THE REALITY OF RANGELAND DEGRADATION MAPPING WITH REMOTE SENSING: THE SOUTH AFRICAN EXPERIENCE.

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Abstract
Globally there is an urgent need for standardized, quantitative measures rangeland degradation. Over the past 10 years in South Africa (SA), significant research efforts have been directed at this challenge, using diverse methods and data. The objective of this paper is to review a number of methods and summarise their common challenges, limitations and ecological realities. Degraded areas have been subjectively mapped as degraded from single-date Landsat TM imagery based on low herbaceous cover. These were analysed using 16 years of 1km AVHRR NDVI data and compared to “non-degraded” adjacent areas. The non-degraded areas had consistently higher vegetation production (average 12%) despite a large variation in annual rainfall. This indicates that the degraded areas produce less vegetation per unit of rainfall and suggests that they may have changed to a different ecological state. Next, trends in rain use efficiency (RUE) was analysed to identify new degradation. However, it was found that RUE was highly correlated with rainfall and did not provide an indicator of degradation which is independent of rainfall. Instead, the Residual Trends (RESTREND) method was evaluated, which should provide more robust results. Methods that identify negative trends in vegetation production through time can only detect degradation that occurred after the inception of satellite record in early 1980’s. Where the non-degraded production potential of a pixel can not be known from the past (before 1981), it may be estimated spatially by using a reference area. Using the Local NPP Scaling (LNS) method, the production of each pixel is expressed relative to the highest values (90th percentile) of ΣNDVI observed in all pixels falling within the same land capability unit (LCU). The persistence of low LNS values is evaluated through 16 years of AVHRR data. Finally, the recent efforts of the FAO’s RUE-based Land Degradation Assessment in Dryland Areas (LADA) are evaluated for SA.

Introduction

There have been a number of to map land degradation at regional to global scales (e.g. (Dregne 1983, Oldeman et al. 1990, UNEP 1997) and most were based on very limited quantitative data and were mainly expert opinions on the susceptibility of areas to soil erosion instead of its actual occurrence (Dregne 2002). Most recently, the Millennium Ecosystem Assessment (MEA) synthesized diverse datasets to produce a global map of degraded drylands (Lepers et al. 2005). The paucity of regional to global scale quantitative data led the MEA to produce a qualitative map that can not be used to assess nor monitor degradation systematically over large areas, and through time (Lepers et al. 2005). Therefore there is an urgent need for standardized, quantitative measures rangeland degradation at global, regional and national scales.

Over the past 10 years in South Africa (SA), significant efforts have been directed at this challenge, using diverse methods and data. Firstly, the “National Review of Land Degradation in South Africa” (NRLD) was based on a systematic survey of the perceptions of 453 agricultural extension workers and resource conservation technicians about the degradation status of 367 magisterial districts. From these surveys various indices of the severity, extent and rates of different types of degradation (such as reduced vegetation cover, plant species composition and bush encroachment) were estimated. Independently, a National Land Cover map (NLC) was prepared using single 1995-96 Landsat TM data, manual photo-interpretation and extensive fieldwork (Fairbanks et al., 2000). 4.8% (5.8 million ha) of the country was mapped as degraded. The “degraded” classes in the NLC were defined as regions with lower vegetation cover and higher reflectance than surrounding areas (Thompson, 1996). Neither of these initial methods were sufficiently repeatable for regular land condition monitoring.

Long-term, coarse resolution satellite data have been widely used to monitor vegetation production for the purposes of mapping land degradation (Tucker et al. 1991, Prince et al. 1998, Diouf and Lambin 2001). Research projects were thus initiated to develop quantitative remote sensing based monitoring methods, mainly sponsored by the National Department of Agriculture. The objective of this paper is to review a number of methods and summarise their common challenges, limitations and ecological realities. This include (i) analysing the long-term growth season sum AVHRR and MODIS NDVI’s of degraded areas, (ii) calculating long-term trends in Rain-Use Efficiency (RUE), (iii) mapping vegetation production relative to spatially-derived estimates of production. The results of the Global Land Degradation Assessment in Drylands (GLADA) pilot study in SA are briefly reviewed and new studies using Lidar and hyperspectral data are introduced.

