MONITORING LAND CONDITION IN TROPICAL SAVANNAH RANGELANDS USING MODIS IMAGERY IN THE NORTHERN TERRITORY.

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ABSTRACT

Normalised Difference Vegetation Index (NDVI) satellite data derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor were used to generate time-series data for discrete landtypes in Northern Territory (NT) tropical savanna rangelands. Measures of vegetation flush were determined using area under the time-series curve for each growing season, and were regressed against the corresponding annual rainfall. Predicted values of flush for any given rainfall value were generated, allowing for variability in vegetation response related to rainfall. Quantile intervals were derived from the residuals and used to determine for a current season, whether the area of interest was behaving as expected given the amount of rainfall received. Residuals found to be outside the interval limits were deemed as having exhibited a response not explained by rainfall, assigned a respective rank and presented in both map format and as tabulated data. These products aim to assist existing land condition monitoring programs of the NT pastoral lands.

INTRODUCTION

There is an acknowledged demand for objective information regarding change within Australian rangelands. For the purpose of this study the definition of condition will be based upon landscape function, or the ability of the landscape to capture, retain and use natural resources (Tongway and Ludwig 1997). Monitoring of the rangelands exists as a means of providing information on condition, focussing on indicators that signal grazing disturbances within pastoral lands, or changes caused by livestock. Currently two monitoring programs exist in the NT: Tier 1 (field based sites only) and Tier 2 (Landsat imagery and field based sites). Despite intense data collection at these sites, there is a need to provide information at a larger spatial scale to encompass broader areas of the rangelands.

The Australian tropical savanna climate is characterised by two very different seasons: the ‘wet’ from November to April during which rainfall is prevalent and vegetation is green and experiencing vigorous growth, and the annual drought or the ‘dry’, from May to October when the vegetation senesces (Taylor and Tulloch 1985). Rainfall is acknowledged as being a major driver for vegetation response throughout rangeland environments and it is important to note that natural fluctuations in rainfall will affect the consequent vegetation response (Nicholson *et al.* 1990). The Bureau of Meteorology produces 5km national monthly rainfall grids which are used in this study to correlate with measured flushes of vegetation growth.

A typical restriction in remote sensing studies is the availability and cost of image data. In this study this was overcome by using moderate resolution 16-day composite MODIS satellite data which is freely available. The aim of this project was not to produce specific cover values for events in time, as NDVI is not appropriate for ‘snapshot’ analyses in these tropical savanna environments. Rather the changing vegetation function over time was measured, as NDVI has historically been used to capture the response of vegetation to rainfall in a measure of greenness.

Time-series analysis of NDVI satellite data describing vegetation response to the wet-dry cycle has been shown to provide seasonal information (Barbosa *et al.* 2006, Jönsson and Eklundh 2004). This is achieved by taking advantage of the annual greening during the wet and curing during the dry, producing a measurable flush. Jönsson and Eklundh (2004) developed a specific method for determining this flush by deriving the area under the curve (integral) for each growing season (Fig. 1). A smoothing filter is first applied to the time-series data from which the area under the curve is

derived. Two integrals are presented in Fig. 1, one measuring total vegetation production (large integral), or the area between the curve and zero level, the second integral representing the vegetation *flush* (small integral), or the area between the fitted function and the average of the start and end of the growing seasons (left and right minimums).
The study area for this project comprises the northern tropical savanna rangelands contained within the Victoria River District, Sturt Plateau and the Barkly district within the NT (Fig. 2).

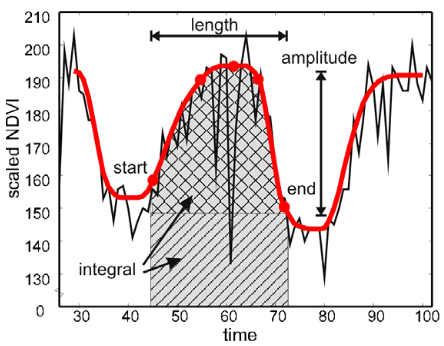

Fig. 1. Area under the curve (Jönsson and Eklundh 2004)

