Bursera microphylla in South Mountain Municipal Park:

Evaluating its Habitat Characteristics

by

Cesar Cordova

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved April 2011 by the
Graduate Supervisory Committee:

Kelly P. Steele, Chair
Abdessaman Tridane
Ward Brady
William Miller

ARIZONA STATE UNIVERSITY

May 2011

ABSTRACT

The elephant tree, *Bursera microphylla*, is at the northern limit of its range in central Arizona. This species is sensitive to frost damage thus limiting its occurrence in more northern areas of the southwest. Marginal populations of *B. microphylla* are found in mountain ranges of Central Arizona and are known to occur in the rugged mountain range system of the South Mountain Municipal Park (SMMP). Little is known of the distribution of this species within the park and details relevant to the health of both individual plants and the population such as diameter and number of trunks, height, and presence of damage have not been examined. This study was designed, in part, to test the hypothesis that favorable microhabitats at SMMP are created by particular combinations of abiotic features including aspect, slope, elevation and solar radiation.

Data on abiotic factors, as well as specific individual plant locations and characteristics were obtained for 100 individuals. Temperature data was collected in vertical transects at different altitudinal levels. Some of these data were used in spatial analyses to generate a habitat suitability model using GIS software. Furthermore, collected data was analyzed using Matlab© software to identify potential trends in the variation of morphological traits. In addition, for comparative purposes similar information at one hundred computer-generated randomly chosen points throughout SMMP was obtained.

The GIS spatial analyses indicated that aspect, slope, elevation, and relative solar radiance are strongly associated as major climatic components of the microhabitat of *B. microphylla*. Temperature data demonstrated that there are significant differences in ambient temperature among different altitudinal gradients with middle elevations being more favorable. Furthermore, analyses performed using Matlab© to explore trends of elevation as a factor indicated that multiple trunk plants are more commonly found at higher elevations than single trunk plants, there is a positive correlation of trunk diameter with elevation, and that canopy volume has a negative correlation with respect to elevation.

It was concluded that microhabitats where *B. microphylla* occurs at the northern limit of its range require a particular combination of abiotic features that can be easily altered by climatic changes.

DEDICATION

To Papa and Mama for their support, sacrifice, and their unsurpassable love.

…por una razón o por otra, yo soy un triste desterrado. De alguna manera o de otra, yo viajo con nuestro territorio y siguen viviendo conmigo, allá lejos, las esencias longitudinales de mi patria.

PABLO NERUDA, 1972

ACKNOWLEDGEMENTS

I would like to thank my advisor, Kelly P. Steele for her mentoring and guidance during my graduate studies experience. I would also like to thank and acknowledge the contributions, guidance and support of the committee members: Abdessaman Tridane, William Miller, and Ward Brady. I must pay my respects to Tod D. Swanson and Ed Gilbert who supported my interest in graduate studies. I am grateful to Douglas Green and Todd Elliot for loaning me research equipment, Matthew Peters for assistance with satellite data, Scott MacAdams, Laura Marshall, Theresa Price and the ASU Polytechnic Applied Biological Science and Mathematics Department for their help and advice, Kim Keith and City of Phoenix Parks and Recreation Department for permission to conduct my research at South Mountain. Lastly, I would especially like to acknowledge family and friends who supported this project, in particular, Jose Luis Ruiz, Kerry Vanden Heuvel, and Kevin Lochhead for their help in acquiring field data.

TABLE OF CONTENTS

Page

LIST OF TABLES……………….…………………..………………………......vii

LIST OF FIGURES…………..………………………………………………......ix

CHAPTER

1 INTRODUCTION…………………………………………………….…..1

Bursera microphylla…………………………………………….…….…..2

Rationale for studying *Bursera microphylla* at South Mountain Municipal Park…………………….…………………………...……….….7

Hypothesis for the distribution of *Bursera microphylla* at South Mountain Municipal Park……….…………….……...………………….…12

Study Area…………………………………...…………………..….14

2 MATERIALS AND METHODS………………...….....……………….…20

Data Collection…………………………...…………………...……20

Descriptive Analyses………………………………………………….25

Linear Regression Analyses….……………………………………….…26

Spatial Analyses……………………………………………………......26

3 RESULTS……………………………………...……...……………46

Descriptive Analyses…………………………………………….…...46

Linear Regression Analyses…………………………………………….…..58

Spatial Analyses………………………………………………………….…61

4 DISCUSSION AND CONCLUSIONS……………………………...…..70

Page

Limitations of current study and directions for future research…..............77

Implications for management……………………………………..……..79

5 APPENDICES……………………………………………………….…..82

Appendix A: Coordinates and elevation information of Hobo data loggers placed at South Mountain Municipal Park from January 18, 2010 through March 16, 2010……..………………………..….…........82

Appendix B: Hourly temperature averages by elevation at South Mountain Municipal Park from January 18, 2010 through March 16, 2010…...………………………………….………….…....…...84

LIST OF TABLES

Table Page

1. Input parameters used to develop hillshade input layers for South Mountain Municipal Park during the time period of January 18 to March 16, 2010. ………….…………………………….……33

2. Classes and radians ranges used for South Mountain Municipal Park for GIS relative solar load analyses, May 2010……………………….…37

3. Degrees ranges for cardinal directions used for South Mountain Municipal Park for GIS aspect analyses, May 2010………………………..39

4. Classes and degree ranges used for South Mountain Municipal Park for GIS slope analyses, May 2010…………………………………...41

5. Classes and elevation ranges in meters used for South Mountain Municipal Park for GIS elevation analyses, May 2010………………….……43

6. Elevation classes, number of Hobos and individual plants of *Bursera microphylla* within transects at South Mountain Municipal Park, January 18 to March 16, 2010.……………….....………………...46

7. Average temperature by elevation class at South Mountain Municipal Park, January 18 to March 16, 2010...47

8. Distribution by aspect of existing damaged plants found in study transects at South Mountain Municipal Park, January 18 to March 16, 2010……………………………………………………..…...51

9. Aspect and damage distribution by elevation classes at South Mountain Municipal Park, May 2010.………..53

Table Page

10. Multiple trunks plants and aspect distribution by elevation at South Mountain Municipal Park, May 2010…………………….………..54

11. Presence of damage and boulders by elevation class at South Mountain Municipal Park, May 2010.…..56

12. Trunk diameter averages by elevation class at South Mountain Municipal Park, May 2010.……………………………...………………..57

13. Chi square tests of abiotic factors at South Mountain Municipal Park, May 2010…………………………………………………………64

14. Input values of abiotic factors for Weighted Overlay analysis at South Mountain Municipal Park, May 2010………………...……….65

15. Results of Weighted Overlay analysis at South Mountain Municipal Park, May 2010……………………………………………..…….65

16. Accuracy assessment of Weighted Overlay Model using randomly generated points at South Mountain Municipal Park, May 2010…………………………………………………………64

LIST OF FIGURES

Figure Page

1. *Bursera microphylla* in South Mountain Municipal Park, Phoenix, Arizona, January 2010……………………………..……….….3
2. Distribution of *Bursera microphylla* in Southwestern United States and Northwestern Mexico. SEINet database, February 12, 2011……..8
3. *Bursera microphylla* collection sites in the Phoenix area. SEINet database, February 12, 2011………..…………………………..…………9
4. Interaction of major geographical, climatic, and biotic components of microhabitat for *Bursera microphylla* at South Mountain Municipal Park……..……………………………………………13
5. South Mountain Municipal Park, Phoenix, Arizona. Google Earth…….14
6. Granite boulders commonly found at South Mountain Municipal Park……..……………………………………...…………16
7. Map of South Mountain Municipal Park trails. City of Phoenix………..18
8. Solar radiation shield for Hobo data loggers used in South Mountain Municipal Park, January to March, 2010……..………………….22
9. Transect of Hobo data loggers at Desert Classic Trail site, January to March, 2010………………………..………………………….23
10. Hobo data logger inside a solar radiation shield at South Mountain Municipal Park, January to March, 2010…………..…………….24
11. Digital Elevation Model of Maricopa County used for GIS analyses, May 2010……………………..…………………………….….28

Figure Page

12. Area of interest (or mask) file for South Mountain Municipal Park May 2010 GIS analyses……………………….……………..…….29

13. Elevation file for South Mountain Municipal Park May 2010 GIS analyses…….……………………………………………………30

14. Slope file for South Mountain Municipal Park May 2010 GIS analyses..31

15. Aspect file for South Mountain Municipal Park May 2010 GIS analyses……………………………………………………..32

16. Hillshade 10 file for South Mountain Municipal Park May 2010 GIS analyses………………..……………………………………34

17. Hillshade 12 file for South Mountain Municipal Park May 2010 GIS analyses……………………………..……………………35

18. Hillshade 15 file for South Mountain Municipal Park May 2010 GIS analyses……………………………..……………………36

19. Accumulated relative solar load file for South Mountain Municipal Park, May 2010 GIS analyses………………………………………38

20. Classified Aspect map for South Mountain Municipal Park, May 2010 GIS analyses………………..………………………………40

21. Classified Slope map for South Mountain Municipal Park, May 2010 GIS analyses……..…………………………………………42

22. Classified Elevation map for South Mountain Municipal Park, May 2010 GIS analyses…………………..………………………………44

23. Temperature averages by elevation class at South Mountain Municipal

Figure Page

Park, January to March 2010…………………..……………………..48

24. Hourly temperature averages by elevation class at South Mountain Municipal Park, January to March 2010……………..…………49

25. Hourly temperatures for January 24, 2010 on transect at Desert Classic Trail site, South Mountain Municipal Park………………..…….50

26. Hourly temperatures for January 24, 2010 on transect at Pima Wash Trail site, South Mountain Municipal Park………………………...50

27. Distribution of plants by aspect and percent damage within each aspect at South Mountain Municipal Park, May 2010……………………..52

28. Aspect and damage distribution by elevation classes at South Mountain Municipal Park, May 2010…………………………..………..53

29. Multiple trunk plants and aspect distribution by elevation at South Mountain Municipal Park, May 2010…………………..……..55

30. Presence of damage and boulders by elevation class at South Mountain Municipal Park, May 2010…………………………………..…..56

31. Distribution of trunk diameter averages by elevation class at South Mountain Municipal Park, May 2010………………..………..57

32. Boxplot for single trunk and multiple trunks plants based on elevation at South Mountain Municipal Park, May 2010……….….…………59

33. Trunk diameter distribution based on elevation range at South Mountain Municipal Park, May 2010……….…………………………..…..60

34. Canopy volume distribution based on elevation range at South Mountain

Figure Page

Municipal Park, May 2010……………………………………61

35. Habitat suitability map for *Bursera microphylla* at South Mountain Municipal Park, May 2010…………..………..…………………67

36. Accuracy assessment of weighted overlay map using the randomly generated points at South Mountain Municipal Park, May 2010…………………………………………………………68

37. Accuracy assessment of weighted overlay map using point data for *Bursera microphylla* at South Mountain Municipal Park, May 2010……………………………………………………...…69

38. South Mountain 620, a 247-acre block of State Trust Land adjacent to SMMP purchased by the City of Phoenix, April 2009…………..80

Chapter I: Introduction

Climatic differences play a key role in species' distribution. Margins of these distribution ranges are of particular interest since they represent the limits of a species' survival. These margins may be influenced and modified by climatic changes. The sedentary nature of plants makes them ideally suited for studying marginal populations and facilitates the mapping of their distribution and making comparisons with historical recordings (Crawford 2008).

A marginal population can be defined as a population of a species occurring at the geographic edge of its distribution range. There may be multiple marginal populations near the edge of the species range or single populations that are widely separated from the main part of the species range. As a result of their adaptation to geographically marginalized locations and their isolation, marginal populations tend to be genetically differentiated with regard to core populations (Leppig and White, 2006). For plants, marginal populations are more prone to be affected by different selective factors in relation with core populations. Some of these selective factors include climate and soils, plant community assemblages, and disturbance regimes (e.g., fire intensity and interval). Ecologically distinct marginal populations also can occur when geographically marginal populations occupy suboptimal or different habitats than more core conspecifics (Leppig and White, 2006).

Although generally speaking public policy supports efforts for the conservation of marginal populations regardless of the commonness elsewhere of the species, this support has been arbitrary and ineffective for significant marginal populations of nonlisted species. Conservation efforts for marginal populations have been hindered by the absence of explicit criteria to determine their conservation value, the shortage of finer scale data on plant distribution, and a general lack of awareness of their value (Leppig and White 2006). However, multiple factors determine the viability, and genetic diversity and structure of a population. Some of these factors include gene flow, varying directional selection, the species' reproductive strategies, and its degree of isolation and spatial patterns. Therefore, the viability of a population can be more dependent on population dynamics and demographic structure (Bevill and Louda 2003). However in some cases climate change might result in migration of populations such that populations that are marginal may no longer be marginal populations. This might be a good reason for conservation of marginal populations in some species.

Bursera microphylla

Bursera microphylla (Figure 1), commonly known as the Elephant Tree, is a good example of a species with marginal populations at the northern limit of its range and is the subject of the research discussed in this thesis. This species belongs to the family Burseraceae in the order Sapindales. The Burseraceae is composed of around 600 species within 20 genera. Its distribution is mainly in Africa, Asia, North America and South America, particularly in the subtropical and tropical regions. The dry tropics of Africa and Mexico seem to have the greatest diversity of Burseraceae (Johnson 1992). Members of this family are characterized by resin ducts containing aromatic triterpenes and ethereal oils (Felger et al. 2001).

Figure 1. *Bursera microphylla* in South Mountain Municipal Park, Phoenix, Arizona, January 2010.

The genus *Bursera* is composed of 104 species of trees and shrubs. As a genus, it has a high species richness and endemism, which makes it a model for biogeographical analyses (Espinosa et al., 2006). The primary distribution of the genus is in Mexico, with some species ranging into northern South America, the Caribbean, and with disjunct populations spread in eastern Brazil. The greatest diversity in the genus occurs in the tropical dry forests of Mexico, where there are about 80 species with 88 percent rate of endemism (Zuñiga et al. 2005). Work on the distribution of *Bursera* by Kohlman and Sanchez-Colon (1984) indicates that the Sonoran Desert region, particularly the Mexican states of Baja California and

Sonora along the United States border, is a center of diversity for the genus. In the northern Mexican state of Sonora, *Bursera* is commonly found throughout the landscape but in the tropical deciduous forest in the central part of Sonora and in the coastal desert in the western side of the state it is locally abundant (Johnson 1992).

The distribution of *Bursera microphylla* is virtually coincident with the limits of the Sonoran Desert (Mooney and Emboden 1968). There are four physiographic regions in the state of Sonora: the Sonoran Desert, the Sierra Madre Occidental, parallel mountains and valleys, and the coast of the sea of Cortez. Extreme temperatures of 50 °C or higher are common during the summer in desert areas while winters, although short, are cool compared with most of Mexico. Most parts of Sonora are located in the desert and are characterized as extremely arid. Some of the state's cities such as Hermosillo and Ciudad Obregón are extremely hot during the summer and mild to warm in the winter due to their elevation of 200 m or less. In the desert surrounding both these cities, Burseras are abundant and appear to have taller canopies than their conspecifics to the north. In contrast to this, cities like Nogales and Cananea are relatively cooler in the summer and have cold winters at an elevation of 1,500 m or more. This higher elevation landscape in the northeastern part of Sonora seems to delineate *Bursera* distribution in the northeast of the state. The colder winters with its short, although frequent, freezes seems to be one of the main factors limiting *Bursera* habitat to the Sonoran Desert, and the Coast of the Gulf of California physiographic regions within Sonora (Johnson 1992). Burseras occur from near sea level along the Gulf of California to 1220 m in the mountain regions occupying a range of habitats in the desert scrub, thorn scrub, tropical deciduous forest, and lower elevations in oak woodland or pine-oak woodland. Ten species are found in Sonora: *B. arborea, B. fagaroides, B. grandifolia, B. hindsiana, B. lancifolia, B. laxiflora, B. microphylla, B. penicillata, B. simaruba, and B. stenophylla*. Two of those species, *B. fagaroides* and *B.microphylla* extend into southwestern Arizona (Johnson 1992). *Bursera microphylla* is the most northerly member of the Burseraceae in North America and also perhaps the most xeromorphic species within the genus as it thrives in the extremely arid desert hills and mountains in northwest Sonora.

Burseras range in size and are shrubs or small trees with a thickened trunk and relatively small branching structure in comparison to the trunk size. The trunks and limbs of many species are distinctly semi-succulent and store water in the conductive and parenchymal tissues of the trunk, lower limbs, and wood (Turner et al., 1995). Shreve (1964) classified the plant as a sarcocaulescent tree. The sarcocaulescent habit acts as a buffer against variation in environmental water balance (Turner et al., 1995). The leaves are alternate, without stipules, and are mostly once-pinnate or twice-pinnate but can be unifoliate or trifoliate in some species (Rzedowski and Kruse 1979).

The leaves are characterized as deciduous, including those on species that occur in tropical subhumid and humid forests (Becerra 2005). As a response to rain and warmer temperatures, *B. hindsiana, B. laxiflora*, and other more tropical species in Sonora begin to leaf out at any time of the year (Johnson 1992). Most species are drought deciduous, but *B. microphylla* keeps its leaves year-round, except under conditions of drought and cold weather. Most of the Sonoran Burseras flower in June and July, just before or just as the leaves are produced. This is probably in response to a lack of rainfall earlier in the summer before the monsoon season as this species is found in the region of Sonora lies at the western edge of an area, which regularly experiences summer monsoon storms.

The fruits of species in the genus *Bursera* are small, drupe-like with a single-seed (Felger et al. 2001). In *B. microphylla*, the fruits develop rapidly and ripen gradually, a few at a time, and in some species many fruits remain on the trees as they begin to flower the following summer (Johnson 1992). Birds appear to be primarily responsible for seed dispersal in *Bursera*. Gray Vireos and Ash-throated Flycatchers feed heavily on the ripe fruits of *B. microphylla* in the Puerto Lobos region of Sonora, Mexico during the winter months (Johnson 1992). The winter range of the Gray Vireo in Sonora closely matches the distribution of *Bursera microphylla* (Bates 1992). Birds do not appear to eat the unripe fruit (Johnson 1992). Rodents sometimes gather fruits and seeds of *Bursera*. Ants have been observed carrying away seeds of *B. microphylla* (Johnson 1992). The exfoliating papery bark of many of the trivalvate species may serve to attract the attention of birds and other animals from a distance as it rustles in the breeze (Rzedowski and Kruse 1979).

In some areas, particularly west of the city of Hermosillo, the largest city and state capital of Sonora, and in the lower Rio Yaqui and Rio Mayo valleys, the clearing of land for agriculture has destroyed the native vegetation. In my opinion the continuing spread of Buffelgrass (*Pennisetum ciliare*) is the most serious threat facing Burseras and many other native plants in Sonora. I have observed this exotic grass seeded in vast areas of central and southern Sonora for cattle forage; these dense stands of Buffelgrass are subject to periodic burning, whether accidental or deliberate. The elimination of many native plants species from Buffelgrass areas can be the unfortunate result. The continued large-scale planting of Buffelgrass poses a grave threat to the vegetation and wildlife of lowland Sonora.

Rationale for studying *Bursera microphylla* at South Mountain Municipal Park

Bursera microphylla is at the northern part of its range in central Arizona, particularly, around the Phoenix area. The Southwest Environmental Information Network (SEINet) database at Arizona State University listed on its website, http://swbiodiversity.org//taxa/index.php?taxon=Bursera%20microphylla, 465 specimens documenting the range of *Bursera microphylla* in the southwest U.S. and northwest Mexico in various herbaria throughout the southwest (Figure 2).

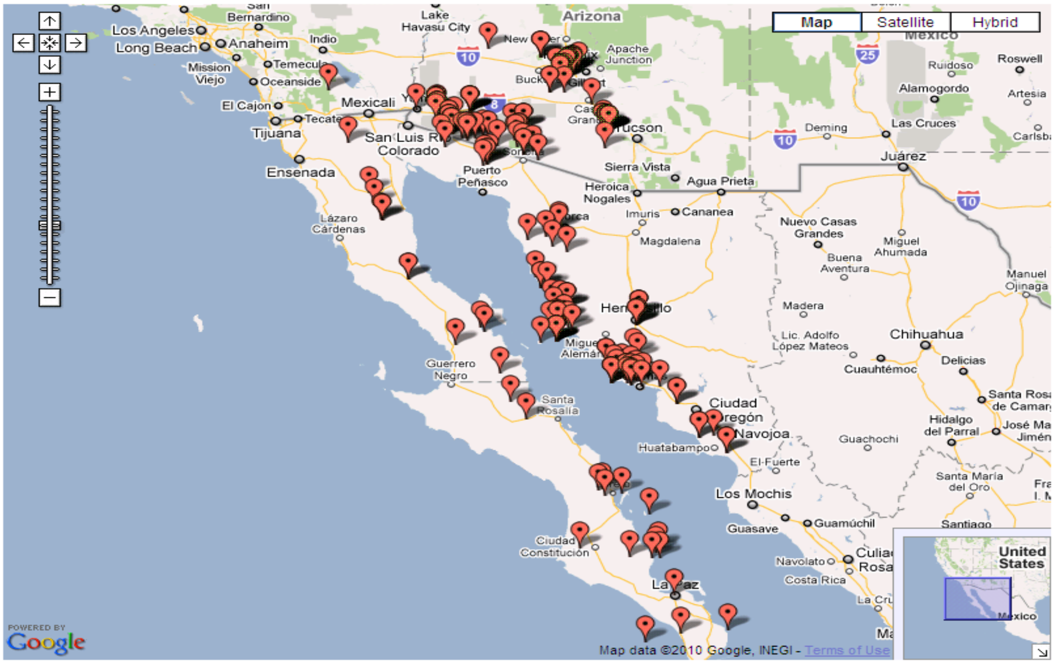

Figure 2. Distribution of *Bursera microphylla* in Southwestern United States and Northwestern Mexico. SEINet database, February 12, 2011.

The species I chose to study, *Bursera microphylla* (Elephant tree), reaches its northern limit in central Arizona. The populations in that region are found only in a few of the mountain ranges that surround the Phoenix Valley, are well-separated from one another and are thus good examples of marginal populations. One important goal of this research is to provide baseline data that could be used as a basis for management decisions that could affect these marginal populations.

