

# **ANALYSING BIOMASS FLUCTUATIONS IN MITCHELL GRASSLAND, AUSTRALIA, IN WET and DRY RAINY MONTHS USING MODIS DATA**

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## **ABSTRACT**

The variation in grassland greenery in rainy months is a critical factor for the large farming community in Queensland, Australia. This study examined the changes in plant biomass due to fluctuations in total rainfall during the wet season on Mitchell Grassland in north central Queensland, using MODIS imagery and precipitation records of extreme events. Though NDVI is a well documented tool to observe grassland greenness, its behaviour for fluctuating wet season is worth to analyse. The present research focused on generating descriptive statistics of NDVI values, analysis of profile transects, and pixel-based image differencing of the two extreme rainfall conditions; extremely high and low November to January rainy months. The results indicated that MODIS NDVI data have captured the variation and spatial distribution of green biomass of Mitchell grassland under these two extreme precipitation events. Also the results of the study showed efficient use of NDVI to estimate the greenness or health of the grassland. The approach has a potential to use as a monitoring tool to assess the quality of the grassland, which is important for farming activities of the region. However, further works are needed to study biomass conditions under intermediate precipitation events and over larger area to efficiently link rainfall amounts with NDVI values.

## **BACKGROUND**

Since late 1990s, satellite data from MODIS sensor (Moderate Resolution Imaging Spectrometer) (Barnes et al, 2003) became widely available for the scientific community. MODIS is currently operating on-board the EOS Terra and Aqua spacecraft, launched in December 1999 and May 2002, respectively (Xiong et al, 2009). Various aspects of earth surface were investigated with medium resolution MODIS data including land cover mapping and clarifying land cover status (Friedl et al., 2002; Price, 2003; Zhan et al., 2002; Perera and Tsuchiya, 2009). The MODIS data products such as Normalised Difference Vegetation Index (NDVI) (USGS, 2007) and spectral band data (NASA, 2009; Gumley et al., 2003) are freely available through NASA for the research community. When dealing with large and homogenous land cover types like grasslands, forest, deserts, or extensive farming areas, MODIS 250m resolution data products are becoming a vital research tool.

In Australia, a number of studies used AVHRR and MODIS products to assess ecosystems and calculate pasture growth rate (PGR), which showed advantages in defining classes and subgroups, limitations faced due to the land mass size and dynamics, and merits in modelling based on modified NDVI calculations (Hill et al., 2004, 2006). In the United States, vegetation indices calculated from MODIS imagery were used to analyse multi-temporal character in crops (Wardlow et al, 2007). The relationship between climate and greenness of land surface has also appeared in many studies (Kaurivi et al, 2003; Deng et al, 2007; Ordoyne and Friedl, 2008). The aim of the present study was to conduct a detail analysis of

changes on greenness in Mitchell grasses due to fluctuating precipitation in November to January rainy months.

## THE MITCHELL GRASSLAND

Mitchell Grass (*Astrebla spp.*), which is a native species to Australia, covers a huge region called Mitchell Grass Downs (335, 332 square kilometres) in central Queensland and Northern Territory of Australia (figure 1). About 72% of this grassland falls within Queensland where extensive cattle and sheep farming are taking place. Mitchell grass is the primary feeding sources for about 12 million cattle in the state. Figure 2 presents a typical view of the Mitchell Grassland from an area closer to Hughenden.

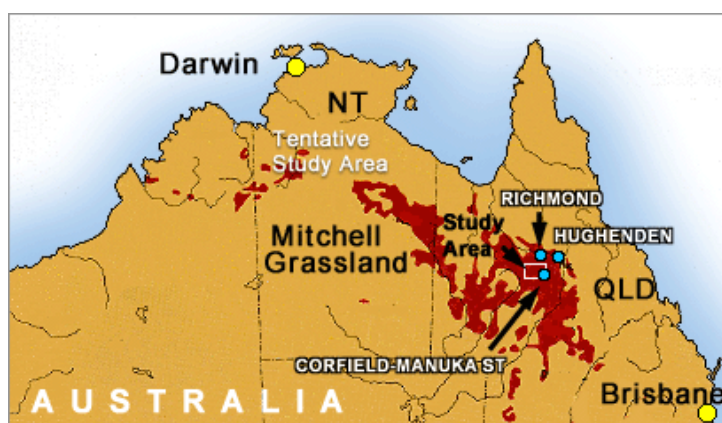


Figure 1. Study area and the location of Mitchell Grassland.