Background: Land degradation in South Africa

In South Africa, land degradation in rangelands has been regarded as a major environmental problem for many years. During the first half of the 20th century the topic was dominated by the “expanding Karoo” theory, which described the alleged expansion of semi-arid Karoo north-eastwards into the grasslands as a result of overgrazing by commercial sheep farmers (Acocks 1953). During the 1990’s an extensive reviews could find no evidence to support this theory.

The SA National Report on Land Degradation (NRLD), subsequently directed attention to severe land degradation in the former “homelands”, now communal areas (Hoffman et al. 1999, Hoffman and Ashwell 2001). The “homelands” or self-governing territories were established under the Natives Land Acts of 1913 and 1936 and during the apartheid-era, prior to majority rule in 1994, indigenous African people were involuntarily resettled and confined to these areas. Stable communities were uprooted and compelled to settle in areas where the unsustainable land use degraded the local resource base upon which their rural livelihoods depended. Today communal areas are generally characterized by high human populations, overgrazing, soil erosion, excessive wood harvesting and increases in unpalatable plant species (Hoffman et al. 1999, SADC-ELMS 1999). Most of large continuous areas of degradation mapped by the NLC using Landsat data occur within the communal areas.

AVHRR and MODIS NDVI of NLC mapped degraded areas

Degraded areas mapped the NLC were analysed using 1km AVHRR (1985-2003) and 500m MODIS (2000-2005) NDVI (growth season sum) data and compared to “non-degraded” adjacent areas within the same land capability units (LCU). The non-degraded areas had consistently higher vegetation production (average 12% AVHRR and 18% MODIS) despite a large variation in annual rainfall. This indicates that the degraded areas consistently produce less vegetation per unit of rainfall and suggests that they may have changed to a different ecological state (Wessels et al. 2004, Wessels et al. 2007a).

Rain-Use Efficiency trends

It has been proposed that Rain-Use Efficiency (RUE), the ratio of modelled Net Primary Productivity (or NDVI) to rainfall, should normalize the inter-annual variability in NPP and consequently provide an indicator of degradation that is independent of rainfall variability (Prince et al. 1998). Trends in RUE were analysed to identify new degradation. However, it was found that RUE was highly correlated with rainfall and did not provide an indicator of degradation which is independent of rainfall. Instead, the Residual Trends (RESTREND) method (Evans and Geerken 2004) was evaluated, which should provide more robust results.

Most of SA had positive residual trends, but areas in the arid Northern Cape and Limpopo province had negative trends, which show some agreement with the perception of experts on the rate of degradation per district reported in the

NRLD. In north-eastern SA, areas of negative RESTRENDS were associated with previously mapped degraded areas in communal areas (Wessels et al. 2007b).

It is important to note that remote sensing based monitoring methods can only detect changes that occurred within the time-series, and since the homelands were created as long ago as 1913 or 1936 much of the degradation could have occurred before the start of the satellite record in 1985 and may not have worsened since. This explains why all the degraded areas did not show continued negative trends.

Recent attempts to validate the RESTREND product by means of a helicopter survey provided positive results in some areas, but conflicting results in others. Changes through time can obviously not be validated without field observations at the beginning of the time-series.

Local NDVI scaling – spatially derived production potential

This study tested the Local NPP Scaling (LNS) method (Prince 2004), where the growth season sum NDVI (ΣNDVI), a surrogate for productivity, of each pixel is expressed relative to the highest values (90th percentile) observed in all pixels falling within the same biophysical land unit. The stratification by land units was used to normalize a significant portion of spatial variations in climate, soils and terrain. The premise of this method is that a reduction in vegetation production below the potential set by the biogeophysical conditions will provide an indicator of degraded areas (Prince 2004). The method has the advantage of providing an objective, repeatable measure of degradation that can vary continuously from non-degraded (LNS=100) to severely degraded (LNS=0).

