HYDROLOGY AND SOLAR RADIATION AS FACTORS FOR DESERT VEGETATION PATTERNS

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DEDICATION

To my grandparents, mother, father, sister and brother-in-law

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by

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ABSTRACT

There is a growing need to predict vegetation spatial patterns for assessing land cover change and to understand how micro-climate influences the growth of plants. The purpose of the present study was to evaluate the relative influence of potential evapotranspiration to solar radiation on vegetation patterns in the West Potrillo Mountains, New Mexico. To accomplish this, vegetation was sampled and environmental parameters were measured over two cindercones in the West Potrillo Mountains. The frequently occurring vegetation species that were considered for the study were *Aloysia wrightii, Larrea tridentata, Parthenium incanum, Ephedra trifurca* and *Lycium berlandieri*. Six other species were identified that were not sufficiently abundant to be considered in the statistical analysis.

A series of solar radiation and evapotranspiration parameters were calculated with a code developed from an existing 'SolPos' code developed by the National Renewable Energy Laboratory (NREL). Solar radiation and potential evapotranspiration parameters estimated for different times of the year were used as independent variables to predict species abundance. Statistical analysis was performed with the Canonical Community Ordination (CANOCO) software package.

Through principal component analysis (PCA) and detrended correspondence analysis (DCA) the relationships between species, and between environmental variables were found. And through redundancy analysis (RDA), Detrended Canonical Correspondence Analysis (DCCA) the species relationship with environmental variables

was estimated. RDA explained 66% of the total variance and DCCA explained 60% of the total variance based upon the species-environmental variables data. While, PCA explained 95% and DCA explained 99% of variance based on the environmental variables data. With the Generalized Linear Model (GLM)/Poisson error model, species responses to the individual environmental variables were evaluated.

This demonstrated that solar radiation and potential evapotranspiration are significant predictors of the distribution of desert mountain vegetation. It was found that solar radiation and potential evapotranspiration were approximately equivalent predictors of vegetation distribution. This suggests that solar radiation primarily influences plant distributions through its influence on evapotranspiration.

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Chapter 1

INTRODUCTION

Incoming solar radiation is fundamental to most physical and biological processes because of its role in energy and water balance. Likewise, evapotranspiration is an important hydrologic process, which has an important role in the energy and water balance of the environment (Penman, 1948). There are many species that are influenced either directly or indirectly by these two major environmental variables contributing to the energy balance. From previous research, it can be stated that vegetation patterns and species distributions are influenced by environmental variables. Previous studies also conclude that vegetation pattern is an important parameter in understanding the microclimate and assessing land cover changes. This creates an objective for the present study to estimate the major environmental variables such as evapotranspiration and solar radiation that influence the vegetation patterns.

Mountains are natural islands of vegetation and have unique vegetation patterns generally different from those on the surrounding lowlands. Studies of mountain vegetation patterns and factors that influence them have been carried out for more than 100 years. Virtually no correlative studies have been conducted on the influence of solar radiation with evapotranspiration on vegetation patterns. Therefore, the main objective of this study was to determine the correlation between environmental variables, solar radiation and evapotranspiration, and vegetation patterns along the mountain slopes.

1.1 Plant Species Considered

Eleven plants were observed and considered for the study. A list of common and scientific names of the shrubs is given in Table 1 along with their official symbols (NRCS).

Table 1.1: Shrubs identified during field data collection

Symbol	Scientific Name	Common Name
ALWR	Aloysia wrightii (Gray) Heller ex Abrams	Wright's Beebush
BRCA3	Brickellia californica (Torr. & Gray) Gray	Californica Brickellbush
CYIM2	Cylindropuntia imbricata (Haworth) F.M.Knath	Cholla
LATRT	Larrea tridentata (Sesse & mocino ex A.P.de candolle) Coville var. tridentata	Creosote-bush
PAIN2	Parthenium incanum Kunth	Mariola
EPTR	Ephedra trifurca Torrey ex S.Watson	Mormon Tea or Longleaf ephedra
FOSP2	Fouquieria splendens Engelm.	Ocotillo
RHMI3	Rhus microphylla Engelm ex Gray	Littleleaf sumac
ATCA2	Atriplex canescens (Pursh) Nuttall	Fourwing Salt Bush
LYBE	Lycium berlandieri Dunal	Wolfberry
ZIAC	Zinnia acerosa (A.P. de candolle) Gray	Desert Zinnia

Basically, equal importance was given to all the species that were found to grow on the mountain. While *Aloysia wrightii*, *Larrea tridentata*, *Parthenium incanum*, *Ephedra trifurca* and *Lycium berlandieri* were the commonly observed species, *Brickellia californica*, *Cylindropuntia imbricata*, *Fouquieria splenders*, *Rhus microphylla*, *Atriplex canescens* and *Zinnia acerosa* were not encountered frequently enough for analysis. A brief description and characteristics of the commonly observed species is given below (Benson, 1981).