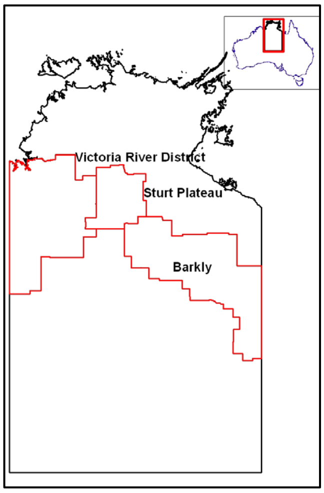

Fig. 2. Study Area

METHODS

Satellite data

The 250m 16-day composite MODIS datasets were acquired from both CSIRO Canberra and the NASA website http://modis.gsfc.nasa.gov, generating an archive spanning from July 2000 to December 2007. The NDVI, Enhanced Vegetation Index (EVI), Red and Near Infrared (NIR) bands from each 16-day dataset were extracted and clipped to the NT. A Modified Soil Adjusted Vegetation Index (MSAVI) image archive was derived from the Red and NIR bands according to Qi *et al.* (1994). The five bands were regressed against Tier 1 and Tier 2 ground cover measurements collected at the time of a satellite overpass to determine a suitable band choice for study within the project.

Rainfall data

National rainfall datasets were obtained from the Bureau of Meteorology and also clipped to the NT. A new dataset was generated using 12 month cumulative rainfall from July to June, providing annual rainfall values respective to each annual season from 2000-01 to 2006-07.

Data hierarchy

An hierarchical approach to data analysis was developed to increase the understanding of the time-series of image data. This was achieved by developing a new MODIS specific stratification product containing a set of landtype classes. The process used MODIS imagery together with ancillary datasets such as major vegetation and pasture types and mapped land systems. The stratification was applied to the data hierarchy, which comprised pastoral district, sub-districts (groups of properties), individual pastoral properties, and sub-property (paddock and discrete landtype areas).

Time-series analysis

A time-series plot of the mean NDVI values for each discrete landtype unit in each level of the hierarchy were produced (Fig. 3), and the area under the curve (vegetation flush) for each annual season extracted using the mathematical algorithms within Timesatseries (Jönsson and Eklundh 2004).

Predictive models

Using the smallest hierarchal stratification level (sub-property) the measured vegetation flush for all units in each landtype class, for each of the annual seasons were linearly regressed against the respective total rainfall value for that 12-month period. The two variables had to be first exponentially transformed to produce normalised results. This regression was then used to generate a predictive model (linear equation) for that particular landtype. Residuals (observed – predicted) were calculated and used to produce various quantile interval limits applied both above and below the predicted vegetation flush. For example the upper 90% limit is the value of the vegetation flush below which 90% of the observations fall, and lower 90% is the value of the flush above which 90% of the observations fall (see Fig. 4). The measured vegetation flushes of the current season of interest (in this case 2006-07) were extracted from the dataset and compared temporally using previously measured vegetation flushes for that polygon and spatially; across sub-properties, properties, regions and districts. The effects of fire were also noted as a possible explanation for an unexpected vegetation response. Those discrete areas falling outside the specified quantile limits were flagged via tabulated data and maps for further analysis.

Field data

Due to time constraints field data collection specific to this project was not possible, therefore relevant field data were collated from Tier 1 and Tier 2 databases.

RESULTS

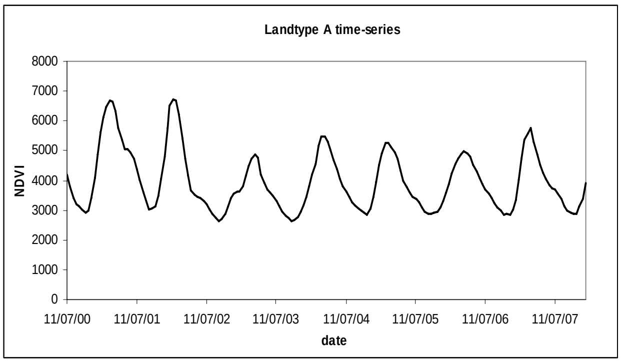

Fig. 3. Time-series of a discrete landtype. Area under the curve is measured for each season.

