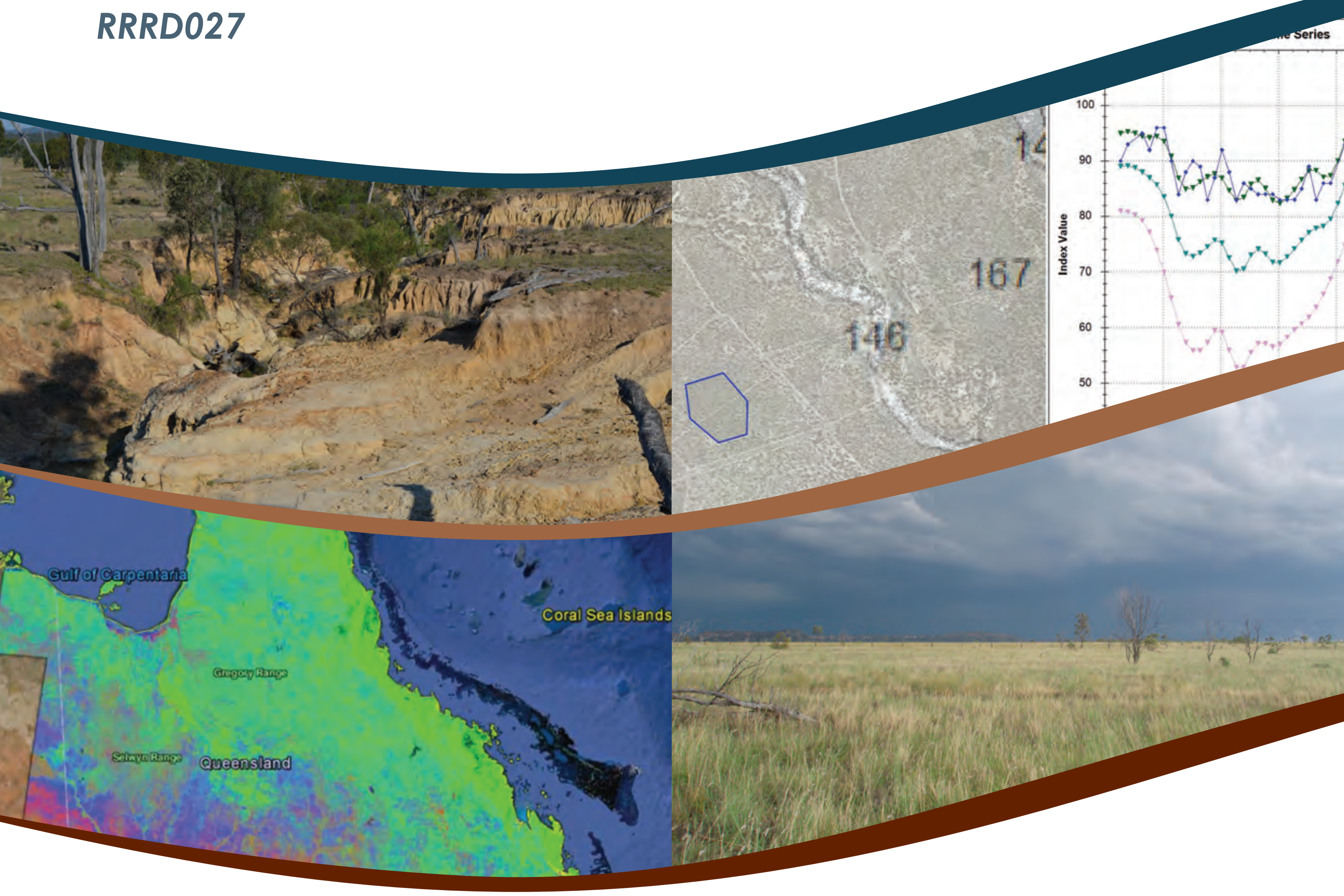
Reef Rescue
Research & Development

Technical Report

Getting ground cover right: thresholds and baselines for a healthier reef

RRRD027



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Peter Scarth, Brett Abbott and Chris Holloway

CSIRO
The University Of Queensland Australia
Queensland Government
Australian Government Department of the Environment
Reef & Rainforest Research Centre

Getting ground cover right: thresholds and baselines for a healthier reef

(Project RRRD027)

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Australian Government
Department of the Environment

Supported by the Australian Government's
Reef Rescue Research and Development Program

Queensland Government
The University Of Queensland
Australia
CSIRO
Reef & Rainforest
Research Centre

National Library of Australia Cataloguing-in-Publication entry:
978-1-925088-20-5

This report should be cited as:
Beutel, T.S., Tindall, D., Denham, R., Trevithick, R., Scarth, P. Abbott, B and Holloway, C. (2014). Getting ground cover right: thresholds and baselines for a healthier reef. Report to the Reef Rescue Research and Development Program. Reef and Rainforest Research Centre Limited, Cairns (64pp.). ISBN: 978-1-925088-20-5.

The Reef Rescue Research and Development Program (Reef Rescue R&D) was funded under the Australian Government's Caring for our Country program, and consisted of 18 projects. The Reef Rescue R&D is designed to improve our understanding of the link between land management practices and environmental impacts, and improve water quality across the Great Barrier Reef by informing on-ground projects to reduce the amounts of nutrients, pesticides and sediments reaching the Reef from agricultural lands.

Cover photographs: Top Left - Grazing land in D condition; Top Right - VegMachine® ground cover analysis; Bottom Left - Queensland fractional cover image (© Google Inc); Bottom Right - Grazing land in A condition. Images supplied by Department of Agriculture, Fisheries and Forestry, Queensland.

