THE QUEENSLAND GROUND COVER MONITORING PROGRAM

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KEY WORDS: Vegetation, Land Cover, Mapping, Landsat, Landscape, Multitemporal

ABSTRACT:

Ground cover plays an important role in Australia's environmental, agricultural and economic sustainability. It is effective in reducing the loss of sediments through wind and water erosion and supports a diverse range of biodiversity. The Queensland Remote Sensing Centre (RSC) in the Queensland Government has an established ground cover monitoring program. The Queensland Ground Cover Monitoring Program (QGCMP) uses satellite imagery and field data to research and develop state-wide, regional and local ground cover mapping and monitoring products. The products support government legislation, conservation efforts and land management initiatives. The QGCMP is based on the extensive archives and processing streams for Landsat and other imagery. The Program developed the Ground Cover Index (GCI) which uses ~25 years of Landsat TM/ETM+ imagery and field data to quantify ground cover levels. The resultant index was applied across Queensland with an RMSE of 12.9%. Subsequent additions and improvements to the QGCMP have included: establishment of a supporting field monitoring program including research of new field-based technologies; development of new unmixing algorithms for fractional vegetation cover; research and development of systems and methods for time-series analysis for more regular monitoring; and, cross-calibrations between sensors for deriving and modelling biomass and other ground cover metrics. This paper outlines some of the research undertaken and products developed for the QGCMP and discusses the application of the products in key state and federal government policies and initiatives.

1. INTRODUCTION

1.1 The importance of ground cover

Ground cover is the non-woody vegetation (forbs, grasses and herbs), litter, cryptogamic crusts and rock in contact with the soil surface (Muir et al., 2011). Ground cover levels are the result of complex interactions between landscape function, climate and land management (Dube and Pickup, 2001). Some areas support naturally higher levels of ground cover due to factors such as high soil fertility and consistently high annual rainfall. Ground cover has an important role in Australia's environmental, agricultural and economic sustainability. It is effective in reducing the loss of sediments through wind and water erosion (e.g. Leys et al., 2009; Bartley et al. 2010). Ground cover supports a diverse range of biodiversity, provides fuel to Australia's complex fire regimes, and is a fundamental component of Australia's pastoral and cropping industries (e.g. Burrows et al., 1990; Bradstock et al., 2002; McCosker et al., 2009; Moss et al., 2012).

1.2 Remote sensing of ground cover in Queensland and Australia

A range of methods and approaches have been developed for mapping and monitoring ground cover in Australia. Each of these derives different estimates of ground cover due to what they measure and the temporal and spatial scale at which they operate. Pickup et al. (1993) developed a vegetation cover index using Landsat MSS imagery (Bands 4 and 5) for Australian rangeland environments. Henry et al. (2002) developed a multi-sensor approach to monitor pasture productivity in Australia's southern temperate grassland environments. Their approach uses empirical pasture data and the Normalised Difference Vegetation Index (NDVI) to calibrate models for Landsat and SPOT imagery to estimate 'feed on offer'. A pasture growth rate model is also applied which uses NDVI derived from AVHRR and MODIS data, as well as climate data. Scarth et al. (2006) developed the Ground Cover Index (GCI) for application in Queensland. The GCI uses 20 years of Landsat TM/ETM+ imagery to quantify ground cover levels based on reflectance of bare ground in bands 3, 5 and 7, calibrated to extensive field-based measurements. The resultant index was applied across Queensland with an RMSE prediction error of 12.9%. Milne et al. (2007) used the GCI to cross-calibrate to MODIS imagery for deriving ground cover for 8-day and 16-day composites at 500m and 1km resolution, respectively. The ground cover measurements derived were then used to estimate biomass as a measure of pasture productivity. Donohue et al. (2008) produced monthly vegetation cover estimates based on a relative reflectance calibration technique that assumes that the position of the vegetation cover triangle is invariant in reflectance space. This technique has been applied nationally to AVHRR data at approximately 1km resolution. Guerschman et al. (2009) used spectral libraries of fractional ground cover derived from field measurements and EO-1 Hyperion hyperspectral imagery to explore the spectral response space to derive fractional cover endmembers. These were used along with the NDVI and the Cellulose Absorption Index (CAI) in a linear mixture approach. The approach is applied to daily MODIS imagery at 500m resolution (coincident with the Hyperion imagery) and then to six years of the MODIS 16-day composites at 1km resolution to resolve quantitative estimates of photosynthetic vegetation (PV), non-photosynthetic

