QUANTIFYING THE SPATIO-TEMPORAL DYNAMICS OF WOODY PLANT ENCROACHMENT: AN INTEGRATIVE REMOTE SENSING, GIS, AND SPATIAL MODELING APPROACH

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Introduction & Problem Statement

- Woody plant encroachment (WPE)—the historically recent replacement of grasslands and savannas with shrublands and woodlands—results in reduced ecosystem value for livestock grazing, the predominant form of land use in grasslands and savannas. The process also produces changes in soils, hydrology, vegetation, animal life, and biogeochemical and biogeophysical feedback cycles. WPE has been documented in drylands around the world (e.g., Archer 1994).
- Despite a longstanding concern for and intensive research into WPE (e.g., Briggs *et al.* 2007, Brown 1950, and Smith 1899), the process continues to constitute a significant challenge for rangeland researchers, managers, and planners. Our accumulated understanding of the process has thus either not been translated into sustainable land use strategies and practices or with only limited success.
- To a large degree, the deficiency of such success stories is due to our limited understanding of the spatio-temporal rates, patterns, and dynamics of WPE.

Objectives

1. Quantify temporal changes in the abundance of woody plants and other land surface materials in a spatially explicit fashion across an entire watershed.
2. Predict a landscape's relative vulnerability to WPE.
3. Assess the relative importance of geoecological and anthropogenic variables in promoting or reducing WPE vulnerability in the watershed.

Methodological Approach

Study Site

- Fish Creek Watershed, southwestern Oklahoma, U.S.A. (~ 80 km^2; 5º 05' N, 99º 52' W) (Fig. 1)

Encroaching woody plant species

- *Prosopis glandulosa* var. *glandulosa* (honey mesquite)
- *Juniperus pinchotii* Sudw. (redberry juniper)

Data

- Landsat TM, Landsat ETM+, and ASTER satellite imagery (1984, 1988, 1994, 2000, 2005)
- GIS data: elevation, slope, aspect, distance from roads, distance from streams, soil texture, soil gypsum content, soil depth, surface geology

Methods (Fig. 2)

- ***Remote Sensing Analysis (Objective 1)***
  - Multiple Endmember Spectral Mixture Analysis (MESMA; Roberts *et al.* 1998)
    - Implemented in ERDAS IMAGINE, ENVI, and ArcGRID software
    - Derive sub-pixel abundances of surface materials for each year of imagery
  - Change detection using fuzzy logic (Zadeh 1965)
    - Implemented in ArcGIS and IDRISI software
    - Quantify temporal changes in the abundance of surface materials
- ***Spatial Modeling (Objectives 2 and 3)***
  - Local Indicator of Spatial Association (LISA, Local Moran's I Statistic; Anselin 1995; Fig. 3)
    - Determine whether temporal abundance changes of woody plants are spatially random or not
  - Conceptual Model of WPE (Fig. 4)
  - Geographically Weighted Regression (GWR; Brundson *et al.* 1996), Weights of Evidence (WoE; Bonham-Carter *et al.* 1988), and Weighted Logistic Regression (WLR; Agterberg *et al.* 1993)
    - Derive weights or regression coefficients of explanatory variables
    - Predict probability of WPE across study area
    - Implemented in GWR, ArcSDM, and IDRISI software

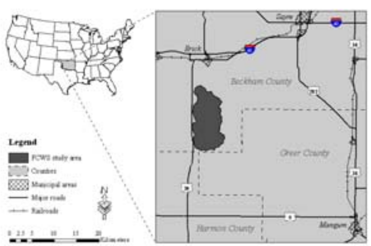

Fig.1: Location of the study area

Questions or Comments? Contact Michaela Buenemann at elabuen@email.arizona.edu.

Results

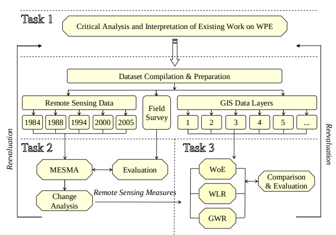

Fig. 2: Flowchart of the research methodology

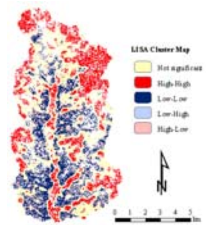

Fig. 3: LISA cluster map for WPE between 1984 and 2005 (P<0.01; 9999 permutations).

