Remote Sensing Models to Quantify Performance Anomalies in Grasslands and Steppes

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Climate, poor management, fire, and pest infestations are stressors that change ecosystem dynamics. As systems become stressed and degraded, there is frequently an increase in runoff, wind erosion, and water erosion. The vegetative composition of grasslands and shrub steppes changes when native species are unable to thrive or if invasive species become prolific. This research seeks to quantify ecosystem changes at a regional scale, both over a growing season and in near real-time. We have developed a regional monitoring approach that is able to identify problematic areas and provide land managers with locations in need of best management practices and other amelioration efforts. Our method integrates multi-sensor and multi-temporal spatial data in a grassland performance model that calculates anomalies between expected and actual performance. Inputs to the model include individual land cover types, mean vegetation indices, and several soil and climate data sets. Outputs include ecological performance maps that show areas with higher or lower performance values than expected.

Northern Great Plains

Methods

We determined expected grassland performance with a regression on multiple spatial datasets. Input data sets, relevant to site potential and climatic variations, were considered for the regression model to predict Time Integrated Normalized difference vegetation index (TIN). These data sets included climate, elevation, soil, Normalized Difference Vegetation Index (NDVI), and NDVI metrics such as start of season, end of season, start of NDVI. Data inputs from multiple years results in a regression model that is robust in a wide range of climatic conditions.

National Land Cover Database (NLCD, 1992) grassland and shrub classes (30m) were combined and processed to create a percent grassland image (250m). Two-thousand random points were generated across four years (n=8000) on pixels containing at least 70 percent grassland (fig. 1). For each random point location, candidate data values were extracted and analyzed in Cubist. The resulting multiple regression determined that long-term average TIN from Advanced Very High Resolution Radiometer (AVHRR) and climate data were the best predictors.

Estimated TIN = 1.31 mean_TIN + 0.085 ppt456 + 1.5 dif_win - 0.47 tmin3 + 0.6 tmin456 where
mean_TIN = mean time integrated NDVI from AVHRR
ppt456 = mean monthly precipitation - April, May, June
dif_win = maximum and minimum mean monthly temperature difference during winter months November - February
tmin3 = mean minimum temperature – March
tmin456 = mean minimum temperature – April, May, June

Final indicators in grassland areas were long-term NDVI and climate.
- USGS National Land Cover Database (NLCD, 1992)
- Long-term Mean NDVI (AVHRR NDVI 1998-2004)
- PRISM climate data (1998-2004)

The regression developed from the indicators (R^2=0.69) was applied to Moderate Resolution Imaging Spectroradiometer (MODIS) 250 meter resolution NDVI for the years 2002 through 2005. Difference maps were created from expected TIN, based on the climatically driven regression model (above), and observed TIN values for each year (MODIS 2002-2005). The annual difference maps account for climatic variations and reveal management and other factors such as performance anomalies. We define **performance anomalies** as pixels outside the 90% confidence limits of the regression between model estimated TIN and observed TIN using a two-tailed *t* test (fig. 2).

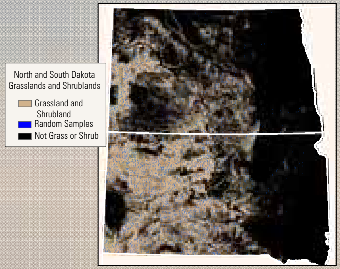


Figure 1 – Study Area: Grassland in North Dakota and South Dakota defined by NLCD, 1992. Grassland areas were randomly sampled at 2,000 locations for the years 2002 though 2005 (n=8000).

Results

Maps were generated identifying under-performing and over-performing pixels for the years 2002 through 2005. A map of the frequency of performance anomalies from each year identified areas with consistent and inconsistent pixels relative to overall conditions. This ensures the results are a relative measure of ecosystem condition.

Anomalies were few and typically dispersed (less than 1.2% of grassland). This indicates poor management, pest distress, or fire. Common examples of performance anomalies included over-grazing (under-performing) and grassland to crop conversion (over-performing).

The frequency maps and the annual performance anomaly trend maps were compared to aerial photos from the National Agriculture Imagery Program (NAIP 2003, 2004, 2005) acquired at three different locations (fig. 3). The left and center image pairs, located in South Dakota, illustrate grassland performing below the expected average three or four years out of four (poor 3/4 and 4/4). The images (NAIP) of pastures confirm minimal vegetation, exposed soil, and evidence of grazing. The right image, located in North Dakota, performed better than expected each year (good 4/4). The aerial photos reveal areas containing dense vegetation. The higher performance value is most likely caused by a recent grassland-to-crop conversion.

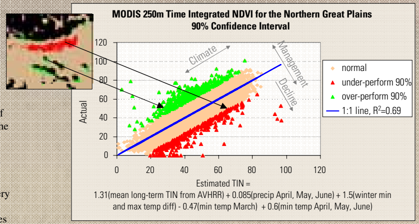
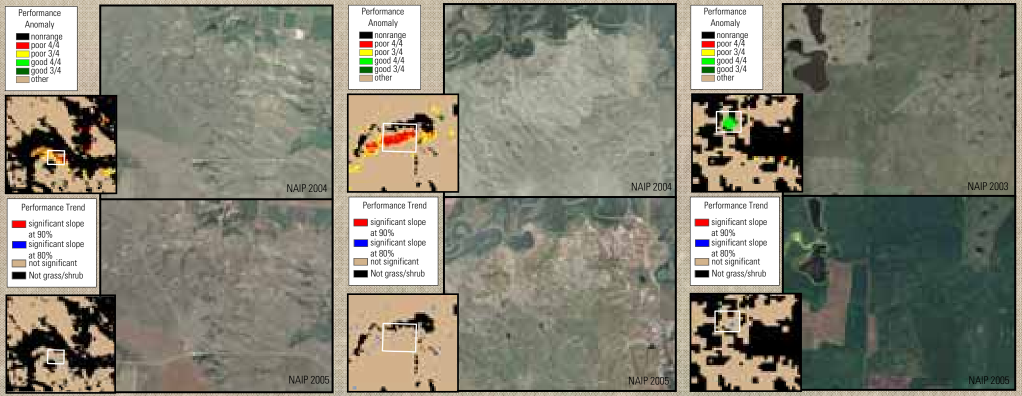