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vegetation (NPV) and bare soil. More recently, this approach has been re-calibrated using additional field data and applied to MODIS 8-day composites at 500m resolution for the entire Australian continent. Lymburner et al. (2011) have developed an approach which uses time-series analysis of the Enhanced Vegetation Index (EVI) derived from MODIS 250m data to map and monitor land cover for Australia. More recently, following the release by the United States Geological Survey and NASA of cost-free imagery from the Landsat archive, Scarth et al. (2010) and Schmidt et al. (2010) have developed new methods for estimating vegetation cover fractions based on all available Landsat 5 TM and Landsat 7 ETM+ imagery. This research is being undertaken as part of the Queensland Ground Cover Monitoring Program and will be discussed further in this paper.

1.3 The Queensland Ground Cover Monitoring Program

The Queensland Government's Remote Sensing Centre (RSC) has an established ground cover monitoring program (Danaher et al., 2010). The program is operated in partnership with the Joint Remote Sensing Research Program (JRSRP) (www.gpem.uq.edu.au/jrsrp), the Terrestrial Ecosystem Research Network's (TERN) Auscover facility (www.auscover.org.au) , and the Australian Collaborative Land Use and Management Program (ACLUMP) (www.adl.brs.gov.au/landuse). Many other state, national and international research and policy partners contribute to the program. The program uses satellite imagery and field data to research and develop state-wide, regional and local ground cover mapping and monitoring products in support of government legislation, conservation and land management initiatives.

This paper will present some of the research undertaken for the Queensland Ground Cover Monitoring Program (QGCMP) and discuss the products and their application and implementation for key state and federal government policies and initiatives.

2. METHODS

2.1 Data management and image pre-processing

The QGCMP is supported by high performance computing infrastructure for the storage, maintenance, processing and analysis of imagery and related data sources. The image archive includes over 33,000 Landsat images for Queensland and Australia, sourced from Geoscience Australia's National Earth Observation Group (NEOG) and, more recently, from the United States Geological Survey (USGS). This archive of Landsat imagery forms the primary basis of the QGCMP. Other imagery in the archive includes MODIS, SPOT 4 and 5, IKONOS, Quickbird, LiDAR, ALOS PALSAR, IceSAT, and aerial photography. Image archiving and processing is primarily based around in-house programming, utilising open source development environments (Trevithick et al., 2010). Image pre-processing and corrections are based on extensive collaborative research efforts, with particular consideration given to environmental conditions in Queensland and Australia (e.g. Danaher et al., 2002; Gill et al., 2010; Gillingham et al., 2012). Recent comparisons of the corrections applied to Landsat 5 and 7 imagery by the USGS and RSC has shown negligible differences in the resultant reflectance and geometric registration. Cloud and cloud shadow masking is implemented via a utility which calls masks derived from either a time-series method (Goodwin et al., 2011), an adaptation of the *fmask* method described by Zhu and Woodcock (2012), or a manually-applied threshold and editing approach. Water masking is based on Danaher et al. (2006).

2.2 Field data program

The QGCMP is supported by a field monitoring program which aims to collate and collect quantitative data about ground cover from the range of environments in Queensland and Australia. The data collected is used for calibration and validation of the models used to estimate ground cover. The primary method for field data collection is based on a modified point-transect approach (Scarth et al., 2006) to measure the ground cover fractions (i.e. green, non-green vegetation cover and bare ground/rock) for a 1ha site. The approach has been adopted as the national standard for collection of ground cover data (Muir et al., 2011). Over 1000 sites from across the continent are currently stored in an SQL database which is linked with the image archive and processing systems. Over 800 of these sites are from Queensland (Figure 1).