Most of the areas with low LNS values persistently coincided with degraded areas mapped by the NLC, with the exception of four LCUs which either contained steep precipitation gradients or landscape variability which obscured the human impacts. The performance of the LNS method is therefore largely determined by the level of detail of the stratification data used (Wessels et al. in press).

Global Land Degradation Assessment in Drylands (GLADA) in SA

Within the GEF-UNEP-FAO program Land Degradation in Drylands (LADA), the Global Assessment of Land Degradation and Improvement (GLADA) strives to determine the trends of land degradation, identify areas suffering from severe degradation (or at severe risk) and also identify places where degradation has been arrested or reversed (FAO 2002). South Africa as one of the six LADA pilot countries was requested to evaluate the results from the GLADA assessment.

The FAO commissioned World Soil Information (ISRIC) to conduct analyses for GLADA. 8km AVHRR data and rainfall data from July 1981 to December 2003 were used to calculate trends in RUE. The analysis and products suffered from all deficiencies described above.

The GLADA map is currently being verified by the Department of Agriculture (DoA) by means of field surveys as well as the visual interpretation of SPOT 5 satellite data. The main challenge of this verification process is to try and distinguish between historical and recent (1981 – 2003) degradation. Initial results from this process indicate that the map contains substantial errors across the country. The verification process will be finalised in June 2008.

Conclusions

Known degraded areas consistently produce less vegetation (estimated with growth season sum AVHRR and MODIS NDVI) per unit of rainfall and suggests that they may have changed to a different ecological state. These areas nevertheless support a large number of livestock and results suggest that they are functionally stable and resilient and thus are not in danger of a catastrophic collapse as historically predicted (Wessels et al. 2004, Wessels et al. 2007a).

The RESTREND method can furthermore only identify areas which experience a reduction in production per unit rainfall, but the actual cause of this, whether it be degradation or natural processes, can not be determined by this method alone. Methods that identify negative trends in vegetation production through time can only detect degradation that occurred after the inception of satellite record in early 1980’s. The greatest challenge in mapping land degradation is therefore not estimating vegetation production from remote sensing data, but rather determining what the “non-degraded” vegetation production or reference condition for any parcel of land or pixel should be (Veron et al. 2006). Whenever the non-degraded production potential of a pixel can not be determined from the historical satellite record, it may be estimated spatially by using a reference area (e.g. (Boer and Puigdefabregas 2003). If the non-degraded, potential production of the land can be inferred, the condition of the rest of the land can be mapped relative to this potential (Prince 2004). The LNS method prodived positive results given suitable stratification data.

Methods that track trends in vegetation production per unit rainfall through time (Evans and Geerken 2004, Wessels et al. 2007b) and the LNS methods which maps low relative vegetation production through space are valuable quantitative methods for measuring land degradation at a regional scale. These methods should be applied as a regional indicator to identify potential problem areas that can then be closer investigated using additional remote sensing data and field data. The recent GLADA RUE trend results for SA, however, demonstrate that products should be interpreted with caution. The National Department of Agriculture is thus in the advanced stages of establishing a network of 2000 survey fixed sites to, amongst other functions, serve as validation sites for coarse resolution satellite data products.

New research efforts have been launched in collaboration with Stanford Universities, Carnegie Airbrone Observatory (CAO), which uses hyperspectral and lidar data to investigate vegetation and landscape structure along a land-use gradient from Kruger National Park to the adjacent communal rangelands. The high resolution data (<50cm) of vegetative, non-vegetative cover, tree cover and bare ground (Asner et al. 2003, Asner et al. 2004) can be used to calculate a “leakiness index” for assessing landscape function at a spatial scale that potentially matches that of the phenomenon (Ludwig et al. 2002, Ludwig et al. 2007). This will hopefully help us understand the fine-scale patterns and processes that are associated with the long-term, consistent reduction in vegetation production of degraded rangelands (Wessels et al. 2004, Wessels et al. 2007a).

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