Figure 2 – Pixels performing better than the expected normal are in green. Red symbolizes performance that is less than the expected. Climate varies along the regression line while the perpendicular axis is associated with management, fire, or pests.

Figure 3 – Example of sites located in western South Dakota, central South Dakota, and central North Dakota. Grassland performance and the trend of performance anomalies for the years 2001-2005 are indicated. The right and center sets confirm bare ground in South Dakota in 2004 and 2005 (NAIP 2004, 2005). The right image set from an area in North Dakota identifies a field planted with crop performing better than surrounding grassland (NAIP 2003, 2005).



Sagebrush-Steppe

Methods

Several data sets and images will be evaluated using a Cubist rule-based predictive model. The site potential indicators for mapping climatically expected MODIS TIN in the sagebrush-steppe areas of Wyoming include:

- Sage Land Cover Map (NLCD 2001, LandSat TM, Fig. 4)
- Aspect (Digital Elevation Model, fig. 5)
- Compound Terrain Index (DEM)
- STATSGO Soil Data (Percent Clay, Carbonates, Available Water)
- PRISM Climate Data
- Long-term Mean AVHRR NDVI

We generated random pixels across a gradient of sage cover with different randomization each year. The pixel values for each random point will be extracted and then evaluated by Cubist. We will apply the predictive model to the yearly mean NDVI (MODIS) for the years 2000 through 2004, determine the confidence limits, and map the frequency of performance anomalies.

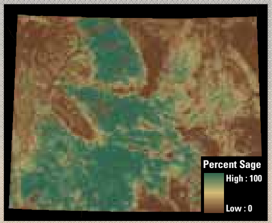


Figure 4– Percent sage in Wyoming was calculated by up scaling 30m shrub classes (NLCD, 2001) to 250m.

Current Status

Annual and seasonal NDVI and sage cover trends were investigated. Tests showed that the mean seasonal NDVI from the months of April through October (fig. 6) was correlated with sage cover (fig. 7). We are currently constructing a database containing site potential values for each random point. The remainder of model development, refinement, and application is expected to be complete in May 2007.

Figure 5 –The aspect of slope in Wyoming was derived from DEMs. Aspect may be required as an input variable for the performance anomaly regression. Slopes facing north generally have better expected performance.

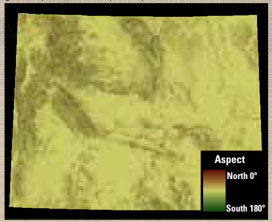


Figure 6 – The mean NDVI for the months of April through October in 2002 were mapped from NDVI (MODIS) composites.

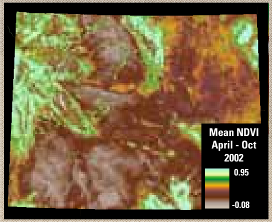
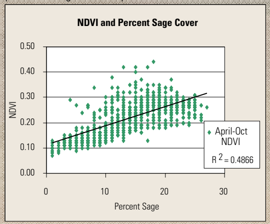


Figure 7 – The mean NDVI from April through October in 2002 and sage cover in Wyoming have a linear trend. The relationship suggest April through October mean NDVI is a possible surrogate for site potential.



Discussion

Northern Great Plains, Dakotas

The majority of anomalous pixels were classified as performing below normal (fig. 8). Field verification is not complete. Preliminary results indicate the model output is consistent with many ground observations and high resolution aerial photography.

Sagebrush-Steppe, Wyoming

The sagebrush project will be a good test of our approach. Issues include the effect of large amounts of bare soil and litter with a reduced amount of vegetation. However, agreement between Sagebrush TIN and carbon flux data were good in Dubois, ID (Wylie et al. 2003). We expect this approach to provide a consistent statewide assessment of under-performing shrublands. Preliminary results will be shared with BLM offices for comment. This work also supports range health studies in the Green River Basin.

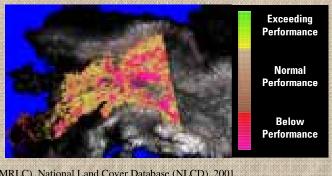
Yukon River Basin, Alaska

The performance anomaly approach, developed with Land Remote Sensing funding, was applied in the Yukon River Basin (fig.9). Land cover is primarily boreal forest and input parameters vary slightly. Model results are not validated, although performance anomalies correlate with fire occurrence and documented forest recovery periods.

Figure 8 – Above-mean and below-mean performance in the Northern Great Plains. Below-normal values occur more frequently than over-performing values.

Number of Pixels	N. Great Plains Performance	Percent of Grassland
16,611	Below	0.83
6,955	Above	0.35

Figure 9 – Ecosystem performance anomalies in the Yukon River Basin of Alaska. Several below-performance areas were recently subject to fire.



Acknowledgements

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