This report is available from the Reef Rescue R&D website: http://www.reefrescueresearch.com.au

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Acronyms

ABCD	Grazing Land Management ABCD land condition framework
AIC	Akieke's Information Criterion
DAFFQ	Department of Agriculture, Fisheries and Forestry, Queensland
DNRM	Department of Natural Resources and Mines, Queensland
DRCM	Dynamic Reference Cover Method
DSITIA	Department of Science, Information Technology, Innovation and the Arts,
FBA	Fitzroy Basin Association Incorporated
FCI	Fractional Cover Index
FORAGE	Framework for online Report Generation (Long Paddock)
GBR	Great Barrier Reef
GLM	Grazing Land Management
NQDT	North Queensland Dry Tropics Group Inc
NRM	Natural Resource Management
RCA	Rapid Condition Assessment
RRRC	Reef and Rainforest Research Centre Limited
RRRD	Reef Rescue Research & Development

Abbreviations

ΔGC	"Delta GC". Ground cover deficit during drought. (see Bastin et al. 2012)

Acknowledgements

We would like to thank The Australian Government's Reef Rescue R&D program for funding this work.

Jane Waterhouse and the team at the Reef and Rainforest Research Centre coordinated many Reef Rescue R&D projects, including ours. They supported us well, kept the projects talking, and provided valuable liaison with the Commonwealth along the way.

The Fitzroy Basin Association and North Queensland Dry Tropics Ltd actively contributed to the project steering group, and have provided valuable feedback in their uptake of our work.

Steven Bray of DAFFQ reviewed the final report and manuscript.

Finally, Scott Wilkinson, Mike Nicholas and Ian Watson of CSIRO provided valuable help with data and logistics.

Thanks to all.

Executive Summary

There is a clear and ongoing need in the Great Barrier Reef (GBR) catchments to quantify changes in the catchment landscape, and to understand how much these changes are driven by climate, management and other factors. This information is fundamental to both risk mitigation on the reef and to ensuring sustainable and productive use of the catchment landscape. *Getting ground cover right* directly addressed these needs in the Burdekin and Fitzroy natural resource management (NRM) regions of the GBR catchment, developing and distributing landscape monitoring resources for reef catchment stakeholders. These resources included:

- remotely sensed, catchment wide ground cover data;
- spatially validated grazing land condition mapping; and,
- customised monitoring support tools for reef stakeholders.

Project partners have processed over 60,000 Landsat images, converted them to fractional cover imagery and generated a time series of seasonal (3 monthly) cover images for the whole state. The fractional ground cover algorithm developed here estimates ground cover more robustly than its predecessor, and so allows better separation of over storey and ground cover. In addition, we have developed an approach to further separate over storey and ground cover, and developed two tools for distinguishing climatic and management impacts on ground cover levels.

The project also produced a new generation of spatially validated, multi decadal mapping of grazing land condition for the Burdekin and Fitzroy regions. The mapping was validated on over 1700 ground sites, and identified a number of spatial and temporal patterns in grazing land condition across the two regions. The new generation of mapping has been used in local Research, Development and Extension (RD&E) projects. In addition, our validation site data is available for future RD&E looking into the region's landscape health, as exemplified by our own investigations of sustainable ground cover thresholds, of which the validation data were a key component.

The project conducted two analyses of potentially sustainable ground cover thresholds for the two regions. One analysis investigated the relationship between catchment ground cover levels and risk of surplus catchment sediment runoff, but did not produce an informative outcome. A second analysis modeled relationships between relative levels of ground cover in dry times, land condition and long term rainfall on our validation sites. It has generated pixel and sub-catchment scale estimates of levels of cover required to maintain land condition for the two regions, and looks likely to be a help improve the setting of regionally-specific ground cover targets in GBR catchments.

The above products have been packaged and distributed via multiple channels. Most notably, we have packaged the seasonal cover time series in the VegMachine® software and trained 32 RD&E staff to use that software. This has resulted in assessments of landscape state and change on over 300 grazing properties to help direct NRM funding and extension work, and to directly provide land managers with landscape monitoring data.

A key point to note about the project has been its impact on other RD&E work in the GBR catchment. Project outputs have been delivered to numerous end users, and are shaping a large part of ongoing RD&E in the region. Direct impacts include:

- provision of cover data for catchment modelling;
- capacity to report on ground cover targets in reef catchments;
- more informed evaluation of NRM funding applications;
- provision of information for Water Quality Improvement planning;
- identification of extension target areas;
- supply of land managers with historical land monitoring data;
- more informed economic assessment of land rehabilitation options;
- identification of appropriate RD&E sites; and,
- generation of fire history mapping for the state.

This is a sizeable and still growing list of activities that have benefitted from the work funded under this project, and represents a very significant return on that investment.

We recommend three core future RD&E directions from this work. These are discussed in greater detail later in the report, but in summary are as follows:

- *Secure the Queensland Ground Cover Monitoring Program.* The Queensland Ground Cover Monitoring Program's ground cover dataset is foundational to RD&E in the GBR catchment and beyond. At this point in time, the funding future of the program is unclear. We see a clear priority in securing the ground cover program and its acquisition and processing capacity.
- *Move VegMachine online.* The VegMachine PC software has proven its capacity to open up the ground cover data for a wide range of users. With current technologies it is eminently feasible to deliver VegMachine through an online platform. This would circumvent the limitations of the current delivery model, and exponentially expand public access to ground cover data.
- *Keep leveraging the ground cover data.* The ground cover data and its associated products are the most detailed dataset we have of physical change in the GBR catchments. Our work around land condition mapping is just one of many examples (see above) of how these data can inform our understanding of the landscape and our roles and options within it. Future RD&E should look for novel ways to leverage this dataset – it has produced a great deal of value already, but we think there is a great deal more value to be realised.

Introduction

In 2010-11 the Queensland grazing industry exported over $3.2 billion worth of goods, or more than half of total agricultural exports for the state (Queensland Treasury, 2011) yet many grazing enterprises still operate with ever-reducing productivity and profitability (Donaghy et al., 2010). Grazing land accounts for approximately 77% of Great Barrier Reef (GBR) catchment, rising to as much as 90% in the Burdekin catchment (DSITIA, 2012). The recent Reef Water Quality Protection Plan Scientific Consensus Statement noted that rangeland grazing is the main land use contributing sediment pollutant loads to the GBR lagoon, and of that the Fitzroy and Burdekin regions contribute at least 70% to the modeled total suspended sediment load to the GBR lagoon, with over three quarters attributed to the grazing lands (The State of Queensland, 2013). Hacker (2010) also noted that landholders aspire to good land stewardship, but short-term economic pressures often prevent these intentions. Clearly, there is a need for tools and information which help land managers maintain a sustainable and profitable grazing industry while ensuring land degradation, including erosion is minimized.