There are herbarium specimens of *B. microphylla* from different mountain ranges in Arizona including the northern-most known sites with 24 specimens from South Mountain Municipal Park (SMMP) (33.33°N, -112.06°W), three specimens from the White Tank Mountains (33.6°N, -112.6°W), two specimens from the Harquahala Mountains (33.7°N, -113.4°W).

The large number of herbarium specimens from SMMP as well as personal observations of the number of individuals seen in the park indicated that there are large populations of *B. microphylla* in central Arizona SMMP (Figure 3). Thus the park is a very suitable site for gathering data to evaluate habitat components of *B. microphylla*. According to label information for specimens in the database, nearly all collections in SMMP have been made along the hiking trails. Recorded information on population size and distribution within SMMP is minimal; although in their flora of the South Mountain Park Daniel and Butterwick (1992) indicated that *B. microphylla* is rare to occasional throughout the range, in part because the park's policy on the public's use of SMMP and guidelines for staying on signed trails. To obtain a better understanding of *Bursera microphylla* habitat components, population size, geographic characteristics, and associated vegetation as well as to examine more closely characteristics of individual plants, it was necessary to conduct further observations and recordings off trails.

Figure 3. *Bursera microphylla* collection sites in the Phoenix area. SEINet database February 12, 2011.

Bursera microphylla occurs in SMMP as a marginal species and clearly satisfies the criteria described for indicator species reviewed below. An indicator species can be defined as any biological species that defines a trait or characteristic of the environment. For example, a species may delineate an ecoregion or indicate an environmental condition such pollution, species competition or climate change. Indicator species can be among the most sensitive species in a region, and sometimes act as an early warning to monitoring biologists and policy makers (Crawford 2008). Plants are dependent on a particular soil type, topography and climate through biological adaptation. Because of their immobility, plants generally require those components that are specific to a site. Indicator species are used as a standard in identifying similar communities. Their decline may indicate a disturbance that alters the ecosystem such as climatic changes, fires, and man-made events (Crawford 2008). In the case of *B. microphylla* at SMMP, it is likely that this population's existence at SMMP is strongly associated with existing microclimates.

In the Sonoran Desert conditions can be harsh for marginal populations and established nurse plants can provide shade, soil moisture, and nutrients for seedlings as in the case of small saguaro (*Carnegiea gigantea*) plants often observed beneath desert trees and shrubs. This results in the creation of localized patches where saguaro seedlings can increase their survival rate (Turner *et al.* 1966). In some habitats, existing adult plants in close proximity of establishing seedlings may enhance the seedlings' survival by ameliorating extreme environmental conditions (Padilla and Pugnaire 2006). A nurse plant can be defined as any plant that facilitates seed germination and survival by alleviating stressful environmental conditions. Padilla and Pugnaire (2006) called the positive influence of adult plants on seedlings the nurse plant syndrome. The nurse plant syndrome is one of the first documented examples of close spatial association between plants as being more beneficial than detrimental, particularly within environments where plant performance is limited by the severity of abiotic factors or herbivory such as in arid or alpine habitats (Padilla and Pugnaire 2006). Padilla and Pugnaire (2006) point to a study by Gómez-Aparicio *et al.* (2004) where the effects of nurse plants were stronger in dry locations and on the south-facing slopes of a Mediterranean mountain. The community structure and dynamics of a habitat is strongly influenced by the interactions of the plants found within, and are responsible for the presence or absence of particular species within that community (Padilla and Pugnaire 2006).

Bursera microphylla is listed as a Salvage Restricted Protected Native Plant in the Arizona Department of Agriculture's Environmental Services Division. This list includes native plant species that are subject to damage by theft or vandalism. Salvage Restricted Native Plants as prescribed in A.R.S. Â§ 3-903(B)(2), require a permit for removal (http://www.azda.gov/ESD/protplant1st3.htm). *Bursera microphylla* is also listed in the California Department of Fish and Game's Special Vascular Plants, Bryophytes, and Lichens List (http://www.dfg.ca.gov/biogeodata/cnddb/pdfs/SPPlants.pdf).

Hypothesis for the distribution of *Bursera microphylla* in South Mountain Municipal Park.

There are microclimatic conditions in SMMP that result from the interaction of existing landscape features. These landscape features include aspect, slope, elevation, and naturally occurring granite boulders. I predict that the interaction of all these landscape features and biotic factors such as associated vegetation and potential nurse plants create a unique microhabitat for *B. microphylla* to exist (Figure 4).

Bursera microphylla is prone to damage from frost; particularly in the harsh and extreme climatic conditions typical of the Sonoran Desert. Thus the specific microclimates where *B. microphylla* is found will have an almost exclusive southern aspect and steeper slope angles. Steeper slopes angles are areas where typically granite boulders are predominant. These granite boulders further modify these microclimates allowing radiant heat collected from the sun during the day to be slowly released after sunset. Therefore, I predict that *B. microphylla* will be found more often near boulders than expected by chance. Altitudinal differences define temperature gradients e.g., between the valley floor and at or near the ridges, so the relatively favorable microclimates for *B. microphylla* will tend to occur in warmer temperature gradients within the elevation of SMMP, so position on the slope may be important. These processes play a key role in the creation of favorable microhabitats and are particularly critical during the winter given the cold-climate sensitivity of *B. microphylla*. Lastly, nurse plants may play an important role in the survival of *B. microphylla* populations and will be closely associated with the locations of *B. microphylla* individuals. To test these interrelated hypotheses data on the abiotic factors, elevation, slope, and aspect, as well as specific plant locations and individual plant characteristics such as height and trunk diameter 15 cm from the ground were obtained for one hundred individual plants. Also, temperature data was collected. Some of these data will be used in spatial analyses to derive a GIS habitat preference model. Furthermore, collected data was analyzed to describe population structure, morphology, and ecological parameters of preferred habitat. In addition, for comparative purposes similar information at one hundred randomly chosen points throughout SMMP was obtained.

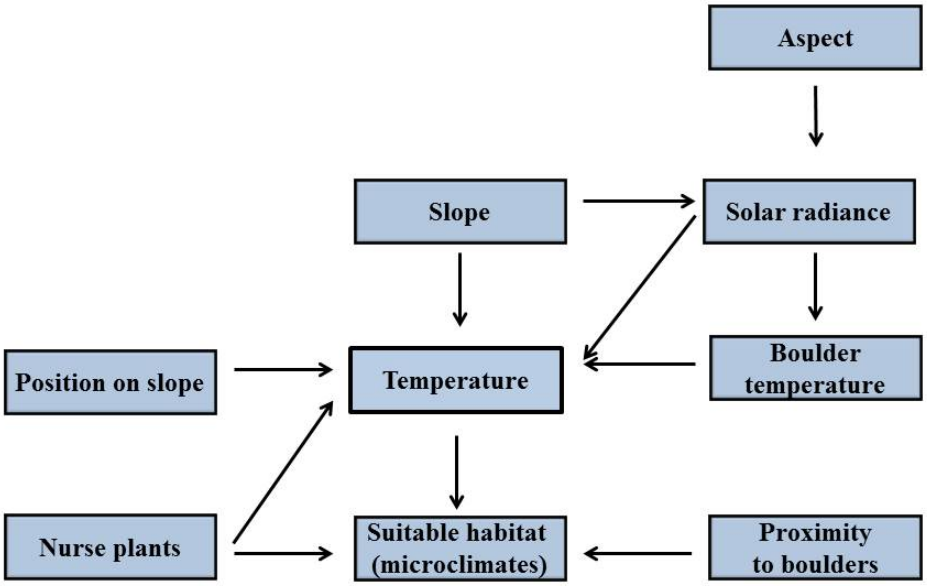

Figure 4. Interaction of major geographical, climatic, and biotic components of microhabitat for *B. microphylla* at South Mountain Municipal Park.

Study Area

South Mountain Municipal Park is a key component of the Phoenix Mountains Preserve System. At 16,500-acres, it is considered the world's largest municipal park by the city of Phoenix. Located at 33.336N, -112.069W, it is 6.5 miles directly south of downtown Phoenix. The park encompasses a vast, rugged mountain range system composed primarily by the Ma Ha Tauk, Gila and Guadalupe ranges which run diagonally in a northeast to southwest direction (Figure 5). In the Sonoran Desert, diagonal mountain ranges like those in South Mountain are typical features of the landscape. The highest point is Mount Suppoa reaching 2,690 feet (820 meters). This point is not accessible to the public. Dobbins Lookout, at 2,330 feet (710 meters) is the highest point in the park accessible by trail (http://phoenix.gov/PARKS/hikesoth.html).

Figure 5: South Mountain Municipal Park, Phoenix, Arizona. Google Earth, May 2010.

Geologically, the Salt River Mountains are thought to be a metamorphic core complex with evidence of movement of the North America tectonic plates from southwest to northeast and northeast to southwest, pushing up a series of mountain ranges including Salt River Mountains, which are some of the few remaining mountains, the other ones having been covered up by silt. The underlying mountains are in the same orientation as Salt River Mountains, about 1 km high, and about 1km apart from peak to peak, perhaps about 15 of them underneath the land (Daniel and Butterwick 1992).

Two main rock types form Salt River Mountains, each of which forms approximately one-half of the range (Figure 6). Metamorphic rocks that formed approximately 1.7 billion years ago during the Precambrian Era compromise the Western half. Isolated regions of Precambrian granite are also found in the extreme western portions of both the Gila and Ma Ha Tuak Ranges. The eastern half of Salt River Mountains is made up of igneous rocks that formed about 25 million years ago during the Cenozoic Era (Daniel and Butterwick 1992). The majority of the Salt River Mountains consist of mountainous slopes of exposed bedrock with shallow, gravelly loams of the Cheroni soil series. The soils at the base of the slopes tend to be deep, well to excessively drained, and gravelly to gravelly sandy loams of various soils series that formed in alluvium deposited as alluvial fans (Daniel and Butterwick 1992).

Figure 6. Granite boulders commonly found at SMMP.

In what is now known as the American Southwest, indigenous peoples left behind many clues of their existence. In the South Mountain area, the Hohokam are the earliest known groups of inhabitants. Hohokam's evidence of their existence and their activities in South Mountain is preserved in the numerous petroglyphs commonly found throughout the range and by the significant numbers of artifacts that have been collected at sites within Salt River Mountains. The term "Hohokam," is Pima in origin and refers to the ancestors of native peoples that have inhabited the Salt River valley since 300 BC. The Hohokam were agriculturalists that created amazing adobe structures, built vast canal systems for irrigation of their cultivated fields in both the Salt and Gila River Valleys, and created intricate rock art designs (http://phoenix.gov/PARKS/hohokam.html).

In 1920, despite the low population (29,033) and small size (5.1 square miles or 13.2 square kilometers) of Phoenix, planning began for acquiring large tracts of desert land for preservation. In 1925 South Mountain Park was patented as the first designated desert preserve (Ewan et al., 2004). Prominent local citizens, with the help of Senator Carl Hayden, bought 13,000 acres from the federal government for $17,000. In 1935 the National Park Service developed a master plan for the park with riding and hiking trails, picnic areas and overlooks, all in rustic regional character. The Civilian Conservation Corps (CCC) built many of the facilities in the park, based on this master plan. The number of visitors at the park has increased from 3,000 a month in 1924 to three million a year today (http://phoenix.gov/PARKS/hikesoth.html).

The state of Arizona has bought, sold, or swapped land several times, including transferring state trust land to developers in controversial auctions in which residents and conservationists have lobbied for the space to be converted to parkland. Since the naming, suburban growth has nearly surrounded the park (http://www.ahwatukeehoa.com/sub_category_list.asp?category=4&title=Origin+of+Ahwatukee).

Over the years the park has increased by 3,500 acres thereby saving the scenic and natural features for the benefit of the entire community, protecting wildlife and natural ecological communities, preserving historic and archaeological sites and providing outdoor recreation opportunities as well as enhancing the community identity of the city of Phoenix. South Mountain Municipal Park has 58 miles of trails for horseback riding, hiking and mountain biking to enjoy the flora, fauna and panoramic views of the pristine desert. All trails vary in length and difficulty. Trailheads and markers are located throughout the park (Figure 7).

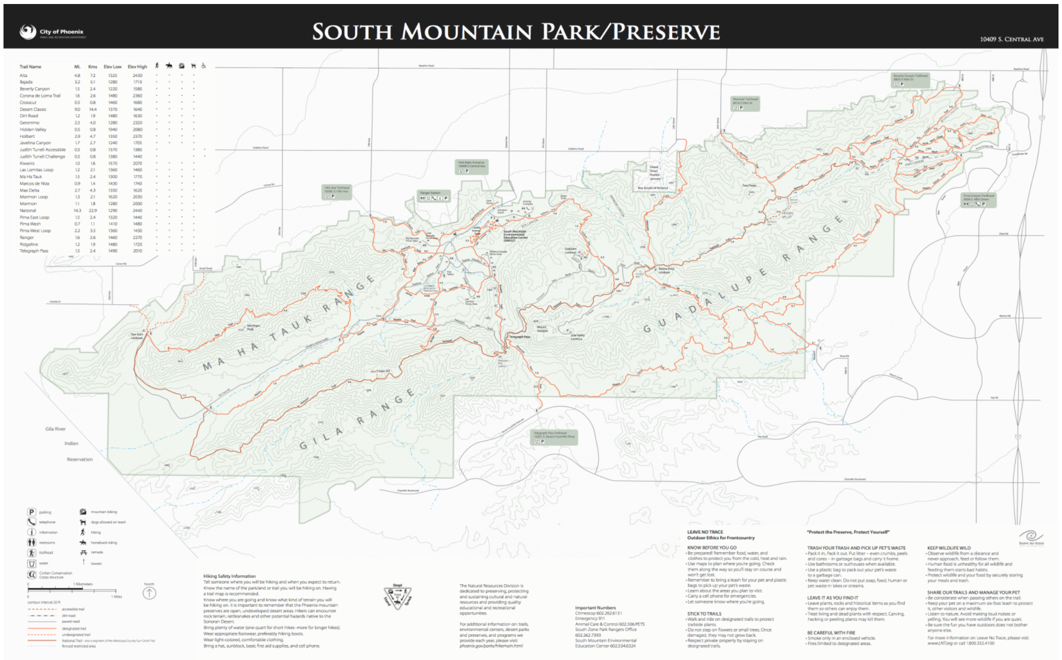

Figure 7: Map of South Mountain Municipal Park trails. City of Phoenix.

The vascular flora of SMMP consists of 274 species in 188 genera and 57 families (Daniel and Butterwick 1992). The most prevalent plant community in South Mountain is the Palo Verde-Cacti Mixed Scrub. Within this series Brown et al. (1979) have identified several associations, some of which are evident in SMMP. The *Ambrosia deltoidea-Parkinsonia microphylla*-Mixed Scrub association is well developed both on steep slopes and dissected plains at the base of the mountains. Other trees and shrubs common within this association include: *Carnegiea gigantea, Echinocereus engelmannii, Encelia farinosa, Fouquieria splendens, Ferocactus acanthodes, Krameria grayi, Larrea tridentata, Olneya* *tesota* (usually restricted to washes), and *Opuntia acanthocarpa*. The *Ambrosia deltoidea-Parkinsonia microphylla*-Mixed Scrub association merges into an *Ambrosia deltoidea-Carnegiea gigantea*-Mixed Scrub association on numerous slopes where Brittlebush replaces Triangle-leaf Bursage as the dominant understory shrub. In this latter association *Parkinsonia microphylla* and *Carnegiea gigantea* usually form a sparse overstory (Daniel and Butterwick 1992). *Larrea tridentata* becomes more abundant on the more moderate slopes. In some areas, it is even dominant, forming a *Larrea tridentata*-Mixed Scrub association. *Ambrosia dumosa* sometimes becomes more common than *A. deltoidea* in these regions. These open areas support a sparse cover of winter ephemerals such as: *Cryptantha maritima, Erodium texanum, Eschscholzia californica, Lesquerella gordonii, Plantago insularis,* and *Schismus barbatus*.

Bursera microphylla is an unusual component of the Sonoran desert scrub vegetation that dominates SMMP. Several taxa such as *Bursera microphylla, Forestiera shrevei*, *Selaginella eremophila*, and *Senecio mohavensis* attain their northeastern most extent of their respective ranges at South Mountain (Daniel and Butterwick, 1992). For instance, *Forestiera shrevei* is well documented for locales further south but like *B microphylla*, it does not occur much further north than the Harquahala Mountains. No species is restricted in its distribution to SMMP.

Chapter II: Materials and Methods

Data Collection

To carry out the fieldwork necessary to test the hypotheses described in the Introduction, it was necessary to conduct further observations off the trails in SMMP. A letter of permission from the City of Phoenix's Parks and Recreation Department was granted to conduct this fieldwork. A preliminary set of hikes on seven commonly used trails was performed. These trails included Alta Trail, National Trail, Desert Classic Trail, Pima Wash Trail, Javelina Trail, Mormon Loop Trail, and Telegraph Pass Trail. Individuals of *B. microphylla* were observed near or were visible from all but two of the seven trails (Mormon Loop and Javelina Trail). Sites along two trails with *B. microphylla* were selected for data collection, Pima Wash Trail and Desert Classic Trail. *Bursera microphylla* in SMMP are found in scattered populations. For the purpose of this research a population within South Mountain Municipal Park is defined as any number of closely-spaced individual plants that are separated by a few hundred meters from another population. These populations are composed of individual plants ranging in numbers from a few plants to estimates of over a hundred plants.

Site 1: Pima Wash. Pima Wash Trail is a relatively high elevation trail that is tucked in between two mountains within the Guadalupe Range in the east side of the park. The landscape is steep with granite boulders. Elevation of the trail at the dry wash is 504 m and rises to 636 m at the highest point for a range of about 132 m from the dry wash floor to the peaks. The terrain is fairly accessible and open and allowed me to conduct an inventory of one of the populations. This population was found on the south-facing hillsides of Pima Wash Trail beginning a few meters from its junction with Mormon Loop Trail and Javelina Trail, on the east end of this site (33º21.605, -112º0.333), to the entrance of Hidden Valley (33º21.297, -112º1.0376) about a mile to the southwest. Data were collected from a population totaling 34 individual plants.

Site 2: Desert Classic. The Desert Classic Trail (33º21.742, -111º59.119) is about nine miles long and runs along the bottom of the mountain in the Guadalupe range extending west to the Gila Range (33º19.381, -112º4.000). It is on the valley floor and extends southward towards Ahwatukee. The elevation at this ranged from 449 m to 684 m for a range of 235 m or 100 m greater than that of Pima Wash. The terrain is much steeper with long and narrow ravines descending from the peaks to the valley floor. Data were collected from 66 individual plants.

Site 3: Mount Suppoa. Along with the two sites just described, Pima Wash and Desert Classic Trail, an additional research site was selected for the collection of weather data. Mount Suppoa is in the southwestern part of SMMP and rises from the valley floor at 427 m to 820 m and is the highest peak in South Mountain Municipal Park. This additional site was selected because it has the greatest elevation range at 393 m of anywhere in the park and has large numbers of *B. microphylla,* particularly in the middle elevations.

Temperature data were recorded using Hobo Temperature External data loggers http://www.onsetcomp.com/data-logger#outdoor. Temperature data were collected from January 18, 2010 through March 16, 2010. The data loggers were programmed to record ambient air temperature at 30-minute intervals, marking the highest and lowest temperature recordings for each day. Before installation of the data loggers in the field, each data logger was calibrated using BoxCar Pro4 software http://www.microdaq.com/occ/software/boxcarpro.php and placed inside a sealed plastic zip-lock bag and secured with gray electrical tape inside a multi-layered, dome-shaped vinyl radiation shield (Figure 8) to minimize the effects of direct sunlight and moisture on the temperature sensor.

Figure 8. Solar radiation shield for Hobo data loggers used in South Mountain Municipal Park, January to March, 2010.

The data loggers were installed in the field in a series of vertical transects to maximize elevational range (figure 9). Each transect consisted of three data loggers; one at the lower elevation, normally the valley floor, one at the middle elevation, and the last one at the highest elevation, usually at or near the peak.

The Pima Wash Trail and Desert Classic Trail sites had three transects each. A seventh transect was placed at Mt. Suppoa.

Figure 9. Transect of Hobo data loggers at Desert Classic Trail site, January to March, 2010.

A total of 21 data loggers were installed. Each was placed in the canopy of a *B. microphylla* shrub or a *Parkinsonia microphylla* about one meter off the ground. (Figure 10) GPS coordinates and elevation data were recorded for each data logger in the field (Appendix A).

Figure 10. Hobo data logger inside a solar radiation shield at South Mountain Municipal Park, January to March 2010.

Field notes were recorded on an Excel spreadsheet with 13 different categories recorded. These categories were: (1) GPS Coordinates, (2) Elevation, (3) Aspect, (4) Diameter at 15cm off the ground, (5) Trunk (single or multi-trunk), (6) Canopy Width, (7) Canopy Height, (8) Flower (present or absent), (9) Seeds (present or absent), (10) Damage (present or absent), (11) Damage Remarks (frost or sun burn), (12) potential Nurse Plant(s) (present or absent), and (13) Associated Vegetation within two m (one species for each cardinal direction).

Global Position System (GPS) coordinates, elevation, and aspect were recorded using a Garmin Forerunner 201 GPS unit. The trunk diameters were measured using a flexible vinyl measuring tape. The canopy widths were measured at the widest part while canopy height was measured from the lowest to the highest point of the canopy. For the purpose of this research, damage was defined into three categories: 1) physical scars on the tissue observed on typically exposed trunk(s) and often near the base on exposed canopy plants that is most likely from sunburn; 2) a distinctively magenta-like coloration on limbs and at times on leaves occurring at the same height level within the canopy and often times near the top of the canopy that suggest frost damage; 3) a combination of both environmental factors. The presence of potential nurse plants was recorded based on the presence of the canopy of a nearby plant covering entirely or partially any part of *B. microphylla* plant(s) recorded. When boulders were present within the two m radius of each *B. microphylla* plant, this was also noted on the associated vegetation column.

Descriptive Analyses

The data (numerical and categorical) collected in the Excel spreadsheet were color-coded by category. The color-coding approach facilitated extraction of percentages for each category in the spreadsheet with multiple variables crossing multiple categories of specific data. The elevation range was divided into classes of 50-meter increments resulting in a total of eight elevation classes described as class one: 400-449 m, class two: 450-499 m, class three: 500-549 m, class four: 550-599 m, class five: 600-649 m, class six: 650-699 m, class seven: 700-749 m, and class eight: 750-800 m. All data points were grouped by corresponding elevation class. Comparisons of *B. microphylla* distributions, damage, and multi-trunk and trunk diameter characteristics were made by aspect, elevation, and presence of boulders. The purpose of categorizing the data by elevation layers was to explore the relationship of different morphological characteristics of *B. microphylla* and geographical features associated with its distribution in SMMP to elevation.

