

Saguaro (*Carnegiea gigantea*) Demography at the Northeastern Extreme of the Species' Range

DRAFT FINAL Report

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Carianne Funicelli Campbell, RECON Environmental, Inc.
Jenny Shrum, Tonto National Monument
Richard Brusca, Arizona-Sonora Desert Museum

Introduction

The saguaro cactus (*Carnegiea gigantea*) is one of the most iconic and ecologically important species in the Sonoran Desert. This species has been extensively studied by botanists and ecologists of the Sonoran Desert, including some of the earliest investigations into Sonoran Desert plant biology at the Desert Laboratory at Tumamoc Hill (Shreve 1910) as well as the longest-running demographic studies of vegetation in plots (Pierson & Turner 1998). National parks have played a prominent role in the body of knowledge about saguaro population dynamics; important study sites for long-term demographic studies have included Organ Pipe Cactus National Monument (Steenbergh & Lowe 1983) and Saguaro National Park (e.g., Gill and Lightle 1942, Niering et al. 1963, Duriscoe and Graban 1992, Orum et al. 1998, Turner and Funicelli 2000, O'Brien et al. in prep). These studies have provided important insights into a variety of factors that have historically affected saguaro populations, including climate, fire, wood-cutting, and grazing. These data sets are likely to become increasingly useful in documenting changes in saguaro demography and distribution in the face of climate change. See Ahnmark and Swann (2009) and McAuliffe (1993) for detailed histories of saguaro studies at Saguaro National Park.

Saguaro populations at the extremes of distribution, such as this study at Tonto National Monument and Tonto National Forest, may be especially demonstrative of how saguaros will respond to changing climate patterns. Although several researchers have collected information on the dense population of saguaros between the Visitor Center and Lower Ruins at Tonto National Monument (Burgess n.d.; Bennett & Kunzman 1990; and others), there have not been long-term saguaro study plots throughout this northeastern extreme of saguaro distribution until this study. Establishment of long-term study plots in this location, in concert with other plots throughout different parts of the range of the saguaro (such as those at other parks and those established by Dr. Ray Turner), may be

used in concert to establish a range-wide view of saguaro response to climate change. This study was timed to coincide with a large-scale demographic study at Saguaro National Park that occurs every ten years (O'Brien et al. 2011).

Study Area

The study area is located in the Tonto Basin, in Gila County, Arizona, within 5 miles of Lake Roosevelt (Figure 1). Lake Roosevelt lies approximately 40 miles east of Phoenix, Arizona, in the Sonoran Desert and at the foot of the Mogollon Rim. Study plots were located within Tonto National Monument and nearby areas of the Tonto National Forest (Figure 2). This location was chosen because little is known about the population ecology of saguaros at this northeastern extreme of their range (Figure 3).

Tonto NM—Tonto NF saguaro study

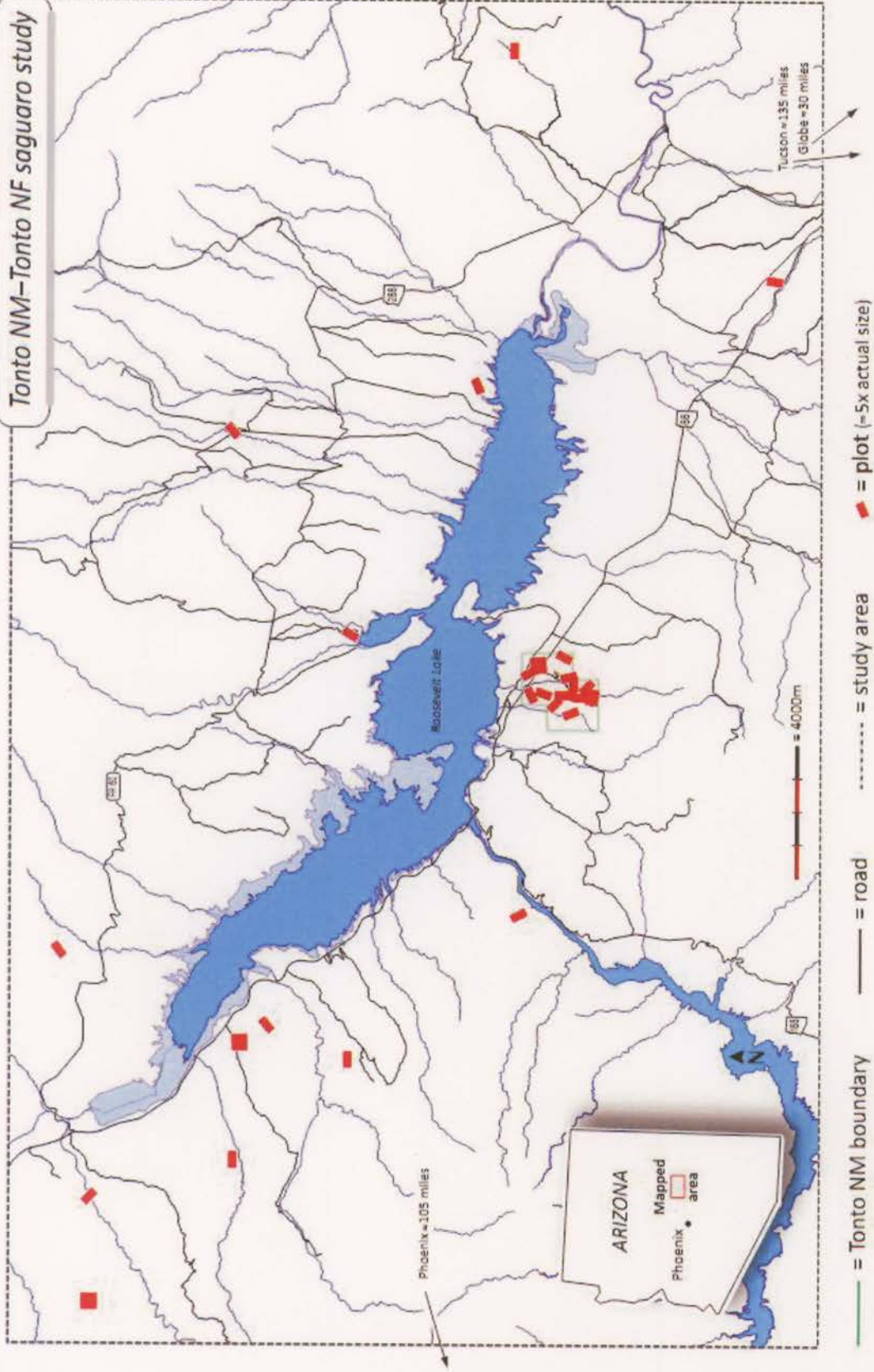


Figure 1: Project Location

Saguaro (*Carnegiea gigantea*) Demography at the Northeastern Extreme of the Species' Range