The maintenance of ground cover has long been recognized as a way of minimizing the effects of wind and water erosion (e.g. Lang, 1979; Leys, 1999; Booth and Tueller, 2004) as well as increasing productivity in grazing systems (e.g. Karfs et al., 2009a). Ground cover is the non-woody vegetation (forbs, grasses and herbs), litter, cryptogrammic crusts and rock in contact with the soil surface (Muir et al., 2011). The quantity and amount of ground cover can have significant influence on pasture productivity, infiltration and runoff, biodiversity and soil carbon sequestration. In the GBR catchments, ground cover targets have been implemented by Regional NRM groups and as part of the Reef Water Quality Protection Plan (Department of the Premier and Cabinet, 2013) in an effort to maintain ground cover, particularly in dry periods, for minimizing erosion and increasing grazing land productivity. Ground cover is affected by, and can change due to factors such as soil type, species composition, climate variability, land management practices and fire. Ground cover can therefore vary, sometimes significantly, in space and time. Targets and land management programs aimed at maintaining or improving ground cover should therefore consider such factors when monitoring and reporting on changes in ground cover and when assessing the environmental and economic implications of the changes. Targets are generally aspirational. In the GBR catchments, some areas may never achieve a target ground cover of 70% in the late dry season. Whilst there is a need for a ground cover target for Reef that would achieve best possible reduction in sediment, there is also a need for some realistic thresholds for ground cover which are regionally sensitive and achieve the best possible outcome for production and sediment reduction in those regions.

The past 10-15 years have seen considerable improvements in ground cover monitoring with satellite imagery. Ground cover data and reporting based on late dry season Landsat satellite imagery (i.e. one image per year). This has been an integral part of the Reef Plan and associated programs since 2009. These data have estimated the amount of ground cover and bare ground in areas of low tree cover. Recently, the entire Landsat archive has been made available by the United States Geological Survey (USGS), significantly expanding the capability for monitoring ground cover seasonally and as early as about 1986. There has also been a number of state and federal initiatives which have collected and complied existing and new field data about *fractional cover* (i.e. green and non-green cover and bare ground) enabling the development of improved algorithms for measuring ground cover using remotely sensed imagery.

A number of studies have attempted to relate ground cover data derived from satellite imagery to land condition in grazing lands to help identify areas with poor land condition or areas at risk of land degradation. Karfs et al. (2009a) broadly assessed and mapped grazing land condition using ground cover information derived from satellite imagery as a surrogate for condition states, calibrated and validated by rapid field assessments. In their study, land condition was defined in the context of the Grazing Land Management (GLM) framework (Chilcott et al. 2003) which is primarily aimed at beef production. The outputs from this work were compiled across the two largest Reef catchments (Burdekin and Fitzroy regions), and have been implemented by NRM planners and landholders. Bastin et al. (2007) used ‘landscape health’ and ‘land condition’ somewhat interchangeably in a project which developed a number of indices as indicators of land condition using limited field data and a range of readily available remotely sensed data and derivative products. Their aim was to develop a metric of ‘Landscape Leakiness’ based on the work of Ludwig et al. (2007) which provides a measure of the ability of the landscape to conserve key elements (e.g. nutrients, water, soil) necessary for plant growth. As with Karfs et al. (2009a), their work was undertaken in the context grazing land production and sustainability. More recently, Bastin et al. (2012) developed an approach that provides a relative measure of landscape resilience using ground cover data derived from Landsat satellite imagery (Scarth et al., 2010). The approach aims to decouple climate effects from management effects based on local benchmark or reference sites which have relatively high ground cover in dry periods. The authors applied the method to northern Queensland grazing lands to report on trends in what they refer to as ‘condition’, again in the context of grazing land productivity.

The primary objectives of this project are to develop and build upon the recent advances in remote sensing of ground cover and to refine and validate existing approaches for the assessment of land condition based on ground cover data. The intention is to improve information for ground cover management in the grazing lands of the Fitzroy NRM region (Fitzroy Basin Association; FBA) and Burdekin NRM region (North Queensland Dry Tropics NQDT) regions. To achieve this, the project set three key objectives with nine aligned activities, described below.

Project Objectives

The objectives of the project are listed below along with related project activities. Methods, Results and Discussion sections of the report are arranged around these activities.

Objective 1. Produce an improved Ground Cover Index (GCI) product and analysis routine to separate management and seasonal effects in grazing lands.

- *Activity 1.* Extend and format the current GCI dataset by incorporating new Landsat data (2007- 2010) into the GCI time series.
- *Activity 2.* Separating the over storey from the ground cover signal using fractional cover.

Objective 2. Produce validated spatial data of ground cover and land condition for the Fitzroy and Burdekin regions.

Activity 3. Analyse change in extent of 'D' (worst) land condition by comparing an updated Landsat 1996-2010 data product with a historical 1986-1995 product. Analyse levels of 'stable ground cover' over these periods as a surrogate of 'A' (best) land condition.

Activity 4. Conduct infill roadside condition assessments (parallel to rigorous ground validation) to extend our verification data for 'vulnerable' (C & D condition) and 'healthy' (A & B condition) land type identification in the Fitzroy and Burdekin regions.

Activity 5. Test and refine field validation model by conducting pilot surveys using existing data.

Activity 6. Conduct rigorous ground validation to quantify error margins in the spatial products, and so provide a robust and durable baseline.

Activity 7. Model multiple streams of data to identify sustainable thresholds of ground cover at sub-catchment and land type scales (i.e. test suitability of the 50% universal ground cover target).

Objective 3. Enhanced land monitoring support packages and publications for the Fitzroy and Burdekin regions.