Linear Regression Analyses

Three variables trunk type, trunk diameter, and canopy volume were further analyzed using Matlab2010b Statistical Toolbook© (The Mathworks Inc., 2003). Boxplots were selected for comparing the distribution between elevation data, single trunk plants data, and multiple trunk plants data graphically. For analyzing the trunk diameter to elevation, and the canopy volume to elevation, Linear Regression analyses were performed.

Spatial Analyses

To gain a better understanding of the data collected and to identify potential relationships between the multiple variables associated with each collection point (an individual plant), a Geographic Information System (GIS) application was created. This application was used to capture, store, analyze, manage, and present data that are linked to location. Plotting the data points spatially in a GIS highlights potential trends among the data points. Using a Digital Elevation Model (DEM) for Maricopa County (Figure 11) as the primary input for the spatial analysis, the GIS application analyzed the features of aspect, elevation, slope, and relative solar exposure. A DEM is a digital representation of ground surface topography or terrain. The results of these analyses were then used to build the input parameters of a predictive habitat model. While the aspect, slope, and elevation values were extracted from the DEM dataset, acquiring the accumulative relative solar exposure required repeating a hillshade analysis four different times. The first three of these hillshade analyses were performed using different input settings of solar azimuth and solar altitude to represent the specific amount of relative solar exposure at specific times of the day (Table 1). The fourth analysis summarized all three hillshade values by creating a new hillshade file representing the total accumulative relative solar exposure on any specific point within the study area

Using ESRI's ArcGIS 9.3.1©, the DEM file was imported into ArcMap and displayed at 25 m increments. To facilitate data processing, a mask or area of interest (AOI) file that encompassed South Mountain Municipal Park was created. (Figure 12) This mask was used to constrain analysis to the study area, thereby reducing the volume of data being processed. The smaller file speeds up the data analysis processing in ArcGIS and is much easier to store than the original DEM file containing 4.25 gigabytes of data.

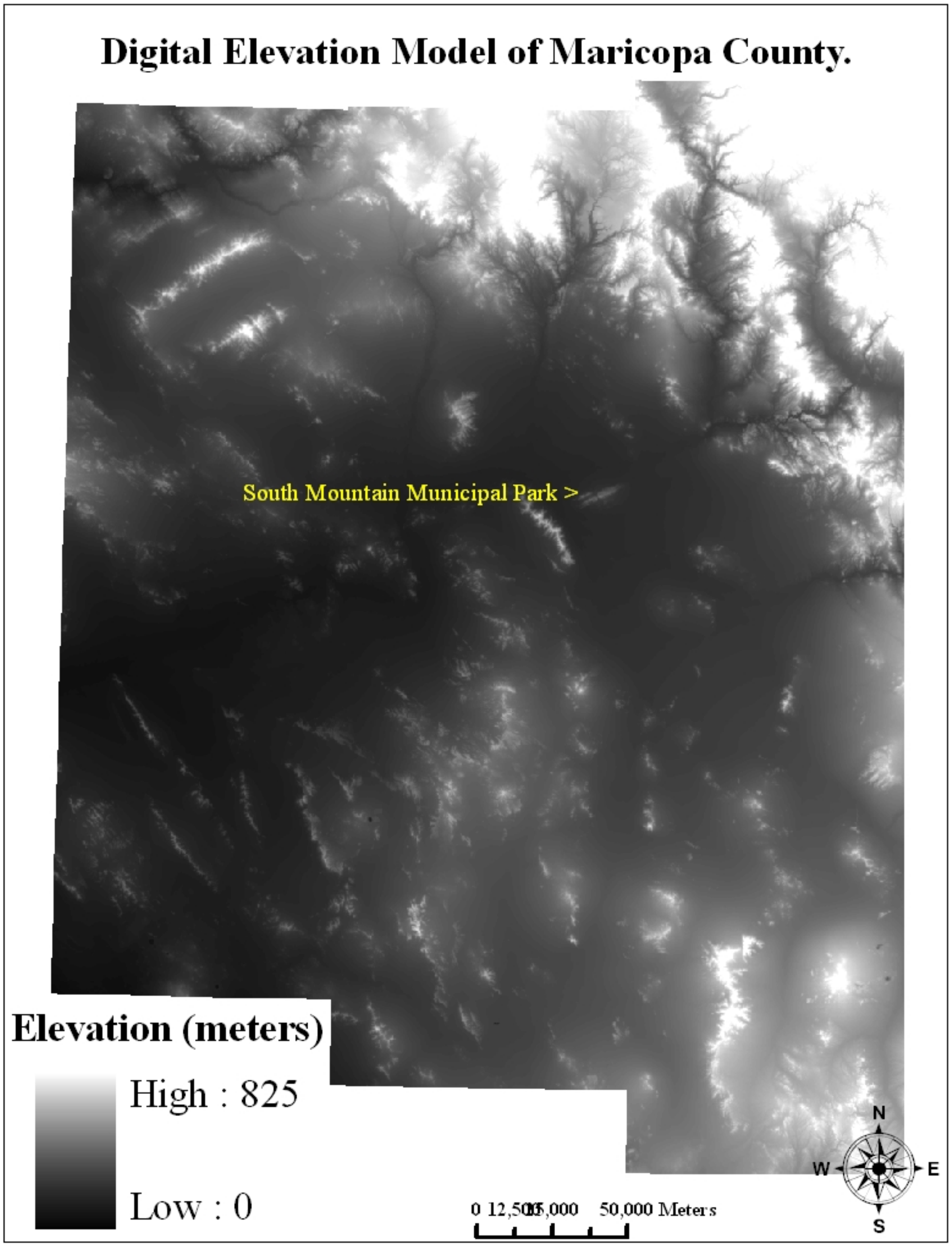

Figure 11. Digital Elevation Model of Maricopa County used for GIS analyses, May 2010.

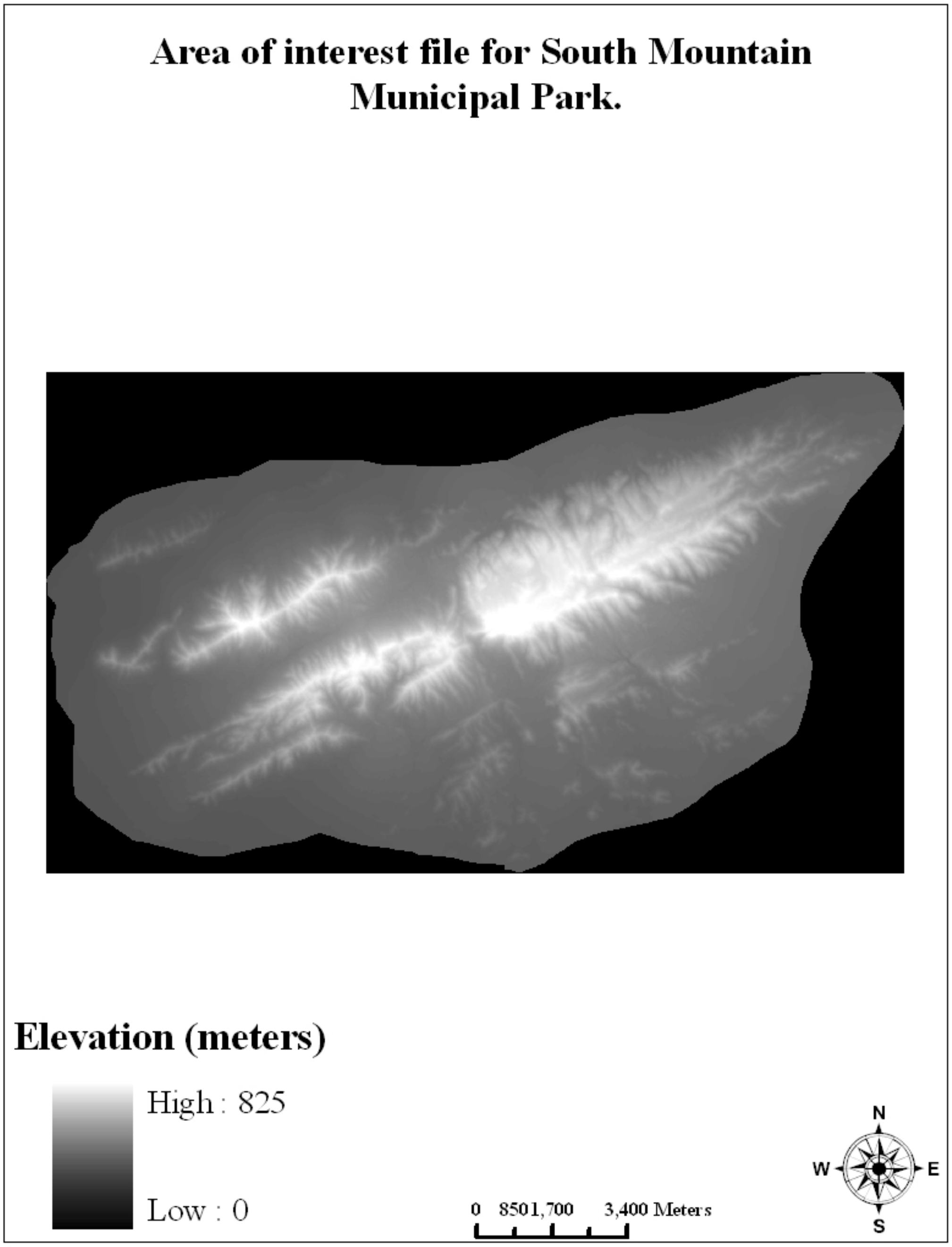

Figure 12. Area of interest (or mask) file for South Mountain Municipal Park May 2010 GIS analyses.

From the mask file, the following files were derived using the Surface Analysis feature in the Spatial Analyst extension of ArcGIS: Elevation (Figure 13), Slope (Figure 14), and Aspect (Figure 15).

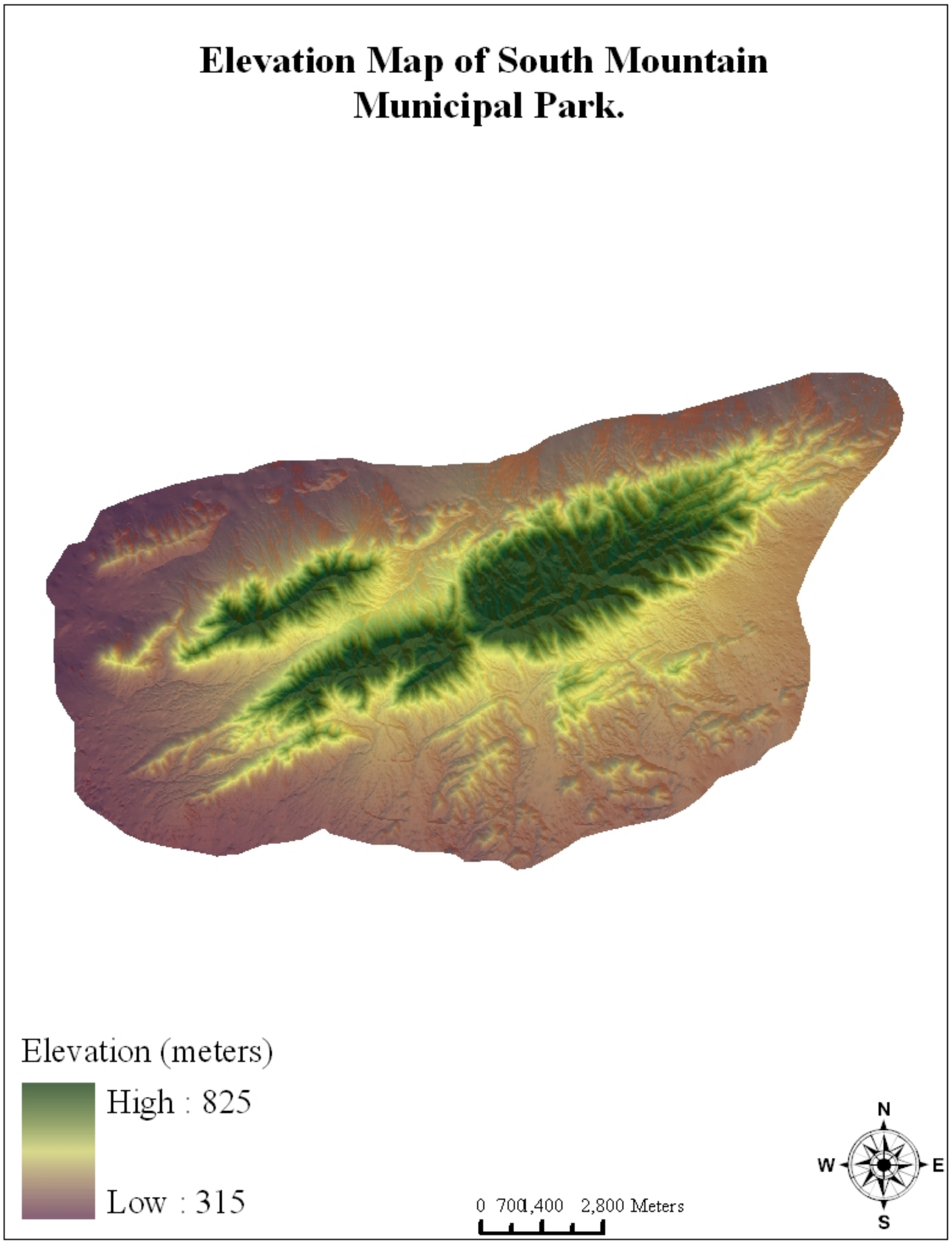

Figure 13. Elevation file for South Mountain Municipal Park May 2010 GIS analyses.

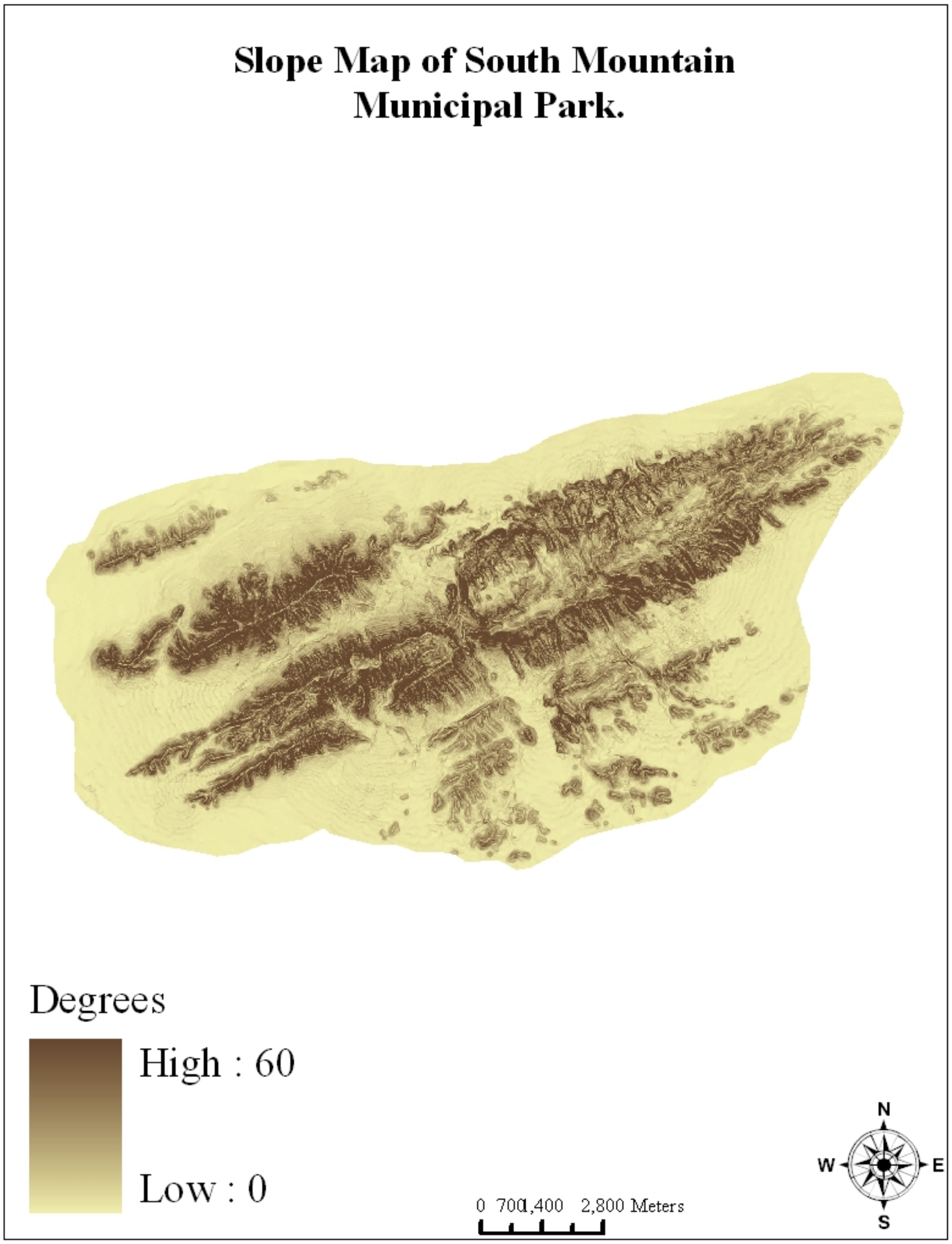

Figure 14. Slope file for South Mountain Municipal Park May 2010 GIS analyses.

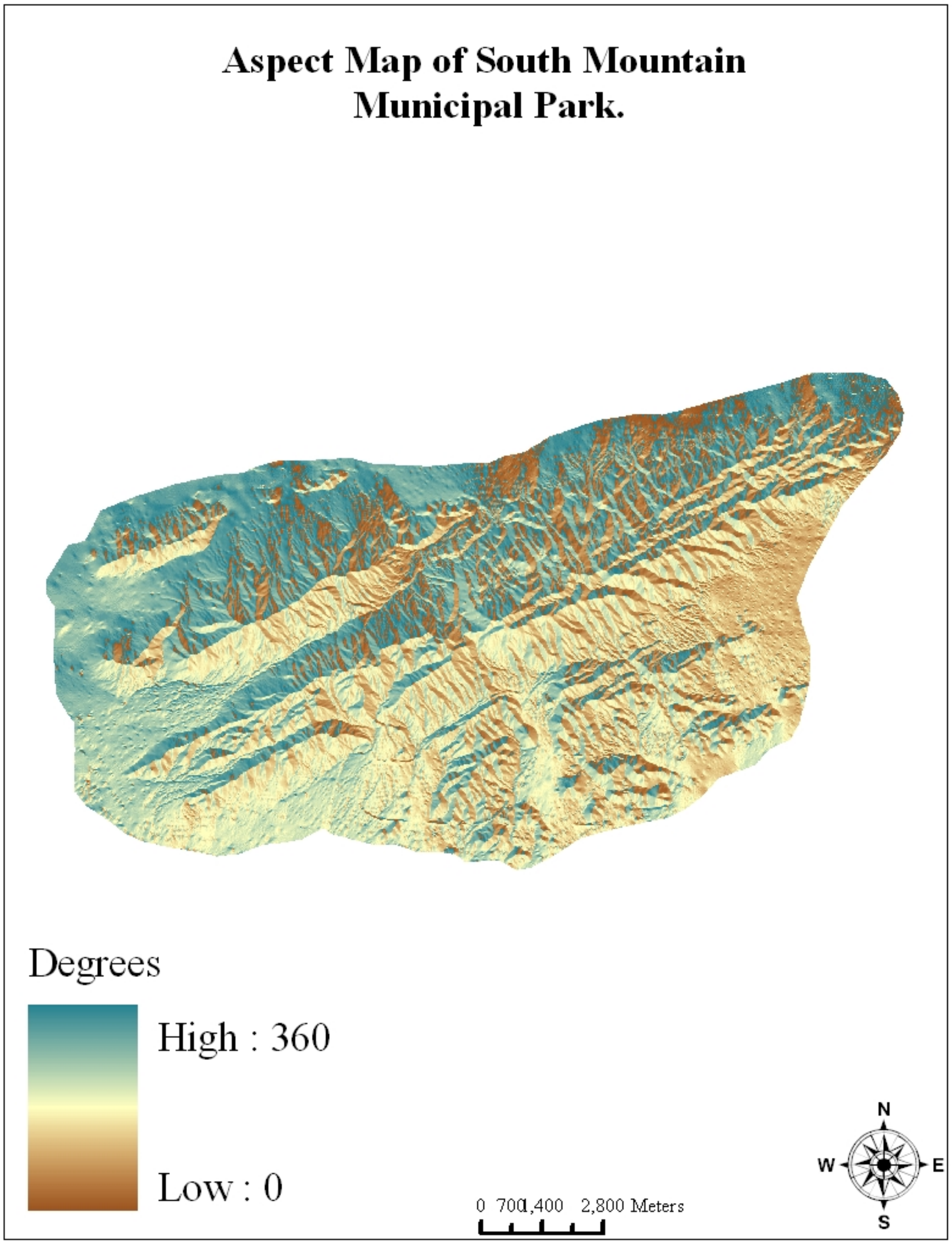

Figure 15. Aspect file for South Mountain Municipal Park May 2010 GIS analyses.

Three hillshade layers created determined the relative solar exposure at different times on any specific point within the study area. Hillshade 10 represents the expected solar conditions at 10:00 hours (Figure 16); Hillshade 12 at 12:00 hours (Figure 17); and Hillshade 15 at 15:00 hours (Figure 18).

Table 1. Input parameters used to develop hillshade input layers for South Mountain Municipal Park during the time period of January 18 to March 16, 2010.

		Settings	
Layer	Time	Solar Azimuth	Solar Altitude
H10	10:00	135°	25°
H12	12:00	180°	48°
H15	15:00	225°	25°

Solar azimuth is a directional measure from the target location to the sun in directional degrees clockwise from north, and solar altitude is the angle of the sun above the horizon at a specified time.