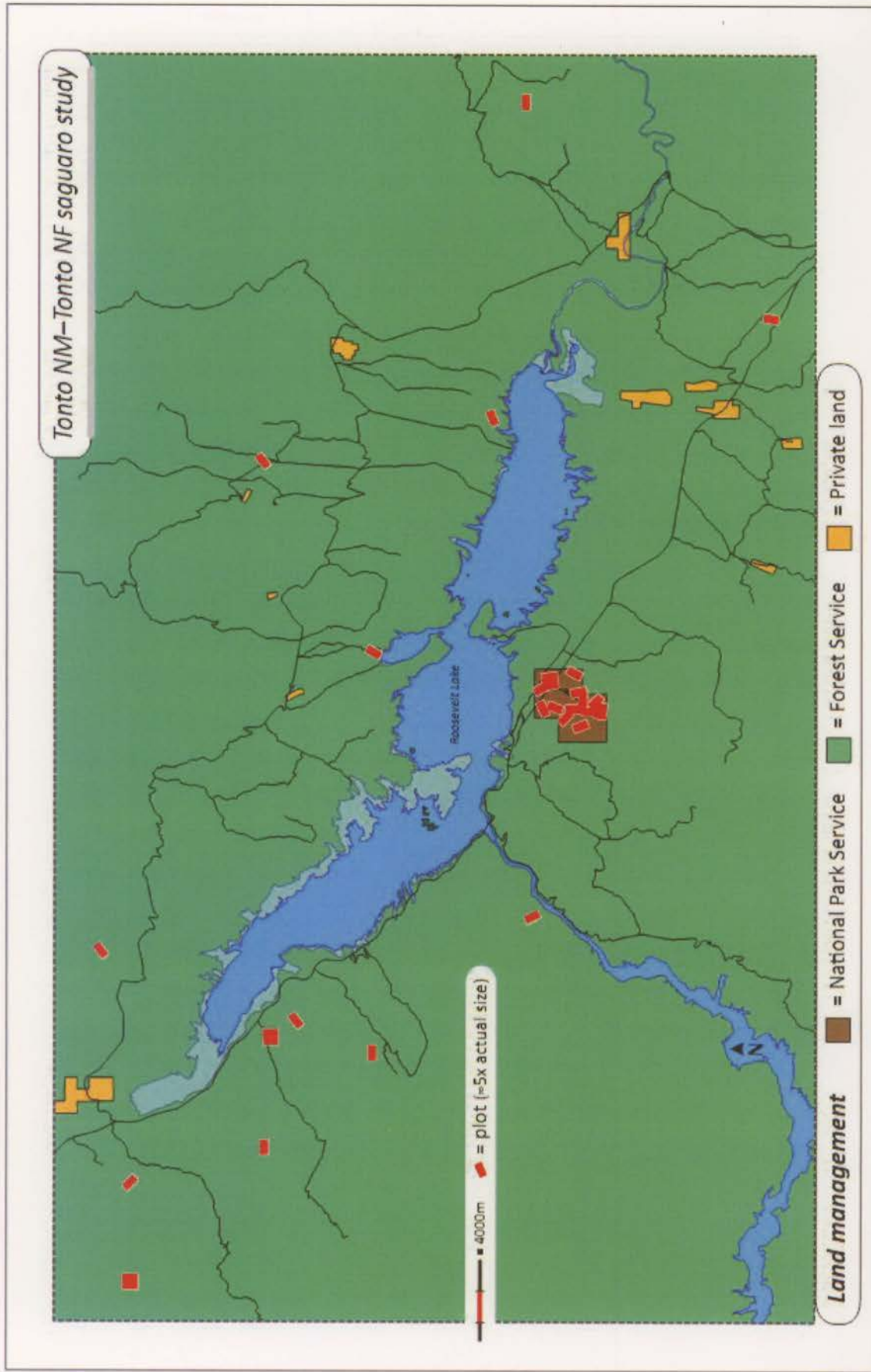


Figure 2: Land Management

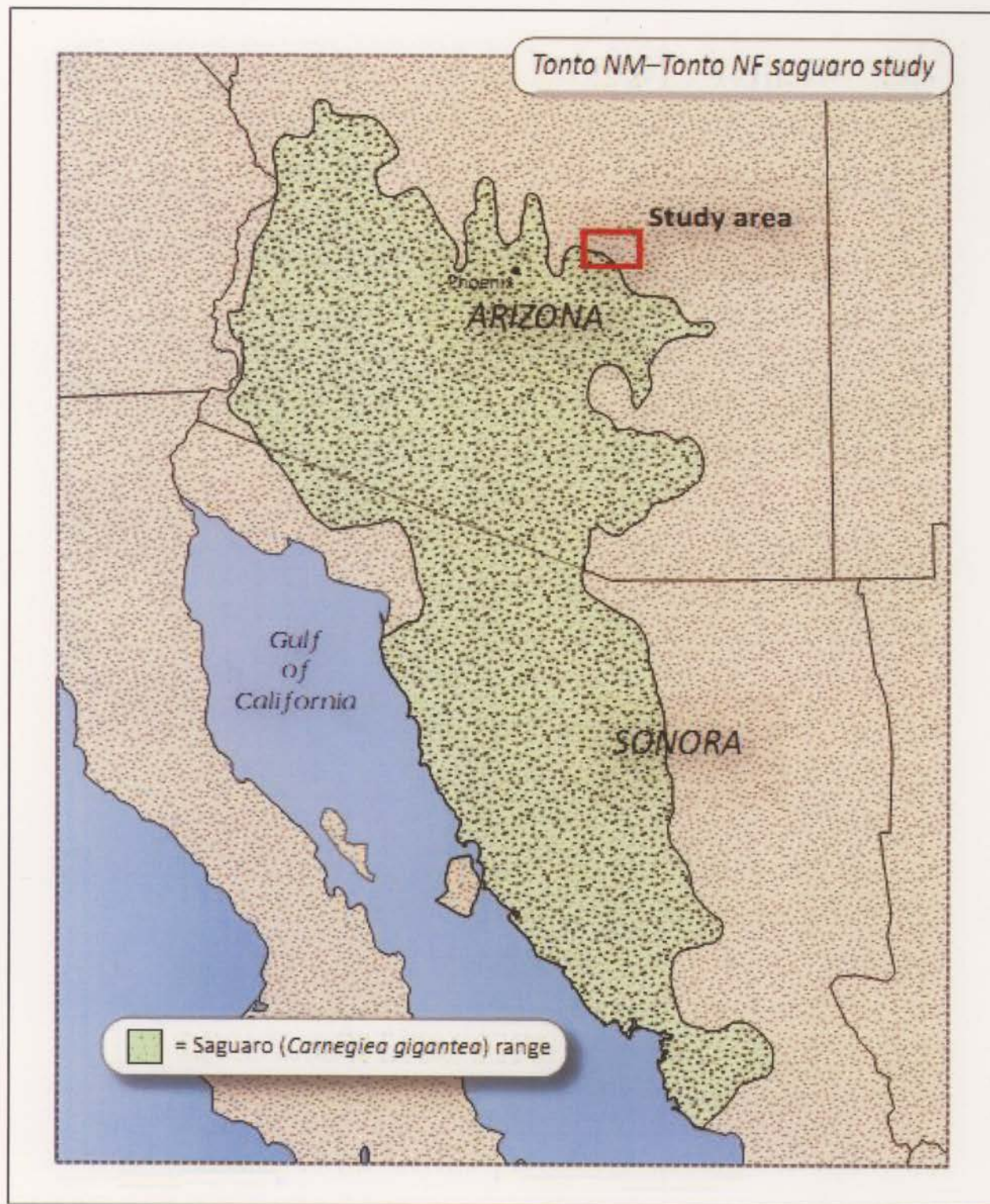


Figure 3. Saguaro Range

Methods

Plot Site Selection

Study plots were located within two separate study areas: Tonto National Monument (NM) and Tonto National Forest (NF) (Figure 2). The NM has been managed by the National Park Service (NPS) since 1933, and grazing largely ceased there in the 1950's (with official termination of grazing rights in 1974 and completion of perimeter fencing in 1978). The NF, on the other hand, is managed by the USDA Forest Service (USFS), and has been consistently grazed since at least the mid-1800s. Geographic Information Systems (GIS) software was used to apply additional limiting parameters to plot location selection according to the following criteria:

- Surface elevation of 1000 meters or less as derived from U.S. Geological Survey (USGS) 10 meter Digital Elevation Model (DEM) quadrants within Tonto Basin. This roughly corresponds to the elevational limit for saguaro distribution in the study area, as determined by casual observation, and was chosen as a convenient limit.
- A buffer zone of 50m was established around roads and streams to limit their influence on the data, and all water features were excluded from the study area.

Plot locations were also stratified by fire history for equal sampling among three coarse fire history categories:

- Not burned in recent history (last 50 years)
- Burned once in recent history
- Burned more than once in recent history

This was accomplished using the USFS Historic Fire Polygon dataset and the ArcGIS Analysis Tools Overlay Toolbox. For the NM study area, more accurate polygons were necessary due to the larger scale. This was accomplished by georeferencing historic park fire maps and digitizing more detailed polygons. Additionally, some fires within the FS dataset were only represented by a point file containing an associated area of effect zone. Extents for these fires were approximated using the Buffer Tool (which may introduce a degree of error into the burn region boundaries). Duplicates were removed by joining the two dataset tables and deleting records in favor of the polygon geometry.

A total of (36) 50x100 meter plots were proposed (6 plots in each category), according to the land management – fire history matrix presented below in Table 1. The actual number of plots surveyed departed from the proposal however, due to two factors. Firstly, the overall project scale and scope was reduced from the original proposal due to unsuccessful acquisition of additional funds. Secondly, in some instances when surveyors did not detect saguaros at a randomly-located plot, an additional alternate plot was established and surveyed¹. A total of 31 plots were completed during this study, 16 in the NM and 15 in the NF, as shown in Table 1.

Table 1. Plot treatments

Fire History	Tonto National Monument (not recently grazed)	Tonto National Forest (currently or recently grazed)	TOTAL # Plots
Unburned	8	4	12
Burned Once	4	4	8
Burned More than Once	4	7	11
TOTAL # Plots	16	15	31

¹ These additional plots were denoted with an "A" after the plot number.

In each fire history category and land management region, 15 points were randomly generated to serve as potential origins for study plots. In all cases, plots were oriented parallel to the contour of the slope. The orientation of the plot also was adjusted based on fire boundaries, the 1000 m elevation limit, known roads and cultural sites, as well as bodies of water (plots were positioned away from these entities). If none of these factors limited the potential plot orientation, the plot location was selected randomly from the given point. Plot locations are presented in Figure 1.

The plots in this study were 0.5 hectare in size; this is 1/8 of the size of plots of saguaro demography studies at Saguaro National Park (Duriscoe and Graban 1992, Turner and Funicelli 2004, and O'Brien et al. 2011, where plots were 4 hectares in size). Our plots were smaller due to the limitation of extreme topography of the area and study parameter (i.e., it would not be spatially possible to establish 4-ha plots that encompassed a single fire history type). Because saguaro densities are lower here than in other study areas, saguaros were not detected in many plots; when this occurred, an additional plot in the same land use category was selected and surveyed (NM), or an adjacent plot was established (NF). This helped to ensure that low-density saguaro stands would be represented in the study.

Elevation, grazing, and fire history information is presented in Figures 4, 5, and 6 respectively.