Activity 8. Customise project outputs for practical use in allied extension activities, fostering user access and consistent uptake across a range of State and Commonwealth funded initiatives (e.g. Paddock to Reef M&E, Sustainable Agriculture, Reef Protection).

Activity 9. Produce scientific and Plain English publications, and a project final report.

Methods

The project team undertook nine major activities, each aligned to one of the three project objectives (as listed above). Below we discuss the methods for eight of theses activities. Please note Activity 9 is dealt with in Results, where a full list of project publications is provided.

Study area

The work in this project focused predominantly on the Fitzroy and Burdekin NRM regions respectively (Figure 1). These include the two largest GBR catchments, those of the Burdekin and Fitzroy Rivers. The combined area of these regions is 297 000 km^2, or 70% of the GBR catchment.

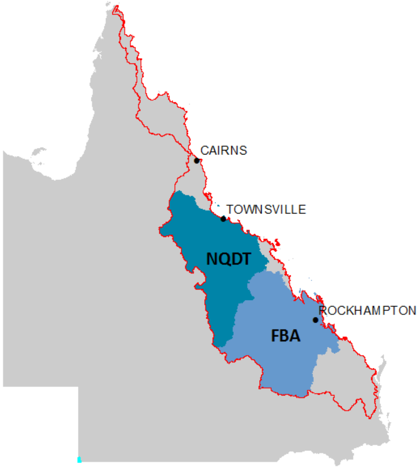

Figure 1. RRRD027 project area. Work focused on the Fitzroy and Burdekin NRM regions (labeled) within the GBR catchment (red line).

Activities 1 and 2

Activity 1 focused on temporally extending of the ground cover data set for the Burdekin and Fitzroy catchments, and Activity 2 on the development of a fractional cover product capable of better separation of the ground cover from over storey. In terms of the objective of separating climate from management, two approaches are described, each based on local reference data but differing in that one approach is a quantitative analysis tool (used later in Activity 7) and the other is intended as an extension and interpretive tool (as part of Activity 8).

Improved ground cover data

Ground cover has previously been monitored in Queensland using the Ground Cover Index (GCI) (Scarth et al., 2006), applied to single annual date, late dry season Landsat 5 TM and Landsat 7 ETM+ satellite imagery for the period 1986 to present. The GCI measures the amount of cover and bare ground and has only been applied in areas of lower tree cover due to occlusion by over storey and mid storey vegetation. Activity 1 developed a new approach for estimating ground cover from Landsat satellite imagery, termed '*fractional cover*' based on additional field data and improved access to Landsat satellite imagery.

Landsat 5 TM and 7 ETM+ data are used in Queensland for production of ground cover data. The archive is stored and managed by DSITIA'S Remote Sensing Centre (RSC). Prior to this study, this archive included around 2500 individual Landsat image scenes for Queensland. These image scenes were mostly single date per year, late dry season imagery, purchased by Queensland Government in support of the Statewide Landcover and Trees Study. In a joint announcement between the United States Geological Survey (USGS) and NASA, the entire Landsat archive has been made available free-of-charge via an online download facility. RSC has now acquired all of these images for Queensland from about 1986 to present (> 60 000 individual images). For reef catchments, there are generally in excess of 500 individual dates for each scene area for the 27 year period (**Figure** 2). The majority of scenes are from post 2000.

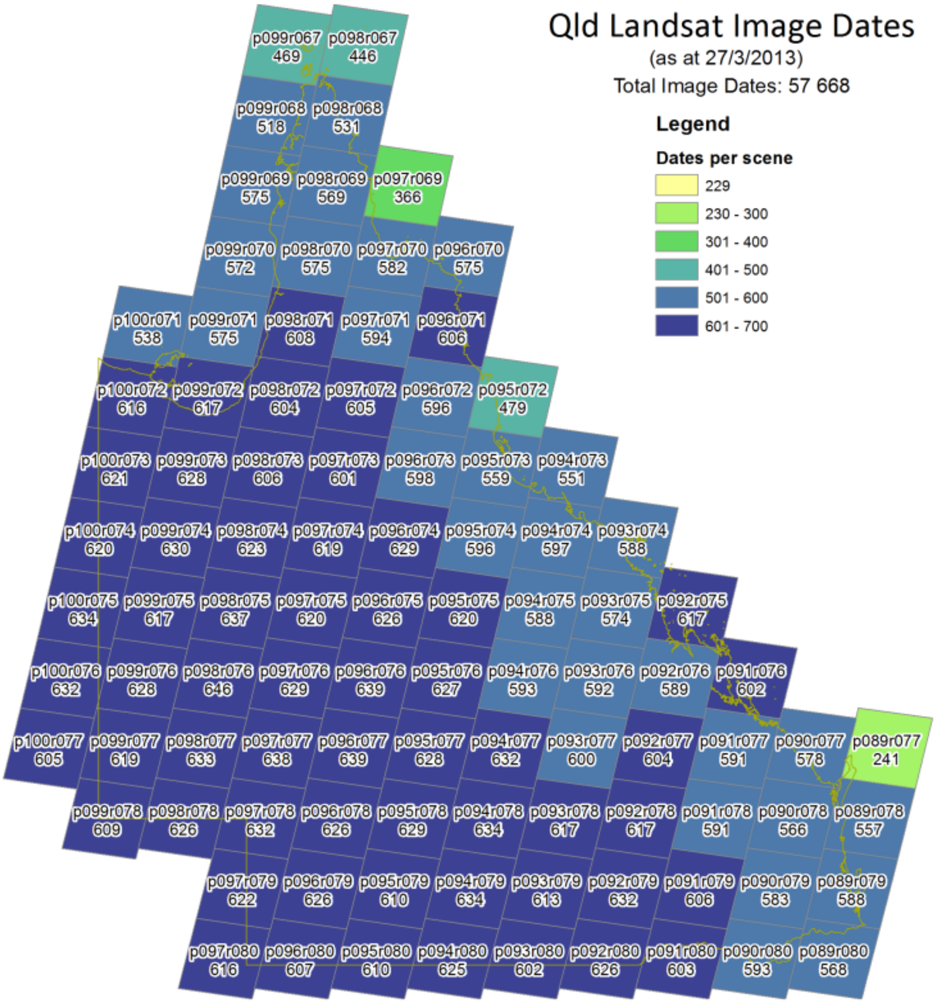

Figure 2. Total number of dates for each Landsat scene archived by DSITIA for Queensland. The archive is complete for the period 1986 to present. For GBR catchments, there are generally in excess of 500 individual dates for the 27 year period. The majority are from post 2000.

