RETROSPECTIVE ASSESSMENT OF SOIL STABILITY ON A LANDSCAPE SUBJECT TO COMMERCIAL GRAZING

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1. INTRODUCTION

Landscape degradation can be characterized as both accelerated soil erosion and a change in soil quality, e.g., a reduction in soil organic matter that affects plant community composition and/or production (Shiflet 1973). Surrogate measures of land degradation have been derived from the spectral and textural content of satellite imagery. A number of studies have directly related soil reflectance characteristics to physical properties of soils that affect reflectance, particularly surface roughness, structure, moisture content, particle size distribution (texture), and the content of organic matter, carbonates, clay, minerals, and iron oxides (Myer and Allen 1968, Baumgardner et al. 1985, Wessman 1991). Increases in soil organic matter content lead to a darkening of soils while increased reddening of soils is due to an increase in iron oxides associated with increased soil erosion (Wessman 1991). Pickup and Nelson (1984) carried out a study on the red-yellow soils within Australia's arid region by stratifying a landscape's land-forms into four categories of erosion status: stable, transitional, depositional, and erosional. They found that the ratio of Landsat Multispectral Scanner (MSS) green (band 1, 0.5 - 0.6 μm) divided by the near infra-red (NIR, band 3, 0.7 - 0.8 μm) or the 1/3 ratio, plotted against the ratio of the red (band 2, 0.6 - 0.7 μm) divided by band 3 (NIR) or the 2/3 ratio best discriminated the four different surfaces in spectral space. Because the vector cloud was roughly a parallelogram, they determined that calculation of the perpendicular distance of each surface's coordinates from either a bounding upper or lower parallel line provided a quantitative measure of soil stability or susceptibility to erosion --the soil stability index (SSI, Pickup and Nelson 1984). However, although they suggested that changes in soil color and brightness were responsible for discrimination between the erosion states, they did not determine what properties of soils affected the discrimination (Pickup and Nelson 1984). Consequently, the purpose of the present research was (1) to determine the possible relationship between the SSI and physical, chemical, and topographic aspects of soils that change with erosion and (2) to describe the temporal dynamics of dry season SSI from 1972 to 1997 on a commercially grazed landscape.

2. HYPOTHESES

We hypothesized that if soil brightness and color are a function of physical, chemical, and topographic characteristics that vary with erosion, e.g., available water capacity (AWC), clay content (cl), soil organic matter (om), and soil erosion [wind erosion index (I)] and erodibility (Kw factor), and slope, then there should be a significant correlation between these properties and the SSI. For example, SSI should increase positively with AWC, clay content, and organic matter (om). SSI should negatively correlate with the wind erosion index (I), Kw and slope degree. Secondly, with calibration/validation to these field indicators of erosion status, the temporal dynamics of the SSI will indicate the different erosion states a landscape may go through. The greatest susceptibility to erosion is expected during severe droughts (Thurow 1991).

3. 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 holding of contiguous private land in the state of Utah at 88,800 ha including 6,800 ha of public and state land. DL&L has been commercially grazed since 1891 and 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 the composition of patches, e.g., shrub, grass, and bare soil, 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

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2670 m above-sea-level. Mean annual temperatures range between -17° C and 27° C. Mean annual precipitation 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 (Jensen 1996) and converted to an SSI image time series using procedures developed by Pickup and Nelson (1984). The DL&L portion of the Rich County, Utah soil survey (SCS 1982) was digitized and attributed. This map contained 517 polygons that contained 61 soil series of which 9 representative pedons were sampled by SCS in 1979. Polynomial regression was used to relate 1979 SSI values to the 1979 field measures for om, cl, Kw, I, AWC, and slope at these locations. This data set was characterized using mean-variance (Pickup and Foran 1987) and k-means cluster analyses. Mean-variance plots are dynamical systems analysis phase portraits that show graphically how the ranch's soil stability changes over time by plotting the mean SSI response versus its variance in the same year.