Tonto NM—Tonto NF saguaro study

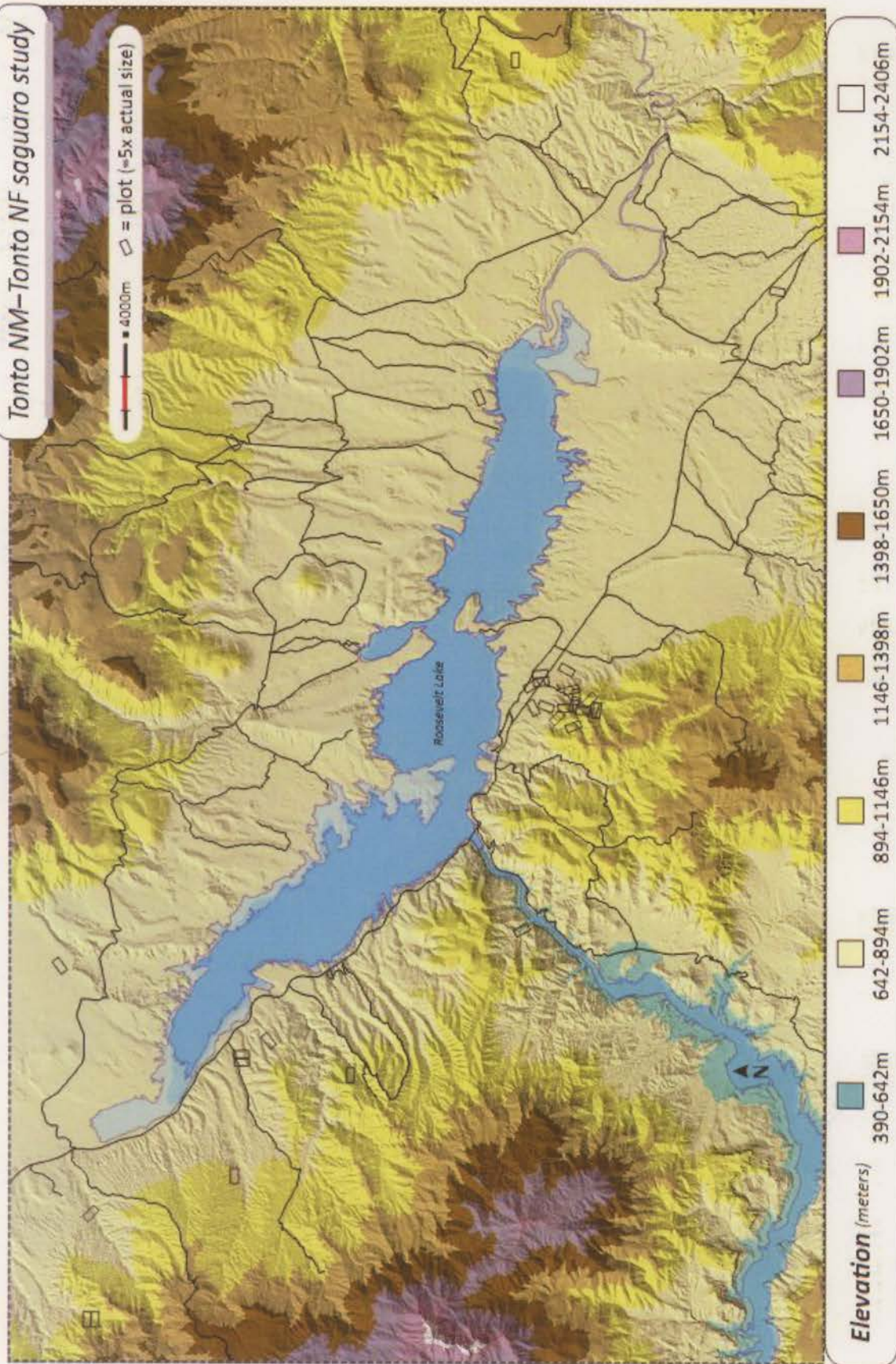


Figure 4. Elevation

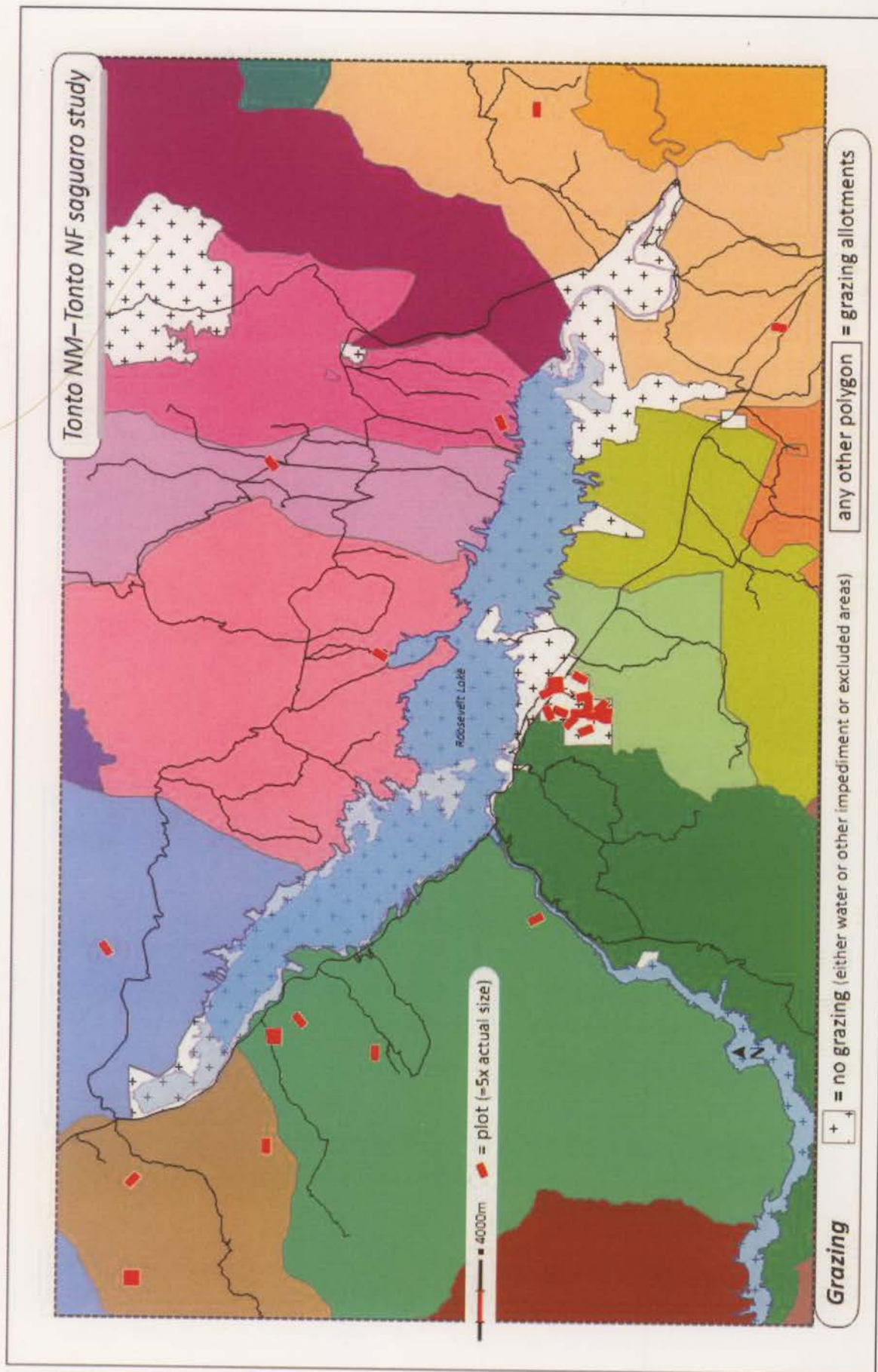


Figure 5. Grazing Allotments

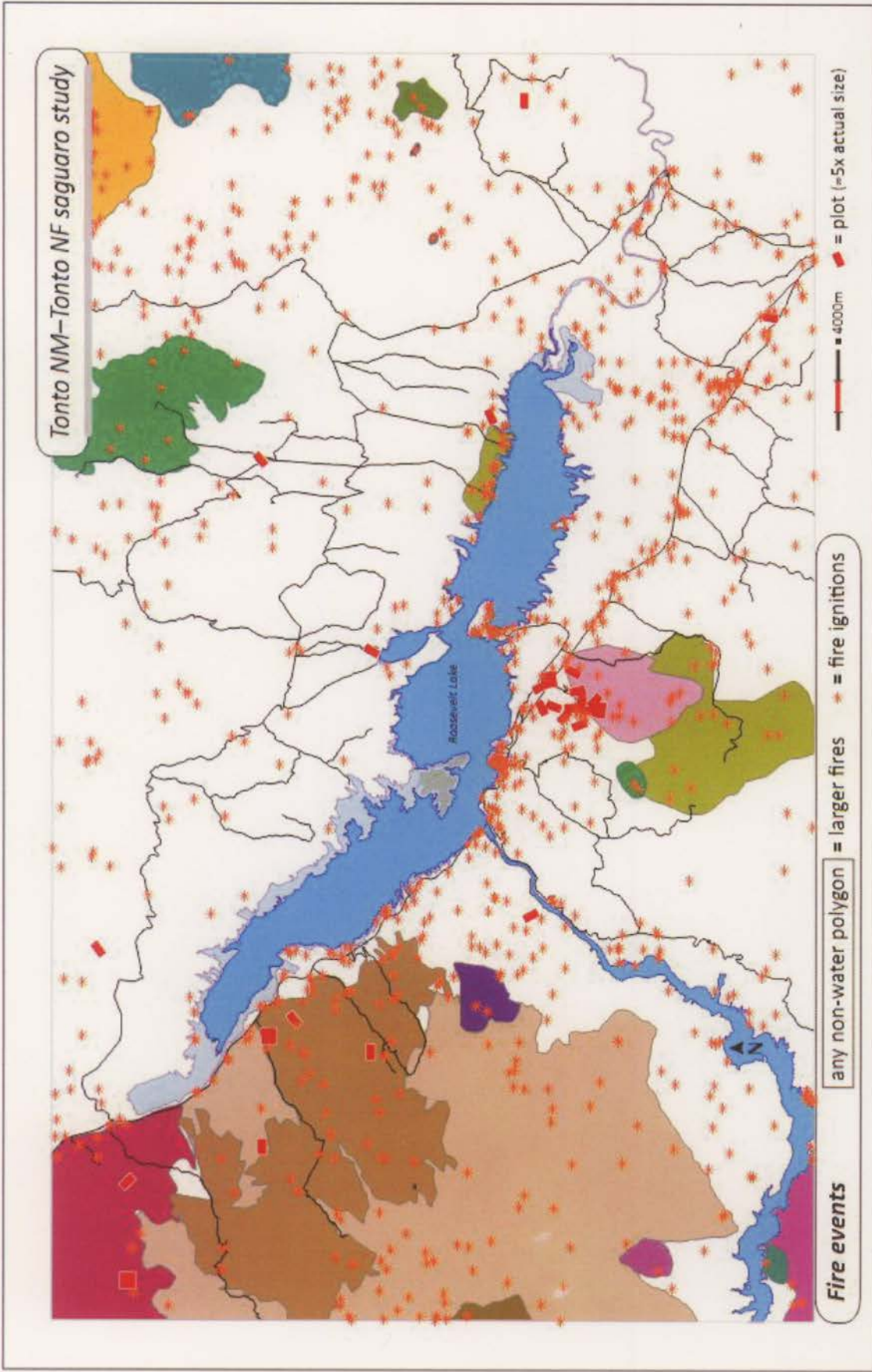


Figure 6. Fire History. Large documented fires are depicted by non-water colored polygons.

Survey Protocol

Stratified Random Plots

Survey protocols were based on the protocols established and implemented at Saguaro National Park (Duriscoe and Graban 1992, Turner and Funicelli 2004, and O'Brien et al. 2011).

Data were collected from the majority of the sites between February 17th and April 7th, 2010 by teams of two or three field biologists. If safety concerns, private land issues, or unmarked roads threatened to affect the intended plot location, the directionality was altered. Teams navigated to the other three plot corners using compass and meter tapes. Plot corners were marked with a 5/8" inch length of rebar driven approximately 10" into the ground. Rebar was capped with an aluminum cap (inscribed with the corner number, site name, and year) and the location was recorded with a Trimble GeoExplorer II Global Positioning System (GPS). Once the plot was set up, the team completed a site description form (Appendix A).

Each plot was divided first in half and then into 25-m survey lanes. Each crew member would then weave through their lane and mark every saguaro encountered with a fluorescent pink pin flag. The height of every saguaro was recorded using either a folding wooden Lefkin tape (ideal for saguaros 4 meters or less) or a clinometer (used on saguaros greater than 4 meters). For a clinometer reading, a line was drawn on the ground 10m from the saguaro. Two crew members would stand