REMOTE SENSING-BASED DYNAMICAL SYSTEMS ANALYSIS OF SAGEBRUSH STEPPE VEGETATION IN RANGELANDS

R.A. Washington-Allen[1,2], N.E. West[2] and R.D. Ramsey[2]

[1]Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6407, USA.
E-mail: washingtonra@ornl.gov
[2]Department of Forest, Range, and Wildlife Sciences, Utah State University, Logan, Utah 84321-5230, USA.
E-mail: new369@cc.usu.edu, and dougr@nr.usu.edu

1. INTRODUCTION

The status and trend of the ecological integrity of drylands within the western United States is unknown because the collection of field data at this scale is economically prohibitive and current data sets have been spatially and temporally insufficient (NRC 1994). Monitoring technologies and data sets must have the capability to capture these scales. For example, climatic phenomena, such as the El Nino-Southern Oscillation (ENSO), act at local to global spatial scales and have temporal return intervals between 3 to 10 years. Monitoring technology must encompass the scales of these phenomena and be able to replicate them at least twice in order to separate their effects from anthropogenic disturbances (Graetz 1987).

Landsat satellite imagery is an affordable technology that meets these scaling criteria. Landsat satellites have been collecting bimonthly spectral and texture data at local to regional scales for 30-years and continuing since 1972. Range scientists have defined one aspect of land degradation as a decrease in plant cover or productivity (Behnkhe and Scoones 1993, Pickup 1989). A surrogate measure of plant cover or productivity is the soil-adjusted vegetation index (SAVI, Huete 1988). SAVI was developed for rangelands to decrease the noise in vegetation response due to soil background effects (Huete 1988). Consequently, nearly thirty years of a SAVI time series can be derived. In this regard, the purpose of this study was to characterize retrospectively the trend of a sagebrush steppe-dominated landscape's dry season vegetation response and infer what constrains this response in regards to grazing and climate using a 27-year time series of Landsat satellite imagery (1972 to 1997).

This research asked: (1) What was the historical variation of vegetation response at the landscape scale? and (2) How is this variation related to the inferred constraints of climate and grazing? The primary research hypothesis is that under commercial grazing the vegetation dynamics of sagebrush steppe is a limit cycle attractor (Hanley 1979). There are four types of attractors including a fixed-point attractor. A limit cycle has trajectories of state variables, e.g., vegetation cover, that oscillate or repeat cycles (Haefner 1996). The vegetation dynamics of sagebrush steppe were predicted to have two stable equilibria that depict periods of low and high plant phytomass separated by an unstable area or threshold in response to variable grazing and fixed climatic conditions (Hanley 1979).

2. METHODS

The study area selected for this research was the 48, 000 ha lower elevation, eastern half of Deseret Land and Livestock Company Ranch (DL&L) which is located in the northeast corner of Utah between latitudes 41° 0' and 41° 30' and longitudes 111° 0' and 111° 30'. DL&L is the largest holdiing of contiguous private land in the state of Utah at 88,800 ha including 6,800 ha of public and state land. The ranch has been commercially grazed since at least 1891 when the initial primary domestic animals were sheep. DL&L is now a commercial mixed grazing operation where primary land-use and income generation is through both a livestock and a recreational wildlife-hunting program. Research was concentrated on the eastern portion of the ranch because it is dominated by sagebrush-grassland (West and Young 2000), a shrub and grass physiognomy within which changes in growth form composition are more readily detected by the spatial grain of Landsat satellites (80 m). The ranch's rolling terrain consists of soils that are predominately Aridisols and Mollisols. Slopes range between 0 - 70 %, with predominately southern aspects. Elevation increases from east to west from 1830 m to 2670 m above-sea-level. Mean annual temperatures range between -17° C and 27° C. Mean annual rainfall varies with elevation, changing from 240 mm in the east to 449 mm in the western portion of the ranch.