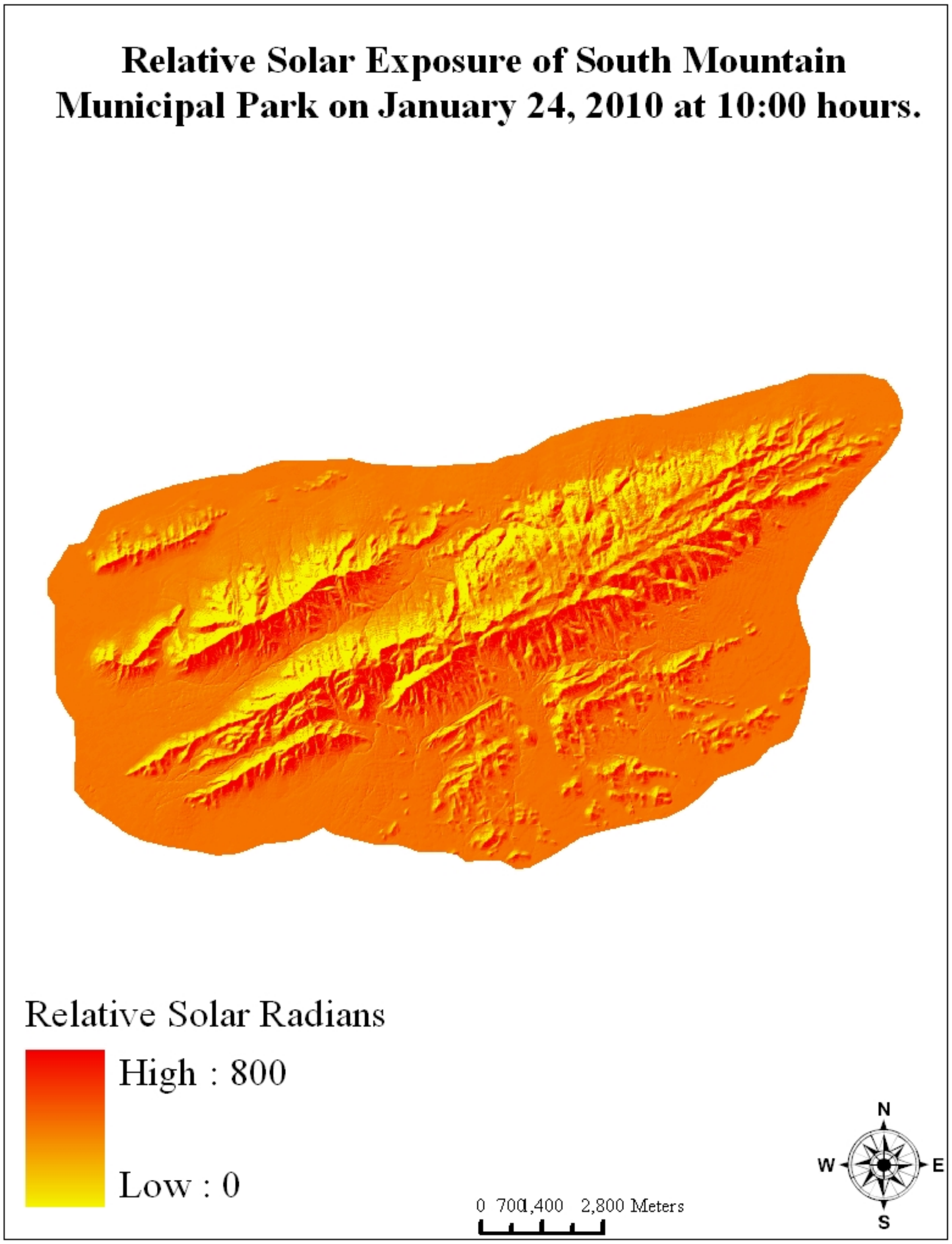

Figure 16. Hillshade 10 file for South Mountain Municipal Park May 2010 GIS analyses.

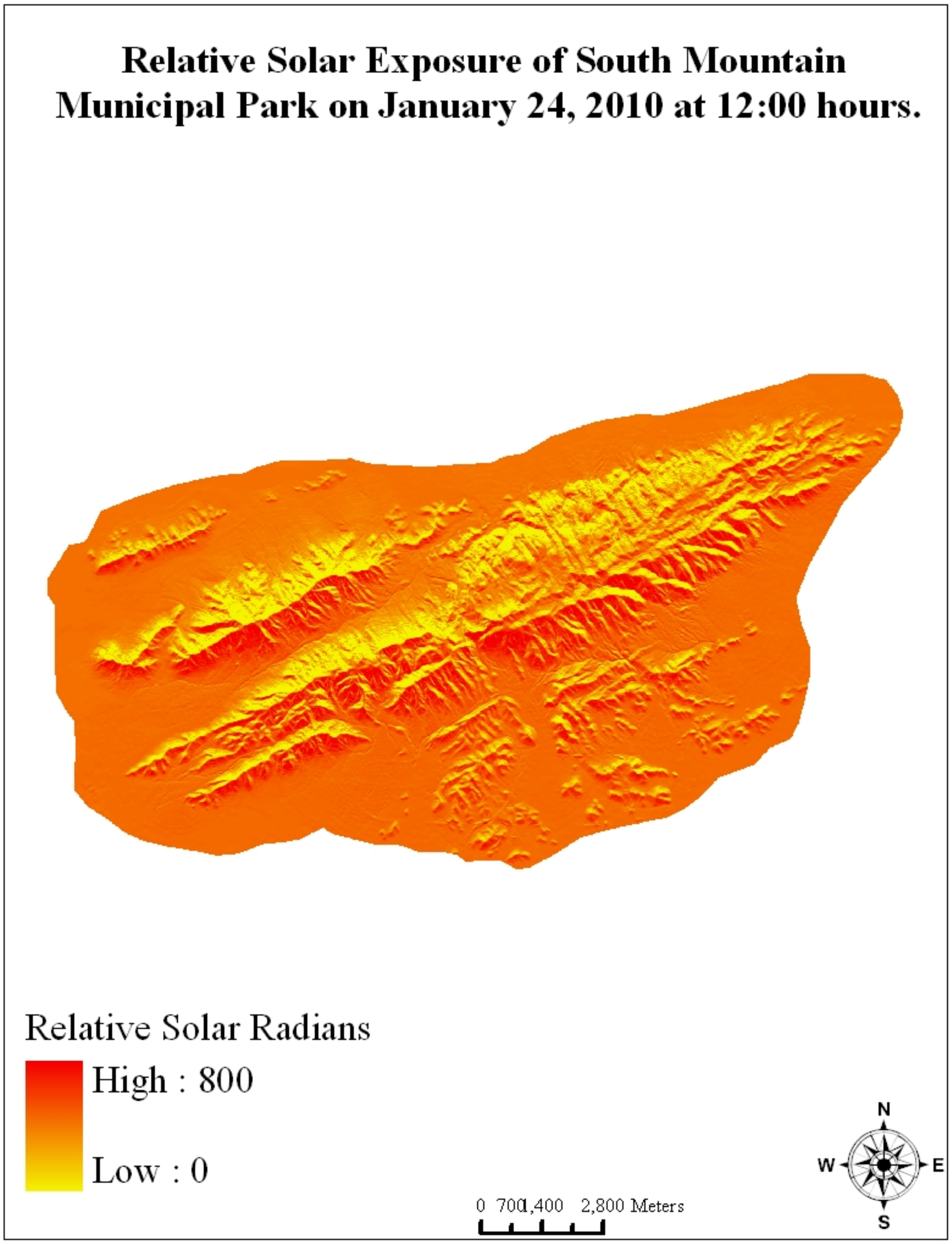

Figure 17. Hillshade 12 file for South Mountain Municipal Park May 2010 GIS analyses.

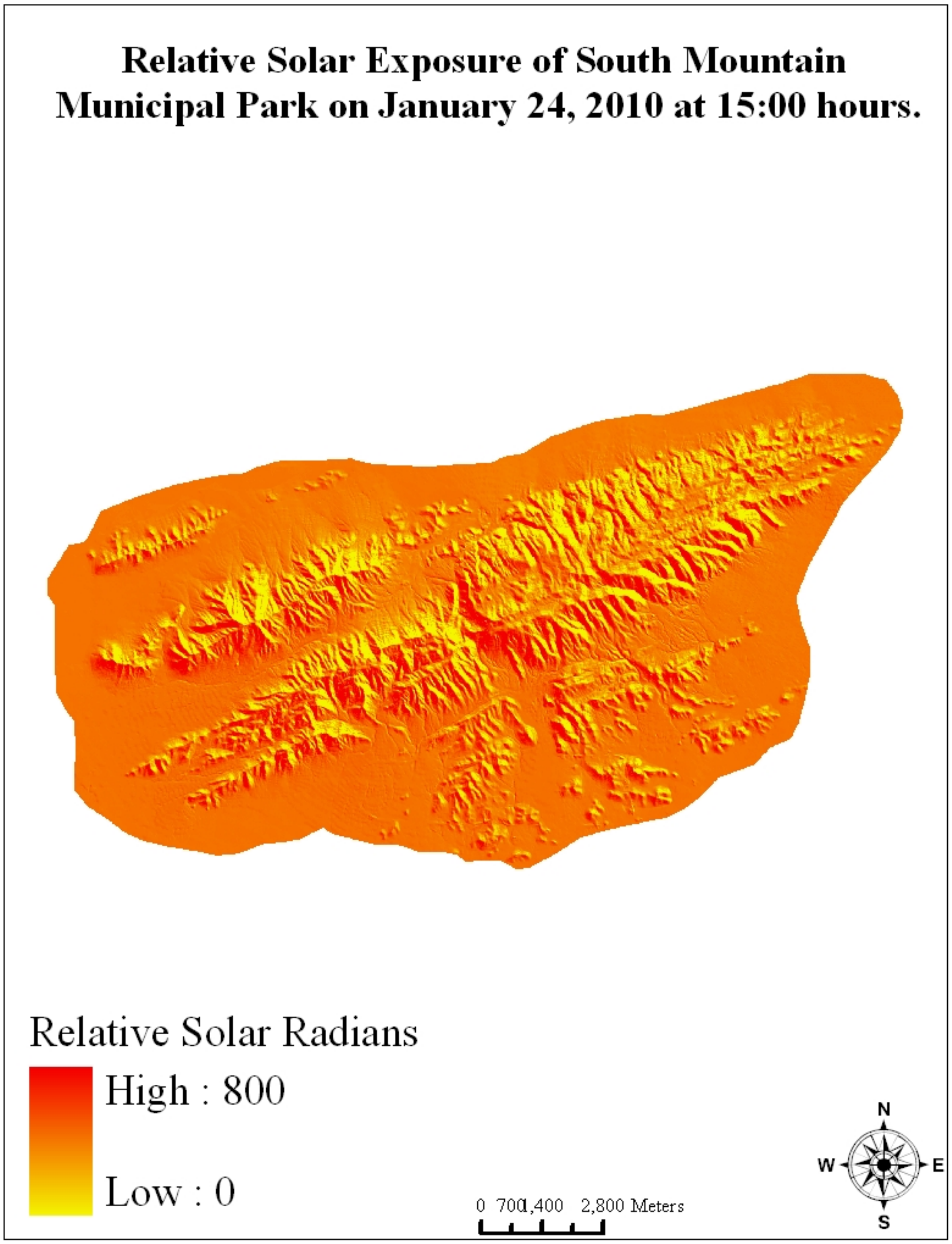

Figure 18. Hillshade 15 file for South Mountain Municipal Park May 2010 GIS analyses.

These three new hillshade files were combined to create a new hillshade file representing the accumulated relative solar exposure load (Figure 19). This accumulated relative solar load layer was classified into seven classes of 100 radians each (Table 2).

Table 2. Classes and radians ranges used for South Mountain Municipal Park for GIS relative solar load analyses, May 2010.

Relative Solar Load	
Class	Radians
1	0-99
2	100-199
3	200-299
4	300-399
5	400-499
6	500-599
7	600-699

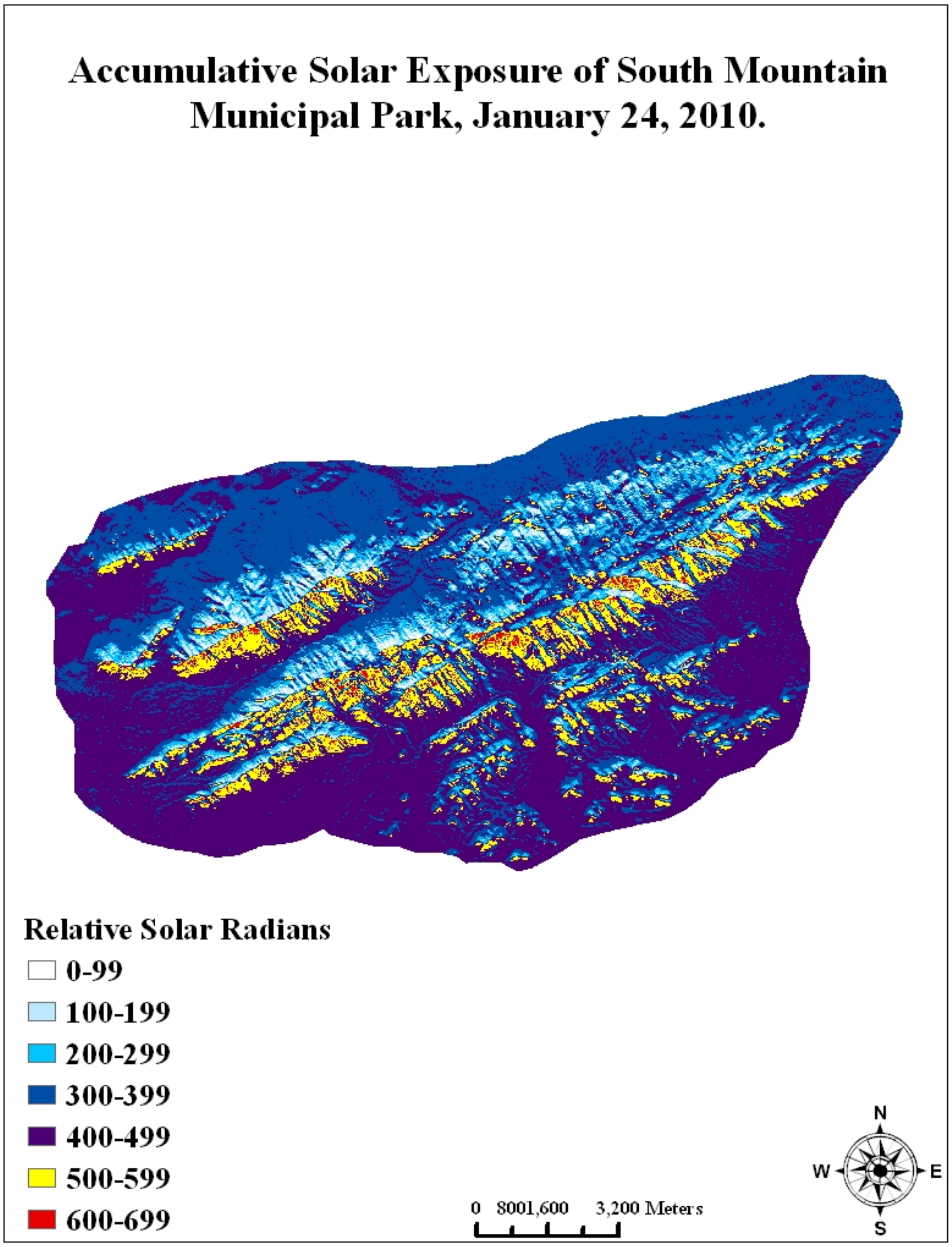

Figure 19. Accumulated relative solar load file for South Mountain Municipal Park, May 2010 GIS analyses.

The aspect layer was classified into eight classes representing each cardinal direction with corresponding degrees in 45° increments (Table 3, Figure 20). The slope layer was classified into five classes of 10° increments (Table 4, Figure 21). The elevation data was classified into five classes in 100 m increments starting at 300 m (Table 5, Figure 22).

Table 3. Degrees ranges for cardinal directions used for South Mountain Municipal Park for GIS aspect analyses, May 2010.

Aspect	
Degrees	Trait
382.5 - 22.5	N
22.5 - 67.5	NE
67.5 - 112.5	E
112.5 - 157.5	SE
157.5 - 202.5	S
202.5 - 247.5	SW
247.5 - 292.5	W
292.5 - 337.5	NW

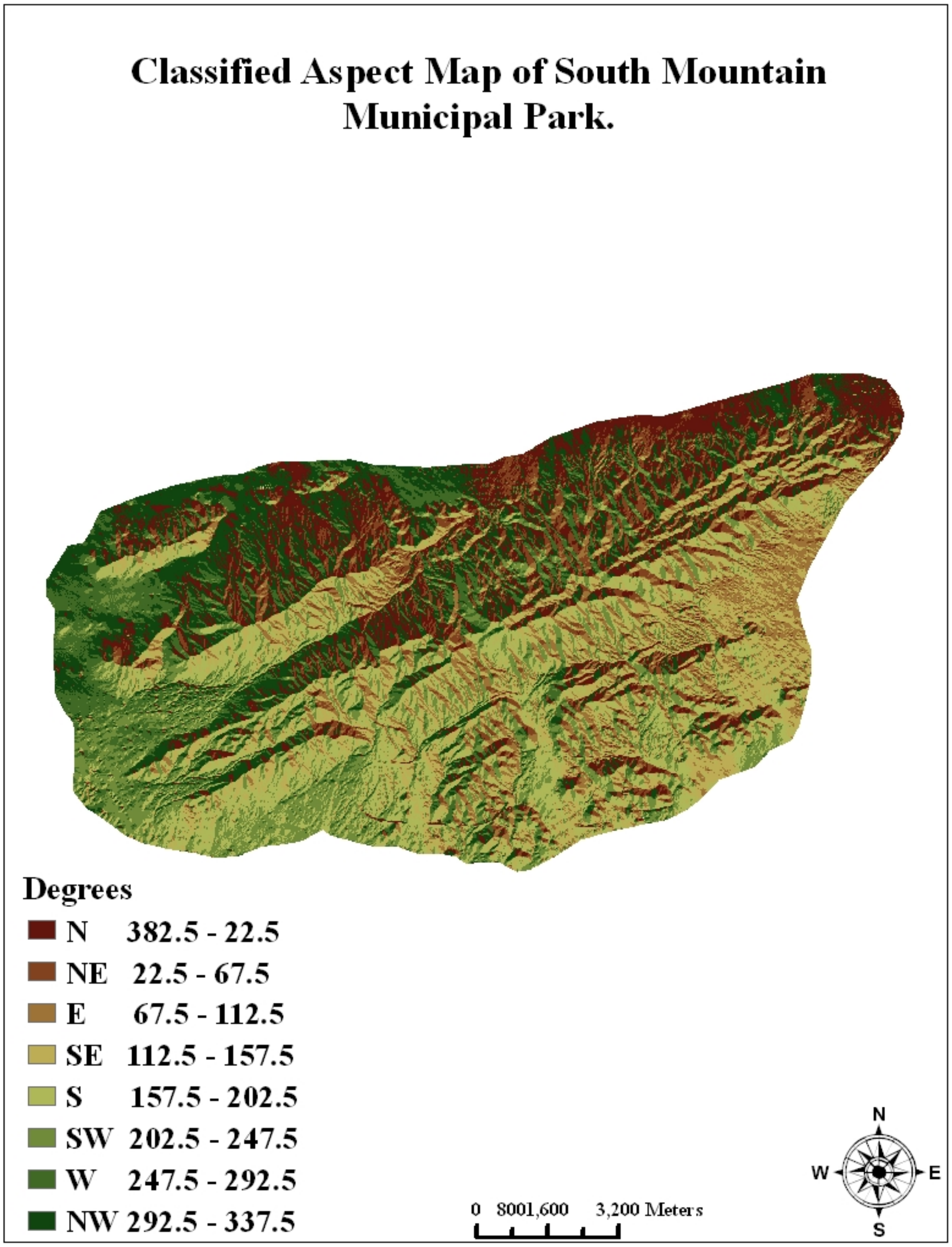

Figure 20. Classified Aspect map for South Mountain Municipal Park, May 2010 GIS analyses.

Table 4. Classes and degree ranges used for South Mountain Municipal Park for GIS slope analyses, May 2010.

	Slope
Class	Degrees
1	0-9
2	10-19
3	20-29
4	30-39
5	40-49

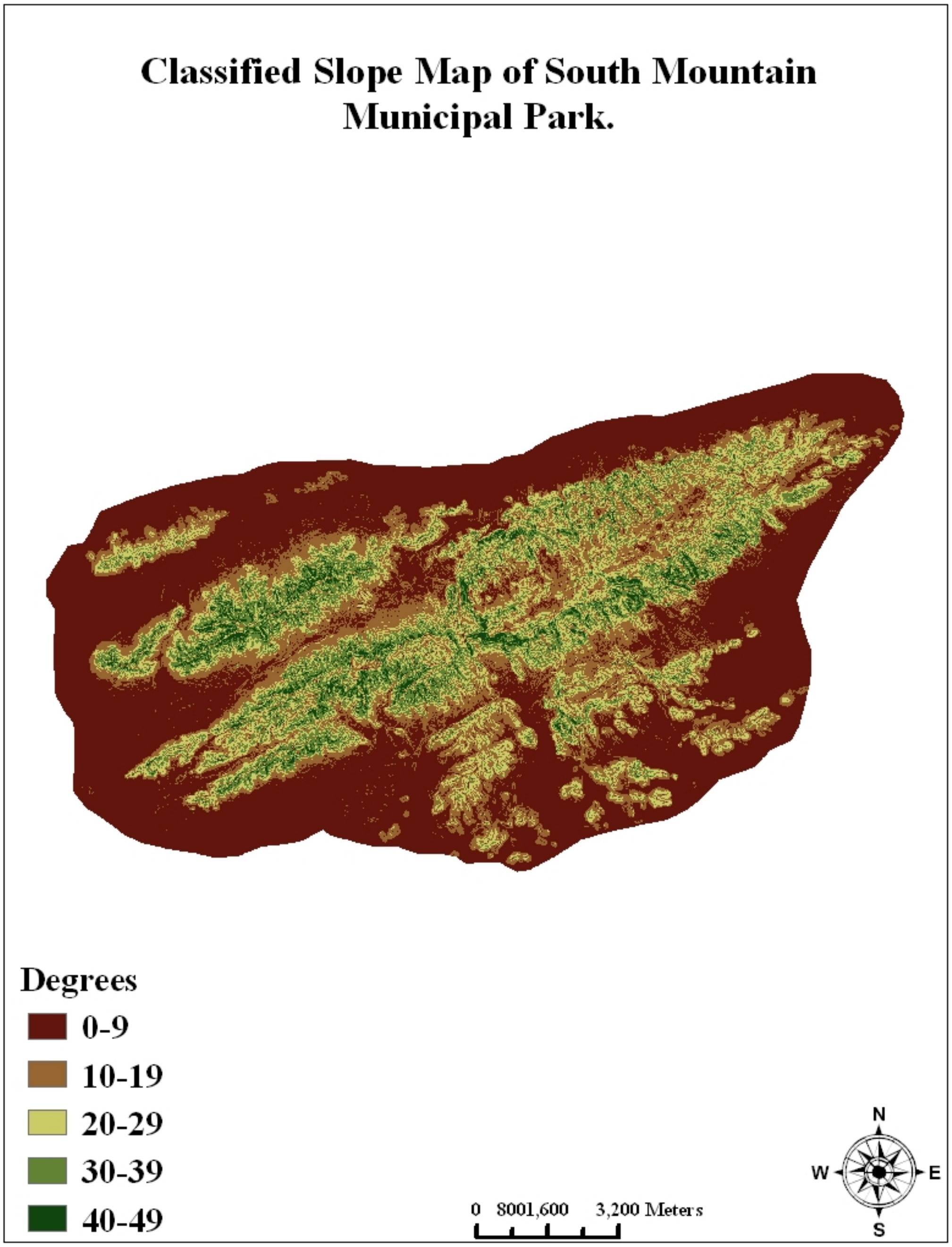

Figure 21. Classified Slope map for South Mountain Municipal Park, May 2010 GIS analyses.