The QGCMP field data collection program also undertakes research and development of new field monitoring techniques for measuring ground cover and for better quantifying error and uncertainty in field-based measurements. This includes, for example, establishing monthly monitoring sites for improved development of time-series products. In collaboration with research partners, we are also investigating methods for use of hemispherical photography and terrestrial laser scanning to improve objectivity and efficiency in the field. In a recent study, Trevithick et al. (2012) investigated the issue of data consistency between operators with different levels of experience using the modified point-transect approach. They found that the method is repeatable, however some inexperienced operators confused different ground cover fractions, particularly the green and non-green components.

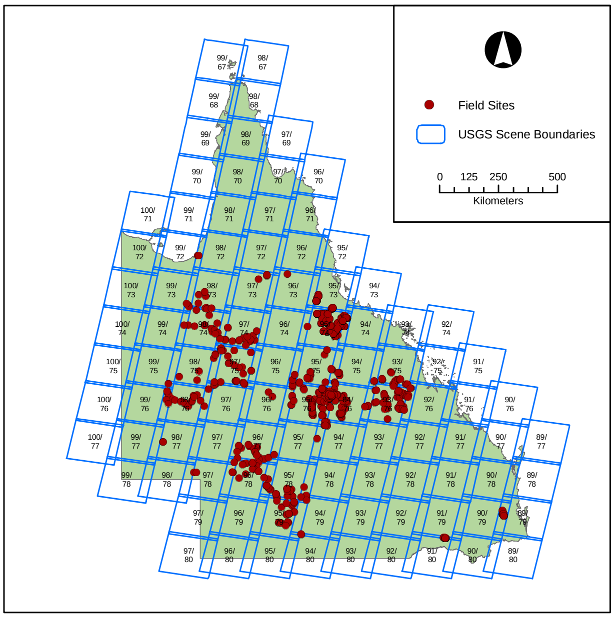

Figure 1. Ground cover field site locations in Queensland. Some sites have repeat measurements.

2.3 The Ground Cover Index (GCI)

In recent years, ground cover monitoring and mapping for the QGCMP has been based on the GCI. The GCI was developed by Scarth et al. (2006) based on earlier methods developed by Danaher et al. (2004) for estimating Foliage Projective Cover (FPC) in Queensland, in support of vegetation management legislation. The GCI uses multiple linear regression applied to Bands 3, 5 and 7 in Landsat TM and ETM+ imagery and quantitative field data, originally from over 400 sites. The GCI estimates, per pixel, the percentage of bare ground. This is then converted to an estimate of cover by subtracting the percentage of bare ground from 100. The RMSE of the model is 12.9%, with the greatest error in the mid-range of cover/bare ground. Estimating ground cover levels in areas of woody vegetation cover becomes increasingly inaccurate at a level of FPC of around 15% or greater. This is due to the influence on reflectance from the mid- and upper-strata of vegetation. Therefore, products derived using the GCI have only been produced for areas with less than 15% FPC. Until recently, the GCI has been applied to annual, late dry season Landsat TM and ETM+ imagery from 1986 to present.

2.4 Improving on the GCI - Fractional ground cover models

As previously mentioned, RSC and collaborative partners have been undertaking research and development of new approaches for improving estimates of ground cover fractions in support of the QGCMP. Two methods have been developed for estimating ground cover fractions using all available Landsat TM/ETM+ imagery and quantitative field data. These methods incorporate earlier work by RSC researchers and use the quantitative field data archive held by the RSC for calibration. Schmidt et al. (2010) have developed a model based on multinomial logistic regression while Scarth et al. (2010) use a linear spectral unmixing model. Both models provide estimates of the green (photosynthetic) and non-green (non-photosynthetic) cover fractions and bare ground (including rock). The models have been calibrated for application across Queensland. Overall RMSE for the two models for total cover are 14.9% (Schmidt et al., 2010) and 11.0% (Scarth, et al., 2010). A comparison showed little difference between the two models for estimates of all three cover fractions (Schmidt et al., 2010). However, the linear spectral unmixing model, with a lower overall RMSE and with less bias, is considered to perform better across the range of environments in Queensland. This approach has therefore been chosen to replace the GCI for operational monitoring of ground cover in Queensland.