Figure 2. The vast Mitchell grasslands near Hughenden (photos acquired in January 2007).

Researchers found a significant overall reduction of Mitchell grasses in long dry-spell recorded after the heavy rainy season in 1989 (Land and Water, Australia, 2006). Mitchell grass is considerably tolerant to changing weather conditions; however, longer dry-spells and over-grazing often damage its life cycle. Because of that, light to moderate grazing practises are helping to restore the mature grass (DPI&F Note, 2005). The sustainability of this Mitchell Grass Downs is the key to assure an efficient farming product chain, as well as to manage healthy fauna environment in grassland ecosystem. However, investigating this vast region at regular basis is a time-consuming and costly exercise. MODIS satellite imagery can provide a valuable monitoring capability, with its daily revisit capability and moderate resolution, multi-spectral data products.

## STUDY AREA AND DATA ACQUISITION

By the end of 2008, northern Queensland experienced heavy rainfall associated with floods. The prime idea for the present study came after observing this extreme precipitation event. As historical precipitation records indicate, Mitchell Grass Downs faces vigorous fluctuations in rainfall even within wet season. The present research analysed November to January (early months of the rainy season) rainfall data to examine this wet season character. The graph in figure 3 presents the Nov-Jan rainfall totals for one of the oldest weather stations (Hughenden Post Office – No. 30024) in Queensland. Due to lack of continuous data in recent years, data from 2001 to 2009 have been replaced by Hughenden Air port data, a recently started observatory, only 4km away from the Hughenden Post office. The precipitation totals for the three months has a wide range (from 20.4mm to 744.2mm) during the period.

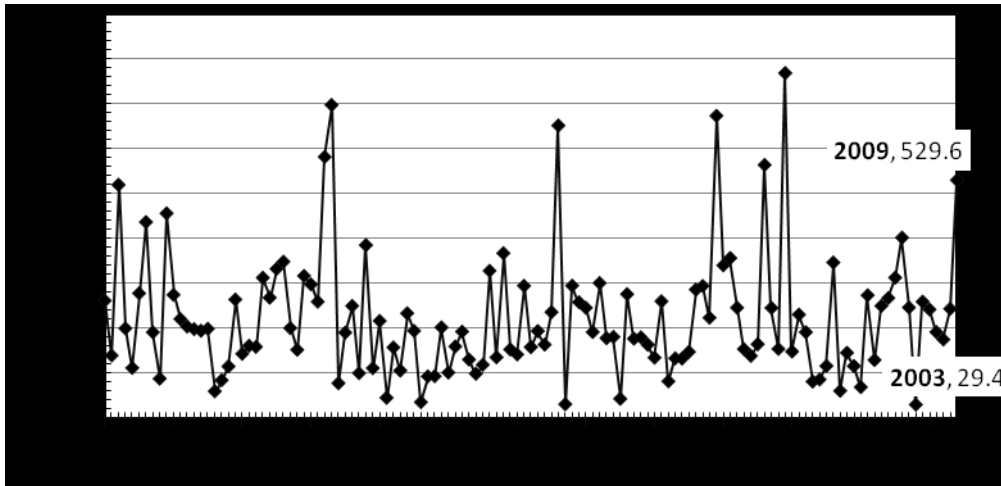


Figure 3. Total of Nov, Dec, Jan rainfall since 1884 to 2009 at Hughenden Station.

