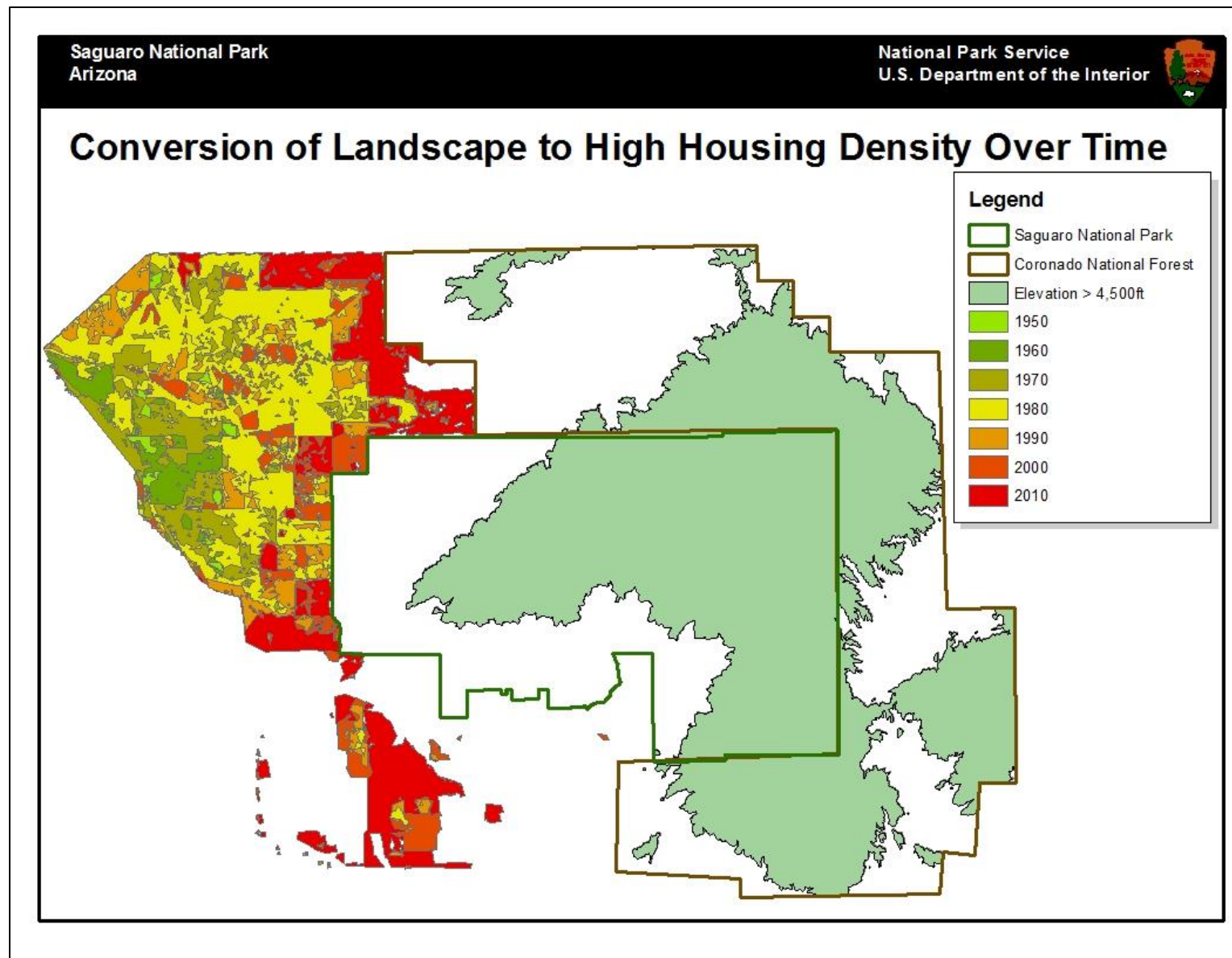


Figure 9. Housing Density Change around Saguaro National Park, Rincon Mountain District; 1950 to 2010 (NPS 2010b).