In a further development, Scarth et al (2010) have developed an approach based on analysis of the green cover fraction trend in a time-series to identify the perennial component of the vegetation. Research is presently being undertaken using FPC derived from field measurements and airborne LiDAR to determine if this perennial green component provides an accurate estimate of woody vegetation. A potential advantage is that once the perennial wooded component is identified and removed, it can be assumed that the variable herbaceous and graminoid understorey component remains. It is expected that this will provide for improved estimates of ground cover in forested and woodland environments.

2.5 Ground cover products

A range of products are produced by the QGCMP. These are all derived for the entire state and some are also produced for NSW and other states and territories in Australia.

2.5.1 Individual-date products

The GCI has been used for operational production of ground cover products in Queensland. Standard products have been based on applying the GCI to individual-date, annual, predominantly late dry season Landsat TM and ETM+ imagery. The current approach is to apply the fractional ground cover method of Scarth et al. (2010) to the RSC's archive of Landsat TM and ETM+ imagery using an automated overnight batch queue function. Masking is applied for areas of water, cloud, cloud shadow, and where FPC >15%. The products are produced for individual Landsat scene areas and state-wide mosaics are generated for each year.

2.5.2 Time-series products

Simple time-series products are generated from the individual-date products by calculating the desired statistic, per pixel, for the ~25 year history of annual ground cover. This includes the minimum, maximum, median, mean and standard deviation. The production of these products is also automated and statistics are re-calculated each time new imagery is acquired.

Simple time-series products can be misleading where outliers occur, especially when only a single date is available annually. To account for these outliers a number of percentile time-series products are calculated and produced. This is done by fitting a beta distribution frequency curve to the range of ground cover values per pixel in the time-series (Figure 2). The time-series statistics are then derived from this distribution where the maximum and minimum are the 95th and 5th percentiles, respectively, and the median is the 50th percentile. The standard deviation is calculated from the original distribution.

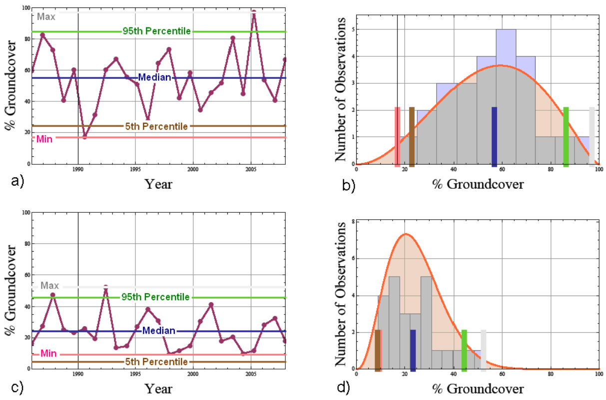

Figure 2. Derivation of percentile time-series products. a) and c) show examples of a 20 year ground cover time series. b) and d) displays the respective histograms of the time series data (blue) and fitted beta distribution (orange). The pink line in a) and d) is the time-series minimum, the light brown line is the 5th percentile. The blue line is the time-series median, the green line is the 95th percentile, and the grey line is the time-series maximum.

2.5.3 Ground cover trend products

A ground cover trend product has been developed to provide an indication of the overall trend (upward or downward), per pixel, over the extent of the time-series. The trend is calculated by deriving the slope of a linear regression fitted to the time-series, and then determining the slope of the upper and lower confidence intervals. Where the direction of the slope of the upper and lower confidence intervals agree, the trend is considered to be statistically significant (Figure 3).

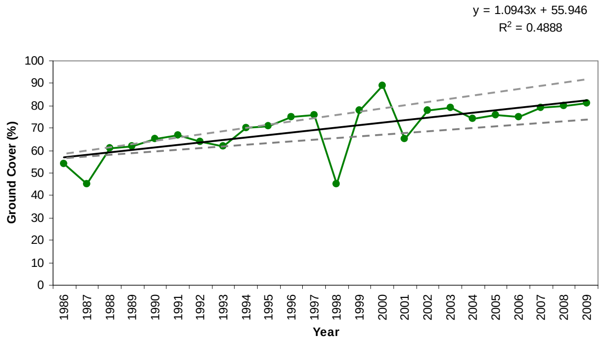

Figure 3. Graph showing regression analysis (black line) of hypothetical ground cover values (green line) over time. Note that although ground cover does not increase every year, in general the trend is upwards. In this case, because the slope of both confidence intervals is positive the increasing trend in ground cover can be said to be statistically significant.