The latest heavy rainfall in Nov-Jan was recorded in 2008/2009, which was unusually high for the last 25 years and exceeded the national weather bureau forecast (Bureau of Meteorology, 2009). This event prompted to investigate Mitchell grassland area just after Nov-Jan three months to estimate greenness with a weak Nov-Jan wet season. The study used highest (529.6) and lowest (29.4mm) rainfall totals recorded for Nov-Jan three months after 2000, since when MODIS satellite data became available for research community (see figure 3).

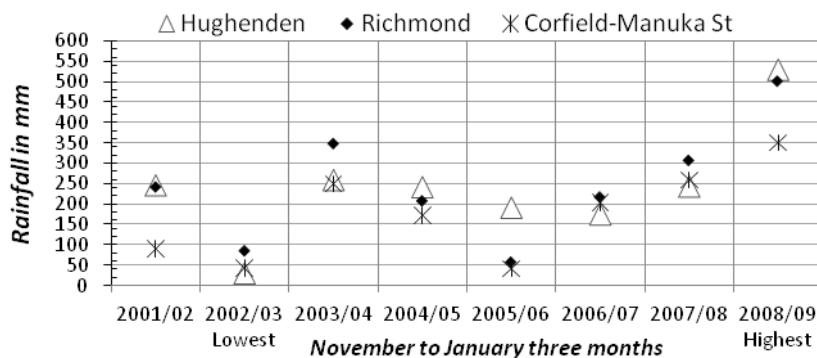


Figure 4. Precipitation totals of Nov-Dec-Jan time durations from 2001/02.

To justify this selection, precipitation data from two observatories closer to Hughenden, Richmond (No. 30045) and Corfield-Manuka St (No. 37081) (see locations in figure 1) were also checked. The total amounts of rainfall for all three locations within Nov-Jan have

recorded lowest in 2002/03 and highest in 2008/09. The data are plotted in figure 4 to show the variation of these extreme incidents. The changes in greenness of Mitchell Grassland when these extreme rainfall events occur within wet season are important to examine, since biomass production of the grassland is directly related to the management of farm animals. Two MODIS data sets were collected at the end of these three-month time blocks, with respect to the selected two extreme precipitation incidents. In this case, it is important to emphasise that the lowest three-month block (2002/03) also recorded a considerable rainfall, when compared to typical dry month. As an example, for seven months from April to October 2002, Hughenden airport observatory recorded only 7.8mm precipitation.

## DATA PROCESSING AND ANALYSIS

The present study combined the multi-temporal character and daily coverage capability of MODIS which permit selected data to match with precipitation events. After observing daily MODIS data over Northern Queensland for the first 10 days of February (days followed by three-month duration), images dated 05<sup>th</sup> February 2003 and 5<sup>th</sup> February 2009 were selected (WIST, 2009). NASA provides these data after correcting geometric and radiometric errors, making the data is suitable for scientific research. Low-level MODIS data are corrected for atmospheric gases and aerosols, yielding a level-2 basis for several higher-order gridded level-2 (L2G) and level-3 products. Although there may be later improved versions, these data are ready for use in scientific publications (USGS-LPDCCA, 2008).

Based on field investigations in Hughenden and Richmond in 2007, a study area was selected with the size of 800 pixels by 400 pixels (20,000 square kilometres). Most of the area is dominated by Mitchell grass but the southwest corner has a forest cover, where some soil patches were also visible. The area with these contrasting land cover types was selected to analyse the response of perennial trees and grasses under fluctuating precipitation conditions. The study area completely falls within the 400-500mm annual rainfall region of Australia (Australian Natural Resources Atlas, 2009); therefore, we assumed that the weather records collected from the three stations are reasonably representative.

NDVI is the most widely utilised vegetation index and it represents the plant photosynthesis efficiency which is directly related to the plant biomass (Houts et al, 2001). The time when vegetation emerges each year can be monitored using remotely sensed data obtained from Earth observation satellites. This measurement, called the onset of greenness, can be calculated using time series data sets of the Normalized Difference Vegetation Index (NDVI), a ratio of red and near infra-red (NIR) light that is strongly correlated to plant biomass (Houts et al, 2001).