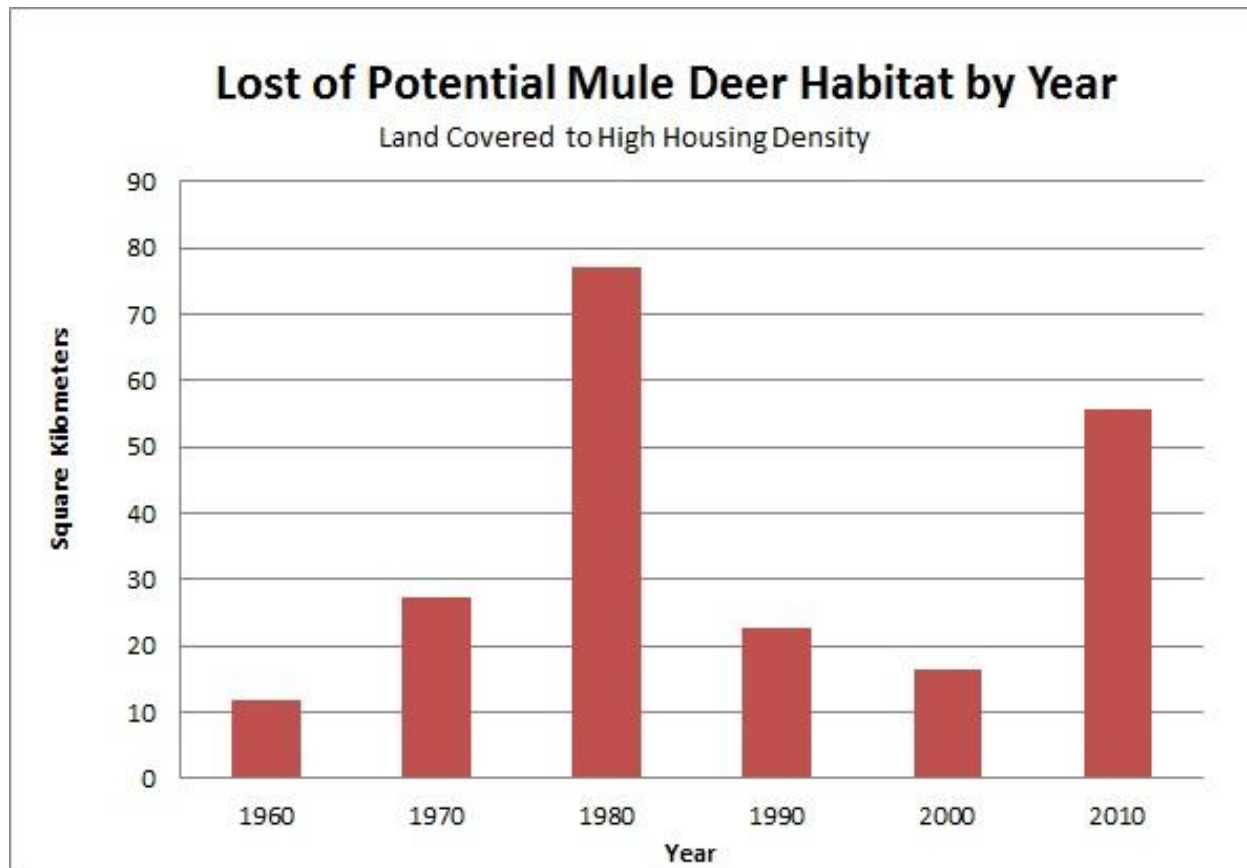


Figure 10. The amount of potential mule deer habitat lost to high density residential land use, by year, around Saguaro National Park, Rincon Mountain District; 1950 to 2010 (NPS 2010b).

## Conclusions

Since 1990, the composition of resident deer in the lower elevations of SNP has shifted from predominantly mule deer to white-tailed deer. This shift is most likely due to an increase in vegetative cover, which is preferred by white-tailed deer, and less preferred by mule deer, as is well established in the literature (Anthony and Smith 1977; Wiggers and Beason 1986; Koenen and Krausman 2002; Avey et al. 2003).

Due to their specific predator detection and evasion tactics, mule deer prefer more open areas than white-tailed deer (Lingle and Wilson 2001). Most of the habitat research on this question was conducted in areas where grasses and large woody vegetation were the dominant life forms, and large cacti (which are common in the Sonoran Desert) were generally absent. However, in the Sonoran Desert, many cacti, such as pricklypear (*Opuntia* sp.), cholla (*Cylindropuntia* sp.), and columnar cacti (e.g., giant saguaro) grow in dense patches and at heights that could obstruct a deer's view across the landscape. For mule deer, whose evasion behavior depends on visual detection of a predator, an increase in cacti would be expected to negatively impact habitat quality. This appears to be the case at SNP, where the cover of pricklypear, cholla, and many large shrubs in field plots increased substantially from 1990 to 2000. This increase was also reflected in the NDVI data for the same period, suggesting that the increase is widespread.

Potential mule-deer habitat at SNP is at the lower elevations of the park, which are generally nearest to the park boundaries. In addition to increased vegetation cover, a reduction in off-park habitat has also likely occurred due to recent dramatic increases in housing densities. Based on U.S census data on housing density, it appears that most of the potential mule deer

habitat in the vicinity of the RMD is now located inside park boundaries or just south of its borders.

Because mule deer and white-tailed deer are sympatric species, interspecific competition is also difficult to rule out. Neither deer species is considered to be socially dominant over the other, which is why both species have been observed in the same area, but seldom at the same time. Like most sympatric species, these two deer species have spatial-temporal tradeoffs (Avey et al. 2003). Therefore, when the habitat favors the preferences of one species over the other, the favored species tends to remain in that area, excluding the other species, until vegetation cover shifts dramatically as to favor the other.

Saguaro National Park could encourage the mule deer population to persist within its boundaries by reducing the cover of large vegetation species, such as shrubs, trees, and succulents, by approximately 10%. This cover could be removed by management actions; controlled burns, grazing, or direct plant removal, in the lower elevations of the park. These management actions are very intrusive and likely detrimental to native plant species (such as the namesake saguaro cactus) in the lower elevation of SNP. These management actions might encourage mule deer to return and even potentially stay within the boundaries of the park, however SNP is mandated to manage for the biodiversity of all native species and protection of saguaro cactus.

Vegetation cover can also be reduced by long term climate events such as drought, extreme frost events, increases in mean annual temperature, and decreases in mean annual precipitation (Munson et al. 2011). The effects of these climate conditions are partially reflected in the data analyzed by this project. The decrease in the NDVI values probably reflect the effects of the drought that began in the late 1990's and ended in the late 2000s. Also data analyzed from

the second phase of the saguaro census project (2000 vs. 2010), also reported a decline in large vegetation life forms (Springer et al *in press*), with succulents being the exception. To better assist SNP with long-term management of its deer population, a future study could better assess habitat quality adjacent to park boundaries, with a focus on vegetative cover.