Table 5. Classes and elevation ranges in meters used for South Mountain Municipal Park for GIS elevation analyses, May 2010.

	Elevation
Class	Meters
1	300-399
2	400-499
3	500-599
4	600-699
5	700-799

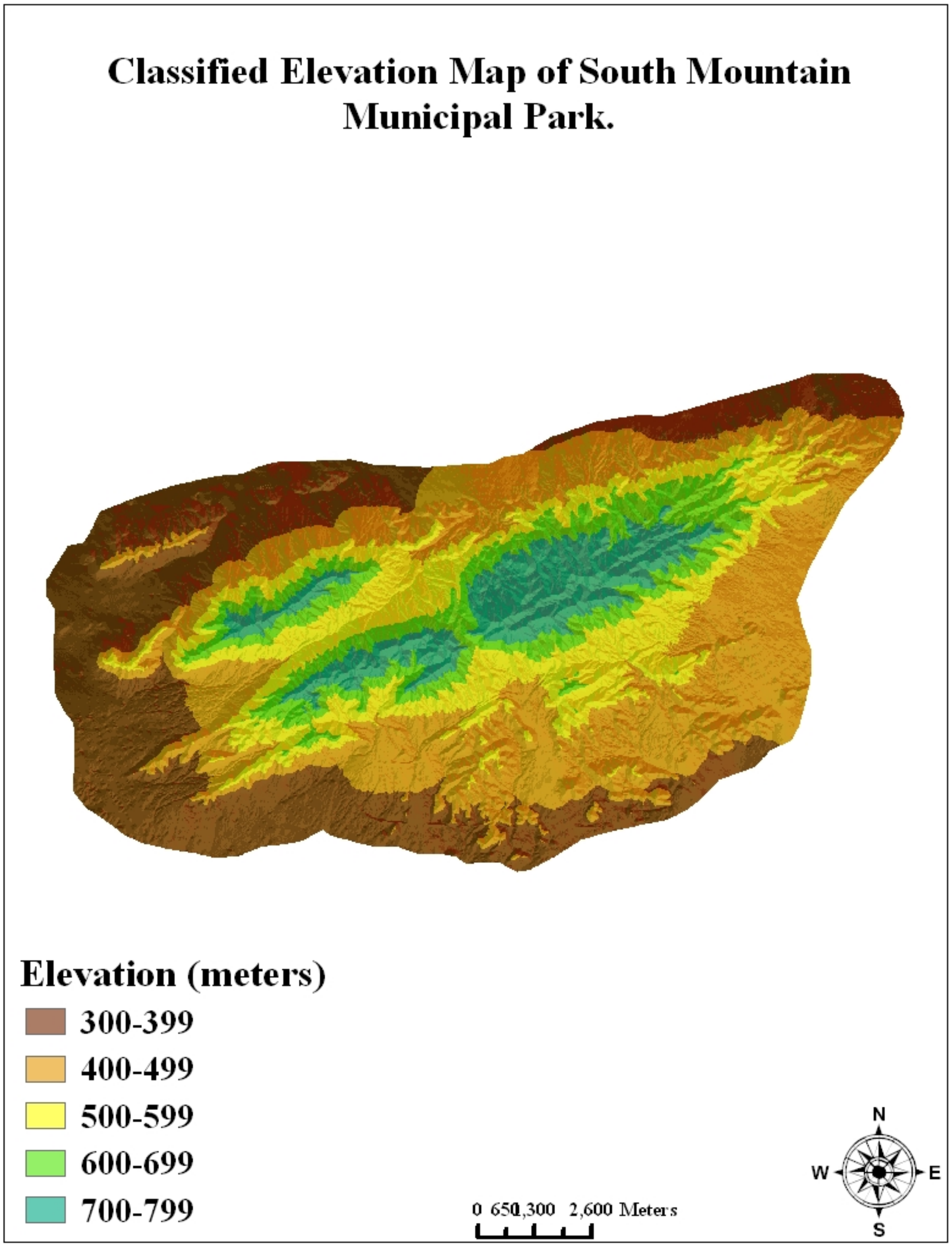

Figure 22. Classified Elevation map for South Mountain Municipal Park, May 2010 GIS analyses.

A Chi Square Test was performed on each of the four features using the data derived from the classified layers as inputs. This process determines the preference type for the classes of each feature. The preference types of each feature and it classes were used as the input parameters for a Weighted Overlay model. Weighted Overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. The weighted overlay output file was classified into four classes with each class describing the habitat preference type for *B. microphylla* within the area of interest file for SMMP. These preferences are described as, unsuitable, marginal, suitable, and highly suitable.

On-ground Verification: Using the accumulative relative solar load output file from the GIS as parameters, a new point data file (shape file) was created containing 100 randomly generated points. Each of the 100 random points was visited in the field to look for the presence of *B. microphylla*. These new randomly generated 100 points were in addition to the 100 points where field data were collected from actual *B. microphylla* plants. These data were used to check the accuracy of the Weighted Overlay model.

Chapter III: Results

Descriptive Analyses

Elevation data is displayed from low to high. For the purpose of evaluating the impact of temperature on *B. microphylla*, elevation was further divided into 50 m increments ranging from 400 m to 800 m. Data from individual plants were recorded in only the four lowest elevation classes. Eighty-nine percent of all *B. microphylla* recorded occurred within 450-499 m and 500-549 m (56%, and 33% respectively), with 7% in the 400-449 m class and 4% in the 550-599 m elevation class. The highest elevation for which plant data were recorded was 570 m and the lowest elevation was 421 m. One hundred percent of the individual plants occurred within a range of 149 m (Table 6). Class seven (>700 m) was classified as 700 m and higher and only occurred on Mt. Suppoa.

Table 6. Elevation classes, number of Hobos and individual plants of *Bursera microphylla* within transects at South Mountain Municipal Park, January to March 2010.

Class (elevation in meters)	Number of Hobo data loggers	Number of plants
1 (400-449)	3	7
2 (450-499)	2	56
3 (500-549)	8	33
4 (550-599)	4	4
5 (600-649)	1	N/A
6 (650-699)	2	N/A
7 (700-749)	N/A	N/A
8 (750-799)	1	N/A

The temperature data collected by the Hobo data loggers were grouped by research site and then distributed by elevation class described above. The temperature data collected were averaged in two ways; first, data from each one of the data loggers were analyzed to extract the highest, lowest and average means (Table 7, Figure 23) and second, data were analyzed for hourly averages.

Table 7: Average temperature by elevation class at South Mountain Municipal Park, January to March 2010.

Class (elevation in meters)	Mean temperature	Mean max. temperature	Mean min. temperature
1 (400-449)	53	78	34
2 (450-499)	55	90	35
3 (500-549)	57	89	38
4 (550-599)	56	86	41
5 (600-649)	52	84	36
6 (650-699)	60	101	38
8 (750-799)	56	92	35

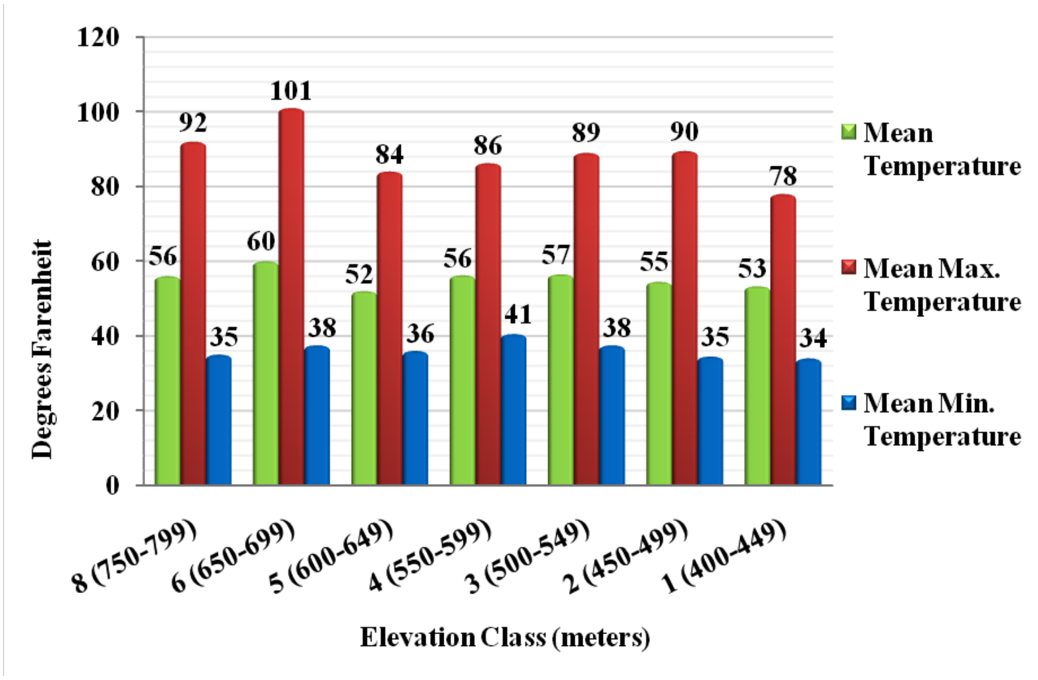

Figure 23. Temperature averages by elevation class at South Mountain Municipal Park, January to March 2010.

Hourly temperature averages were extracted for each of the seven elevation classes and are shown in Appendix B. These data indicate that the 7:00 am to 8:00 am hour was the coldest and the hours between 2:00 pm and 4:00 pm were the warmest. Elevation classes two, three, and four (450-499 m, 500-549 m, and 550-599 m respectively) were the most stable in terms of temperature fluctuations and indicated a more gradual rate of change of heat gain and loss per hour as compared to the rest of the elevation classes (Figure 24).

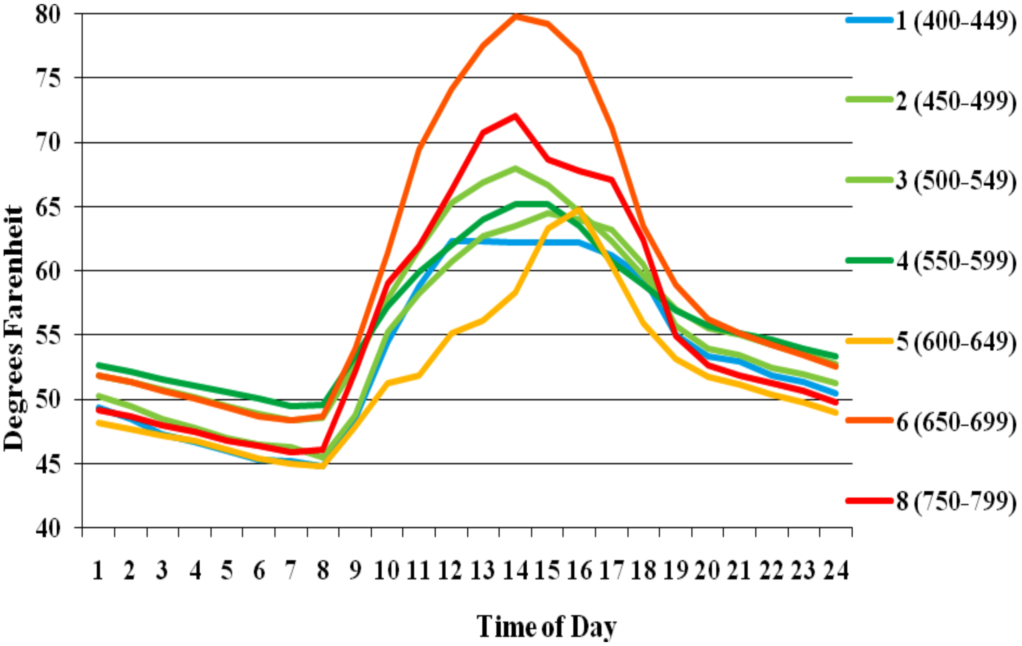

Figure 24: Hourly temperature averages by elevation class at South Mountain Municipal Park, January to March 2010.

The official temperature readings from Sky Harbor International Airport in Phoenix indicate that January 24, 2010 was the coldest of all the days (41º Fahrenheit) for which temperature data were recorded at SMMP (January 18, through March 16, 2010). In reviewing the temperature data recorded on that day, there are differences of a minimum of four degrees Fahrenheit and a maximum of

11º Fahrenheit between the elevations on the transects. The areas that had the smallest range in temperature differences, and were therefore more stable were the middle elevations where boulders are common. For example, in one of the transects for the Desert Classic Trail site, the temperature at the middle elevation (562 m) was 41º Fahrenheit while on the same transect, at the lower elevation (438 m) it was 30º Fahrenheit (Figure 25). Similar temperature fluctuations were also recorded at a transect for the Pima Wash Trail site, the temperature at the middle elevation (557 m) was 46º Fahrenheit while on the same transect, at the lower elevation (507 m) it was 35º degrees Fahrenheit (Figure 26).

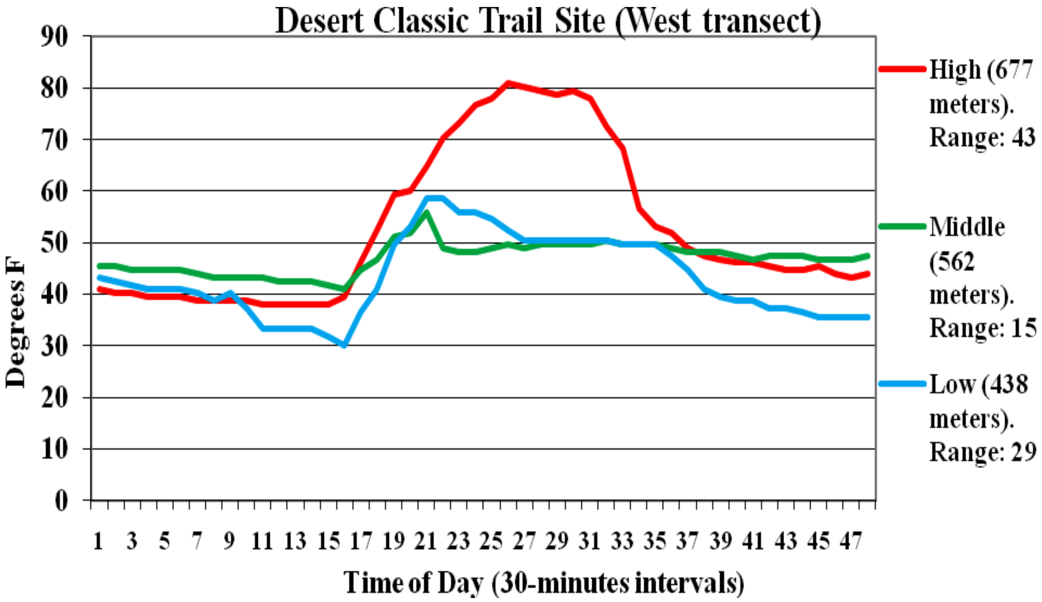

Figure 25. Hourly temperatures for January 24, 2010 on transect at Desert Classic Trail site, South Mountain Municipal Park.

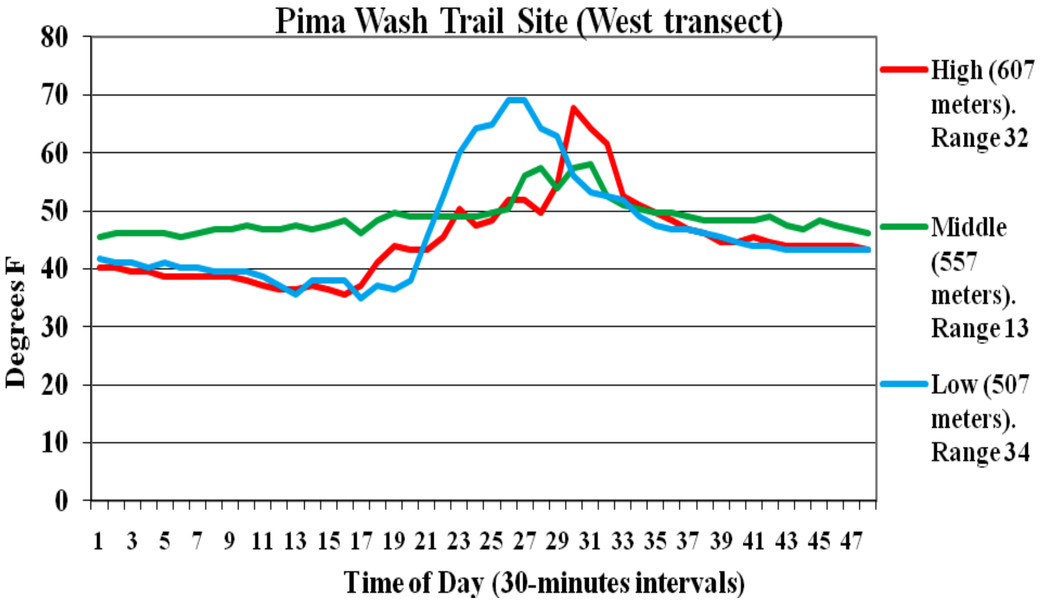

Figure 26. Hourly temperatures for January 24, 2010 on transect at Pima Wash Trail site, South Mountain Municipal Park.

Aspect was analyzed in two phases. In the first phase the variables of damage present on individual plants and overall distribution was analyzed by aspect (Table 8). All 100 individual plants for which data were recorded were found on southern slopes. Three aspect categories within that larger category were used. The plant data points were distributed into those three aspect categories. Evidence of damage was present in 52% of all plants, but it was not distributed evenly throughout the elevation classes. Habitat with southwest aspect, although it had a relatively smaller sample size, exhibited a slightly higher proportion of damaged plants (Figure 27).

Table 8. Distribution by aspect of existing damaged plants found in study transects at South Mountain Municipal Park, 2009 to 2010.

Aspect	Total number of plants	Number with damage	Percent Damaged
SE	32	16	50
S	52	25	48
SW	16	11	69

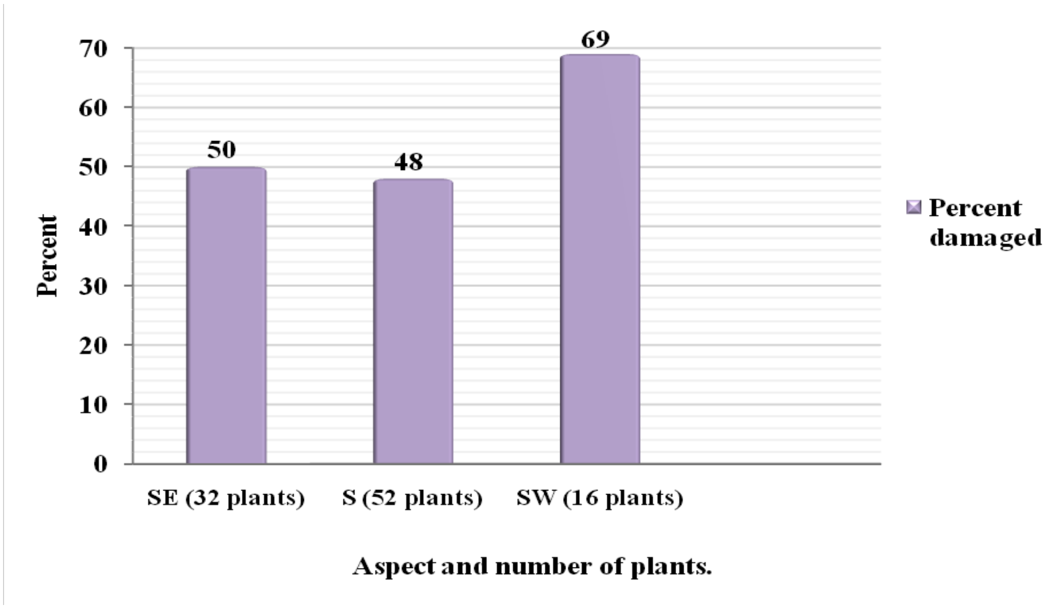

Figure 27. Distribution of plants by aspect and percent damage within each aspect at South Mountain Municipal Park, May 2010.

In the second phase, the variables of aspect and damage distribution were analyzed by elevation class (Table 9, Figure 28). The percentage of plants with damage in each elevation class varied, but it may not be significantly different due to the relatively few plants in the highest and lowest elevation classes. Damage is not confined to plants found at one aspect and in fact, for each elevation class the highest percentage of damaged plants is found at a different aspect. The distribution of damage by elevation layer in relation to aspect is as follows: at 400-449 m, 43% of the plants exhibited evidence of damage with 100% of the damage occurring in the S aspect, at 450-499 m, 50% were damaged with 18% of this damage occurring in the SE, 43% in the S and 39% in the SW aspects, at 500-549 m, 55% were damaged with 50% of this occurring in the SE aspect and 50% in the S aspects, and at 550-599 m, 75% had damage with 67% of this damage occurring in the SE and 33% in the S aspects.