When the area is wide and contains homogenous land cover type, researchers have found both NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index) are producing similar seasonal variations highly correlated for grass like crops (Wardlow et al., 2007). Also, the selected image portion in this study contains no snow, sand dunes, or large cloud patches to distract vegetation index calculation (Nascom., 2006). Therefore, NDVI was selected as a suitable candidate to conduct image analysis to extract plant biomass characters in Mitchell grassland. Image processing was conducted using ENVI 4.4 software package, after installing MODIS conversion toolkit into it to convert MODIS HDF file format. NDVI for both images were computed using MODIS Band 01 and Band 02 data as in equation [1]: where  $\rho_{NIR}$  (846-885 nm) and  $\rho_{red}$  (600-680 nm) are the bidirectional surface reflectance for the respective MODIS bands.

$$\text{NDVI} = \frac{NIR - Red}{NIR + Red} \quad [1]$$

After generating descriptive NDVI values, we comparatively analysed pixel-based image differencing results of the two extreme rainfall conditions, the NDVI values of 100% grass only image plot and the two horizontal profiles to examine spectral responses in different land cover types. The 2003 NDVI data values were subtracted from the 2009 NDVI to evaluate the quantitative differences in increases or decreases of greenness in the 2009 image.

## RESULTS AND DISCUSSION

Quantification of land resources may range from simple area calculations to produce biomass amounts in tn/yr (Reeves, 2001; Chen et al, 2002). Precise assessments in biomass quantity as well as trends in biomass of the grassland are important for the sustainable management of the region. In the present study, histograms and area under different NDVI values, two random west-east profiles over NDVI images, a grass-only plot, and descriptive statistics of NDVI images were analysed to estimate the changes in greenness of the grassland.

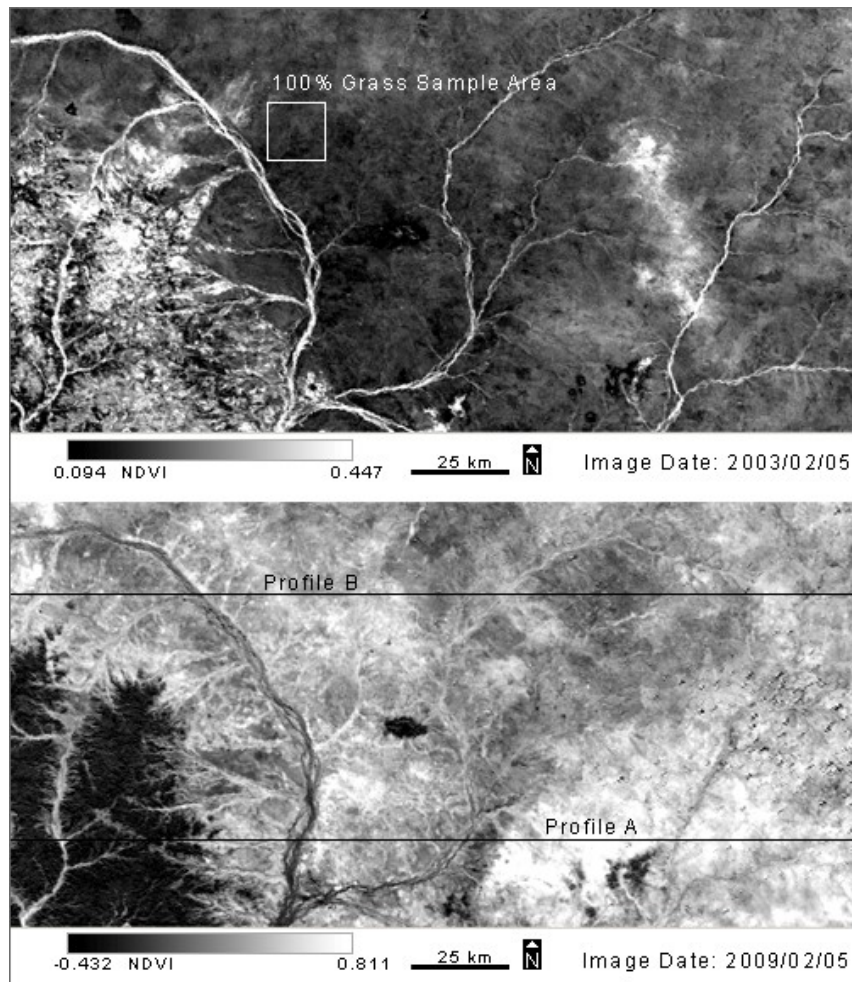


Figure 5. NDVI products calculated from 2003 and 2009 MODIS band 1 and band 2 data (The randomly selected Profiles A and B were used in the analysis).