Aloysia wrightii commonly known as Wright's Bee Bush is a sweet aromatic desert shrub in the family of Verbenaceae. It is usually 1-2 m high, stems 4-angled, leaves opposite, ovate to orbicular, strongly veined and white-hairy beneath. It flowers in April-May with flowers more of less dense, a short cylindroid shape, densely hairy with petals about 4 mm long.

Figure 1.1: Desert shrub Aloysia writhtii

It is found in the desert grasslands, rocky or gravelly slopes or arroyo banks and canyons of the upper parts of the Mojavean, Sonoran, and Chihuahuan deserts at 2000-6000 ft elevation. In New Mexico, it is found in the Gila River and Rio Grande drainages southward from Socorro. In Texas it is found in the Edward Plateau and the plains of the Rio Grande (Vines, 1960; Benson, 1981).

Larrea tridentata commonly known as Creosote bush is one of the major shrub invaders of grassland in desert areas of southern New Mexico. It is a resinous, rhizomatous, ill-smelling shrub that is usually 1-2 m high.

It is one of the most common and widely distributed shrub in the North American deserts occurring on the plains and slopes of foothills from sea level to about 4,000 feet elevation.

Figure 1.2: Desert shrub Larrea tridentata

It is distributed in the Mojave, Colorado, Sonoran and Chihuahuan Deserts of the North America, South in Mexico to Queretaro. It is also found in southern Utah on the Virgin River drainage, Rio Grande, and Pecos River drainages (Benson, 1981).

Parthenium incanum commonly known as Mariola is a low bushy shrub usually about 4-6 dm high. Leaves are ovate in outline, 1-2 cm long, about 1-1.5 am broad, pinnately parted with the parts again lobed of toothed, gray in color, and with heads of small flowers in dense clusters.

Figure 1.3: Desert shrub Parthenium incanum

It is generally found in gravel slopes and plains, usually on caliche (cementer calcic soil) soils, in the Mojavan, Sonoran and mostly Chihuahuan deserts and in desert grassland at 2,500 to 5,000 feet elevation (Benson, 1981).

Ephedra trifurca commonly known as Mormon or Mexican Tea is a member of a geologically ancient group of about 40 species that are distributed over the desert and semidesert regions of Asia, Northern Africa and North America (Correll, 1970).

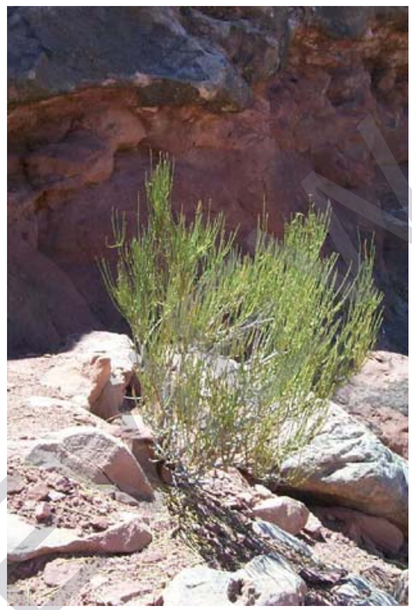

Figure 1.4: Desert shrub Ephedra trifurca

It is a shrub growing 1-2 m high. It has an intricate network of brittle, practically leafless green, yellow-green, or blue-green branches. It occurs on dry hills, rocky ravines, flat and grassy slopes, mesas, plains, and sandhills of the Mojavean and Colorado and Chihuahuan deserts and sometimes in the desert grassland from sea level to 5000 ft elevation. In New Mexico it is found along the Gila River drainage and in the Rio Grande Valley southward from Albuquerque.

Mormon Tea is supposed to have some medicinal uses. It is considered as a shrinking agent for tissues of the nasal passages when inflamed by colds (Benson, 1981).

Lycium berlandieri Dunal belonging to the potato family is more commonly known as the Desert Thorn or Wolfberry.

Figure 1.5: Desert shrub Lycium berlandieri

The shrub is up to 2.5 m high, somewhat thorny, reclining or spreading, glabrous or hairy. It can be distinguished from other desert shrubs by the thorny woody branches, the small, somewhat funnel-shaped corollas, and the berrylike fruits. It is generally found on alluvial plains and rocky foothills in the Colorado, Sonoran, and Chihuahuan deserts and the desert grasslands mostly at 2000-3000 ft elevations. In New Mexico it can be found in the Rio Grande drainage below Socorro and in the Tularosa basin (Benson, 1981).

1.2 Research Objective

There is a growing need to predict vegetation spatial patterns for assessing land cover change and to understand how micro-climate influences the growth of plants. This research should help us in improving our knowledge and understanding on how climate changes will cause vegetation patterns to shift. The objective of the present study was to evaluate the influence of evapotranspiration as against solar radiation on the vegetation patterns in the West Potrillo Mountains. This can be achieved by determining if there is a correlation between environmental variables, like evapotranspiration, solar radiation, and the plant species. The vegetation pattern at a location may be dependent on several environmental variables like slope, aspect, type of soil, precipitation, evapotranspiration and solar radiation. This research was focused only on the evapotranspiration and solar radiation as the determinant factors in the estimation of vegetation patterns on desert mountains.