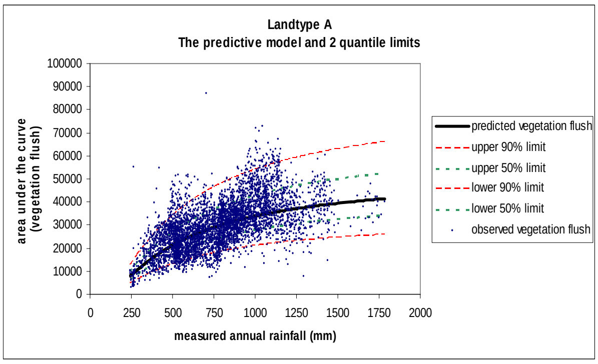

Fig. 4. Scatterplot describing the model data and quantile limits

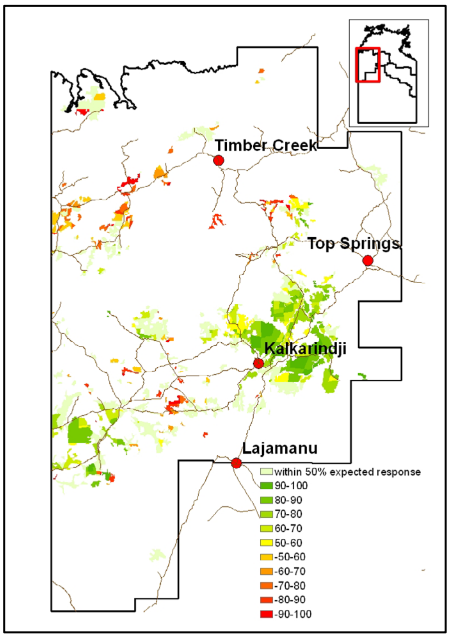

Fig. 5. Map output

Three indices (NDVI, EVI and MSAVI) and the Red band were initially considered. Previous studies have used the Red band as a surrogate for cover, however as the project's objective was to measure a greenness flush rather than discrete cover values (snapshots in time) the indices NDVI, MSAVI and EVI were deemed more appropriate. Correlation against historical ground cover data favoured the NDVI and MSAVI data in similar proportions over the EVI. Unlike the MSAVI which must be derived according to Qi *et al.* (1994), the NDVI is provided as a single band in the MODIS dataset and was therefore chosen due to benefits in reduced processing time.

Using predicted values and quantile limits such as shown in Fig. 4, observed measures from the season of interest were tested. Flushes falling in 10% intervals above and below the 50% mark were ranked accordingly, and for the purpose of this project considered to represent the degree by which the measured vegetation response is not explained by rainfall. This categorised rank is therefore judged as illustrating the landscape function for that discrete area; effectively a rank of condition relative to the model and not only describes those areas that have performed poorly but also those that have performed above what was expected.

The final output (Fig. 5) maps deviations from the modelled result, depicting how the vegetation condition or landscape functions of particular land type areas behave with respect to each other. Fire effects will be considered as potential influences for the deviation, and the data then intended for use in assisting existing monitoring programs within the NT.

DISCUSSION

This project describes how the condition of discrete landtype areas are trending compared with other locations in space and time. The methodology has been developed as a series of automated processes, allowing the end user to quickly and easily test a new season's data and/or update the predictive model. A future endeavour to improve the initial predictive model might be to selectively choose discrete areas that have known historical condition and land management practices, and to remove any areas of suspect nature using local knowledge and/or ancillary datasets such as bore locations. Ideally the model would use a repeated measures analysis to produce this regression model, to take into account the multiple measures of vegetation flush for each discrete area in the dataset. More accurate models could also be generated using discrete datasets according to hierarchal levels so taking into account the rainfall gradient and produce more realistic predictions of areas in certain localities.

One restriction this project encountered was the limited historical image data available. MODIS imagery only began production in early 2000 and seven years of data is not ideal for use in the production of robust models. A recommendation is therefore to test the applicability of 1km Advanced Very High Resolution Radiometer (AVHRR) NDVI to derive the model.

The original intention was to use Bidirectional Reflectance Distribution Function (BRDF) to reduce the illumination effects of sun angle on the vegetation reflectance, thus gaining a more accurate depiction of vegetation response. However BRDF-corrected 250m products are not currently available so must be independently derived; another future recommendation arising from this project.

At the time of writing a full accuracy assessment of the product output had not been completed, however the project aims to use field measurements of Tier 1 monitoring sites that occur within the highlighted areas. An additional proposal is to derive a method for scaling up ground data to MODIS satellite data, thus producing a relationship between vegetation cover and vegetation flush.

The map and tabulated output will be accompanied with the recommendation that those flagged areas are more thoroughly investigated using finer resolution (e.g. ground data) information.

This project was undertaken from 2007 to mid 2008 and complements a separate methodology related to the southern rangelands (Barnetson & Allan 2008), forming part of a Territory wide investigation into the use MODIS imagery as a monitoring tool.

ACKNOWLEDGEMENTS

The authors are grateful to the National Heritage Trust for financing the project, and to the following of people for their assistance Gary Bastin (CSIRO), Kathleen Richardson (NRETA), Grant Allan and Brett Murphy (Bushfires NT) and Ian Fox (NRETA).

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