4. RESULTS AND DISCUSSION

Table 1 lists the correlations between soil attributes and SSI. Correlations were low and not significant with percent clay (cl), AWC, and Kw (Table 1). SSI was significantly correlated with om, I, and slope (Table 1) However in regards to I, only two data points were really available for comparison to SSI. The mean SSI was expected to be negatively correlated with slope degree, i.e., decrease with an increase in slope degree. However, the results were contrary to this hypothesis, where a significant positive correlation with SSI resulted (Table 1).

Table. 1. The relationships between the dry season soil stability index (SSI) and field measures of soil physical and chemical attributes that change with erosion status.

Statistic	% Clay	Slope	AWC	% Organic matter	Kw (erodibility)	Wind Erosion (I)
Correlation (r)	-0.45	0.73	-0.45	0.75	-0.52	-0.75
Probability (p)	0.22	0.03	0.22	0.02	0.15	0.02

The SSI had a restricted range of values (between 6.0 and 9.0) which corresponded to the low variability of DL&L's land forms, the majority of which are depositional flood plains and alluvial fans (SCS 1982). The SSI mean-variance dynamics from 1972 to 1997 orbit very tightly about the mean where the majority of values reside (Fig. 1). Mean conditions for the time series appear to be poised between the erosional and stable sectors (Fig. 1). The cluster-years 1976 and 1988 and 1972, 92, and 94 appear to be outliers. However 1972, 92, and 94 were wet years and 1988 was the Great North American Drought of 1988, a very strong La Niña event (Trenberth et al. 1988).

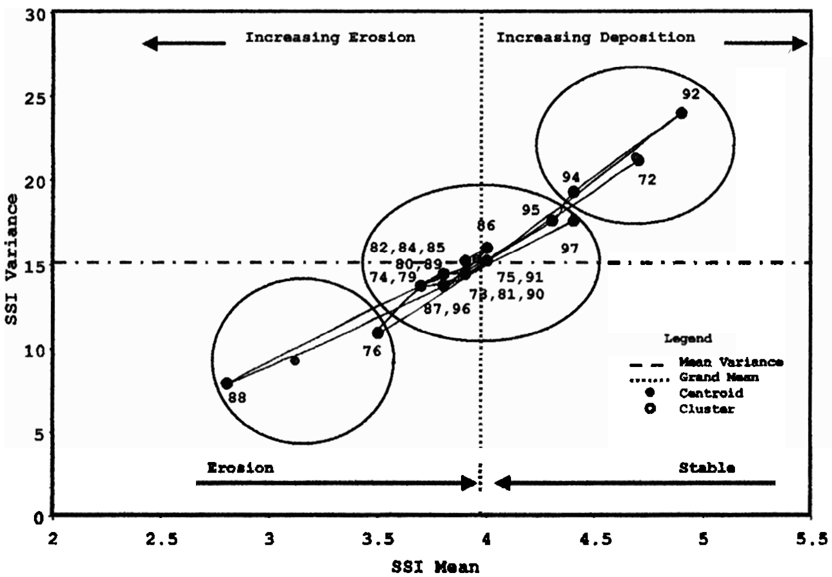

Figure 1. The phase diagram of the dry season soil stability index (SSI) for the eastern lowlands portion of Deseret Land & Livestock Co. Ranch from 1972 to 1997. Missing years are interpolated and the trajectories are smoothed. Clusters were delineated using a k-means cluster procedure.

5. CONCLUSION

Soil organic matter, which is reduced with erosion, was significantly correlated with dry season SSI, a finding consistent with past remote sensing studies in the literature. For much of its history, 1972 to 1997, the overall SSI trend was slightly increasing ($r^2 = 0.25$) towards stable conditions. Where the variance is greater than the mean indicates a negative binomial and a contagious spatial pattern. Consequently, under harsh drought conditions, e.g., 1988, the landscape became more susceptible to erosion and less contagious. With the improved forecasting of ENSO and La Niña events (Glantz 2001), land mangers are now able to adjust their grazing management to minimize land degradation and economic impact.

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