A 27-year dataset from 1972 to 1997 of 20 dry season (late August to early September) Landsat satellite images of DL&L were standardized and converted to soil-adjusted vegetation index image (SAVI, Huete 1988) time series. This data set was characterized using mean-variance analysis developed by Pickup and Foran (1987) and a k-means cluster analysis procedure (Davis 1986). Mean-variance plots graphically depict dynamical systems or time-evolving processes. Phase portraits show graphically how the landscape's vegetation response changes over time by plotting the mean SAVI response versus its variance for each year. Polynomial regression and three-dimensional response surfaces were used to relate SAVI to both grazing and climate from 1980 to 1996. DL&L provided a meticulous record of grazing management for this period and the Palmer Drought Severity Index (PDSI), a measure of site-water availability was used as a regional surrogate of climate. PDSI values less than –4 indicate extreme drought and values greater than 4 indicate extreme wetness.

3. RESULTS

The phase portrait shows how and when the landscape's SAVI transitions from one state to another through time (Westoby, Walker, and Noy-Meir 1989). The k-means cluster procedure is an objective way of identifying areas of "attraction". Mean dry season SAVI had an increasing trend from 1972 to 1997. Two main attractors were identified in areas of low mean-low variance and high mean-high variance or landscapes with low vegetation response and low heterogeneity and landscapes with high vegetation response and increased heterogeneity from 1972 to 1997 (Figure 1).

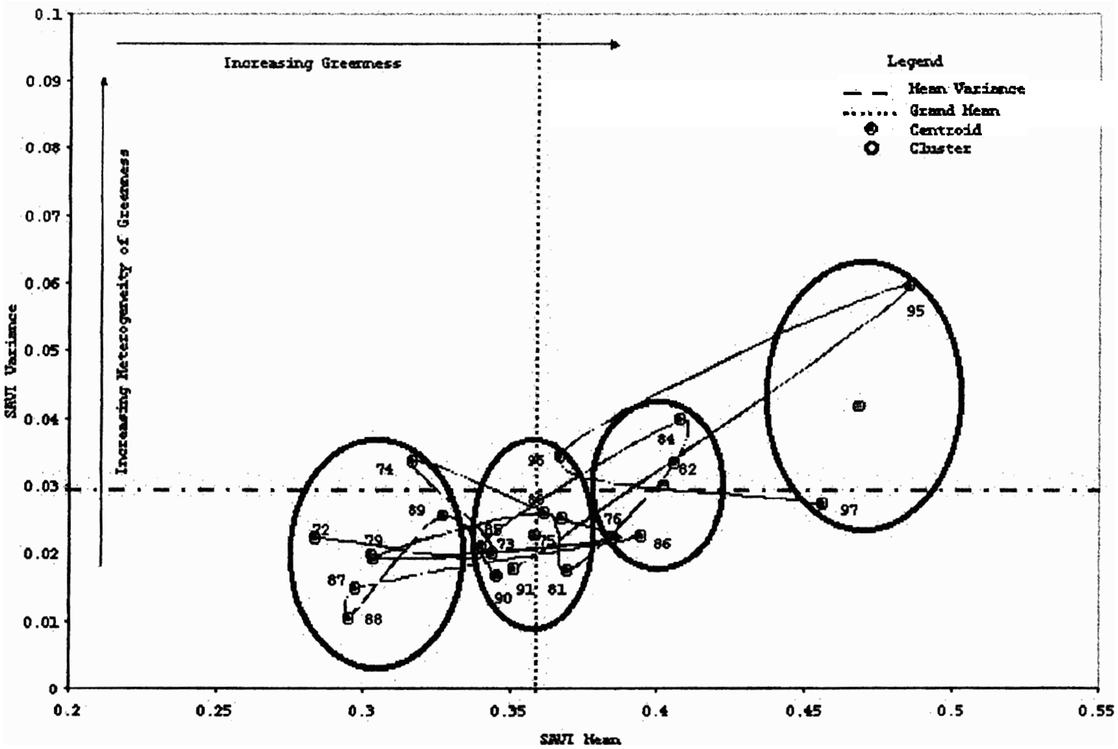

Figure 1. The SAVI mean-variance phase portrait from 1972 to 1997 for the sagebrush-grassland community on DL&L

The dry season SAVI time series had a significant (p = 0.047) cubic correlation with herbivory (r = 0.63). The PDSI (r = 0.62, p = 0.006) was linearly correlated with one-year lagged SAVI. The response surface depicts the one-year lagged SAVI response to cattle grazing and the PDSI and is a combination of these correlations (Figure 2).