Table 9. *Bursera microphylla* individual plant and damage distribution by aspect and elevation within South Mountain Municipal Park, Phoenix, Arizona, May 2010.

Class (elevation in meters)	Total number of plants	Percent plants with damage	Percent with damage by aspect		
			SE	S	SW
1 (400-449)	7	43	N/A	100	N/A
2 (450-499)	56	50	18	43	39
3 (500-549)	33	55	50	50	N/A
4 (550-599)	4	75	67	33	N/A

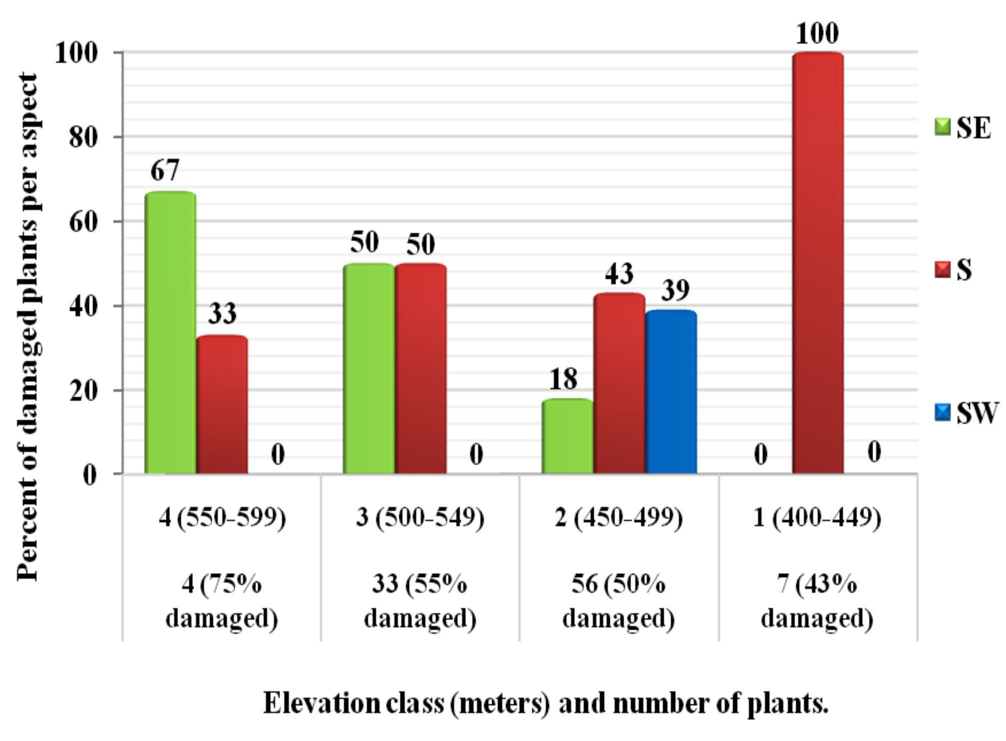

Figure 28. Aspect and damage distribution by elevation classes at South Mountain Municipal Park, May 2010.

The distribution of multiple-trunk *B. microphylla* plants by aspect and elevation are presented in Table 10, Figure 29. Thirty-nine percent of all individual *B. microphylla* plants had multiple-trunks. The distribution of multiple-trunk plants within these elevation classes is as follows: 29% at 400-449 m, 32% at 450-499 m, 48% at 500-549 m, and 75% at 550-599 m. There is an apparent trend for the increase number of multiple-trunk *B. microphylla* plants with increasing elevation (Table 10). The distribution of multiple-trunk *B. microphylla* plants by elevation class in relation to aspect was also determined. There was no clear pattern of multiple-trunk *B. microphylla* plants distribution by elevation and aspect. At the lowest elevation 400-449 m, multiple-trunk plants were only found on south facing aspects, while at the 450-499 m and 500-549 m elevation multiple-trunk individuals were found on all of the southern aspects, and at the 550-599 m elevation they were restricted to the southeast and south facing aspects (Table 10).

Table 10. Multiple trunks plants and aspect distribution by elevation at South Mountain Municipal Park, May 2010.

Class (elevation in meters)	Number of plants	Percent with multiple trunks	Percent with multiple trunk plants by aspect		
			SE	S	SW
1 (400-449)	7	29	N/A	100	N/A
2 (450-499)	56	32	22	39	39
3 (500-549)	33	48	44	56	N/A
4 (550-599)	4	75	67	33	N/A

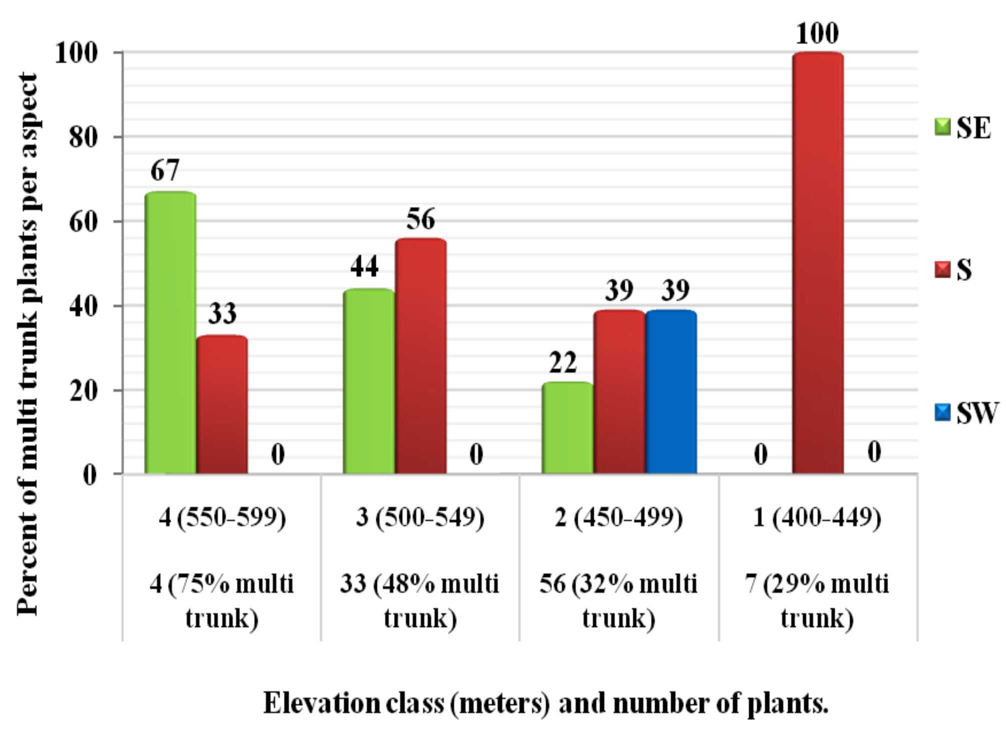

Figure 29. Multiple trunk plants and aspect distribution by elevation at South Mountain Municipal Park, May 2010.

The presence of boulders within two m of each individual plant was noted. Sixty-three percent of all individual *B. microphylla* plants recorded had boulders within the 2 m of the plant. The presence of boulders was compared to the presence of damage within the elevation classes (Table 11, Figure 30). The distribution of boulders and damage in respect to elevation is as follows: 400-449 m, 71% had boulders and 43% had evidence of damage; 450-499 m, 48% had boulders and 50% had evidence of damage; 500-549 m, 58% had boulders and 55% had evidence of damage; and at 550-599 m, 50% had boulders and 75% had evidence of damage.

Table 11. Presence of damage and boulders by elevation class at South Mountain Municipal Park, May 2010.

Class (elevation in meters)	Number of plants	Percent with boulders present	Percent plants with damage
1 (400-449)	7	71	43
2 (450-499)	56	48	50
3 (500-549)	33	58	55
4 (550-599)	4	50	75

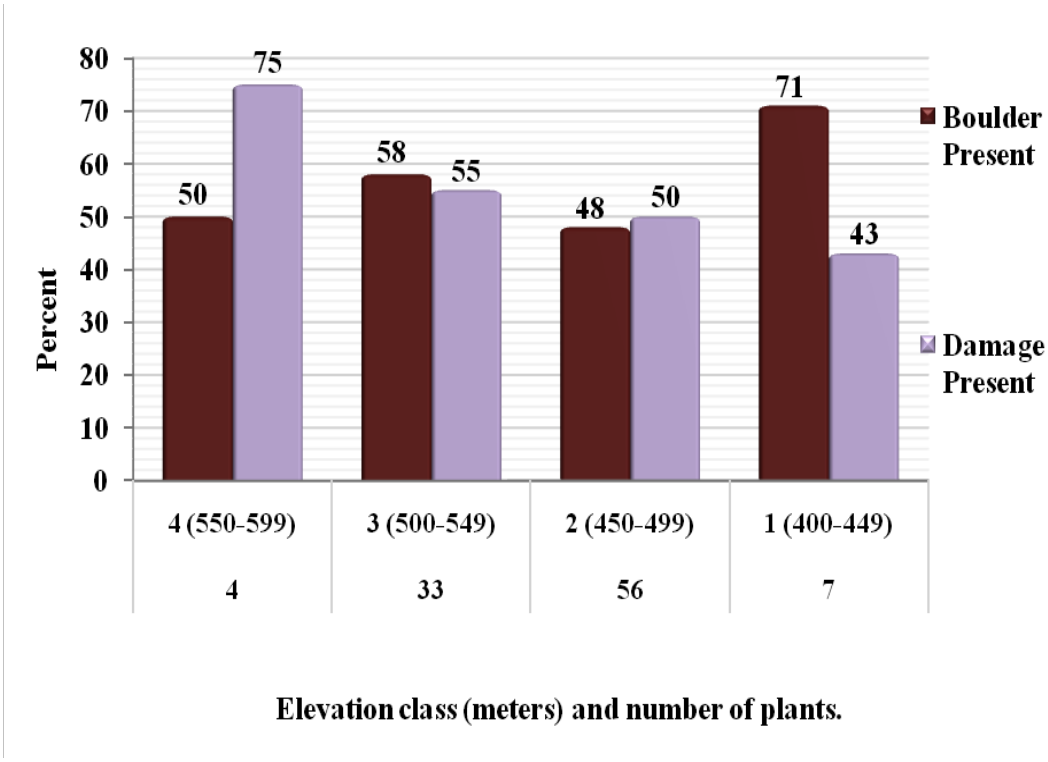

Figure 30. Presence of damage and boulders by elevation class at South Mountain Municipal Park, May 2010.

Trunk diameters were measured at 15 cm. from the ground for each of the 100 individual plants (Table 12, Figure 31). Trunk diameter data were averaged for each elevation class with *B. microphylla* plants at the 400-449 m and 450-499 m elevation having the smallest diameters (0.46m and 0.44 m, respectively), while the those plants from 500-599 m averaged 0.54 m in diameter (Table 12).

Overall, 95% of plants have a trunk diameter of 0.99 m or less and an average elevation distribution of 493 m, with *B. microphylla* plants at the 400-449 m and 450-499 m elevation having the smallest diameters (0.46m and 0.44 m, respectively), while the those plants from 500-599 m averaged 0.54 m in diameter (Table 12).

Table 12. Trunk diameter averages by elevation class at South Mountain Municipal Park, May 2010.

Class (elevation in meters)	Number of plants	Average Trunk Diameter
1 (400-449)	7	0.46
2 (450-499)	56	0.44
3 (500-549)	33	0.54
4 (550-599)	4	0.54

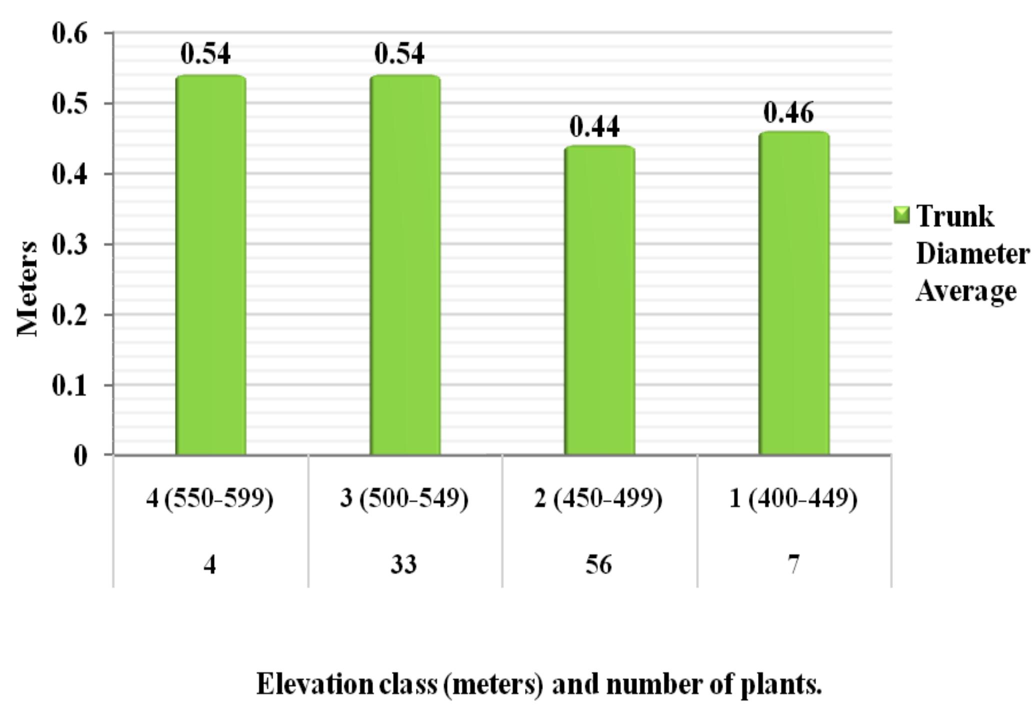

Figure 31. Distribution of trunk diameter averages by elevation class at South Mountain Municipal Park, May 2010.

Thirty percent of individual *B. microphylla* plants had a potential nurse plant associated with it. Potential nurse plants were *Parkinsonia microphylla* (67%) with smaller percentages of the following plants *Larrea tridentata* (16%), *Olneya tesota* and *Bursera microphylla* (seven percent each), and *Cylindropuntia* spp. (three percent).

Linear Regression Analyses

Three variables trunk type, trunk diameter, and canopy volume were further analyzed using elevation as the independent variable in Matlab2010b Statistical Toolbook© (The Mathworks Inc., 2003). Boxplots were selected for comparing the distribution between elevation data, single trunk plants data (61n), and multiple trunk plants data (39n) graphically. In Figure 32, the single trunk is skewed towards the lower elevation with long tail towards higher elevation. The lowest observation (sample minimum) is 440 m, the lower quartile (Q1) is 465 m, the median (Q2) is 478 m, upper quartile (Q3) is 505 m, and the highest observation (sample maximum) is 549 m. An outlier is observed at 570 m for the single trunk data. The multiple trunk plants had a more symmetrical distribution in comparison to the single trunk plants. The lowest observation (sample minimum) is 425 m, the lower quartile (Q1) is 470 m, the median (Q2) is 495 m, upper quartile (Q3) is 530 m, and the highest observation (sample maximum) is 570 m. Multiple trunk plants are more commonly found at higher elevations than single trunk plants.

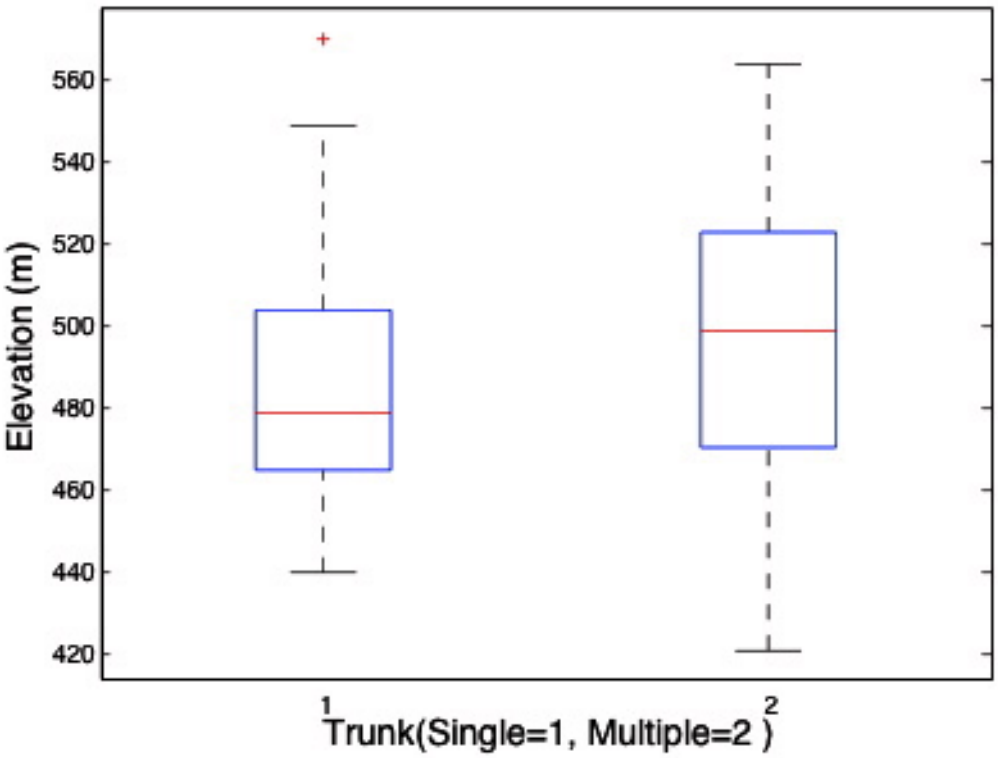

Figure 32. Boxplot for single trunk and multiple trunks plants based on elevation at South Mountain Municipal Park, May 2010.

Trunk diameter was measured at 15 cm from the ground. The relationship of the trunk diameter data to elevation is shown in a scatter plot and in results of a Linear Regression Analysis (p=0.028, trunk diameter=0.4816*elevation-0.3517) (Figure 33). There is a positive but weak correlation of trunk diameter with elevation. Our predictions bands are not the best estimation of the relationship of the diameter to elevation which is due to other lurking variables.

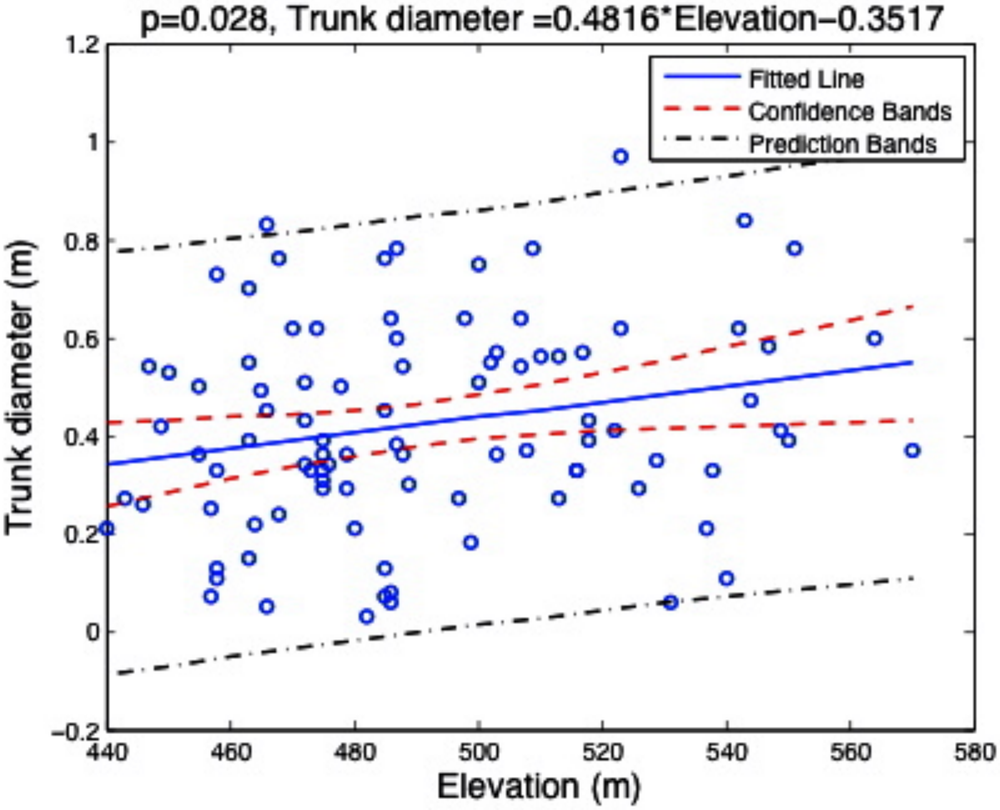

Figure 33. Trunk diameter distribution based on elevation range at South Mountain Municipal Park, May 2010.

Using Linear Regression (p=0.0033, canopy volume=0.4816*elevation+291.543), the relationship of canopy volume to elevation is shown in a scatter plot (Figure 34). The result is a negative correlation of the canopy volume with respect of the elevation with a high value of R, which is reflected by the range of the p-value between 0.0033 and 0.0158. Thirty percent of the data points are within the 90% confidence interval, and 97% are within the fitting band.