Data were pre-processed to a standard and consistent surface reflectance image product following Flood et al. (2013). Corrections and masks are applied for cloud and cloud shadow, topographic shadow, geometric accuracy and water bodies (Goodwin et al., 2013; Zhu and Woodcock, 2012; Danaher and Collett, 2006). It is important to note that since 2003, Landsat 7 has been operating in SLC-off mode (scan-line-corrector-off), which results in about 20% of any image not being collected for any single date. In addition, Landsat 5 was effectively decommissioned in late 2012.

Fractional ground cover is produced following Scarth et al. (2010). The approach uses spectral unmixing techniques to solve for the proportion of green vegetation, non-green vegetation and bare ground based on the corrected Landsat satellite imagery reflectance measures and calibrated by field data. Therefore, there is greater discrimination of the ground cover components into the green and non-green than was the case with the previous approach using the GCI. In some activities undertaken for this project, *total cover* has been used for analyses. This means that the green and non-green cover fractions have been summed to provide an estimate of total cover (and the remaining fraction of bare ground). The fractional cover approach has been applied to the entire archive of surface reflectance-corrected imagery held by DSITIA.

Calibration data used for the development of the fractional cover approach has been collected from a range of vegetation cover and community types across a representative range of soil types for all of Australia. These data have been collected using systematic, quantitative sampling of fractional cover following Muir et al. (2011). The field sites have been collected over the past 10-15 years as part of previous work for the Queensland Ground Cover Monitoring Program, and more recently as part of this study and the National Ground Cover Monitoring Project, coordinated by ABARES. Figure 3 shows the distribution of the sites nationally. Approximately 1500 sites have been collected to date.

The *seasonal fractional cover* is a composite product produced from the single-date product and at present is produced for four calendar seasons from 1986 to present: summer, autumn, winter and spring. The product is produced by selecting on a pixel by pixel basis, the fractional cover values which are most representative for a season. The selection of representative pixels is based on the 'medoid', a multi-dimensional derivative of the median which maintains the sub-pixel relationship between the cover fractions (Flood, in prep). The calculation of the medoid is dependent upon a minimum of three valid measurements in any one season. The product accounts for extremes and is therefore expected to provide a better representation of the 'typical' cover levels for a given season. Analyses in this project are based on the seasonal fractional cover (and total cover) product.

Estimating cover under trees

A previous limitation of the estimation of ground cover using satellite imagery was the ability to measure and report on the level of ground cover in areas with higher tree cover. This is due to the amount of the ground layer that is visible to the satellite due to occlusion by the mid- and over storey vegetation. The additional time-series data available in the Landsat archive and the implementation of the fractional cover approach has facilitated the development of a model, based on field data, which accounts for relative contributions of the mid- and over storey vegetation and the bare ground to the reflectance signal received by the satellite sensor. Thus the result is an estimate of the remainder, which is assumed to be the cover of the ground layer. A brief overview of the theoretical model follows.