To strengthen the correlative argument presented in this paper, that the decline of mule deer in SNP is linked to vegetation change, one would have to determine if mule deer are actually staying within the park boundaries. This question could be addressed by putting radio collars on deer found in and around the park. Continuing vegetation and deer observation monitoring within the park is also very important. I also believe that future research and monitoring of vegetation cover should be measured by height, specifically the total vegetation cover at heights which would hinder a mule deer's view of the landscape. Other data that affect deer population should also be collected, such as disease and predation, within the park boundary.

How mule deer and, Coues white-tailed deer react to urbanization now around SNP should also be further researched. Research on white-tailed deer in other parts of North America indicate that urban development and agriculture can greatly favor population increases (Grund et al 2002), but does the same relationship hold for the Coues subspecies in the American Southwest? Deer survey data reported by AZGFD, in Unit 33, have similar mule deer to white-tailed deer ratio as SNP (AZGFD 2009). To determine if what is occurring within the park is similar to the broader landscape, vegetation plots could be established throughout Unit 33. Addressing these additional research and monitoring issues would help park managers answer a critical question: can mule deer persist within Saguaro National Park?

## APPENDICES

### Appendix A: Glossary

**Abundance:** the total number of individuals of a taxon or taxa in a given area, volume or population; in this study it is given as the amount of deer in an area.

**Forb:** is a herbaceous flowering plant without significant woody tissue above or at the ground and always lack significant thickening by secondary woody growth and have perennating buds borne at or below the ground surface.

**Grass/Graminoid:** are monocotyledonous, usually herbaceous plants with narrow leaves growing from the base. They include the "true grasses", of the Poaceae (or Gramineae) family, as well as the sedges (Cyperaceae) and the rushes (Juncaceae).

**Habitat:** is a species specific set of resources and conditions which allow for an organism to live and reproduce.

**Intraspecific:** (*within species*) is a term used in biology to describe behaviors, biochemical variations and other issues within individuals of a single species.

**Interspecific:** (*between/among species*) is a term used in biology to describe behaviors, biochemical variations and other issues between individuals of separate species.

**Land Use:** is the human use of land. Land use involves the management and modification of natural environment or wilderness into built environment such as fields, pastures, and settlements.

**Land Cover:** is the physical material at the surface of the earth. Land covers include grass, asphalt, trees, bare ground, water, etc. There are two primary methods for capturing information on land cover: field survey and analysis of remotely sensed imagery.

**Observation:** is an act or instance of viewing or noting a fact or occurrence for some scientific or other special purpose.

**Population:** are all the organisms that both belong to the same group or species and live in the same geographical area.

**Subshrub:** is a low-growing plant with overwintering perennial woody; usually under 0.5 m (1.5 feet) tall, never exceeding 1 meter (3 feet) tall at maturity.

**Shrub:** is a perennial, multi-stemmed woody plant that is usually less than 4 to 5 meters (13 to 16 feet) in height. Shrubs typically have several stems arising from or near the ground, but may be taller than 5 meters or single-stemmed under certain environmental conditions.

**Succulent:** are water-retaining plants adapted to arid climates or soil conditions. Succulent plants store water in their leaves, stems, and also in roots.

**Sympatric:** is the process through which new species evolve from a single ancestral species while inhabiting the same geographic region. In evolutionary biology and biogeography, sympatric and sympatry are terms referring to organisms whose ranges overlap or are even identical, so that they occur together at least in some places.

**Tree:** is a perennial, woody plant with many secondary branches supported clear of the ground on a single main stem or trunk with clear apical dominance, normally greater than 4 to 5 meters (13 to 16 feet) in height; under certain environmental conditions, some tree species may develop a multi-stemmed or short growth form (less than 4 meters or 13 feet in height).

**Vine:** is a plant with a growth habit of trailing or scandent that is to say climbing, stems or runners. Twining/climbing plant with relatively long stems, can be woody or herbaceous.

## Appendix B: Results

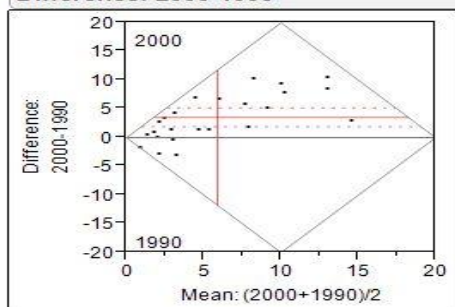
## Saguaro Census Vegetation Results

## Cactus

## Increase (S)

## Matched Pairs

## Difference: 2000-1990



|                 |         |           |          |
|-----------------|---------|-----------|----------|
| 2000            | 7.63971 | t-Ratio   | 4.457375 |
| 1990            | 4.09224 | DF        | 24       |
| Mean Difference | 3.54746 | Prob >  t | 0.0002*  |
| Std Error       | 0.79586 | Prob > t  | <.0001*  |
| Upper 95%       | 5.19005 | Prob < t  | 0.9999   |
| Lower 95%       | 1.90488 |           |          |
| N               | 25      |           |          |
| Correlation     | 0.73491 |           |          |

## Wilcoxon Signed Rank

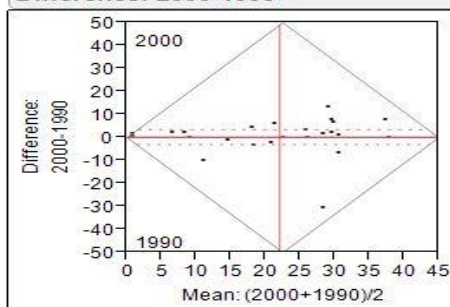
|                  |           |
|------------------|-----------|
|                  | 2000-1990 |
| Test Statistic S | 127.500   |
| Prob> S          | 0.0001*   |
| Prob>S           | <.0001*   |
| Prob<S           | 0.9999    |