2.5.4 Seasonal products

Access to denser time-series of Landsat imagery provided by the USGS and Geoscience Australia has allowed for increased number of observations during seasons over the past decade for Queensland and longer in some locations. Preliminary products summarising the ground cover time-series statistics for wet and dry seasons have been developed. At present, seasons are defined by a pre-determined date range (Schmidt and Trevithick, 2010).

3. RESULTS AND DISCUSSION

3.1 Ground cover products

3.1.1 Individual-date products

Individual-date products are produced using both the GCI and fractional cover models. Figure 4 shows an example of individual-date ground cover derived from the GCI for an area in central Queensland. Darker shades of brown indicate higher ground cover. The effects of drought in the early to mid 1990's and 2000's can be seen in the image dates from these periods. The dark green areas are those areas of FPC >15% which are masked out. Figure 5 shows state-wide mosaics of the fractional cover products. The percentages of cover in each of the three cover fractions can be represented. These products have been generated for the entire archive of Landsat TM and ETM+ imagery held by the RSC.

The individual-date products provide the foundation for all other products. As a stand-alone product they are a useful tool to indicate the state of ground cover at any one point in time. This provides a useful communication aid for extension work as they provide a visual representation for land managers which is tangible and can be directly related to their own observations. There remains some issues with perceived over-estimation of ground cover in the products. This is due to the difference between what is mapped from remote sensing (i.e. all ground cover fractions) and land managers' understanding and interpretation of ground cover (i.e. alive and dead pasture), particularly in a grazing/pastoral setting. There are some environments where it is known that the ground cover models do not perform well (e.g. black soil areas, red ironstone landscapes and higher FPC areas). These areas are being addressed through additional field data and use of other imagery to attempt to characterise the spectra in these environments. Improvements to woody vegetation masking using the methods of Scarth et al. (2010) will also reduce uncertainty in higher FPC areas. Despite these known issues, education about the products remains the greatest challenge for the QGCMP and its partners to ensure appropriate use of the information it produces.

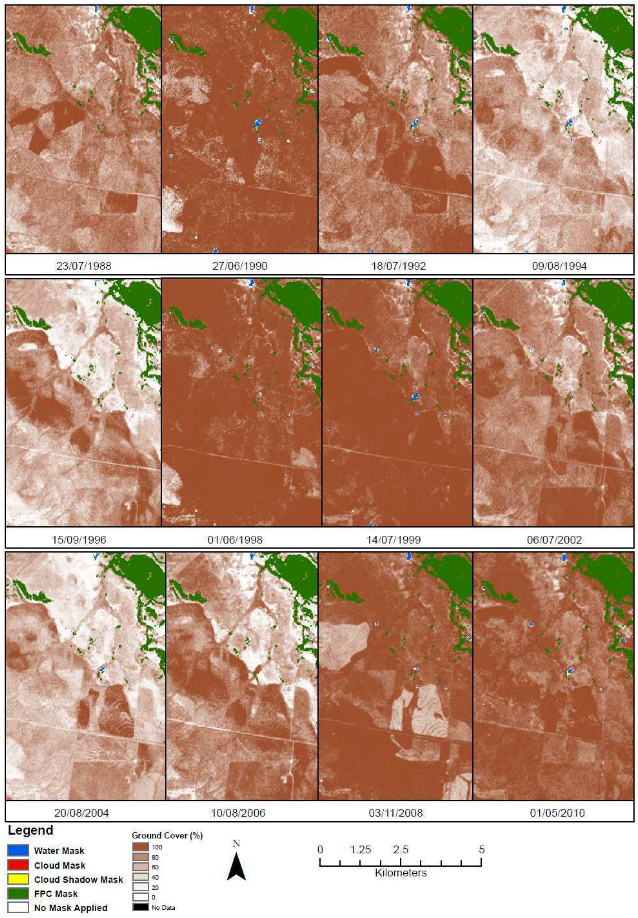

Figure 4. Example of individual-date ground cover product for an area near Emerald, central Queensland.