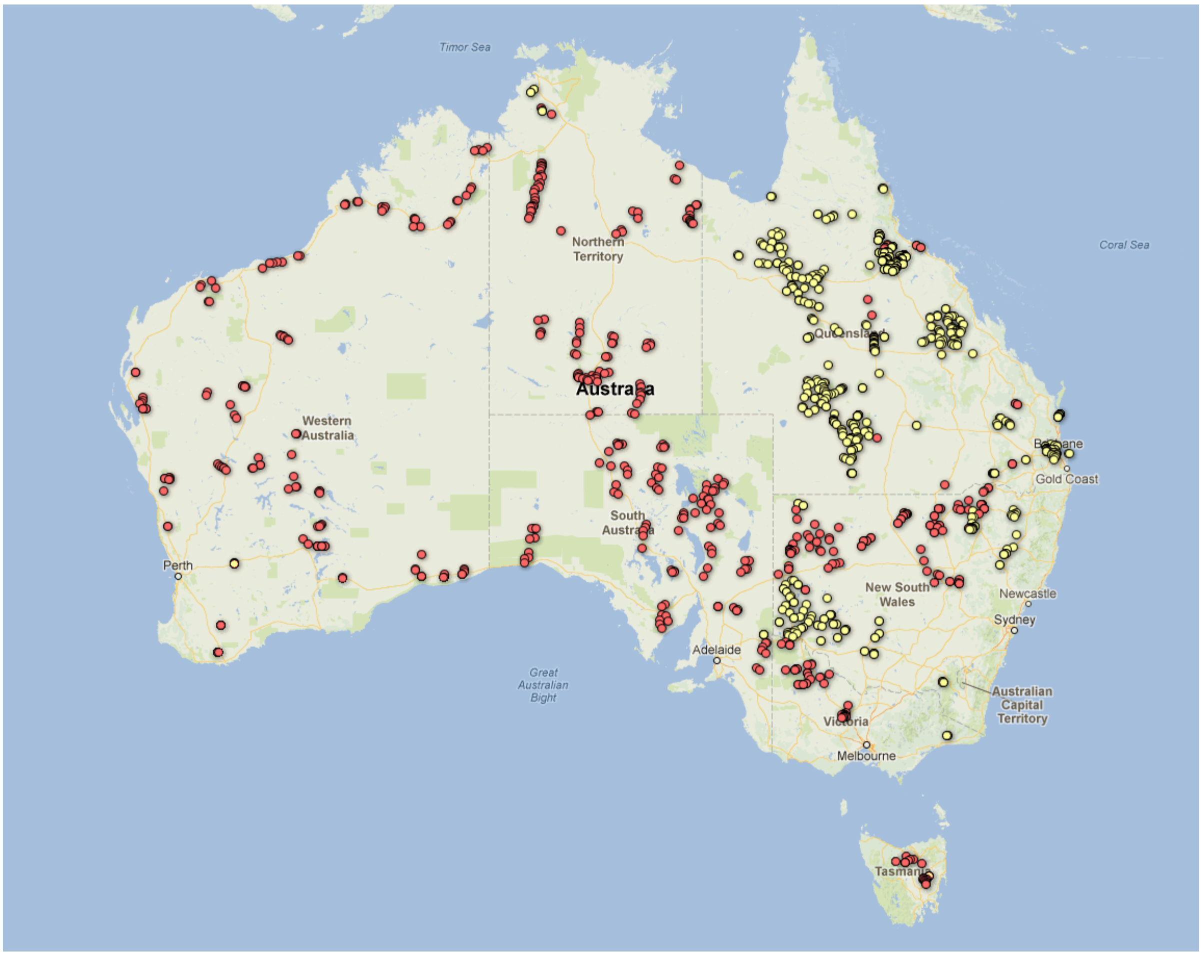

Figure 3. Location of fractional cover field sites for Australia. These sites have been used to calibrate the fractional cover data for this project and have been collected following Muir et al. (2011). Sites were located to obtain a representative sample of cover types and background soil reflectance types across Australia. Map © Google.

'Persistent green' vegetation is defined as the visible green fraction which is the most seasonally invariant. It is assumed to be the visible green fraction present in the mid and over storey:

$$Persistent_{green} = Visible\ Mid_{FPC} + Canopy_{FPC}$$

Similarly, 'Persistent dry' vegetation is the visible dry fraction present in the mid and over storey:

$$Persistent_{dry} = Visible\ Mid_{dry} + Canopy_{dry}$$

These initial equations can be rewritten as:

$$FCI_{green} = Visible\ Ground_{green} + Persistent_{green}$$

$$FCI_{dry} = Visible\ Ground_{dry} + Persistent_{dry}$$

$$FCI_{bare} = Visible\ Ground_{bare}$$

The amount of each fraction visible at the ground layer is the area not occluded by the combined persistent dry and persistent green in the mid and upper strata. That is, all vegetation in the mid- and upper- strata.

$$Proportion\ of\ ground\ occluded = persistent_{green} + persistent_{dry}$$

$$Total\ gap = 1 - (persistent_{green} + persistent_{dry})$$

Assuming that cover fractions in each vegetation layer are independent, that is that the presence of mid and over storey vegetation does not influence the distribution of the ground cover fractions, we can estimate the ground cover fractions by the following equation:

$$Visible\ Ground_{fraction} = Actual\ Ground_{fraction}\ X\ Total\ Gap$$

This is applied to each cover fraction (i.e. the green, non-green and bare) to estimate the actual ground fractions. Note that the adjustments made by these equations rely on satellite estimates of persistent green and persistent dry, as the calculation of total gap is dependent on these estimates.

Separating climate from management

Two approaches have been developed to help separate or de-couple the influence on ground cover levels from climate and land management practices. The first, the *dynamic reference cover method* (DRCM), is a quantitative approach for assessing local and regional trends in ground cover, particularly in dry periods. The second, the *regional ground cover comparison* is a somewhat qualitative tool for assessing differences in cover between a chosen property or location and the local area or region.

1. Dynamic reference cover method

In a collaboration between RRRD027 project partners and the Australian Collaborative Rangelands Information System (ACRIS), an approach has been developed which uses a reference cover method to compare any given pixel with an ensemble of nearby reference pixels. The approach is termed the ‘dynamic reference cover method’ (DRCM) (Bastin et al., 2012). The reference sites are chosen as areas with high cover in dry periods and are compared between dry periods to provide an indication of areas of improving or declining ground cover, or areas which have maintained similar levels of cover relative to the reference conditions. The comparison with nearby pixels assumes that climate effects on the cover levels estimated have been minimized locally and the use of dry periods accounts for the time where the greatest variability in cover levels is evident. Mean difference between the cover in a pixel and its reference pixels is called ΔGC. Large ΔGC values are assumed to be due to management.

2. Regional ground cover comparison

The regional ground cover comparison compares total cover for a given property or selected area with the range of cover for the same land types within a local region. The range of cover in the local region is represented as percentiles of cover over time, enabling the property or selected area to be compared or ranked to determine what their cover levels were like compared with the local region. The use of a local region and land type constraint assumes that the rainfall and soil effects are consistent and therefore the differences observed in ground cover levels are due to management. This approach has been incorporated into VegMachine and the development of an online report via FORAGE on the Long Paddock website (refer to Activity 8 for further details).

Activity 3

Grazing land condition is an idea that has been used in rangeland contexts for many decades (Dyksterhuis 1949, Lamar Smith 1979). Effective assessment of grazing land condition implies better capacity to understand the effects of management on grazing country, to continue management that produces favourable outcomes for the land, and to cease or amend management that degrades grazing land resources. Consequently many tools and systems have evolved to measure in some way the 'condition' of grazing country (e.g. Tongway and Hindley 2004, Watson et al. 2007). These systems vary considerably, not least of all because there is no universally accepted definition for grazing land condition itself.

In Queensland, the GLM ABCD framework (Table 1) defines land condition as both *the capacity of land to respond to rain and produce useful forage*, and *a measure of how well the grazing ecosystem is functioning*, classifying the landscape in one of four classes from best (A) to worst (D) (Chilcott et al. 2003). This framework has provided a simple and popular means of characterizing grazing land condition, and has gained significant traction among RD&E providers and their clients.

Table 1. ABCD land condition framework (from Karfs et al. 2009b).