## Tree

## Increase (NS)

## Matched Pairs

## Difference: 2000-1990



|                 |         |           |          |
|-----------------|---------|-----------|----------|
| 2000            | 22.1784 | t-Ratio   | 0.176393 |
| 1990            | 21.8989 | DF        | 24       |
| Mean Difference | 0.27953 | Prob >  t | 0.8615   |
| Std Error       | 1.58468 | Prob > t  | 0.4307   |
| Upper 95%       | 3.55015 | Prob < t  | 0.5693   |
| Lower 95%       | -2.9911 |           |          |
| N               | 25      |           |          |
| Correlation     | 0.77075 |           |          |

## Wilcoxon Signed Rank

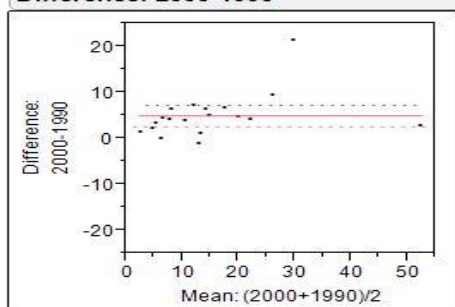
|                  |           |
|------------------|-----------|
|                  | 2000-1990 |
| Test Statistic S | 46.500    |
| Prob> S          | 0.2176    |
| Prob>S           | 0.1088    |
| Prob<S           | 0.8912    |

## Shrub

## Increase (S)

## Matched Pairs

## Difference: 2000-1990



|                 |         |           |          |
|-----------------|---------|-----------|----------|
| 2000            | 17.464  | t-Ratio   | 4.483684 |
| 1990            | 12.5322 | DF        | 18       |
| Mean Difference | 4.93185 | Prob >  t | 0.0003*  |
| Std Error       | 1.09995 | Prob > t  | 0.0001*  |
| Upper 95%       | 7.24277 | Prob < t  | 0.9999   |
| Lower 95%       | 2.62093 |           |          |
| N               | 19      |           |          |
| Correlation     | 0.92816 |           |          |

## Wilcoxon Signed Rank

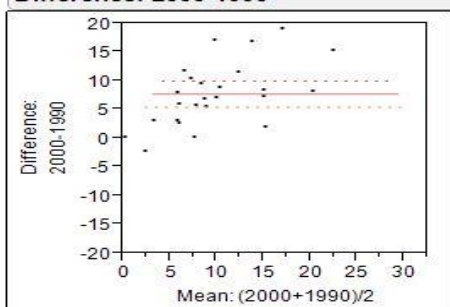
|                  |           |
|------------------|-----------|
|                  | 2000-1990 |
| Test Statistic S | 92.000    |
| Prob> S          | <.0001*   |
| Prob>S           | <.0001*   |
| Prob<S           | 1.0000    |

## Subshrub

## Increase (S)

## Matched Pairs

## Difference: 2000-1990



|                 |         |           |          |
|-----------------|---------|-----------|----------|
| 2000            | 13.6621 | t-Ratio   | 7.009541 |
| 1990            | 5.92396 | DF        | 24       |
| Mean Difference | 7.73812 | Prob >  t | <.0001*  |
| Std Error       | 1.10394 | Prob > t  | <.0001*  |
| Upper 95%       | 10.0165 | Prob < t  | 1.0000   |
| Lower 95%       | 5.4597  |           |          |
| N               | 25      |           |          |
| Correlation     | 0.66738 |           |          |

## Wilcoxon Signed Rank

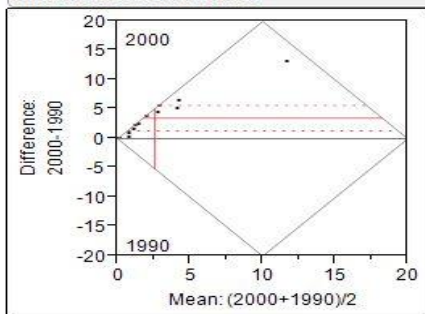
|                  |           |
|------------------|-----------|
|                  | 2000-1990 |
| Test Statistic S | 158.500   |
| Prob> S          | <.0001*   |
| Prob>S           | <.0001*   |
| Prob<S           | 1.0000    |

## Vines & Forbs & Grasses

Increase (S)

### Matched Pairs

#### Difference: 2000-1990



|                 |         |           |         |
|-----------------|---------|-----------|---------|
| 2000            | 4.32046 | t-Ratio   | 3.52348 |
| 1990            | 0.79336 | DF        | 12      |
| Mean Difference | 3.5271  | Prob >  t | 0.0042* |
| Std Error       | 1.00103 | Prob > t  | 0.0021* |
| Upper 95%       | 5.70815 | Prob < t  | 0.9979  |
| Lower 95%       | 1.34605 |           |         |
| N               | 13      |           |         |
| Correlation     | 0.91978 |           |         |

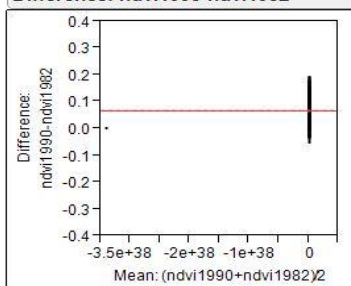
### Wilcoxon Signed Rank

|                  |                  |
|------------------|------------------|
|                  | <b>2000-1990</b> |
| Test Statistic S | 45.500           |
| Prob> S          | 0.0002*          |
| Prob>S           | 0.0001*          |
| Prob<S           | 0.9999           |