4. CONCLUSION

The vegetation dynamics on DL&L confirm Handley's hypothesis that sagebrush steppe is a limit cycle attractor (Hanley 1979). However, the focusing (low SAVI mean in concert with low variance) and unfocusing (high SAVI mean in concert with high variance) suggests that this portion of sagebrush steppe is an unstable limit cycle. The dry season mean SAVI had an increasing trend from 1972 to 1997 that was linearly influenced by water availability (PDSI), particularly the very strong ENSO events in 1983-84 and 1997, and non-linearly affected by grazing. ENSO events appear to be responsible for vegetation recovery from severe droughts in 1987 to 1989 and grazing. The results of this study and evidence presented by Holmgren and Sheffer (2001) indicate that very strong ENSO events provide the opportunity for both vegetation resistance and recovery from drought and grazing and for ranchers to introduce range improvement practices, e.g., reseeding.

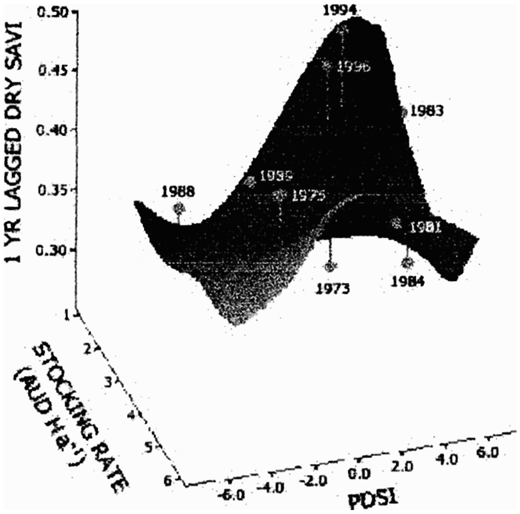

Figure 2. The one-year lagged soil-adjusted vegetation index (SAVI) response surface with respect to grazing (AUD Ha^{-1}) and climate (PDSI).

5. ACKNOWLEDGEMENT

This research was funded by a grant from the U.S. Environmental Protection Agency through Science To Achieve Results grant #GADR826112 to Dr. Neil E. West (it has not been subjected to the Agency's required peer and policy review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred) ORNL is managed by the University of Tennessee-Battelle LLC for the U.S. Department of Energy under contract number DE-AC05-00OR22725.

5. REFERENCES

Behnke, R.H. and I. Scoones. 1993. Rethinking range ecology: Implications for rangeland management in Africa, p. 1-30. *In:* Behnke, R.H., I. Scoones and, C. Kerven (eds.), Range ecology at disequilibrium. Overseas Development Institute, International Institute for Environment and Development, and Commonwealth Secretariat, London.

Davis, J.C. 1986. Statistics and data analysis in geology. 2nd ed. John Wiley and Sons, New York. Graetz, R.D. 1987. Satellite remote sensing of Australian rangelands. Remote Sensing of Environment 23:313-331.

Haefner, J. W. 1996. Modelling biological systems: Principles and applications. Chapman & Hall, New York.

Hanley, T.A. 1979. Application of an herbivore-plant model to rest rotation grazing management on shrub-steppe rangeland. Journal of Range Management 32:115-118.

Holmgren, M. and M. Scheffer. 2001. El Niño as a window of opportunity for the restoration of degraded arid ecosystems. Ecosystems 4:151-159.

Huete, A.R. 1988. A soil-adjusted vegetation index (SAVI). Remote Sensing of Environment 25:295-309.NRC (National Research Council). 1994. Rangeland health: New methods to classify, inventory, and monitor rangelands. National Academy Press, Washington D.C.

Pickup, G. 1989. New land degradation survey techniques for arid Australia: problems and prospects.Australian Rangeland Journal 11:74-82.

Pickup, G. and B.D. Foran. 1987. The use of spectral and spatial variability to monitor cover change on inertlandscapes. Remote Sensing of Environment 23:351-363.

West, N.E. and J.A. Young. 2000. Intermountain valleys and lower mountain slopes, p.255-284. *In:* M.G.Barbour and W.D. Billings (eds.), North American terrestrial vegetation, 2nd ed. Cambridge Univ. Press, New York

Westoby, M., B.H. Walker, and I. Noy-Meir. 1989. Opportunistic management for rangelands no atquilibrium. Journal of Range Management 42:266-274.