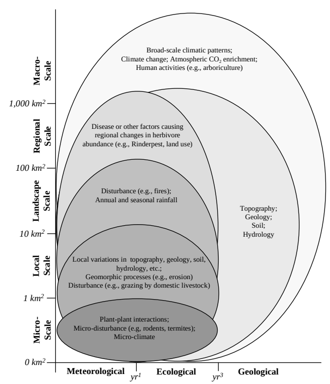

Fig. 4: Spatial and temporal scales and processes influencing woody plant / grass ratios (modified from Gillson 2004).

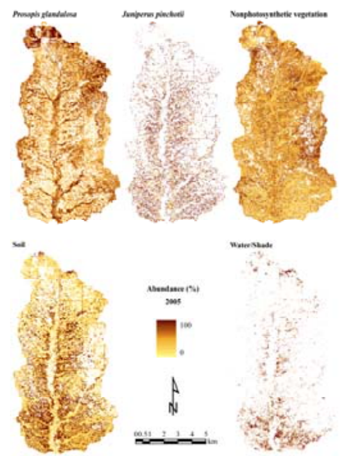

Fig. 5: 2005 MESMA endmember fractions (White areas represent the cumulative unmodeled areas from all years of imagery.)

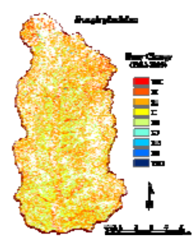

Fig. 6: Fuzzy magnitudes of change in mesquite and juniper endmember fractions between 1984 and 2005 (White areas represent the cumulative unmodeled areas from all years of imagery.).

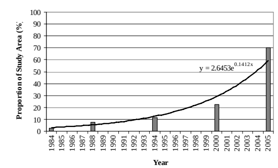

Fig. 7: Increase in the proportion of the study area characterized by a mesquite abundance of greater than 5 % (The solid black line is an exponential trend line.).

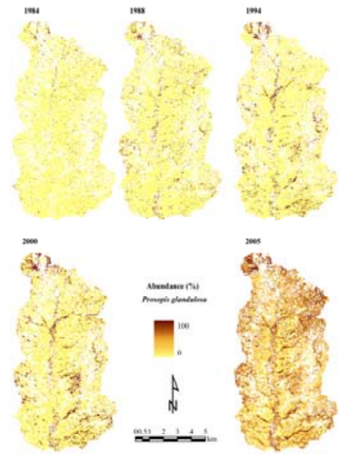

Fig. 8: Change in mesquite endmember fractions between 1984 and 2005 (White areas represent the cumulative unmodeled areas from all years of imagery.).

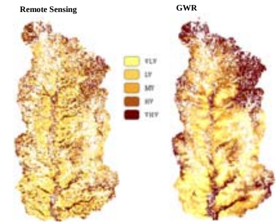

Fig. 9: Comparison of "actual" WPE vulnerability (left) and WPE vulnerability predicted with GWR (right).

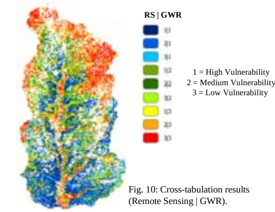

Fig. 10: Cross-tabulation results (Remote Sensing | GWR).

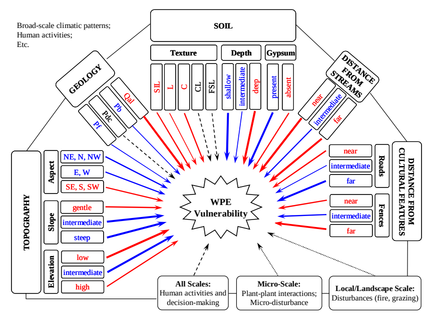

Fig. 11: Conceptual model showing the magnitude and direction of influence that the explanatory variables have on WPE vulnerability (Red and blue arrows indicate if a variable increased or decreased WPE vulnerability. The strength of the arrows indicates the relative importance of a variable. Dashed black arrows denote variables whose influence is uncertain or unknown. Dotted black arrows denote variables whose influence is described elsewhere. Note that all variables are linked across space and through time.).

Discussion

- WPE occurs in a temporally non-linear, spatially variable, yet predictable manner.
- Environmental variables may be more important in determining WPE vulnerability than previously thought.
- Integrative remote sensing, GIS, and spatial modeling approaches can help elucidate rates, patterns, and dynamics of WPE and help synthesize data from a multitude of studies but much work remains to be done...

Implications

- Rangeland management (e.g., restoration, conservation, protection, ranching) should be done in a temporally *and* spatially explicit fashion.
- In conjunction with field data and techniques, geospatial approaches may be invaluable for rangeland management.

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