## NDVI – Lower Elevation

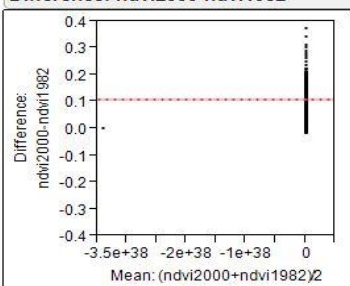
### Matched Pairs

Difference: ndvi1990-ndvi1982



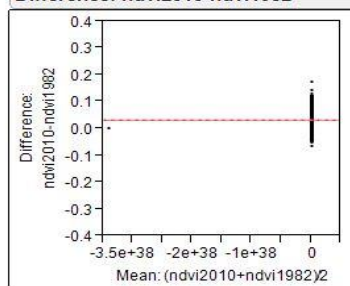
|                 |         |           |          |
|-----------------|---------|-----------|----------|
| ndvi1990        | -1e+36  | t-Ratio   | 81.26745 |
| ndvi1982        | -1e+36  | DF        | 1732     |
| Mean Difference | 0.06728 | Prob >  t | <.0001*  |
| Std Error       | 0.00083 | Prob > t  | <.0001*  |
| Upper 95%       | 0.0689  | Prob < t  | 1.0000   |
| Lower 95%       | 0.06565 |           |          |
| N               | 1733    |           |          |
| Correlation     | 1       |           |          |

Difference: ndvi2000-ndvi1982



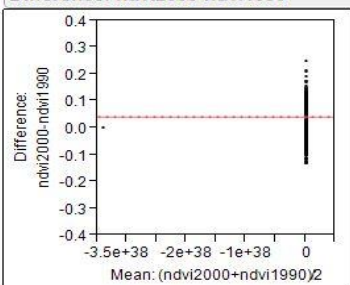
|                 |         |           |          |
|-----------------|---------|-----------|----------|
| ndvi2000        | -1e+36  | t-Ratio   | 111.6181 |
| ndvi1982        | -1e+36  | DF        | 1732     |
| Mean Difference | 0.10942 | Prob >  t | <.0001*  |
| Std Error       | 0.00098 | Prob > t  | <.0001*  |
| Upper 95%       | 0.11134 | Prob < t  | 1.0000   |
| Lower 95%       | 0.1075  |           |          |
| N               | 1733    |           |          |
| Correlation     | 1       |           |          |

Difference: ndvi2010-ndvi1982



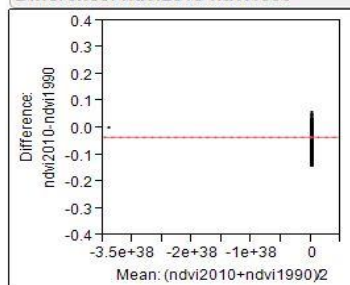
|                 |         |           |          |
|-----------------|---------|-----------|----------|
| ndvi2010        | -1e+36  | t-Ratio   | 49.04579 |
| ndvi1982        | -1e+36  | DF        | 1732     |
| Mean Difference | 0.03287 | Prob >  t | <.0001*  |
| Std Error       | 0.00067 | Prob > t  | <.0001*  |
| Upper 95%       | 0.03418 | Prob < t  | 1.0000   |
| Lower 95%       | 0.03156 |           |          |
| N               | 1733    |           |          |
| Correlation     | 1       |           |          |

Difference: ndvi2000-ndvi1990



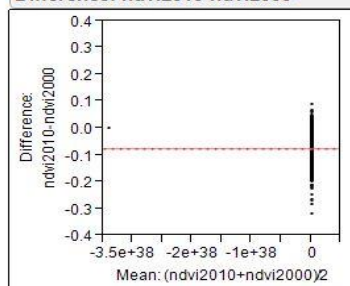
|                 |         |           |          |
|-----------------|---------|-----------|----------|
| ndvi2000        | -1e+36  | t-Ratio   | 38.18125 |
| ndvi1990        | -1e+36  | DF        | 1732     |
| Mean Difference | 0.04214 | Prob >  t | <.0001*  |
| Std Error       | 0.0011  | Prob > t  | <.0001*  |
| Upper 95%       | 0.04431 | Prob < t  | 1.0000   |
| Lower 95%       | 0.03998 |           |          |
| N               | 1733    |           |          |
| Correlation     | 1       |           |          |

Difference: ndvi2010-ndvi1990



|                 |         |           |          |
|-----------------|---------|-----------|----------|
| ndvi2010        | -1e+36  | t-Ratio   | -45.8919 |
| ndvi1990        | -1e+36  | DF        | 1732     |
| Mean Difference | -0.0344 | Prob >  t | <.0001*  |
| Std Error       | 0.00075 | Prob > t  | 1.0000   |
| Upper 95%       | -0.0329 | Prob < t  | <.0001*  |
| Lower 95%       | -0.0359 |           |          |
| N               | 1733    |           |          |
| Correlation     | 1       |           |          |

Difference: ndvi2010-ndvi2000



|                 |         |           |          |
|-----------------|---------|-----------|----------|
| ndvi2010        | -1e+36  | t-Ratio   | -72.0564 |
| ndvi2000        | -1e+36  | DF        | 1732     |
| Mean Difference | -0.0765 | Prob >  t | <.0001*  |
| Std Error       | 0.00106 | Prob > t  | 1.0000   |
| Upper 95%       | -0.0745 | Prob < t  | <.0001*  |
| Lower 95%       | -0.0786 |           |          |
| N               | 1733    |           |          |
| Correlation     | 1       |           |          |