Chapter 2

LITERATURE REVIEW

Literature concerning vegetation patterns is considerable. Controversy has existed in recognizing the main environmental factors that control vegetation patterns in general, and particularly on mountains. There were many studies conducted addressing the factors that affect vegetation patterns on mountains (Merriam, 1894; Merriam 1899; Bailey 1913; Watson, 1912; Shreve, 1915; Shreve, 1924; Daubenmire, 1943; Whittaker and Niering, 1965; Freeman, 1966; Dick-Peddie and Moir, 1970; Stephenson, 1990; Ghazanfar, 1991; Montana and Valiente-Banuet, 1998; Mata-Gonzalez, 2002; Dymond and Johnson, 2002; Martinez-Gonzalez, 2003). Some of the important factors affecting vegetation patterns on mountains reported in the studies were aspect, elevation, evapotranspiration, precipitation, solar radiation, temperature and topographic variations. There has been much debate on which of the factors is the primary controller for vegetation distribution. Each of these factors has its own influence, direct or indirect, on the plant distribution.

It can be observed that in many cases vegetation on mountains is visibly different from its surrounding lowlands. Diamond and May (1981) stated that the lowlands represent a distributional barrier for some species. In other words, they implied that the mountains impose changes in the factors and processes responsible for determining plant distribution.

More than a century and two decades ago, Merriam indicated that temperature is the most important single factor that controls plant distribution (Merriam, 1894, 1899). He also gave several descriptions of vegetation on mountains based on his assumptions. This view was held until 1912, when Watson followed by others came up with the theory that moisture availability was the major factor influencing vegetation patterns (Watson, 1912; Shreve, 1924; Whittaker and Niering, 1965). Daubenmire (1943) supported most of the previous theories by stating that temperature was an important factor in explaining the upper altitudinal limits of plant communities on mountains, while moisture availability is more likely to determine the lower limits.

Stephenson (1990) found that there is a strong correlation between energy and water in determining the distribution of vegetation. With net radiation being the major measure of energy supply and evapotranspiration managing the water balance, a better understanding of the mechanisms controlling the distribution of vegetation might arise by considering the parameters, radiation and evapotranspiration. Later in an aim to compare and critique some climatic parameters used in correlative studies of climate and vegetation distribution, Stephenson proposed actual evapotranspiration as a much better correlate than temperature over other climatic parameters (Stephenson, 1998).

Dick-Peddie (1993) pointed out that both temperature and available moisture are the main factors responsible for vegetation patterns, and the features that affect these two factors should be considered as secondary. These features are typically radiation and evapotranspiration, among others.

Keeping the literature in mind, solar radiation and potential evapotranspiration were used as the main variables in this study.

With evapotranspiration as one of the most basic components of hydrologic cycle that affects the water balance, the estimation of potential evapotranspiration has become an essential requirement (Penman, 1948). Potential evapotranspiration has been used to provide a reference level for actual evapotranspiration in many studies of land surface heat and water balance (Stephenson, 1998). While Thornthwaite's formula (1948) has been used in many regional and global studies, the Penman-Monteith equation has been proven to give the best results in the estimation of potential evapotranspiration (Moran, 1995; Alexandris, 2002; Choudhury, 1996). It became popular as a good estimator of evapotranspiration for a wide variety of climate conditions. References from the literature suggest that the Penman-Monteith formula is preferred to other empirical methods. Nevertheless, the main shortcoming of the Penman-Monteith method is that it requires data for a large number of climatic parameters that are not always readily available for many locations. Many modified and updated equations have been suggested to the Penman-Monteith equation, which would use small number of readily available weather parameters with a satisfactory degree of accuracy (ASCE, 1990; Alexandris, 2002; Choudhury, 1996). One such equation for estimating evapotranspiration was the Priestley-Taylor's equation (1972) proposed for use over substantial land areas. Its basic data requirements were net radiation that can be derived using mean air temperature, and relative humidity. The data that Penman-Monteith equation would additionally require was wind speed.

Studies on comparison of the two methods produced estimates with variations of approximately 5% in humid tropical climates or areas of low moisture stress (Gunston, 1982; Shuttleworth, 1979). With a satisfactory estimation of PET for tropical and moist climates, question arises if the Priestley-Taylor equation can be used in arid or semi-arid climatic regions. By increasing the value of a parameter ‘α’ in the equation, ASCE in 1990 suggested that the Priestley-Taylor equation can be used in the estimation of potential evapotranspiration in arid regions (ASCE, 1990; Vishwanadham, 1991; Antonio, 1992) where ‘α’ is an adjustment factor known universally as the Priestley-Taylor parameter. For arid or semi-arid regions, 1.61 can be used as a value for ‘α’ (ASCE, 1990).

Keeping in mind the literature and studies previously conducted, the present study was conducted. The description of the study site, methodology followed and results obtained are explained in the following chapters.