at this line and independently determine the height of the saguaro based on the angle of incline added to the angle of decline to the tip and base of the saguaro respectively. If their calculations deviated by more than 30 cm, they repeated the exercise. Once they were within an acceptable range, the calculations were averaged and the height of the saguaro recorded. The number of arms and bird holes were also recorded. GPS locations were not

recorded for each saguaro due to funding limitations and associated time-manpower constraints.

Once the opposing end of the survey lane was reached, team members would switch lanes and work their way back, searching for saguaros that may have been missed during the first pass. All previously unrecorded saguaros were flagged and recorded. The survey lanes were walked a third time to remove pin flags. The procedure was then repeated on the remaining half of the plot.

Historic Visitor Center Plot

On November 10th, 2010, a crew of three conducted a survey of an additional plot, NM-15, located behind the Tonto NM Visitor Center (Figure 7). This stand of saguaros is of particular interest as it is the densest stand at Tonto NM, has high visitor visibility due to its location, and has never burned according to NM records. This plot was surveyed in the same manner as the other plots, although additional data were collected, including GPS locations for each saguaro and a digital photograph was taken of each saguaro (Appendix B).

Data Archival

Tabular data from this study are presented in Appendices C and D. These data, as well as GIS data, will be submitted to resource management personnel at Tonto National Monument and NPS Sonoran Desert Network for archival.