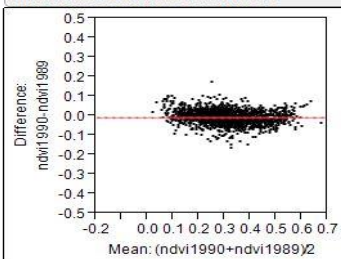
### Wilcoxon Signed Rank

|                  | ndvi1990-<br>ndvi1982 | ndvi2000-<br>ndvi1982 | ndvi2000-<br>ndvi1990 | ndvi2010-<br>ndvi1982 | ndvi2010-<br>ndvi1990 | ndvi2010-<br>ndvi2000 |
|------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Test Statistic S | 741796                | 745826                | 588851                | 672588                | -671180               | -735022               |
| Prob> S          | <.0001*               | <.0001*               | <.0001*               | <.0001*               | <.0001*               | <.0001*               |
| Prob>S           | <.0001*               | <.0001*               | <.0001*               | <.0001*               | 1.0000                | 1.0000                |
| Prob<S           | 1.0000                | 1.0000                | 1.0000                | 1.0000                | <.0001*               | <.0001*               |

## NDVI – Higher Elevation

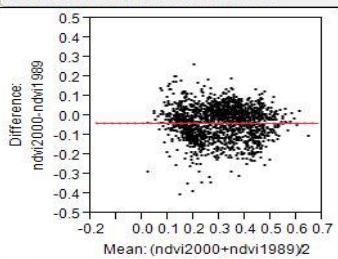
### Matched Pairs

Difference: ndvi1990-ndvi1989



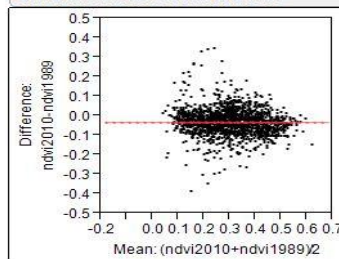
|                 |         |           |          |
|-----------------|---------|-----------|----------|
| ndvi1990        | 0.30914 | t-Ratio   | -11.1707 |
| ndvi1989        | 0.3188  | DF        | 1698     |
| Mean Difference | -0.0097 | Prob >  t | <.0001*  |
| Std Error       | 0.00086 | Prob > t  | 1.0000   |
| Upper 95%       | -0.008  | Prob < t  | <.0001*  |
| Lower 95%       | -0.0114 |           |          |
| N               | 1699    |           |          |
| Correlation     | 0.95546 |           |          |

Difference: ndvi2000-ndvi1989



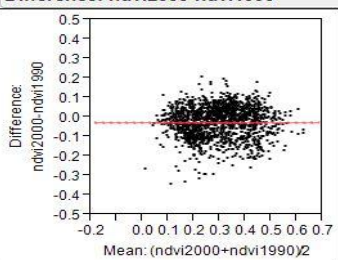
|                 |         |           |          |
|-----------------|---------|-----------|----------|
| ndvi2000        | 0.2812  | t-Ratio   | -18.9115 |
| ndvi1989        | 0.3188  | DF        | 1698     |
| Mean Difference | -0.0376 | Prob >  t | <.0001*  |
| Std Error       | 0.00199 | Prob > t  | 1.0000   |
| Upper 95%       | -0.0337 | Prob < t  | <.0001*  |
| Lower 95%       | -0.0415 |           |          |
| N               | 1699    |           |          |
| Correlation     | 0.76769 |           |          |

Difference: ndvi2010-ndvi1989



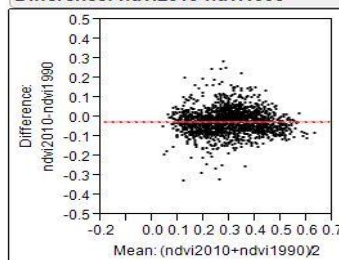
|                 |         |           |          |
|-----------------|---------|-----------|----------|
| ndvi2010        | 0.285   | t-Ratio   | -20.8579 |
| ndvi1989        | 0.3188  | DF        | 1698     |
| Mean Difference | -0.0338 | Prob >  t | <.0001*  |
| Std Error       | 0.00162 | Prob > t  | 1.0000   |
| Upper 95%       | -0.0306 | Prob < t  | <.0001*  |
| Lower 95%       | -0.037  |           |          |
| N               | 1699    |           |          |
| Correlation     | 0.83952 |           |          |

Difference: ndvi2000-ndvi1990



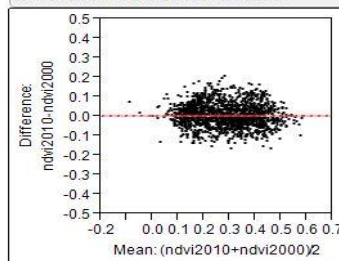
|                 |         |           |         |
|-----------------|---------|-----------|---------|
| ndvi2000        | 0.2812  | t-Ratio   | -14.817 |
| ndvi1990        | 0.30914 | DF        | 1698    |
| Mean Difference | -0.0279 | Prob >  t | <.0001* |
| Std Error       | 0.00189 | Prob > t  | 1.0000  |
| Upper 95%       | -0.0242 | Prob < t  | <.0001* |
| Lower 95%       | -0.0316 |           |         |
| N               | 1699    |           |         |
| Correlation     | 0.78043 |           |         |