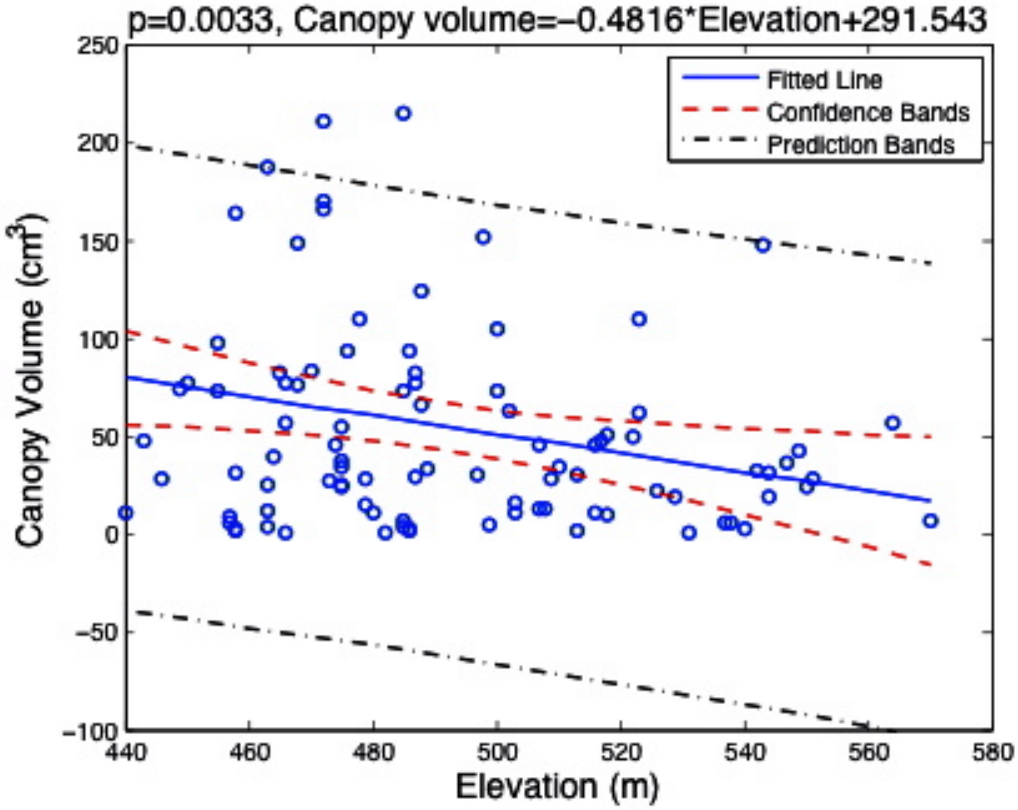

Figure 34. Canopy volume distribution based on elevation range at South Mountain Municipal Park, May 2010.

Spatial Analyses

The GIS application analyzed four key features used in predictive habitat-type models: aspect, elevation, slope, and relative solar radiance. In this case, a Weighted Overlay analysis was used. A Weighted Overlay is an analytical approach that applies a common measure scale of values to different and dissimilar inputs in order to create an integrated analysis. This type of modeling technique allows for different values to be given to the different input features and prioritizes the classes by allowing values to be assigned to each class (a scale of one to ten used). The continuous (floating point) raster files were converted as integer raster files in order to be used as inputs in the Weighted Overlay analysis. A Chi Square test was performed on each of the four features using the data derived from the reclassified layers as input values. In this GIS application, units refer to cells on a raster file. Each cell represents a 30 m by 30 m square on the ground. Chi Square analysis was used to determine if there was a significant impact of a specific habitat parameter on the presence of absence of *B. microphylla.* If the habitat parameter was significant, then the nature of that significance was further determined using a test of proportion. All analyses were performed at the $P \leq 0.1$ level. Analysis of the impact of aspect on the presence of *B. microphylla* indicated the two aspects had a positive impact (south and southeast), one aspect had a neutral impact (southwest) and the remaining five aspects had an negative impact on the presence of *B. microphylla* (west, northwest, north, northeast, and east) (Table 13). Slopes of 20 39% had a positive impact, while slopes <10% had a negative impact, and all other slopes had a neutral impact on *B. microphylla* presence (Table 13). The only relative solar load classification of 500 – 599 radians has a positive impact on *B. microphylla* presence, with the 0-99 and 600-699 classes being neutral, and all other class having a negative impact (Table 13). Of the five potential elevation classes, the highest elevations (>700 m) was neutral, with both the next highest and the lowest elevations classes (600-699 m and 300-399 m, respectively) having a negative impact, and the mid-elevations (400-599 m) having a positive impact on the presence of *B. microphylla* (Table 13).

The impact type for each individual class within each habitat component was then given a value from one to ten. Each of the four habitat components was assigned an input value of 25% for the Weighted Overlay analysis. These input values were the parameters for the model (Table 14). The weighted overlay output file (Figure 35) was reclassified into four classes with each class having a value representing the habitat potential type for *B. microphylla* within the area of interest file for SMMP. These potential types are described as, class one (unsuitable), class two (marginal), class three (suitable), and class four (highly suitable) (Table 15).

Table 13. Chi square tests of abiotic factors at South Mountain Municipal Park, May 2010.

	Trait	Observed %	Available %	Z	Preference
ASPECT	N (382.5–22.5)	0	14	3.9578	Negative
	NE (22.5–67.5)	0	8	2.7913	Negative
	E (67.5–112.5)	0	9	3.0506	Negative
	SE (112.5–157.5)	32	13	5.5084	Positive
	S (157.5–202.5)	52	15	10.1007	Positive
	SW (202.5–247.5)	16	12	0.9616	Neutral
	W (247.5–292.5)	0	11	3.4294	Negative
	NW 292.5–337.5)	0	16	4.2511	Negative
	n=100 136581	df=7	$\Sigma X^2=148.696$	P=1.64	
	Degrees	Observed %	Available %	Z	Preference
SLOPE	0-9	1	64	12.9889	Negative
	10–19	14	19	1.0552	Neutral
	20-29	42	11	9.7746	Positive
	30-39	43	6	15.2515	Positive
	40-49	0	0	-0.0433	Neutral
	n=100 136581	df=4	$\Sigma X^2=376.04168$	P=1.64	
	Radians	Observed %	Available %	Z	Preference
RELATIVE SOLAR LOAD	0-99	0.0	0.8	0.3149	Neutral
	100-199	0.0	3.6	1.6693	Negative
	200-299	0.0	8.7	2.9066	Negative
	300-399	1.0	29.9	6.2083	Negative
	400-499	10.0	47.9	7.4934	Negative
	500-599	87.0	8.1	28.7482	Positive
	600-699	2.0	1.0	0.5488	Neutral
	n=100 136581	df=6	$\Sigma X^2=842.014314$	P=1.64	
	Meters	Observed %	Available %	Z	Preference
ELEVATION	300-399	0.0	49.7	9.8369	Negative
	400-499	63.0	29.0	6.2731	Positive
	500-599	37.0	10.8	16.6626	Positive
	600-699	0.0	7.9	10.5840	Negative
	700-799	0.0	2.7	1.3401	Neutral
	n=100 136581	df=4	$\Sigma X^2=163.9512$	P=1.64	

Table 14. Input values of abiotic factors for Weighted Overlay analysis at South Mountain Municipal Park, May 2010.

WEIGHTED OVERLAY MODEL ANALYSIS INPUT VALUES							
Aspect		Slope		Relative Solar Load		Elevation	
Degrees	V	Degrees	V	Radians	V	Meters	V
N (382.5–22.5)	2	0-9	1	0-99	5	300-399	2
NE (22.5–67.5)	2	10-19	5	100-199	3	400-499	8
E (67.5–112.5)	2	20-29	8	200-299	2	500-599	9
SE (112.5–157.5)	8	30-39	9	300-399	1	600-699	2
S (157.5–202.5)	10	40-49	5	400-499	1	700-799	4
SW (202.5–247.5)	5			500-599	10		
W (247.5–292.5)	2			600-699	5		

Value scale: 1 to 10 25% input value assigned to each abiotic factor (aspect, slope, relative solar load, and elevation). V = Input Value

Table 15. Results of Weighted Overlay analysis at South Mountain Municipal Park, May 2010.

WEIGHTED OVERLAY MODEL ANALYSIS		
Class	Available %	Preference
1	54	Unsuitable
2	37	Marginal
3	6	Suitable
4	3	Highly Suitable

The 100 randomly generated points were in addition to the 100 points where field data were collected from actual *B. microphylla* plants. Each of these randomly generated 100 points was visited in the field to look for the presence of *B. microphylla*. These data were used to check the accuracy of the Weighted Overlay model and to furthermore, test the hypotheses of this research on the ground. Out of the 100 randomly generated points, five percent were within 20 to 50 m of individuals of *B. microphylla* plants in the field (table 16). When these 100 randomly generated points were plotted over the Weighted Overlay output map file, the same five percent were within class three (suitable) and class four (highly suitable) (Figure 36). Furthermore, in assessing the accuracy of the Weighted Overlay model, plotting the 100 points of actual recorded *B. microphylla* plant locations indicated a 95% accuracy for class three (suitable) and class four (highly suitable) combined. Only one location at Pima Wash Trail site was found in class two (marginal) but within 20 m of class three (suitable), while the remaining four locations were found at the Desert Classic Trail site in class two (marginal) and within 10 m of class three (suitable) (Figure 37).

Table 16. Accuracy assessment of Weighted Overlay Model using randomly generated points at South Mountain Municipal Park, May 2010.

		Randomly generated point data			
		Suitable	Marginal	Unsuitable	
Weighted Overlay Model	Suitable	0	5	0	
	Marginal	5	0	0	
	Unsuitable	0	0	95	
				Totals 95/100	Accuracy: 95%

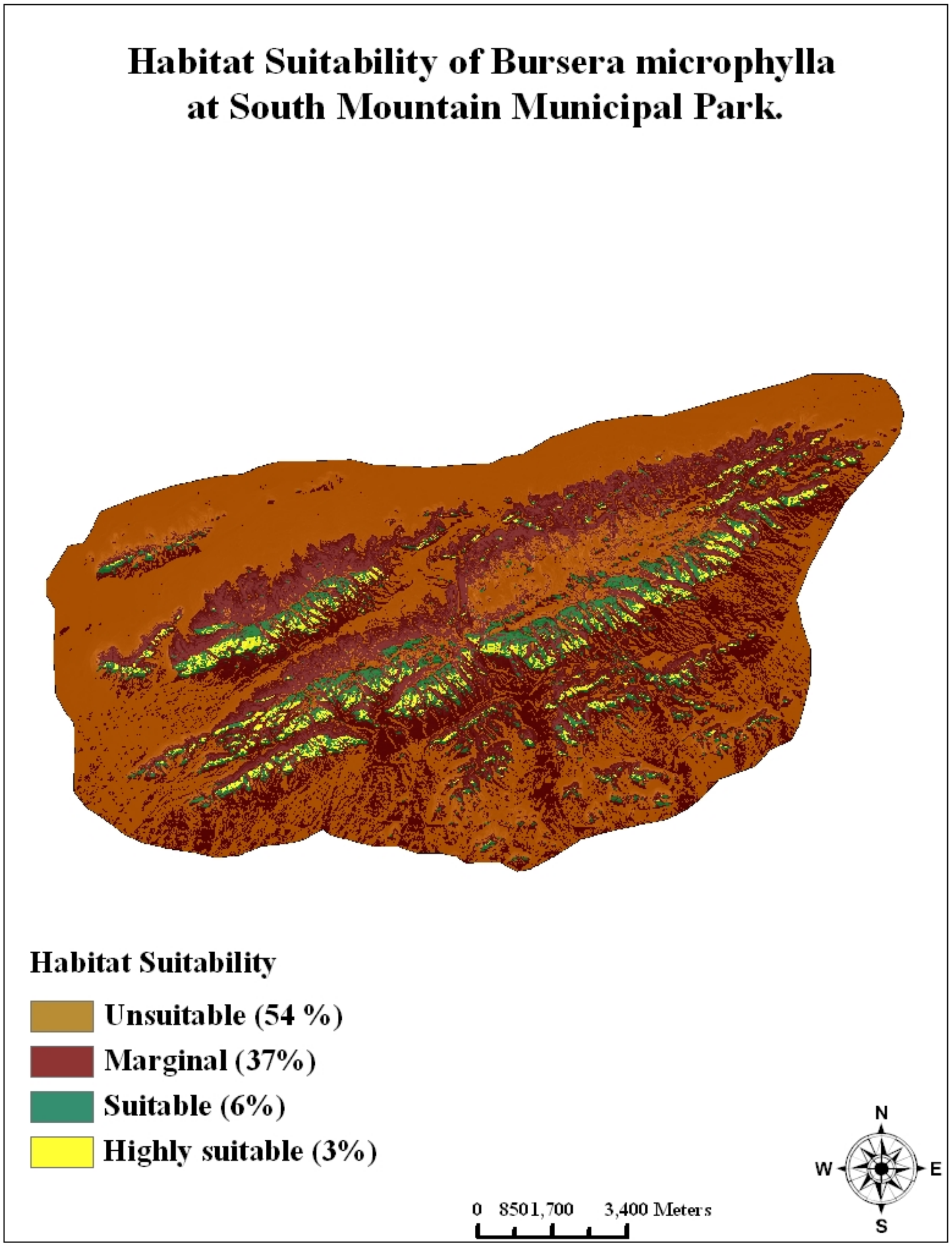

Figure 35. Habitat suitability map for *B. microphylla* at South Mountain Municipal Park, May 2010.

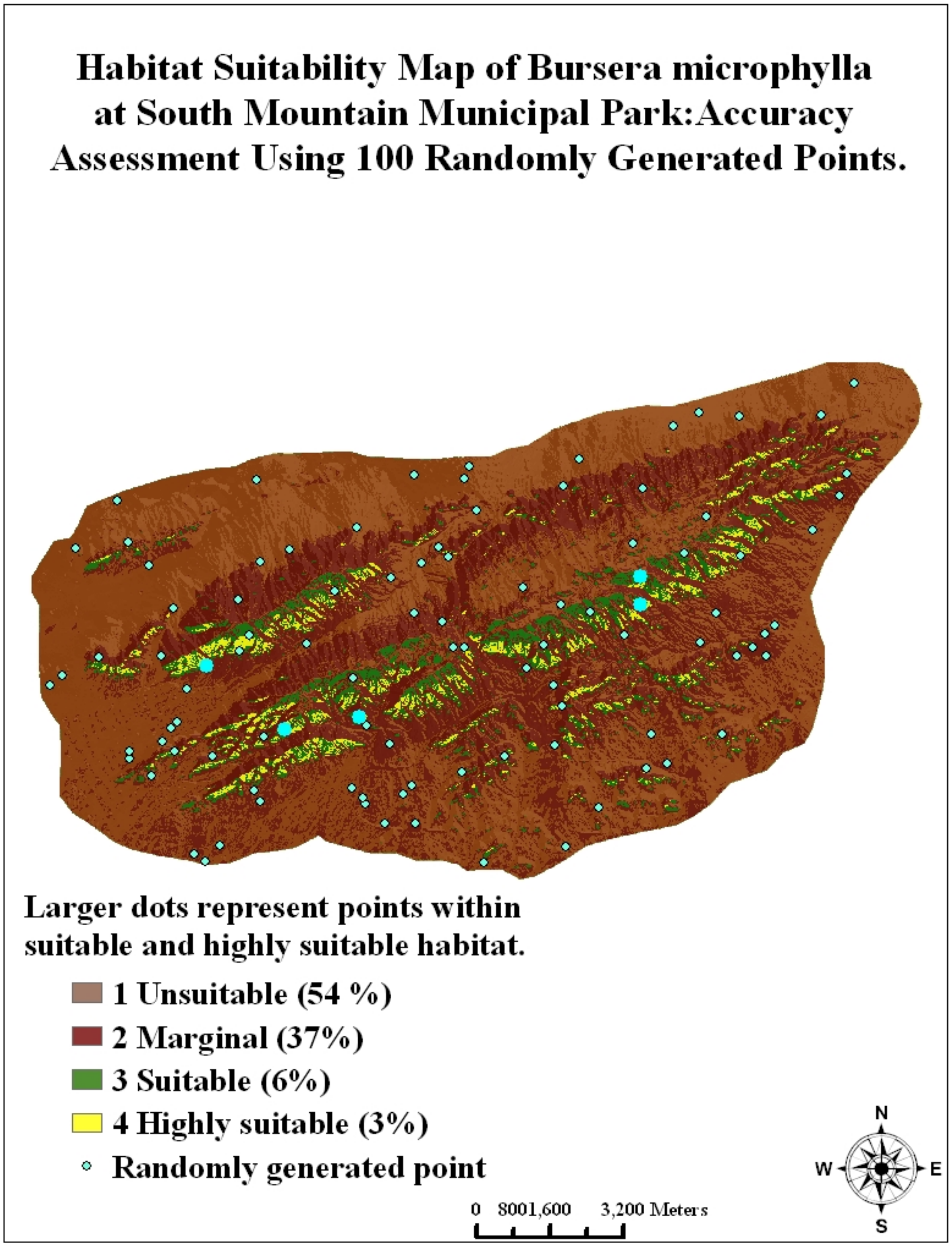

Figure 36. Accuracy assessment of weighted overlay map using the randomly generated points at South Mountain Municipal Park, May 2010.

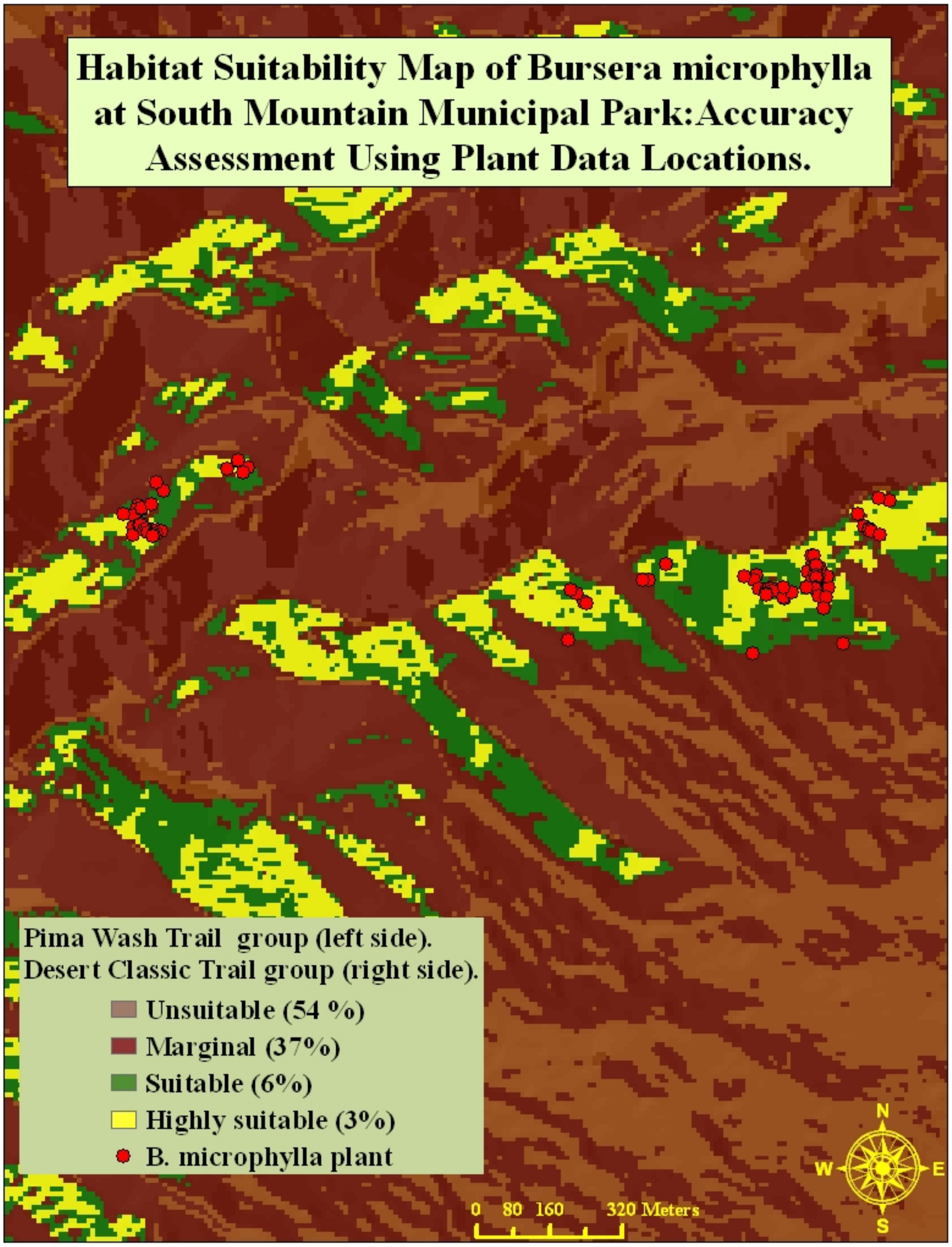

Figure 37. Accuracy assessment of weighted overlay map using point data for *B. microphylla* at South Mountain Municipal Park, May 2010.

Chapter IV: Discussion and conclusions

The initial hypothesis for this study, predicted that within SMMP existing landscape features including aspect, slope, elevation, and a proximity to naturally occurring granite boulders, as well as associated vegetation, and potential nurse plants will interact to create a unique microhabitat for *B. microphylla* to exist (Figure 4). The results from the analyses in the GIS application support that hypothesis and indicate that aspect, slope, and elevation are strongly associated as major climatic components of this microhabitat as seen in the habitat suitability map generated for the Weighted Overlay model (Figure 35) which supports the findings from the data in the field, randomly generated points, and actual point (plant) data (Table 16). Furthermore, the habitat suitability map is positively correlated with the aspect, elevation, slope, and temperature predictions mentioned in the hypothesis. While the GIS application identified the habitat characteristics by defining spatially the parameters of these microclimates, the Matlab© linear regression analyses of recorded plant data explored trends of morphological traits as a result of abiotic factors within these parameters.

In discussing each of the spatial parameters, both the observations of individual plant distributions and GIS analyses demonstrate the importance of aspect for the distribution of *B. microphylla* at SMMP. Specifically, the plant data recorded showed that *B. microphylla* was only found on the south facing aspect (Table 15). Eighty-four percent were found on the south and south-east aspects combined, while the remaining 16% were found on the south-west aspect.

Furthermore, results of the randomly generated points analysis over the weighted overlay habitat suitability model also demonstrate the importance of aspect. Five percent of the random points, when plotted over the habitat suitability map, were within class three (suitable) and class four (highly suitable) habitat; both classes have a southern aspect (Figure 36). The five percent of the points located in suitable or highly suitable habitat did have individual plants of *B. microphylla* within 10 to 20 m, although none of the randomly sampled points observed in the field had individual plants of *B. microphylla* at those locations.

All data and analyses also support the importance of slope as part of a suitable microhabitat for *B. microphylla*. The GIS application analyses indicated that *B. microphylla* prefers the steeper terrain within SMMP and the vast majority (85%) of all *B. microphylla* plants recorded occurred on slopes ranging from 20 to 39 degrees (Table 13). Drainage patterns for both cold air and rainfall as well as heat radiance might be partially responsible for this terrain preference.

Elevation is also an important component of the microhabitat of *B. microphylla*; the GIS analyses indicated the effect of elevational differences at SMMP on temperature gradients as elevation affects relative solar radiance (Table 13). Note that 100% of recorded plant data occurred within a specific altitudinal range (400-600 m) (Table 13). As will be discussed below it is likely that the specific elevation is less important than position on the slope.