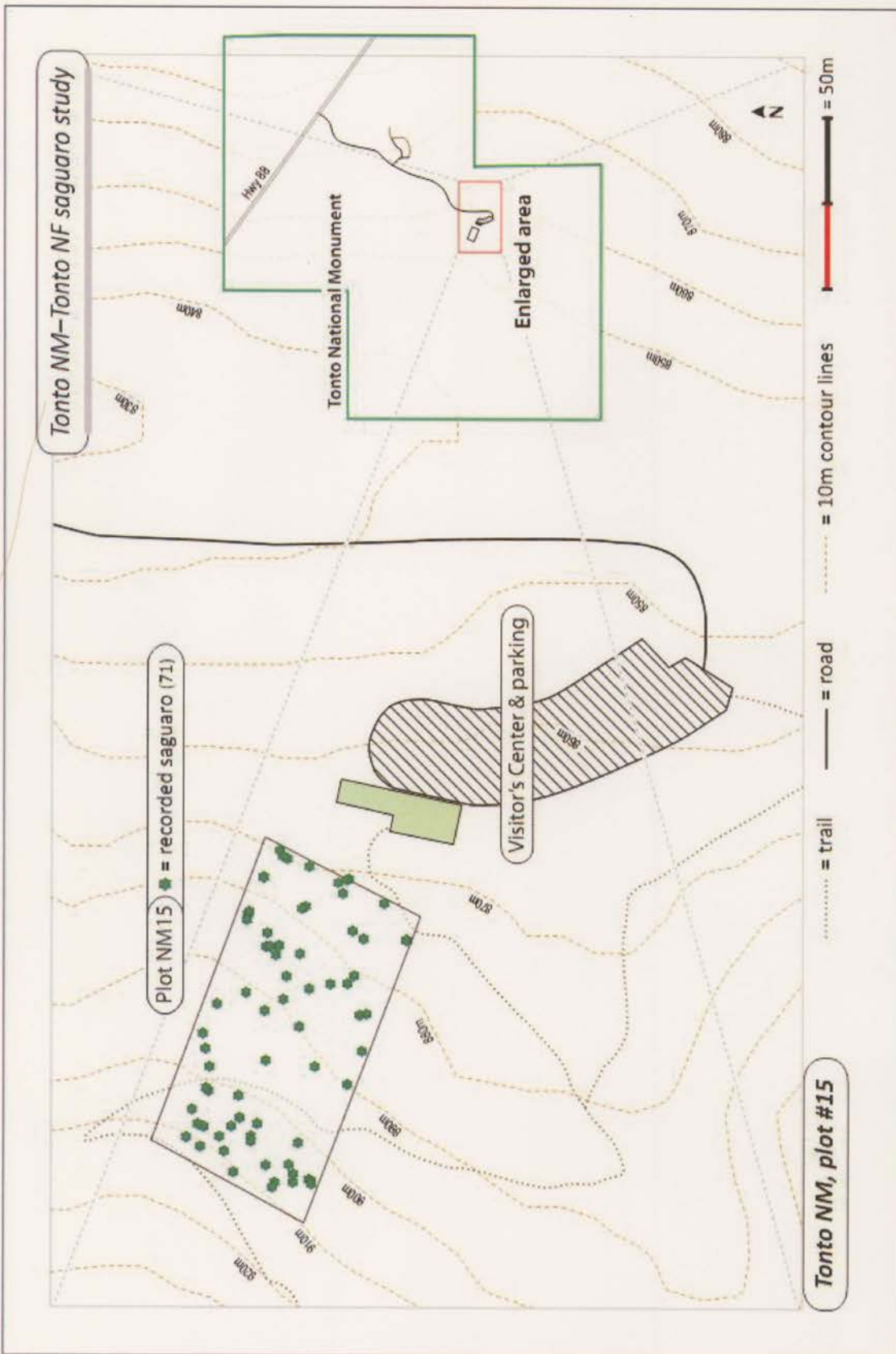


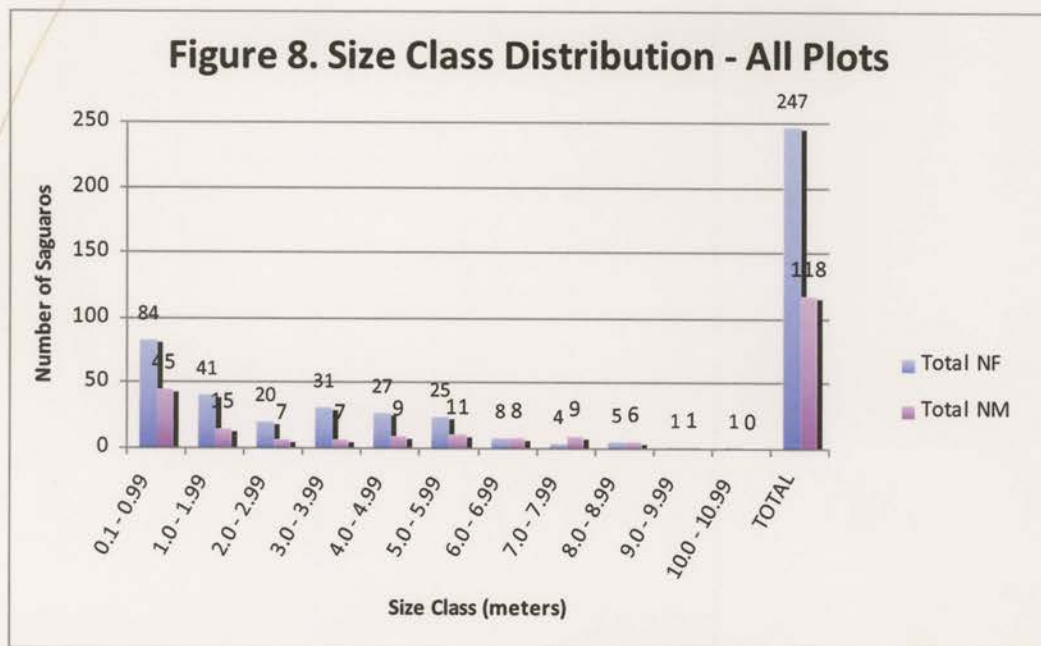
Figure 7. Plot 15 Location

Results

Basic Demographic Data

A total of 365 saguaros were recorded during the study (247 in the NF and 118 in the NM). The mean density of saguaros per plot at Tonto NF was 16 (65 per hectare) – higher than at Tonto NM, where it was 7 (29 per hectare), including the non-randomly chosen plot NM-15. The mean number of saguaros per hectare, including all plots surveyed, was 24.

Similar to recent patterns described at Saguaro National Park, the smallest size class included the most detected saguaros, with numbers generally decreasing as size classes increase, both within the NF and NM (Figure 8).



Slope, Aspect, and Insolation

GIS was used to describe slope, aspect, and insolation (annual solar watts per meter) across the study area (Figures 9, 10, and 11, respectively), and mean values were calculated for each plot (Appendix C). Slope did not appear to affect saguaro density. Plots with the most saguaros all had southerly (south, southeast, or southwest) aspects; however, many plots with southerly aspects had few or no saguaros, so aspect alone is not predictive. We assume that insolation values are correlated at least somewhat with aspect (although also influenced by other variables not included here such as vegetative cover and geologic surface). The highest saguaro densities were recorded in plots with high insolation values, although this relationship was not statistically analyzed (Figure 12).