Difference: ndvi2010-ndvi1990



|                 |         |           |          |
|-----------------|---------|-----------|----------|
| ndvi2010        | 0.285   | t-Ratio   | -16.0184 |
| ndvi1990        | 0.30914 | DF        | 1698     |
| Mean Difference | -0.0241 | Prob >  t | <.0001*  |
| Std Error       | 0.00151 | Prob > t  | 1.0000   |
| Upper 95%       | -0.0212 | Prob < t  | <.0001*  |
| Lower 95%       | -0.0271 |           |          |
| N               | 1699    |           |          |
| Correlation     | 0.85199 |           |          |

Difference: ndvi2010-ndvi2000



|                 |         |           |          |
|-----------------|---------|-----------|----------|
| ndvi2010        | 0.285   | t-Ratio   | 2.618216 |
| ndvi2000        | 0.2812  | DF        | 1698     |
| Mean Difference | 0.00379 | Prob >  t | 0.0089*  |
| Std Error       | 0.00145 | Prob > t  | 0.0045*  |
| Upper 95%       | 0.00663 | Prob < t  | 0.9955   |
| Lower 95%       | 0.00095 |           |          |
| N               | 1699    |           |          |
| Correlation     | 0.87055 |           |          |

### Wilcoxon Signed Rank

|                  | ndvi1990-<br>ndvi1989 | ndvi2000-<br>ndvi1989 | ndvi2000-<br>ndvi1990 | ndvi2010-<br>ndvi1989 | ndvi2010-<br>ndvi1990 | ndvi2010-<br>ndvi2000 |
|------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Test Statistic S | -215902               | -332990               | -251955               | -433163               | -334255               | 335920                |
| Prob> S          | <.0001*               | <.0001*               | <.0001*               | <.0001*               | <.0001*               | 0.0878                |
| Prob>S           | 1.0000                | 1.0000                | 1.0000                | 1.0000                | 1.0000                | 0.0439*               |
| Prob<S           | <.0001*               | <.0001*               | <.0001*               | <.0001*               | <.0001*               | 0.9561                |

## REFERENCES

- Addinsoft, 2011. XLSTAT Version 2011.3.02. Addinsoft SARL, Paris, France, Europe.
- Anthony, R.G., and N.S. Smith. 1977. Ecological relationships between mule deer and white-tailed deer in southeastern Arizona. *Ecological Monographs* 47(3):255-277.
- Arizona Game and Fish Department. Hunt Arizona 2009 Edition; Survey, harvest and hunt data for big and small game. AZ Game and Fish Department, Phoenix, AZ, USA.
- Avey, J.T., W.B. Ballard, M.C. Wallace, M.H. Humphrey, P.R. Krausman, F. Harwell, and E.B. Fish. 2003. Habitat relationships between sympatric mule deer and white-tailed deer in Texas. *Southwestern Naturalist* 48(4):644-653.
- Beguin, J., D. Pothier, and S.D. Cote. 2011. Deer browsing and soil disturbance induce cascading effects on plant communities: a multilevel path analysis. *Ecological Applications* 21(2): 439-451.
- Beyer, H. L. 2004. Hawth's Analysis Tools for ArcGIS. Available at <http://www.spatial ecology.com/htools>).
- Bezy, J. V. 2005. A guide to the geology of Saguaro National Park. Volume 18. The Arizona Geological Survey, Tucson, AZ, USA.
- Brunjes, K.J, W.B. Ballard, M.H. Humphrey, F. Harwell, N.E. McIntyre, P.R. Krausman, and M.C. Wallace. 2006. Habitat use by sympatric mule and white-tailed deer in Texas. *Journal of Wildlife Management* 70(5):1351-1359.
- Brunjes, K.J, W.B. Ballard, M.H. Humphrey, F. Harwell, N.E. McIntyre, P.R. Krausman, and M.C. Wallace. 2009. Home-range size and overlap of sympatric male mule and white-tailed deer in Texas. *Western North American Naturalist* 69(1):125-130.
- Bucci, M. 2007. Review of deer surveys at Saguaro National Park. Internal Report. U.S. National Park Service, Saguaro National Park, Tucson, Arizona, USA.
- Davis, G. H. 1987. Saguaro National Monument, Arizona: Outstanding display of the structural characteristics of metamorphic core complexes. In *Cordilleran Section of the Geological Society of America*, ed. M. L. Hill, 35-40. Boulder, CO: Geological Society of America, Centennial Field Guide 1.
- Day, G. 1977. Climate and its relationship to survival of young javelina. Research Division. Arizona Game and Fish Department, Tucson, Arizona, USA.
- Dobson, A.P., J.P. Rodriguez, W.M. Roberts, and D.S. Wilcove. 1997. Geographic distribution of endangered species in the United States. *Science* 275(5299):550-553.

ESRI, 2011. ArcGIS Desktop: Release 10. Environmental Systems Research Institute, Redlands, California, USA.

Gill, R.M.A., and V. Beardall. 2001. The impact of deer on woodlands: the effect of browsing and seed dispersal on vegetation structure and composition. *Forestry* 74(3):209-218.

Grund, M.D., J. B. McAninch, and E.P. Wiggers. 2002. Seasonal movements and habitat use of female white-tailed deer associated with an urban park. *Journal of Wildlife* 66(1):123-130.

Heffelfinger, J. 2006. Deer of the Southwest: a complete guide to the natural history, biology, and management of mule deer and white-tailed deer. 1<sup>st</sup> Edition. Texas A&M University Press, College Station, Texas. USA.