Condition	Possible descriptors
A	• High density and coverage of preferred grasses • High organic matter
B	• Moderate density and coverage of preferred grasses or high density of intermediate grasses • Moderate organic matter
C	• Moderate to low density of preferred grasses or moderate density of intermediate grasses • Higher number of annual grasses and forbs, few weeds • Some erosion • Some woody thickening
D	• General lack of perennial grasses or forbs • Severe erosion and large bare areas • High numbers of weeds/annuals • Thickets of woody plants covering much of the area

The rise of satellite data availability has provided significant opportunities to leverage the physical coverage of satellites for mapping condition across the landscape, and numerous approaches to the problem have been trialed (Pickup and Chewings 1994, Tanser and Palmer 1999, Ludwig et al. 2007, Bastin et al. 2012). Karfs et al. (2009a) document an approach based on long term mean and trend in remotely sensed ground cover data that produced spatially explicit mapping of likely D condition areas in the Burdekin basin. This project extends that approach by generating mapping of the full ABCD condition spectrum for both the Fitzroy and Burdekin NRM regions over two periods (1988-1995 and 1996-2010). The goal of the work was to trial the approach as a tool to understand interdecadal changes in land condition across the region, to assess the capacity of this approach to discriminate areas of different condition, and to provide baseline mapping of recent grazing land condition for the two regions.

ABCD mapping was generated as per Karfs et al. (2009a) from annual end-of-dry ground cover data for the period 1988 to 2010. Separate ABCD images were developed for the periods 1988-1996 and 1997-2010 to allow interdecadal assessment of change. The two periods were chosen on the basis of seasonal cycles; 1988 marks the start of the satellite time series and is close to the end of the 1980s drought while 1995 marks the approximate end of the 1990s drought, so 1988-1995 approximates one climatic cycle. The next cycle beginning in 1996 concluded around 2005, and a decision was made to include 2006-2010 data (an incomplete climatic cycle), allowing calculations to include data from recent years.

The original ABCD mapping mapped condition as per ‘most likely’ class, so that at any pixel a single assignment (A, B, C or D) was attached to that pixel. Validation work (Activities 4-6) transformed this mapping into four probability layers, each defining the probability of the pixel area having A, B, C or D condition. It should be noted that Activity 3 analyses were conducted on the validated data, not the original mapping. One cost of analyzing such data is the complexity of pixel by pixel comparisons between time periods, since you are comparing two probability distributions in each pixel, rather than just two single condition classes. To quantify interdecadal change, we aggregated the probability layers across a set of subcatchments (Figure 4). The average probability of each condition class in each subcatchment was used to estimate the proportion of that subcatchment in that condition class in each period, and thus provide subcatchment scale assessments of condition.

Figure 4. Subcatchment stratification used to assess land condition change. (Burdekin = green; Fitzroy = purple).

Activities 4, 5 and 6

These activities are grouped and discussed together because they are all steps in the validation the ABCD land condition mapping developed in Activity 3. Infill roadside condition assessments (Activity 4) gathered validation data during the project, the pilot survey work (Activity 5) collected and evaluated historical datasets suitable for validation, and the rigorous ground validation (Activity 6) collated the datasets from Activities 4 and 5, then statistically compared their fit to the post 1995 ABCD mapping (the period in which all our validation data were collected).

Karfs et al.'s (2009a) mapping focused primarily on 'candidate' D condition areas. These are areas with severe erosion and/or chronically low levels of ground cover. This focus on D condition was partly related to its importance to sediment supply and to productivity. But it also occurred because cover is simply a better surrogate for condition at the lower end of the land condition spectrum (Table 1), since lower condition is more dependent on ground cover levels than on pasture composition. Given this challenge, any attempt to map the full condition spectrum required a substantial validation process.

Karfs et al. (2009a) validated their mapping with data collected at 212 D condition sites across the Burdekin. Most sites were assessed from moving vehicles using an approach called Rapid Condition Assessment (RCA). RCA is a free survey methodology that allows collection of large number of landscape observations along a road network from a moving vehicle. One of the key disadvantages though of RCA is its spatial precision. GPS data collected from a vehicle moving at 80 km/hour frequently have errors of ~50-100m. In addition, assessments are made of land beyond the road corridor, and this varies in width along the network. Consequently spatially mapping the actual area assessed for any assessment point is problematic. Given the emphasis in this work on spatially validating the ABCD mapping, a decision was made to use validation data only from stationary assessment sites. This greatly reduced the volume of historical test data, but it allowed much more robust assessment of the match between ground observations and modeled land condition mapping.

Activity 4 used two separate methodologies to collect validation data; DAFFQ assessments were based around the ABCD land condition framework (Chilcott et al. 2003) while CSIRO used the Patchkey methodology (Corfield et al. 2006). These are discussed separately below.

DAFFQ sites were surveyed in October 2011 and 2012 (Table 2). Site assessments involved visual inspection (most sites were viewed from the fence line) of the nearest hectare to the inspection point. Observations included 1-3 photos and a list of visually assessed variables including grazing land condition (Appendix 2).

Sampling in 2011 was extensive, covering both the Fitzroy and Burdekin NRM regions. Sites were selected through several processes. We used an existing ABCD version of Karfs et al.'s (2009a) mapping to identify routes that intersected higher mapped densities of C and D condition country, and placed sites *apriori* within those areas. We also placed planned random sites *apriori* in A and B condition mapped areas along the same routes. Finally we opportunistically sampled C and D condition sites that were not mapped as such whenever possible. A total of 959 useable site records were collected from this work over about 4000 km of the road work (Table 2).

Table 2. Data sets used to validate ABCD mapping.

Dataset	Locality	Collection date	N	Notes
ABCD_book	Burdekin	2006-2008	106	Sites sampled in the making of Karfs et al. (2009b).
CSIRO_patchkey	Fitzroy & Burdekin	2011-2012	124	Roadside assessments by CSIRO
FBA_RCA_0408	Fitzroy	2004-2008	332	DAFFQ RCA sites assessed *in situ* during mobile RCA work.
FBA_sites	Fitzroy	2009-2010	27	Subset of largely poor condition sites sampled by FBA field staff.
Moranbah_ABCD	Moranbah	2006	43	Detailed DAFFQ land condition study sites in the Moranbah area.
NQDT_patchkey	Burdekin	2012	53	Sites sampled by NQDT staff using Patchkey methodology.
RD27_2011	Fitzroy & Burdekin	2011	959	Roadside assessments by DAFFQ.
RD27_2012	Fitzroy	2012	90	Roadside assessments by DAFFQ.