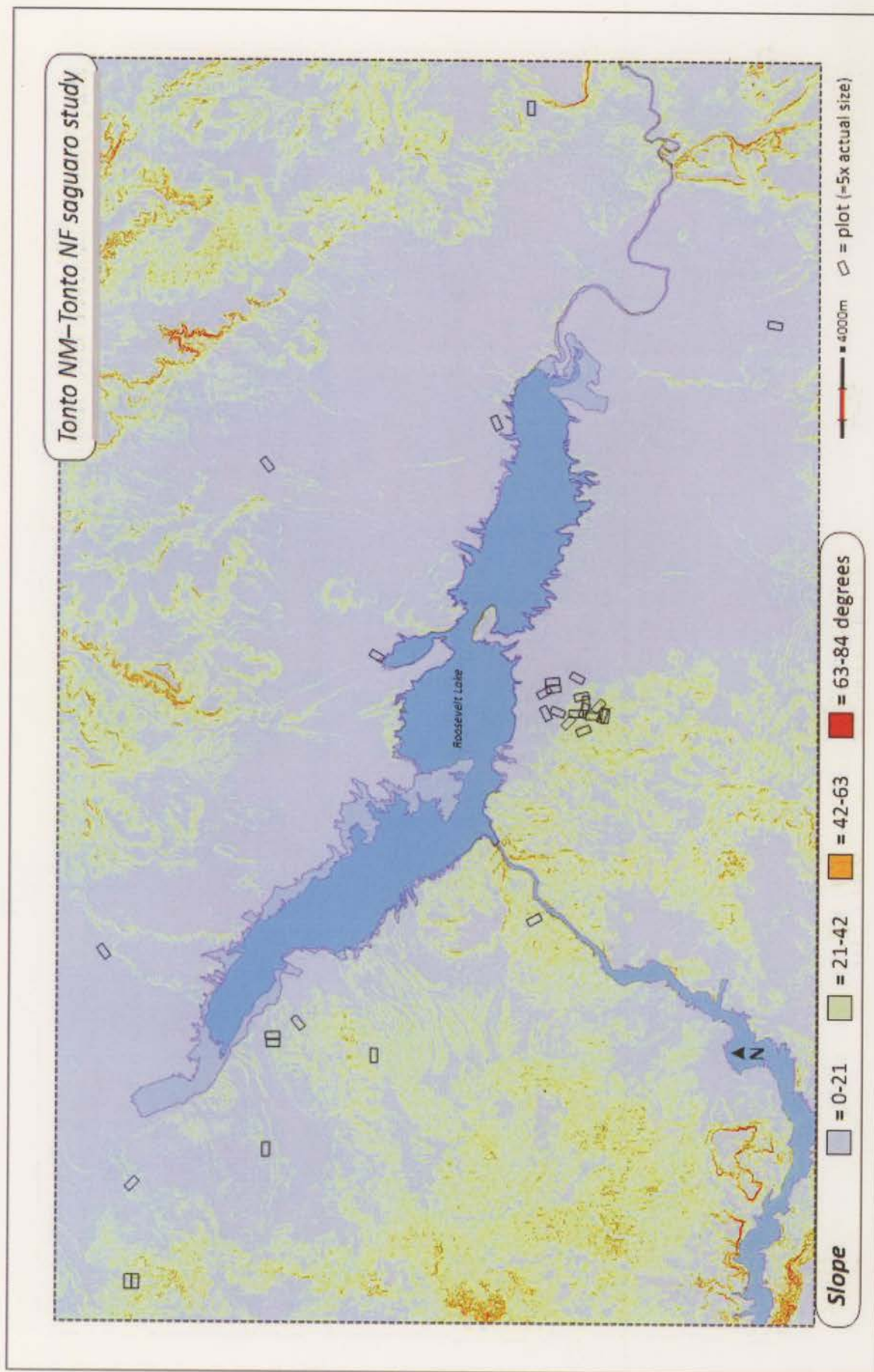


Figure 9: Slope

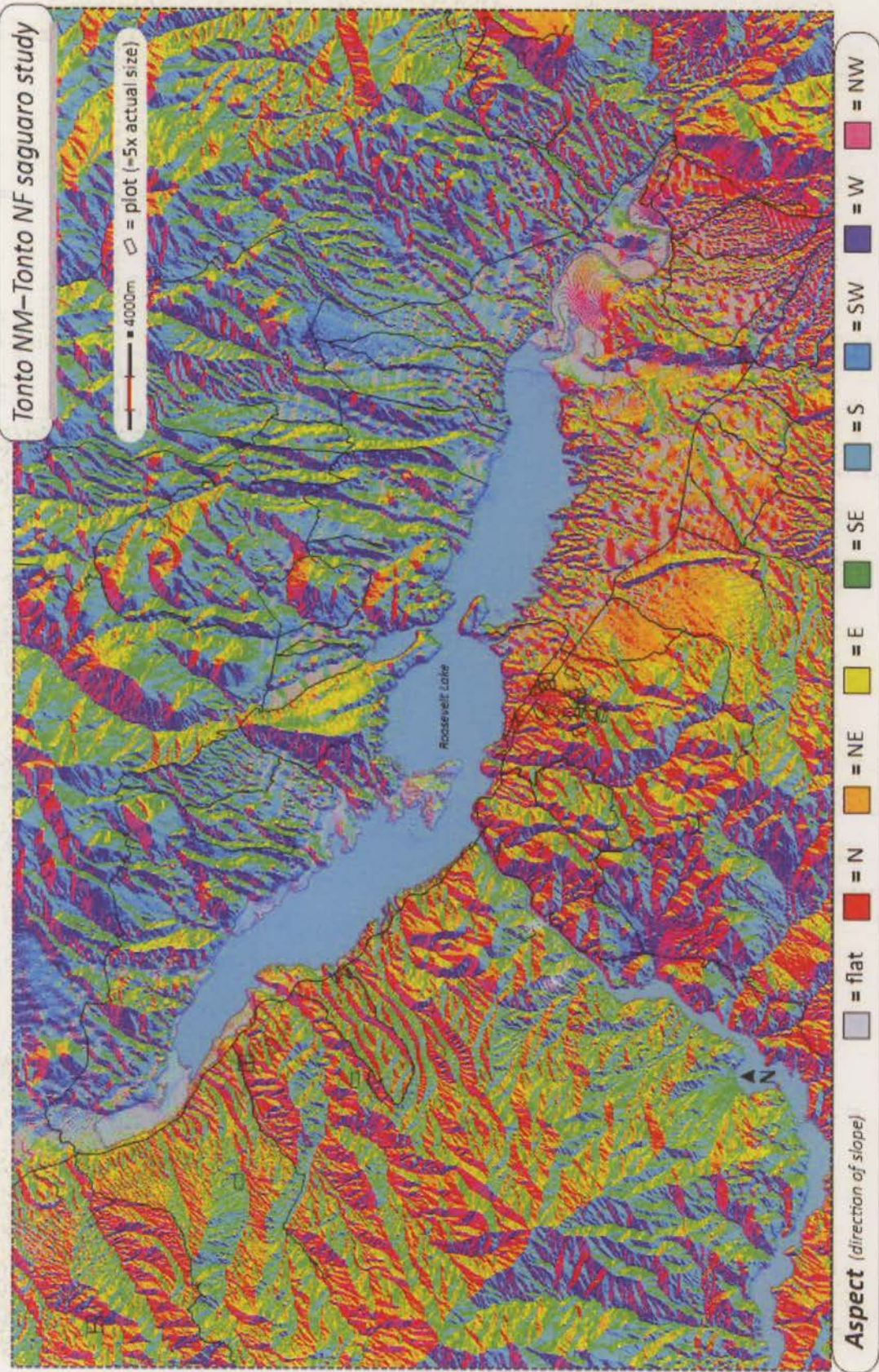


Figure 10: Aspect

Tonto NM—Tonto NF saguaro study

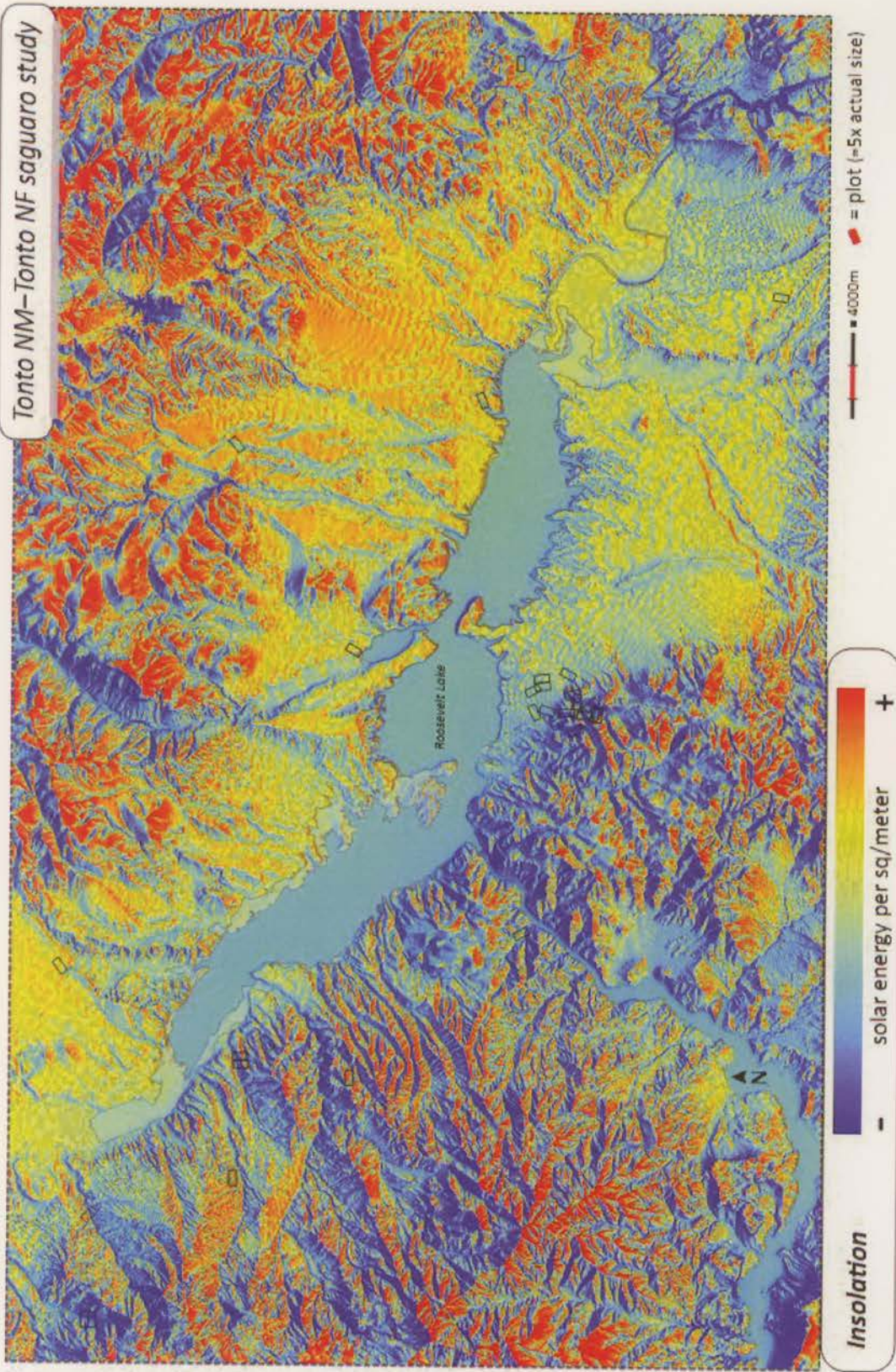


Figure 11: Insolation

Figure 12. Insolation and Saguaro Density



Discussion

We were not able to detect or describe the relationship between the distribution of saguaros in the vicinity of Tonto National Monument and cattle grazing, as detailed information regarding historical stocking rates and dates were not available for the allotments. In addition, clear patterns regarding demographic impacts from fires were not elucidated by our work, due to the coarse nature of the data that were available and our small sample size. The negative impacts of these factors on the vegetation of the Sonoran Desert, and on saguaro populations in particular, have, nonetheless, been clearly documented by previous research (e.g., Niering et al. 1963; Esque et al. 2004; Rogers 1985; Alvord et al. 2005, Phillips 1992, and many others).

The true value of this work is in the establishment of permanent, baseline monitoring saguaro plots; we recommend that they be re-visited every 10 years, to coincide with the census efforts at Saguaro National Park. The baseline data that we have collected shows a similar overall pattern of size class distribution at our project area as at Saguaro National Park, with the majority of saguaros detected in the smallest size class, indicating that there has been a surge in recruitment over the past 20 years or so. This is an encouraging outlook for these populations, as it can be inferred that they will persist because abundant young plants are present to replace senescent individuals as they die. However, we found much lower densities of saguaros at this northeastern extreme of their distribution than reported from Saguaro National Park – our overall saguaro density per hectare was 24, compared to 113 in the 2010 census at Saguaro National Park (O'Brien et al., 2011).

Recently, Don Swann at Saguaro National Park summarized information on saguaro research at Tonto National Monument by evaluating materials that were unearthed and given to the NPS Sonoran Desert Inventory and Monitoring Network by University of Arizona professor Bill Halvorson (Appendix E). This revealed that there have been at least three studies of the saguaro population between the Visitor Center and Lower Ruins in the time period spanning 1961 through 1988 (Burgess n.d.; Bennett & Kunzman 1990; and others). Some of these studies may be repeatable, although many key figures and attachments are missing. A focused and detailed inquiry into these data would be a valuable exercise, but unfortunately beyond the scope of what we could accomplish in this study. We hope that future researchers pursue this and integrate it into future monitoring events.

Acknowledgments