Hubbard, J.A., C.L. McIntyre, S.E. Studd, T. Nauman, D. Angell, K. Beaupre, B. Vance, and M.K. Connor. 2012. Terrestrial Vegetation and Soils Monitoring Protocol and Standard Operating Procedures; Version 1.1. Natural Resource Report 2012/509. U.S. National Park Service, Ft. Collins, Colorado, USA.

Koenen, K.K.G., and P.R. Krausman. 2002. Habitat use by desert mule deer in the semidesert grassland. *Southwestern Naturalist* 47(3):353-362.

Kramer, A. 1973. Interspecific behavior and dispersion of two sympatric deer species. *Journal of Wildlife Management* 37(3):288-300.

Krausman P.R., A.J. Kuenzi, R.C. Etchberger, K.R. Rautenstrauch, L.L. Ordway, and J.J. Hervet. 1997. Diets of desert mule deer. *Journal of Range Management* 50(5):513-522.

LaGory, K.E. 1987. The influence of habitat and group characteristics on the alarm and flight response of white-tailed deer. *Animal Behavior* 35:20-25.

Lingle, S. 2001. Anti-predator strategies and grouping patterns in white-tailed deer and mule deer. *Ethology* 107:295-314.

Lingle, S., and W.F. Wilson. 2001. Detection and avoidance of predators in white-tailed deer (*Odocoileus virginianus*) and mule deer (*O. hemionus*). *Ethology* 107:125-147.

National Park Service. 2010a. NPScape housing measure – Phase 1 metrics processing SOP: Landcover area per category, natural vs. converted landcover, landcover change, and impervious surface metrics. Natural Resource Report 2010/252. U.S. National Park Service, Ft. Collins, Colorado, USA.

National Park Service. 2010b. NPScape housing measure – Phase 1 metrics processing SOP: Current housing density, historic housing density, and projected housing density metrics. Natural Resource Report 2010/251. U.S. National Park Service, Ft. Collins, Colorado, USA.

Markovchick-Nicholls, L., H.M. Regan, D.H. Deutschman, A. Widyanata, B. Martin, L. Noreke, and T.A. Hunt. 2008. Relationships between human disturbance and wildlife land use in urban habitat fragments. *Conservation Biology* 22(1):99-109.

Marshal, J.P., P.R. Krausman, and V.C. Bleich. 2005. Dynamics of mule deer forage in the Sonoran Desert. *Journal of Arid Environment* 60:593-609.

Munson, S.E., R.H. Webb, J. Belnap, J.A. Hubbard, D.E. Swann, and S. Rutman. 2011. Forecasting climate change impacts to plant community composition in the Sonoran Desert region. *Global Change Biology* 10.1111:1-13.

Ordaway, L.L., and P.R. Krausman. 1986. Habitat use by mule deer. *Journal of Wildlife Management* 50:677-683.

Pierce, B.M., R.T. Bowyer, and V.C. Bleich. 2004. Habitat selection by selection by mule deer: forage benefits or risk of predation?. *Journal of Wildlife Management* 68(3):533-541.

Powell, B. F., W.L. Halvorson, and C.A. Schmidt. 2006. Vascular plant and vertebrate inventory of Saguaro National Park, Rincon Mountain District. U.S. Geological Survey Open-File Report 2006-1075. U.S. Geological Survey, Tucson, Arizona, USA.

Rooney, T.P., and D.M. Waller. 2003. Direct and indirect effects of white-tailed deer in forest ecosystems. *Forest Ecology and Management* 181:165-176.

SAS Institute Inc., 2010. JMP system for Windows. Version 9.0.2 user manual. SAS Institute, Cary, North Carolina, USA.

Sonnenschein, R. T. Kuemmerle, T. Udelhoven, M. Stellmes, and P. Hostert. 2011. Differences in Landsat-based trend analysis in drylands due to the choice of vegetation estimate. *Remote Sensing of Environment* 115:11408-1420.

Springer, A.C., C. Hannaum, and D.E. Swann. *In press*. Two decades of vegetation change in Saguaro National Park, 1990-2010.

Sumner, L. 1951. A biological survey of Saguaro National Monument. Research Division. Arizona Game and Fish Department, Tucson, Arizona, USA.

Swann, D.E. 2011. Mammals of the Rincon Mountain District, Saguaro National Park. Natural Resource Report 2011/437. U.S. National Park Service, Ft. Collins, Colorado, USA.

Swann, D.E., J.A. Hubbard, A.C. Springer, K.A. Beaupre, and B. Hontz. *unpublished report*. A repeat survey of vegetation plots established to evaluate grazing effects at Saguaro National Park, 1976 and 2007.

Tull, J.C., and P.R. Krausman. 2007. Habitat use of a fragmented landscape by females in a small population of desert mule deer. *Southwestern Naturalist* 52(1):104-109.

U.S. Census Bureau [USCB]. 2012. < <http://www.census.gov/main/www/access.html>>. Accessed 17 February 2012.

U.S. Congress. 1916. National Park Service Organic Act. 16 U.S.C

U.S. Geological Society [USGS]. 2012. < <http://ivm.cr.usgs.gov/whatndvi.php>>. Accessed 26 February 2012.

Wiggers, E.P., and S.L. Beasom. 1986. Characterization of sympatric or adjacent habitats of 2 deer species in west Texas. *Journal of Wildlife Management* 50(1):129-134.

Xiao, J., and A. Moody. 2005. A comparison of method for estimating fractional green vegetation cover within a desert-to-upland transition zone in central New Mexico, USA. *Remote Sensing of Environment* 98:237-250.