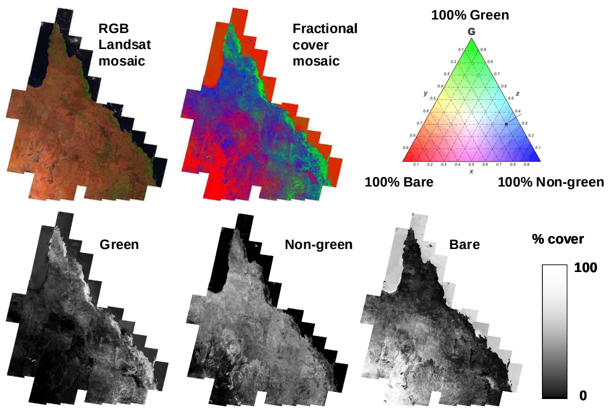

Figure 5. Example of state-wide mosaics of fractional cover.

3.1.2 Time-series products

Figure 6 shows an example of state-wide mosaics of the percentile time-series products, derived for the period 1986-2010 and based on annual imagery. It shows that over the period of observations, ground cover can fluctuate significantly across the state and through time. The number of observations is included to provide an indication of how representative each pixel is of the time-series as some years may not be included due to masking.

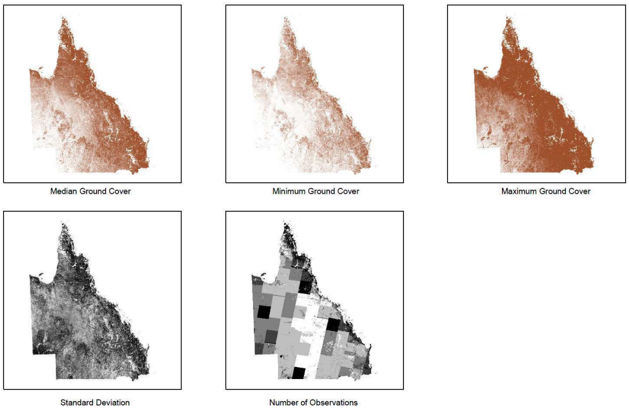

Figure 6. Example of state-wide mosaics of time-series ground cover products. The period shown here is 1986-2010.

The time-series products provide valuable information about the long-term ground cover for any particular area in Queensland. As mentioned, the simple-time series products can be misleading, particularly where outliers occur or the number of observations has been limited due to masking or unavailable imagery. A further limitation in the past has been access to Landsat imagery representative of all of the seasons and therefore capturing the intra-annual dynamics of ground cover. This has been greatly improved by the recent availability of the Landsat archive, and will be further improved as the full archive of Landsat imagery for Australia is repatriated from Geoscience Australia to the USGS. From a land management perspective, the use to date of late dry season imagery for the ground cover time-series has had advantages. The likelihood of any given pixel having a valid observation is increased due to less cloud and water. It can also be assumed that ground cover will be at its lowest in the late dry season. Any estimates and subsequent management decisions are therefore based on the worst-case scenario and maximum benefit will be gained from any conditions that exceed those in the driest times. It could be argued that a dense 10-year history and less-dense ~25 year history is not an adequate representation of the changes and time-lag effects on ground cover due to short- and long-term changes in management and climate. Incorporation of modelled information such as is derived by AussieGRASS (Carter et al., 2000) and possibly earlier Landsat data, may help to improve this historical record.

3.1.3 Ground cover trend products

The ground cover trend products provide additional information to augment the individual-date and time-series products by providing statistical interpretation of the time-series. The regression slope product can be used to indicate the amount of change that has occurred where a statistically significant change has been determined. Figure 7 shows an example of the current trend product. The area highlighted by the red point (and red line in the graph) shows a significant decrease in ground cover between 1986 and 2009. This area also has a steeper slope in the regression slope product, indicating that decreasing trend may be due to change in management. In this example, the area has changed from fallow pasture to crop. The trend data should be interpreted with some caution and climate effects and ground cover model error considered. With denser time-series and an improved ground cover model now available, further work will be undertaken to investigate improved statistical approaches for calculating the trends where greater observations are available.