In January of 2008, the NPS Denver Service Center Revegetation Group hosted the "Southwest Regional Workshop: Revegetation in a Changing Environment" in Tucson, Arizona. This workshop provided a phenomenal opportunity for information exchange amongst southwest NPS units and between restoration professionals, and also an unexpected chance for the authors to meet and discuss the potential for a saguaro demography project at Tonto National Monument. Thank you to the workshop organizers (Sarah Wynn, Russ Haas, Joyce Lapp, Robin Gregory, Jessica Hendryx, and Linda Leidecker) for the unintended consequence of putting Jenny Shrum and Carianne Funicelli Campbell in the same room together!

A generous grant from the Desert Southwest Cooperative Ecosystem Studies Unit provided the impetus for additional funding from Tonto National Monument; we thank in particular Larry Norris (DSCESU) and Duane Hubbard (Chief of resources at Tonto National Monument) for supporting this project with funding and staffing resources. Eddie Colyott (Lead Interpreter at Tonto National Monument) and Michelle Girard (Ecologist at NPS Southern Arizona Office) provided invaluable encouragement for the project. We also thank Todd Esque (Ecologist at the USGS Las Vegas Field Station) for assistance with grant application and guidance regarding study design and field protocols.

This project is indebted to the large body of saguaro research that has occurred over many decades in Arizona's National Parks, particularly Saguaro National Park. We ride on the coat-tails of our saguaro research heroes, including Forrest Shreve, Ray Turner, Stan Alcorn, Warren Steenbergh, Charles Lowe, Tom Orum, and Nancy Ferguson. We are grateful to the steadfast natural resources staff at Saguaro National Park, who has continued to recognize the importance of

long-term monitoring of saguaros, and who have been able to tease out increasingly complicated interactions between saguaros and our ever-changing environment. Hat's off in particular to Don Swann, for spearheading the Herculean 2010 Saguaro Census project and invaluable advice on how to conduct our study in a coordinated manner for increased relevance.

Tonto National Forest was a gracious and supportive cooperator for this project. Shannon Torrence and Amy Madera Yagala were valuable liaisons between the USFS and the NPS, and we appreciate their assistance greatly in coordinating permissions and logistical support. David Bailey and Debbie Cress provided USFS GIS layers regarding fire history and grazing allotments.

The NPS Sonoran Desert Network (SODN) and Southern Arizona Office donated the use of Trimble GeoExplorer GPS units for this project. Thanks in particular to Sarah Studd at SODN, who was also integral to the initial study design and in coaching us through the GIS process.

Our field crew was fearlessly led by Justin Kolb, and included Jake DeGaynor (also invaluable with GIS coordination), David Klingbeil, and Katie Sosayachan. Volunteer crew members included Brian Dykstra and Shannon Torrence. These troopers risked life and limb (and killed a rental truck) on steep slopes to acquire the important data presented here. Thank you to Christine Hitzmann for help with hiring and personnel issues.

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