Based on the NDVI images of the study area, a clear improvement in greenness of the grassland can be observed even visually. In figure 5, Bright white to gray areas are representing higher NDVI or greener pixels. In 2003, riparian vegetation along the rivers is clearly visible among relatively dry Mitchell grass. But in the 2009 heavy precipitation season, high NDVI values of these trees along rivers have disappeared among the greener grass. All NDVI values were less than 0.447 in 2003 image while 2009 image recorded values as high as 0.81 ( $-1 < \text{NDVI} < 1$  and values closer to 1 is greener). Changes of the greenness is directly related to the precipitation, hence, quantitative relationship between precipitation-greenness has examined. As figure 5 shows, NDVI images gave clear evidence of significant difference in biomass with respect to each extreme precipitation event. Figure 6 presents histograms of NDVI at lowest (2002/03) and highest precipitation (2008/09) events. Under the assumption of bulk area covered by grass, the biomass increase can be explained by the rightward shift of the curve, as a result of heavy rains. The noise around the NDVI 0.20 in 2003 graph presents the impact of open soil patches within grassland in 2003 weak wet season. By heavy rains in 2009, these temporary openings have been covered by grass.

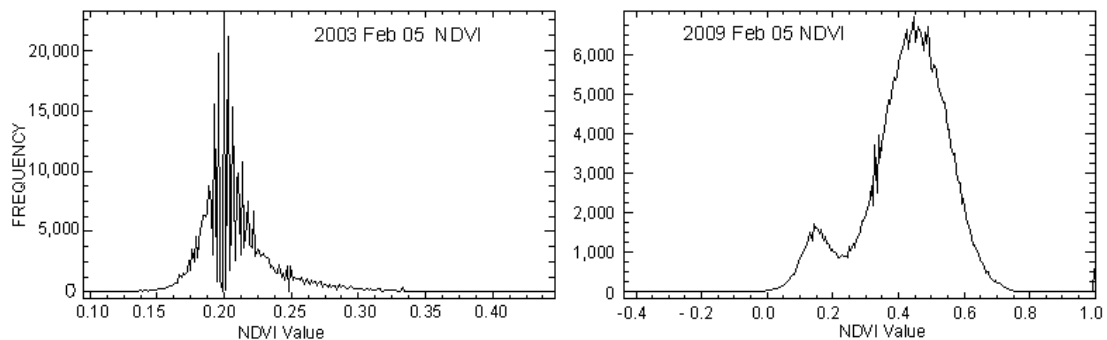


Figure 6. Histograms of NDVI values of 2003 and 2009.

The values of NDVI images indicated only 1.4% of area had 0.3 NDVI or higher values in 2003 against the 85.3% (1.706 million ha) in 2009. Furthermore, as the change detection calculation (2003 image subtracted from 2009 image) showed, 90.9% of the area had higher levels of NDVI (light to dark green in figure 7).