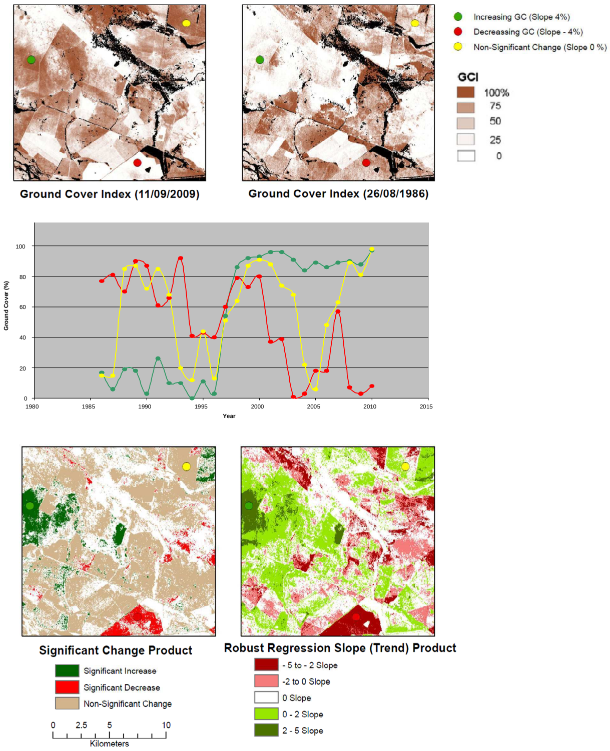

Figure 7. Ground cover trend products. The top images show the ground cover calculated for a date in September 2009 (left image) and a date in August 1986 (right image). Three points are marked in green, red and yellow. The graph in the middle shows the time-series trend calculated from the GCI for the three points. The images below show the areas where a significant trend has been determined (left image) and the slope of the fitted regression used to help determine the trend (right image). A significant increase in ground cover has been calculated for the location at the green point, a significant decrease for the red point, and no significant change for the area around the yellow point.

3.1.4 Seasonal products

Seasonal products (Figure 8) have the advantage of informing land managers about the intra-annual dynamics of ground cover with climate, especially rainfall. They can help indicate where ground cover is low in dry seasons or leading into the wet season when soils are particularly susceptible to erosion. Conversely, the products may also indicate high cover leading into dry seasons, a potential risk for fire management. They can also provide an indication of ground cover changes due to grazing management such as wet season spelling. A grazing land manager may use the information to adjust stocking rates based on actual representation of the current state rather than modelled information or past history. The current approach for seasonal products does not consider climate information and therefore may not accurately represent the actual seasons. Queensland also ranges from tropical to temperate biomes and seasons can vary markedly. Further work is planned to better characterise seasons based on climate information and high temporal frequency satellite imagery such as MODIS.

