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Shrub-Grass Transitions and Multiscale Temporal Variation in Water Availability in the Jornada Basin

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ABSTRACT—Desert regions in the southwestern United States and Northern Mexico exhibit a high degree of temporal variability in water availability with important consequences for transitions between grasslands and shrublands. This temporal variability is a result of: shifting climate regimes over centuries and decades, interannual variation in weather patterns, seasonal differences in the nature of winter and summer precipitation, within-season variability in precipitation frequency and magnitude, and feedbacks between vegetation and soil water.

RESUMEN—Las regions áridas del suroeste de los Estados Unidos y norte de México muestran un alto grado de variabilidad estacional en disponibilidad de agua. Esta variabilidad temporal es el resultado de: variaciones en los regímenes climáticos por siglos y décadas, variación interanual en patrones climáticos, diferencias estacionales en las naturaleza del invierno y precipitación del verano, variabilidad intra-estacional en la frecuencia de la precipitación y magnitud e interacción entre la estructura de la vegetacioìn y el agua del suelo.

Note: This is an executive summary of the full length paper: Snyder, K.A. and S.L. Tartowski. 2006. Multi-scale temporal variation in water availability as a driver for woody plant encroachment. *Journal of Arid Environments* 65(2):219–234.

Semi-arid and arid regions exhibit a high degree of temporal variation in water availability. The invasion of C_3 shrubs into areas formerly dominated by C_4 grass is a common problem throughout the Chihuahuan Desert region with high spatial and temporal variation in shrub invasion success (Peters and Havstad 2006). Although the interaction of multiple factors such as grazing, fire suppression, and increased carbon dioxide play a role, it is important to consider how changes in water availability at multiple time scales appear to facilitate the encroachment of shrubs.

Water is the most limiting resource to plant growth in semi-arid and arid regions (Noy-Meir 1973). Therefore management of ecosystem-, community-, or plant-level composition and productivity must take into account the inherent temporal variation in water availability. Correlation of yearly rainfall totals with the aboveground net primary productivity of different community types does not significantly explain variability in plant community production (Huenneke et al. 2002). This poor correlation is in part because rainfall is not delivered in annual totals. The Chihuahuan Desert has distinct pulses of rainfall followed by dry interpulse periods. This pulsed nature of the Chihuahuan Desert is a defining characteristic of this region. The intervening dry periods frequently limit biotic activity, therefore the timing and magnitude of rainfall, in conjunction with temperature and plant phenology, are critical for understanding complex patterns of productivity in these heterogeneous landscapes.

Several scales of temporal variability must be taken into consideration in the Chihuahuan Desert region when considering how to predict future dynamics and manage these systems. In this paper, we discuss both broad and fine scale patterns in water availability. Broad scale patterns include centurial variation in water availability and decadal scales of variability whereas fine-scale patterns are within-year pattern of seasonal variability and within-season patterns of the frequency and magnitude of individual rainfall events. In addition to this inherent climatic variability, the interactions between different plant functional types with variation in water availability will need to be considered to predict future patterns in ecosystem composition and plant productivity.

The different scales of temporal variability are likely to have different ecological impacts with interactions also occurring across temporal scales. It seems likely that vegetation dynamics interact with climate characteristics, such as the magnitude and timing of rainfall, but the temporal scale of these interactions produces different outcomes. For example, variation in precipitation over hundreds of years may interact with the temperature responses of plants to determine the suite of potential functional types, while decadal patterns may have more impact on community composition, and isolated yearly variation may only affect productivity and have limited effect on species composition.

Broad Scale Variation—Within a century there can be oscillation around the mean as well as directional changes in rainfall. Within the last century in the Jornada Basin, there has been a slight increase in precipitation resulting from a more noticeable increase in winter precipitation and less noticeable increase in summer precipitation (Conley et al. 1992; Wainwright 2006). Winter rainfall is generally long duration-low intensity rainfall that percolates to greater depth than summer rainfall. Increased winter rainfall may have facilitated shrub encroachment by providing more water at deeper depths accessible by the more extensive roots systems of shrubs. At the decadal scale, the Chihuahuan Desert has experienced several extreme droughts in

1916 to 1918, 1921 to 1926, and 1951 to 1957. Long-term permanent quadrats on the Jornada found the extreme drought of the 1950s resulted in a loss of grass cover, and an increase in mesquite (Herbel 1972; Yao et al. 2006). The drought of the 1950s was severe enough to affect community composition, as normal rainfall patterns did not restore grass cover in many of the quadrats.

Fine-scale Patterns—Within a year, the Chihuahuan Desert is characterized by the majority of rain (53%) falling during the months of July to September. There is another slight peak in rainfall during the winter months (December to February). Walter (1971) proposed that seasonal precipitation characteristics determine large-scale patterns in community composition, with the grass to shrub ratio being controlled by the mean annual summer rainfall. The patterns of discrete pulses of rainfall within the summer growing season is likely important in determining community productivity. On average, the Chihuahuan Desert is characterized by a greater frequency of small (less than 5 mm) rainfall events, with larger events being less common. During the months of June to September the mean number of rainfall events less than 5 mm is 14 ± 7 (+1 SD) based on 81 years of records in the Jornada Basin. The mean number of rainfall events between 5 to 10 mm is only 5 ± 3, and rainfall events between 10 to 15 mm occur on average less than 3 times during these months (2.5 ± 1). The frequency and size of precipitation pulses produces differential patterns in the depth of soil wetting. Because various ecosystem components (grass roots, shrub roots, biological soil crust, and the bulk of soil microbes) vary with depth in the soil profile, these complex-wetting patterns often affect ecosystem productivity and biogeochemical cycling (Austin et al. 2004; Huxman et al. 2004). Frequent small pulses of rainfall may favor shallowly-rooted grass species, while larger rainfall may favor deeper-rooted shrubs. The interplay of storm magnitude and frequency will determine how long different species and ecosystem components are able to maintain increased biological activity and will affect yearly ecosystem production.

Plant-Water Interactions—Feedbacks between plants and hydrologic processes can accentuate the temporal variability in water availability. Increased shrub density in the Chihuahuan Desert results in larger bare spaces between plants, which can change surface energy budgets and the duration of soil wetting. Additionally woody shrubs have been found to redistribute water (i.e. hydraulic redistribution) via their root systems in response to soil water potential gradients, which can lift water to the surface during dry periods (Richards and Caldwell 1987), and after rainfall events may redistribute water through roots systems to deeper soil depths (Ryel et al. 2002).

Summary—Temporal variation in water availability interacts with spatial variability and is important in explaining complex patterns in these heterogonous desert landscape systems (Peters and Havstad 2006). Interactions between scales are also important; the effect of one-year drought and proper management response may be quite different than the strategy for a prolonged multi-year drought. Although managers cannot predict when the next wet or dry period will occur, it is necessary to understand the inherent pulsed nature of these systems and use these pulse patterns as critical junctures in land management.

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