Furthermore, the analyses from the temperature data collected from the Hobo sensors complement the results of the GIS application analyses and the interactions in the creation of suitable microhabitat described in the hypothesis.

These sensors were placed in seven different vertical transects to measure temperature fluctuations every 30 minutes at three elevations on the southern slopes of SMMP (Figure 9). Substantial differences in temperature fluctuations based on elevation were recorded (Table 7, Figure 23). These data demonstrated that existing temperature differences between the different positions on the slope based on elevation (high, middle and valley floor) vary by as much as 11° F (Figures 25 and 26).

Solar radiance had a greater effect on temperatures at higher elevations; those elevations received the highest amount of relative solar radiance (Table 7, Figure 24). The greater angle of solar altitude at or near the ridge of the mountains exposed the higher terrain to solar radiance earlier in the day than the terrain in the middle and lower elevations. Although this higher terrain recorded the fastest rates of heat gain, it also recorded the fastest rates of heat loss and was therefore the least stable of all three elevations in terms of temperature fluctuations (Figures 25 and 26).

On the other hand, locations at the lowest elevations, at or near the valley floor receive the lowest solar radiance (Table 7), were the coldest and were the only locations where below freezing temperatures (30° F) were recorded (Figure 24). These colder temperatures were likely due to existing cold air drainage flows; at night, the surface of the valley floor cools radiatively as long wave radiation is lost to the night sky. Because air becomes denser as it cools, the cooler air “slides” (advects) downhill along gravity-driven pathways, often mimicking the pathways of stream systems (Pypker et al., 2007). Temperature fluctuations in locations at the lower elevations were relatively smaller in magnitude than those at higher elevations. On average, locations at lower elevations reached their maximum relative heat gain at 62° F by noon and remained relatively static for the next four hours before drastically collapsing again for the evening and continuing to fall into the early morning hours. By comparison, the middle and higher elevations continued to gain more relative heat and reached their maximum gain much later in the afternoon (Figure 24).

The most remarkable temperature fluctuations (Figures 25 and 26) were recorded on the coldest day, January 24 during the period temperatures were recorded (January 18, through March 16, 2010). The official minimum temperature reading on that day was 41° F according to Sky Harbor International Airport in Phoenix about 8 kilometers from the transects at SMMP. Analyses of the temperature data for hourly readings showed that locations at the middle elevations retained their relative heat gain far better than locations at the highest and lowest elevations. Graphing the temperature data analyses showed the trend in relative heat gain and loss for locations at all three elevations in which there were more abrupt spikes for the higher and lower elevations while the middle elevation had a gradual curve (Figures 25 and 26). Locations at the middle elevations retained most of their relative heat gain throughout the colder hours after sunset and in particular retained heat well into the coldest hours around 7:00 a.m. and 8:00 a.m. Therefore, the middle elevations were the most stable in terms of temperature fluctuations. Note that it is the position on the middle of the slope that is the important factor rather than a specific elevation as position on the slope directly influences temperature gain and loss as described above.

Furthermore, the presence of boulders in the landscape of SMMP is also hypothesized to be an important factor in creating a suitable microclimate for *B. microphylla*. Specifically, granite boulders are thought to act as radiators of heat for *B. microphylla* allowing radiant heat collected from the sun during the day to be slowly released after sunset creating a favorable microclimate for *B. microphylla* during the winter. The elevation and slope where major concentrations of granite boulders are found might also provide drainage that is favorable to the establishment of *B. microphylla* roots. It was predicted that *B. microphylla* will be found more often near boulders than expected by chance and in fact, 63% of all recorded plants were found within a 2 m radius of boulders. Originally, this 2 m radius was selected to record vegetation associated with each *B. microphylla* plant in each of the four cardinal directions. When no vegetation was present in one of these cardinal directions, the presence of boulders was recorded within the 2 m radius. Boulders were recorded in 63% of locations, but the percentage would be much higher if the radius were to be increased by just a few meters. This is implied in the GIS application analyses for accumulative relative solar radiance (Figure 19) and can also be verified using high-resolution satellite imagery such as Google Earth. Recall that all 100 of the plants recorded were found within a single altitudinal range, between 400 m and 600 m in elevation (Table 6). This is also the same altitudinal range, based on observations while conducting the fieldwork, that the greatest concentrations of granite boulders were found. As discussed above, this middle altitudinal range was the most stable in terms of temperature fluctuations and it may be that the granite boulders are at least partially responsible for modifying the ambient temperature.

Another prominent hypothesized variable in evaluating the microhabitat characteristics of *B. microphylla* was the presence of potential nurse plants; however, only thirty percent of individual *B. microphylla* plants had a potential nurse plant associated with it. But, it is possible that a higher percentage of *B. microphylla* plants at SMMP might have relied on annual or perennial nurse plants (e.g., *Encelia farinosa* occurred 101 times in associated vegetation within the 2 m radius) in their lifetime especially during and immediately after their germination. Nevertheless, the associated plants that were found may be in part responsible for making shade, soil moisture, and nutrients available for seedlings and younger *B. microphylla* plants thus enhancing their survival by ameliorating the extreme environmental conditions common at SMMP. *Parkinsonia microphylla,* (67%), was the most common of these associated plants, while *Larrea tridentata*, *Olneya tesota*, and *Cylindropuntia spp.* were present as associated plants in smaller proportions, although it is unlikely that *Cylindropuntia* spp. would function as nurse plants. The nurse plant trend at SMMP, as a biotic component of *B. microphylla* microhabitat in this case, seems consistent with the findings by a Gómez-Aparicio *et al.* (2004) study where the effects of nurse plants were stronger in dry locations and on the south-facing slopes of a Mediterranean mountain.

The discussion above, as indicated in the first paragraph of this chapter, describes the spatial parameters of abiotic factors within these microclimates. This is followed by a discussion of how analyses of actual temperature data collected support the hypotheses. And lastly, the interaction of boulders with these microclimates, and the potential effects of nurse plants are discussed.

In the following discussion of the linear regression analyses from Matlab© of recorded plant data, the principal goal is to explore potential trends in variation of morphological traits within the microclimate parameters discussed above. For instance, consideration of elevation as a factor in canopy volume, trunk diameter, and single trunk versus multiple trunk plants variations revealed some interesting trends. Multiple trunk plants are more commonly found at higher elevations within these elevation parameters (400 to 600 m) than single trunk plants. It may be possible that multiple trunk plants are the result of damage to young plants that initially had a single trunk and then sustained significant damage. For example, a severe frost might damage the apical meristem of a single shoot, and new multiple trunks could grow from the base as a survival mechanism. Another interesting trend is that there is a positive correlation of trunk diameter with elevation, in other words plants with multiple trunks had a larger total trunk diameter than those with single trunks. Lastly, another interesting trend is that canopy volume has a negative correlation with respect to elevation. This may be related to trunk diameter, which shows a positive correlation with elevation where the greater biomass in the trunk may preclude a larger canopy volume.

Limitations of current study and directions for future research.

The study was carried out in multiple stages. In the initial stage, the actual numerical and categorical plant data on each of the 100 plants' location in the field were recorded. In later stages of the study, weather data was collected to explore temperature fluctuations between the different elevations as a factor in determining their distribution at SMMP. As described earlier, this was done using vertical transects in seven different areas of SMMP including the areas where the plant data was recorded. The weather data focused on winter temperatures (January through March 2010) given the sensitivity of *B. microphylla* to frost. But due to time constraints, only one year's winter temperatures were obtained. Having multiple data sets of multi-year temperatures would be beneficial in further documenting differences among temperatures at different elevations to help explore how *B. microphylla* copes with harsh winters in the Sonoran Desert and in particular winters at SMMP. Gutschick and BassiriRad propose that these extreme events play a disproportionate role in shaping the physiology, ecology, and evolution of many organisms including terrestrial plants (2003). It is likely that occasional extreme temperature events such as those that occurred January 1, 2011 where temperatures of 30º Fahrenheit were recorded at Phoenix Sky Harbor Airport have an important effect on the northern distribution of *B. microphylla*.

Conducting this study for multiple years would allow for a closer look at *B. microphylla* and its relationship with potential nurse plants. Documenting new seedlings and their proximity to potential nurse plants could reveal a strong association between *B. microphylla* and their nurse plants that would not be possible without examining seedlings given that a successful *B. microphylla* shrub could have outlived a shorter lived nurse plant. It may also be that *B. microphylla* acts as a nurse plant for various species of cacti. Individuals in the population in the White Tank Mountains were often very closely associated with saguaros (J. Sturla pers. comm.). Studies could be designed to test both of these hypotheses.

It would be of interest to test the habitat predictive model presented here (Figure 35) to identify and map potential *B. microphylla* habitat in the other two northernmost populations in the White Tank Regional Mountain Park and the Harquahala Mountains and then to ground truth the highly suitable habitat in those two mountain ranges to check for the presence of *B. microphylla*. Those two locations are ideally suited for testing this habitat predictive model because given the close proximity to SMMP at both locations the aspect, elevation, slope, and temperature requirements are similar to those of SMMP.

In climate change studies such as those that are part of the CAP-LTER project (http://caplter.asu.edu/research/long-term-monitoring/), *B. microphylla* at SMMP might be considered a biological sensor *in situ* given their sensitive nature to cold temperature and their existence as indicator species. Further comparative studies among marginal populations of *B. microphylla* at its northern limits and also at the southern part of its distribution combined with comparisons to core populations in northern Mexico (the middle of its range) would be a good long-term study. *Bursera microphylla*'s adaptation to its marginal limits implies that it is very likely that their morphological and geographical characteristics might be quite different than those of core populations.

At the northern limit of its range further studies of the association of *B. microphylla* with the presence of boulders within its microhabitat could perhaps reveal interesting findings in whether the specific habitat of individual groupings of plants is contracting or expanding away from their boulder sites. This would most likely require multiple years of data but might further explore their level of reliance on boulders for required heat in the winter time.

Implications for management.

Results of the GIS habitat predictive model may have implications for management of the populations of *B. microphylla* at SMMP. The City of Phoenix recently (April 2, 2009) purchased 247 acres of the block of State Trust Land commonly referred to as the South Mountain 620 (Figure 38) (http://phoenix.gov/recreation/rec/parks/preserves/locations/south/index.html). The City of Phoenix plans to allocate 165 of the 247 acres to be added to SMMP and an additional five acres to be used for a trail access point. In this particular case, the predictive habitat model produced in this study can be a useful research, mapping, and planning tool as trail development gets underway in this newly acquired land by the City of Phoenix.

The numbers of individual plants existing at each of the two study sites (Pima Wash Trail and Desert Classic Trail) is in the hundreds, although before the study the number of individual plants of *B. microphylla* was thought to be low, because many of the individual plants are not visible from the trails. The predictive habitat model finds similar microclimatic conditions as at those two sites scattered throughout SMMP (Figure 35). Based on the size of both study sites combined and using the 95 % accuracy of actual plant locations collected that are within the suitable and highly suitable terrain, it is estimated that there could be approximately 6700 *B. microphylla* plants within the suitable and highly suitable areas combined (9% of the total terrain sampled), plus an additional approximately 1,500 plants within the marginal area (37% of total terrain sampled). Knowing the locations within SMMP of these sensitive microhabitats and determining the conservation value of *B. microphylla* at SMMP can better indicate where new trails are to be created.

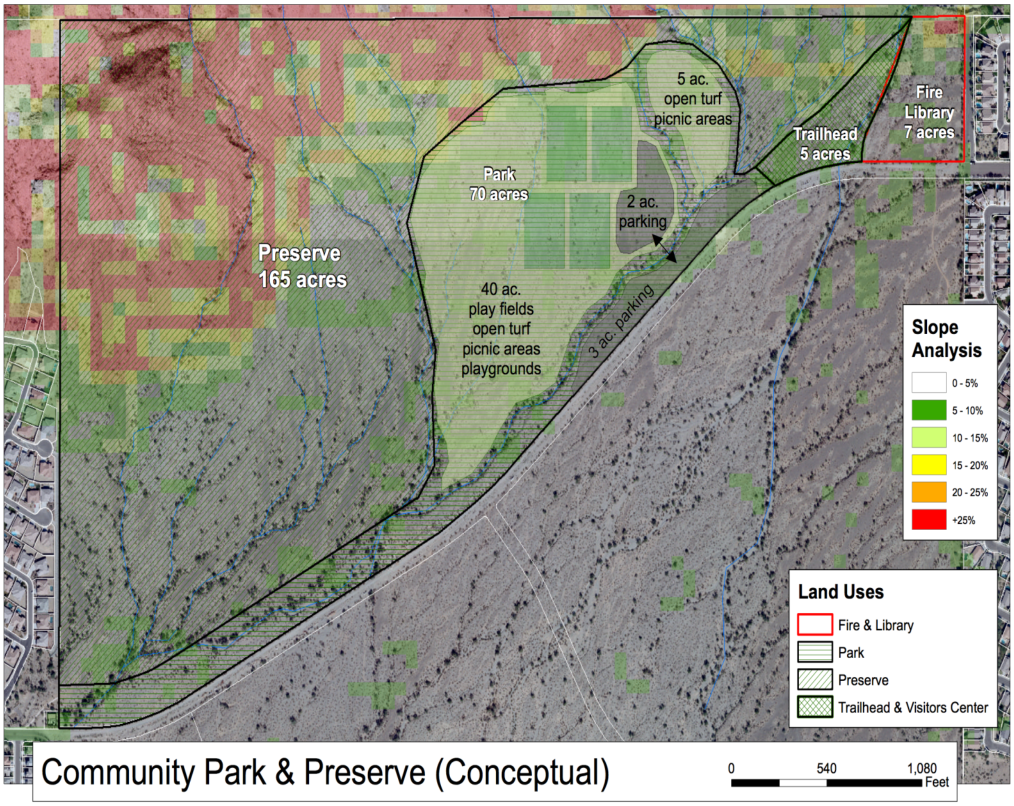

Figure 38. South Mountain 620, a 247-acre block of State Trust Land adjacent to SMMP purchased by the City of Phoenix, April 2009.

Furthermore, this habitat predictive model can also be useful to other management agencies, i.e., Maricopa County Parks and Recreation Department, and the Bureau of Land Management, that manage locations where *B. microphylla* is found such as the White Tank Regional Mountain Park and Harquahala Mountain respectively. Conservation of *B. microphylla* populations in these mountain ranges would be aided by more detailed knowledge of the location and number of *B. microphylla* plants.

APPENDIX A

COORDINATES AND ELEVATION INFORMATION OF HOBO DATA LOGGERS PLACED AT SOUTH MOUNTAIN MUNICIPAL PARK FROM JANUARY 18, 2010 THROUGH MARCH 16, 2010.

APPENDIX A

Hobo	Coordinates		Elevation in meters
1	-112º00.566	33º21.466	507
2	-112º00.713	33º21.384	540
3	-112º00.411	33º21.574	491
4	-112º03.632	33º19.834	773
5	-112º03.614	33º19.753	682
6	-112º04.028	33º19.474	455
7	-112º00.480	33º21.586	508
8	-112º00.508	33º21.600	532
9	-112º00.657	33º21.496	566
10	-112º00.650	33º21.472	546
11	-112º00.695	33º21.445	557
12	-112º00.837	33º21.395	607
13	-112º01.087	33º20.780	677
14	-112º00.921	33º20.659	562
15	-112º00.770	33º20.515	438
16	-112º00.334	33º20.839	438
17	-111º59.952	33º21.108	428
18	-112º00.184	33º21.178	500
19	-112º00.247	33º21.237	547
20	-112º00.553	33º21.194	549
21	-112º00.677	33º21.233	584

APPENDIX B

HOURLY TEMPERATURE AVERAGES BY ELEVATION AT SOUTH MOUNTAIN MUNICIPAL PARK, FROM JANUARY 18, 2010 THROUGH MARCH 16, 2010.

APPENDIX B

	Elevation (meters)						
Time of Day	400-449	450-499	500-549	550-599	600-649	650-699	750-799
1:00	49	50	52	53	48	52	49
2:00	49	50	51	52	48	51	49
3:00	47	49	51	52	47	51	48
4:00	47	48	50	51	47	50	47
5:00	46	47	49	51	46	49	47
6:00	45	47	49	50	45	49	46
7:00	45	46	48	50	45	48	46
8:00	45	46	49	50	45	49	46
9:00	49	49	53	53	48	54	52
10:00	55	55	58	57	51	61	59
11:00	59	58	62	60	52	69	62
12:00	62	61	65	62	55	74	66
13:00	62	63	67	64	56	78	71
14:00	62	64	68	65	58	80	72
15:00	62	65	67	65	63	79	69
16:00	62	64	65	63	65	77	68
17:00	61	63	62	61	60	71	67
18:00	60	61	60	59	56	64	62
19:00	55	56	57	57	53	59	55
20:00	53	54	56	56	52	56	53
21:00	53	54	55	55	51	55	52
22:00	52	53	54	55	50	54	51
23:00	51	52	54	54	50	53	51
24.00	51	51	53	53	49	53	50

BIBLIOGRAPHY

Ahwatukee Board of Management. "Origin of Ahwatukee." Accessed September 30, 2010. http://www.ahwatukeehoa.com/sub_category_list.asp?category=4&title=Origin+of+Ahwatukee

Arizona Department of Agriculture. "B. Salvage Restricted Protected Native Plants." Accessed September 30, 2010. http://www.azda.gov/ESD/protplantlst3.htm

Bates, John M. 1992. Frugivory on *Bursera microphylla* (Burseraceae) by Wintering Gray Vireos (Vireo vicinior, Vireonidae) in the Coastal Deserts of Sonora, Mexico. *The Southwestern Naturalist* 37 (No. 3): 252-258.

Becerra, Judith X., D.L. Venable, P.H. Evans, and W.S. Bowers. 2001. Interactions Between Chemical and Mechanical Defenses in the Plant Genus *Bursera* and Their Implications for Herbivores. *American Zoologist* 41: 865-876.

Becerra, Judith X. 2005. Timing the origin and expansion of the Mexican dry forest. *Proceedings of the National Academy of Sciences* 102 (31): 10919-10923.

Bevill, R.L. and S.M. Louda. 1999. Comparisons of Related Rare and Common Species in the Study of Plant Rarity. *Conservation Biology* 13 (No. 3): 493-498.

California Department of Fish and Game. "Biogeographic Data Branch Vegetation Classification and Mapping Program. List of California Vegetation Alliances." Accessed September 30, 2010. http://165.235.95.70/search?q=bursera+microphylla&output=xml_no_dtd&site=ca_dfg&client=ca_dfg&proxystylesheet=ca_dfg

City of Phoenix. "South Mountain Park/Preserve." Accessed September 30, 2010. http://phoenix.gov/PARKS/hikesoth.html

City of Phoenix. "South Mountain Educational and Environmental Center-The http://phoenix.gov/PARKS/hohokam.html

Crawford, R. M. M., 2008. *Plants at the Margin: Ecological Limits and Climate Change*. Cambridge: Cambridge University Press.

Daniel, Thomas F., and Mary L. Butterwick. 1992. Flora of the South Mountains of South-Central Arizona. *Desert Plants* 10 (No. 3): 99-119.

Espinosa, David, Jorge Llorente and Juan J. Morrone. 2006. Historical biogeographical patterns of the species of *Bursera* (Burseraceae) and their taxonomic implications. *Journal of Biogeography* 33:1945-1958.

Ewan, Joseph, Rebecca Fish Ewan, and James Burke. 2004. Building ecology into the planning continuum: case study of desert land preservation in Phoenix, Arizona (USA). *Landscape and Urban Planning* 68: 53-75.

Felger, Richard S., Matthew B. Johnson, and Michael F. Wilson. 2001. *The Trees of Sonora, Mexico*. Oxford: Oxford University Press.

Gorelick, Root. 2007. Northernmost sightings of Bursera microphylla. *Cactus and Succulent Journal* 79 (No. 3): 108.

Gutschick, Vincent P., and Hormoz BassiriRad. 2003. Extreme Events as Shaping Physiology, Ecology, and Evolution of Plants: Toward a Unified Definition and Evaluation of their Consequences. *New Phytologist* 160 (No. 1): 21-42.

Johnson, Matthew. 1992. The Genus *Bursera* (Burseraceae) in Sonora, Mexico and Arizona, U.S.A. *Desert Plants* 10 (No. 3): 126-144.

Leppig, Gordon and Jeffrey W. White. 2006. Conservation of peripheral plant populations in California. *Madroño* 53: 264-274.

MATLAB Version 6.5.1. Natick, Massachusetts: The Mathworks Inc. ©, 2003.

Mooney, H.A., and W.A. Emboden, Jr. 1968. The Relationship of Terpene Composition, Morphology, and Distribution of Populations of *Bursera Microphylla* (Burseraceae). *Brittonia* 20 (No. 1): 44-51.

Padilla, Francisco M., and Francisco I. Pugnaire. 2006. The role of nurse plants in the restoration of degraded environments. *Frontiers in Ecology and the Environment.* 4 (4): 196-202.

Pypker, Thomas G., Michael H, Unsworth, Alan C. Mix, William Rugh, Troy Ocheltree, Karrin Alstad, and Barbara J. Bond. 2007. Using Nocturnal Cold air Drainage Flow to Monitor Ecosystem Processes in Complex Terrain. *Ecological Society of America* 17 (No. 3): 702-714.

Rzedowski, J., and H. Kruse. 1979. Algunas tendencias evolutivas en *Bursera* (Burseraceae). *Taxon* 28 (No. 1/3): 103-116.

Southwest Environmental Information Network. "SEINet Collections Search Results. Specimen List. University of Arizona Herbarium." Accessed February 12, 2011.
http://swbiodiversity.org/seinet/index.php

Turner, Raymond M., Stanley M. Alcorn, George Olin, and John A, Booth. 1966. The Influence of Shade, Soil, and Water on Saguaro Seedling Establishment. *Botanical Gazette* 127 (No. 2/3): 95-102.

Turner, Raymond M., Janice E. Bowers, and Tony L. Burgess. 1995. *Sonoran Desert Plants: An Ecological Atlas*. Tucson: The University of Arizona Press.

Zuñiga, Beatriz, Patricia Guevara-Fefer, Josefina Herrera, Jose Luis Contreras, Luis Velasco, Francisco Javier Perez, Baldomero Esquivel. 2005. Chemical Composition and Anti-Inflammatory Activity of the Volatile Fractions from the Bark of Eight Mexican *Bursera* Species. *Planta Med* 71: 825-828.