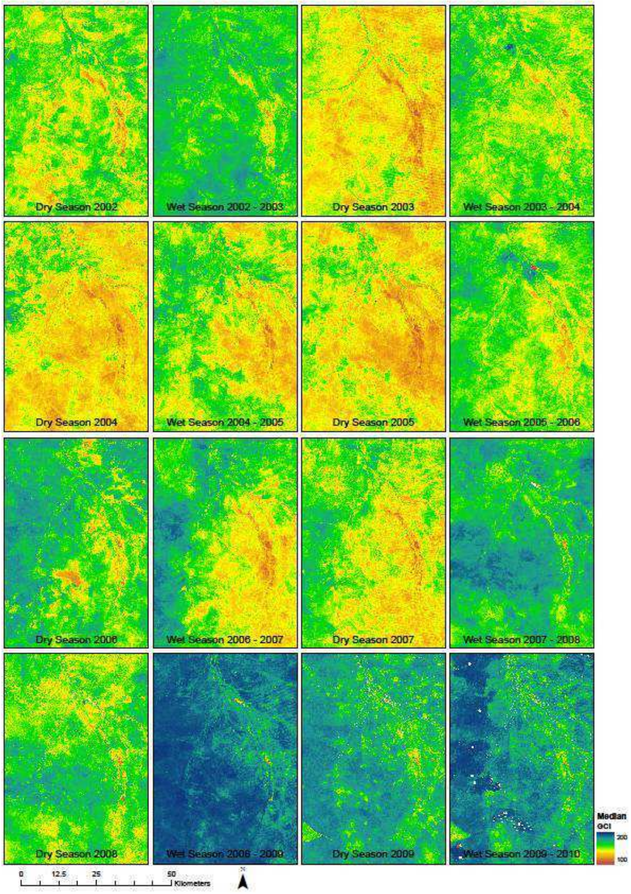

Figure 8. Example of seasonal ground cover. Wet and dry season median ground cover is shown for the period 2002 to 2010. Blue and green colours indicate higher ground cover and yellow and red colours indicate lower ground cover.

3.2 Application of ground cover information in Queensland

The ground cover products are used for a range of applications in Queensland in support of policy and initiatives. The annual, individual-date and time-series products are used by the Reef Water Quality Protection Plan (Reef Plan Secretariat, 2009) for reporting on targets and as a key input to the water quality modelling undertaken in support of the Plan. The products are also a key information source for the Reef Protection Program (www.reefwisefarming.qld.gov.au) and Delbessie Rural Leasehold Land Strategy (The State of Queensland, 2007) for monitoring land condition and for extension work for improved grazing land management. Karfs et al. (2009) and Bastin et al. (2012) used the data to infer grazing land condition due to management in rangeland environments. Pringle et al. (2011) used the data to monitor sugar cane crop management. The data is used by government agencies for State of the Environment reporting, biodiversity assessment, monitoring impacts and recovery due to recent natural disasters in Queensland and for targeting investment for restoration and improved land management. Regional Groups incorporate the information for their Regional Plans. National initiatives such as TERN's Auscover are funding development of the products for national monitoring applications and research activities. Challenges remain for government in the application and delivery of this information. Delivery and extension packages such as Forage (www.longpaddock.qld.gov.au/forage) and VegMachine (Beutel et al., 2004) use the data to make comparative assessments of ground cover across a range of scales. Identifying objective reference data and de-coupling climate and management effects are required to ensure defensible land management decisions are being provided. The denser Landsat time-series now available is enabling the research required to address some of these issues.

3.3 Further research

Future work in the QGCMP will focus on improved field techniques, multi-temporal monitoring, and investigating new methods for comparative analysis of properties and regions which de-couple climate and management effects. Research is also being undertaken to improve ground cover estimates in higher FPC areas using the fractional cover and time-series. Research is also planned with collaborative partners to integrate ground cover estimates with biomass estimates derived from radar. A fundamental requirement of the research program in the next few years will be to develop the appropriate systems, processes and cross-calibrations to make use of imagery from new sensors such as Landsat 8 and those planned for the Sentinel program.

4. CONCLUSION

The QGCMP is a well-established program which uses remote sensing and field measurements to produce a range of ground cover products in support of government programs and policies and a range of research activities. The program has been founded upon strong partnerships and Queensland Government's commitment to research and development of accurate and comprehensive information about ground cover in Queensland and Australia. A challenge remains for the Program to continue to educate end users about the benefits and limitations of the products. With adequate resourcing and continued research and development, it is expected that the Program will continue to provide fundamental, accessible, land management data and information into the future.

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ACKNOWLEDGEMENTS

The QGCMP has many contributors from government, academic institutions and the general public. They are too numerous to list but their contributions are gratefully acknowledged. Special mention to the Delbessie Program, Reef Programs, ABARES and TERN Auscover for their funding support and contributions. The authors are also indebted to the legacy of field data collected over the years by diligent scientists in Queensland and Australia. The ongoing supply of imagery and support from Geoscience Australia, the United States Geological Survey and other imagery providers is fundamental to the Program. Their services are greatly appreciated. Finally, the past and present efforts and commitment of staff from the Remote Sensing Centre and the Joint Remote Sensing Research Program has ensured the continued development of the QGCMP. Their contributions are acknowledged.