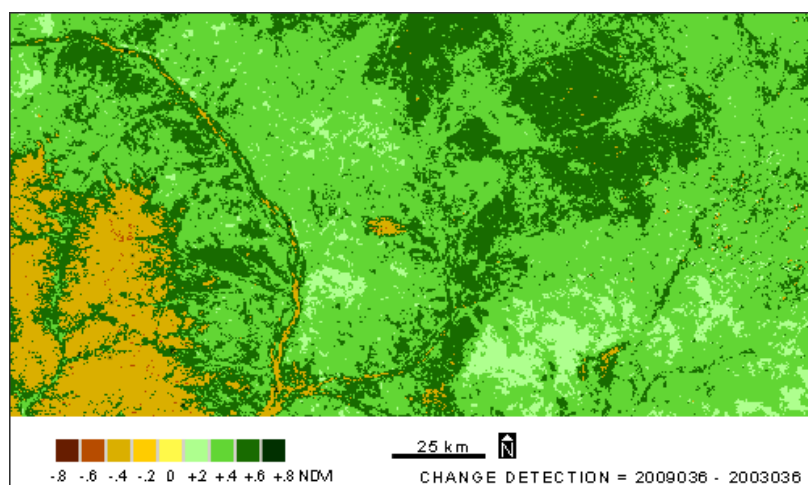


Figure 7. Change detection between 2003 and 2009 NDVI images.

To examine precisely the NDVI values in grassland, a small grass-only pocket was isolated (see the location in figure 5) and compared it against both precipitation incidents. Results

showed a solid increase of greenness in this grass-only plot, from 0.190 mean value of NDVI in 2003 to 0.508 in 2009. NDVI statistics in table 1 show very low standard deviation and mean values in 2003 grass-only plot due to dry conditions. The very low mean value indicates, even the rainfall is significantly higher than dry seasons, the low rainfall in wet season is not strong enough to produce enough greenness. Heavy rains have increased the NDVI values in 2009, representing dynamic photosynthesis conditions in the grassland.

Table 1. Basic descriptive statistics of NDVI images.

NDVI Product	Min	Maximum	Mean	STDEV
2003_NDVI	0.095	0.448	0.21	0.029
2009_NDVI	0.438	0.811	0.428	0.134
2003_grass_only plot	0.154	0.241	0.190	0.011
2009_grass_only plot	0.176	0.682	0.508	0.057

The conditions of the grassland under each precipitation incident was further analysed using NDVI profile transects A and B, (figure 5). The NDVI values along these two profile lines are plotted in figure 8 graphs. Both profiles against 2003 image show very low deviation of NDVI values from the mean, 0.208 in A and 0.209 in B. Profiles of 2009 exhibit higher values, 0.448 and 0.439 for A and B, respectively. In profile A, values in the southwest corner of the image show lower NDVI values in low and high rainy seasons compared to other parts of the profile. This is mainly due to the sharp changes in land cover. The region dominated by Mitchell Grass, but, this southwest corner of the study area has highly irregular land cover pattern including soils, sand, rocks in mountains, riparian forests, and savanna type lands. A high resolution DigitalGlobe image portion of a selected spot (22 11 54.84 S, 141 57 13.58 E) on profile A, accompanied in figure 8, shows some of these land cover types. The sharp rise near pixel number 50 in Profile A, in 2009, shows lush riparian forests, but other areas are closer to 0.2 NDVI, which represents dry grasslands with occasional trees and open soil/sand patches.

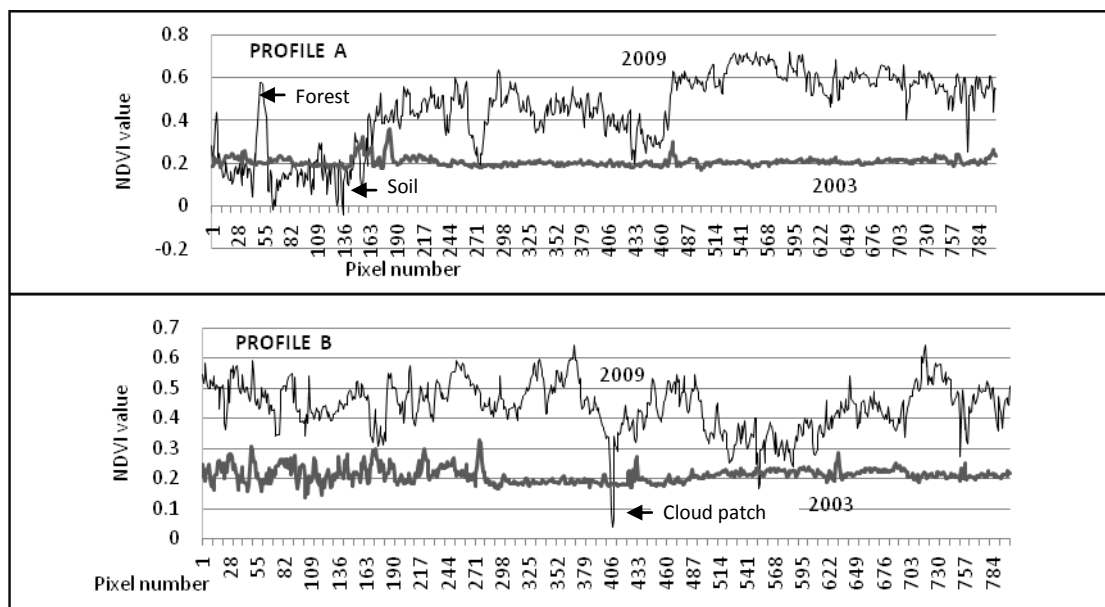




Figure 8. NDVI values of crossing pixels of profile line A and B (see profiles figure 5) with respect to 2003 and 2009 rainfall events are plotted here. The satellite image below the graphs represents the spot marked as forest in profile A. In the image, R = riparian forest, SV= savanna, and SD = sand/soil

On the other hand, during the very high rainy season, other vegetation types may outgrow weaker spots in Mitchell grass caused by the drought and over-grazing. A research team found that forest cover within Northern Territory Mitchell Grassland has increased from 0.07% in 1991 to 0.14% in 2004 (Land and Water, Australia, 2006). However, the highly drought-tolerant inherent Mitchell grass has a higher possibility to survive in droughts and can regrow rapidly through seed germination within few good summer rainy seasons. This finding would be useful to isolate grassland dynamics in future studies. Particularly, NDVI responses to fluctuations in wet season can be linked to establish a threshold to use in grazing practises. Here, further research is needed to obtain NDVI values responding to intermediate rainfall occurrences.

## CONCLUSIONS

Assessing the health of Mitchell grassland has environmental and economical advantages, due to its vast land area and agricultural dependency in Queensland and Northern Territory. Evaluating the greenness of the grassland is the key to characterising and quantifying biomass. Historical precipitation records for November to January three-month block of Hughenden region are showing very high fluctuations. Under the assumption of positive relationship between rainfall and plant greenness, extremely low (2002/03) and high (2008/09) precipitation incidents of November to January early wet season were used to acquire MODIS data. The results of MODIS data analysis for each precipitation incident indicated significant variation in NDVI. In 2003 image, only 1.4% of the study area had greener NDVI values (higher than 0.3), but under high rainfall in 2009, the figure became 85.3%. In the change detection calculation, 90.9% of the area had higher NDVI values in 2009 compared to 2003. Although Mitchell grass is highly tolerant to dry weather, satellite imagery based results clearly showed weaker conditions under low rainfall and a tremendous increase of greenness under high rainfall. Future research work would consist of studying biomass under intermediate precipitation conditions, as well as detailed image analysis, to establish a rainfall responsive threshold to use in grazing practises in Mitchell Grassland.

## ACKNOWLEDGMENTS

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## **BRIEF BIOGRAPHY OF PRESENTER**

Kithsiri Perera received his bachelor's degree from University of Colombo, Sri Lanka, in 1984 and M Eng (1992) and PhD (1995) from Chiba University, Japan, both in remote sensing and GIS. He gained over 12 years of industrial experiences mainly in Tokyo and later in Brisbane. Kithsiri has a sound record of research activities conducted with the UN University, Tokyo, Japan Science Council, and CEReS, Chiba University. He has university level teaching experiences in Sri Lanka, Japan, and Australia and currently working at faculty of Engineering and Surveying, University of Southern Queensland, as a research and teaching fellow. Kithsiri's research interests are in of remote sensing (mapping land cover, land use, and catchment area mapping) and GIS (predictive mapping, disaster management).