DAFFQ sampling in 2012 was more focused. A review of all validation data to that point identified a shortage of D condition sites in the Fitzroy NRM region, so subsequent RCA focused almost exclusively on those sites, targeting them on routes with high mapped densities of D condition land, and again also opportunistically sampling any D condition found *en route*. This work sampled 90 extra sites over approximately 2000 km of road work, of which 26 were in D condition, effectively doubling the previous year's take of D condition sites in the Fitzroy NRM region.

Patchkey sites were sampled between October 2011 and April 2012 (Table 2). 124 sites were sampled in five localities across the Fitzroy and Burdekin regions; Greenvale, Charter Towers, Duaringa, Alpha and Collinsville. Sites were randomly located in roadside paddocks. Sites were assessed using the Patchkey methodology (Corfield et al. 2006) on 1–3 x 100m transects. Patchkey divides transects into patches of different function/condition, the proportions of which are indicated by their respective transect lengths. As such, sites do not have a single land condition rating, rather proportions of a site that fall in each condition class (e.g. A:60% and B:40%). For the purposes of this work however, and to equate the Patchkey results with other validation data sets, we used the median condition rating for the site to define the entire site's condition. It should be noted we did investigate alternative analyses that took advantage of the finer scaled spatial data provided by Patchkey, but none were suitable for these analyses.

Activity 5 evaluated a number of historical datasets for their suitability to validate the ABCD mapping. Potential datasets were considered on their fit to four selection criteria;

- assessments made *in situ*;
- a photo of the site available for corroboration of the site assessment;
- a GPS location of site and a mappable boundary available;

- an ABCD condition assessment made at the site on a known date.

Of 10 historical datasets considered, these criteria identified five as suitable for validation work (Table 2).

For activity 6, the above datasets were cleaned, organized and aggregated into a single dataset incorporating 1734 observations from across the two regions (Figure 5). Polygons were mapped for each site, and these polygons used to extract the proportion of each validation site mapped in A, B, C and D condition in the post 1995 ABCD mapping. For each polygon, we also collated a number of other variables relevant to that site (Appendix 3).

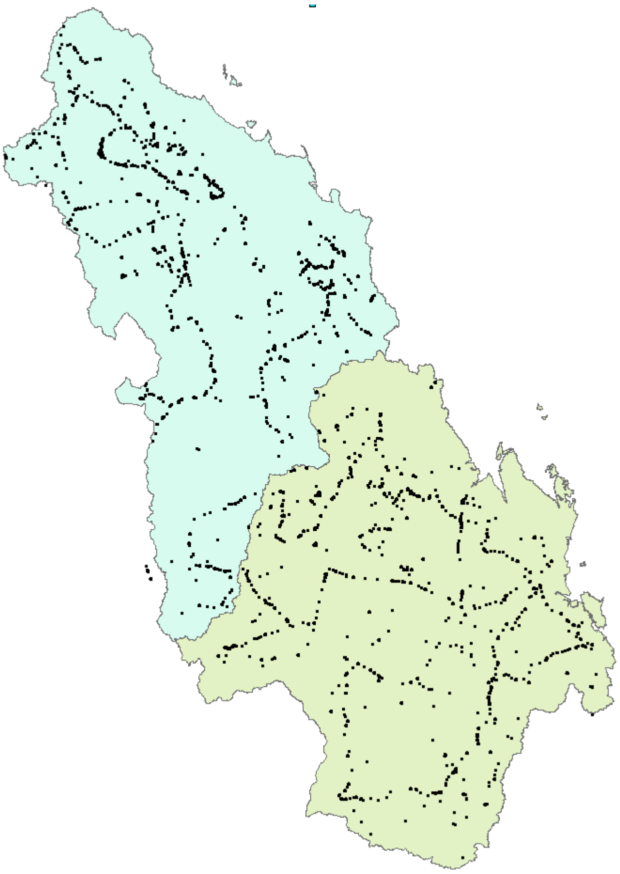

Figure 5. Distribution of ABCD validation sites in the Fitzroy and Burdekin regions.

These data were then used to fit two ordinal logistic regression models of grazing land condition on the validation sites. Model 1 assessed the fit of the post 1995 ABCD mapping to the validation data, using three terms (%A, %B, and %C). Model 2 used a forward stepwise process to try and identify a better model of observed site condition based on the full set of predictors in Appendix 3. Terms were selected and added on the basis of overall significance of individual terms, and on the model AIC (Akieke 1974). The selected model included three terms (Appendix 4). The two models were statistically compared to determine whether the validation model better fitted the land condition observations.

While Model 2 fitted the validation data better than Model 1 (see Results), we conducted an additional reality check on Model 2 by comparing predicted region wide condition distributions from Model 2 with those from the post 1995 mapping. These proportions were shown to local DAFFQ staff experienced in land condition assessment. Staff were not told the source of each data set, and asked to rate each model for each region on a 5 point Likert scale from *Very Likely* (=5) to *Very Unlikley* (=1).

As a result of the above comparisons, the validation model was accepted, and used to recalibrate the original post 1996 ABCD mapping. This process attached probabilities for each condition class to each map pixel, and in this way four map layers were constructed for each region, each indicative of the probability of a single land condition class at that point.

Activity 7

Ground cover is a critical aspect of landscape health. The ground cover dataset (Activites 1 and 2) and its previous iterations are critical elements of the regional planning space in the reef catchments, and ground cover targets have been a part of regional planning frameworks for some years (Reef Water Quality Protection Plan Secretariat 2009). Historically though, these targets have been arrived at largely through consensus among catchment modelers, rangeland ecologists and assorted other technical experts. There is a clear need for more robust analysis of ground cover data in relation to the ecological functioning of the landscape to help provide a better definition of ‘how much ground cover is enough?’

The project team undertook two analyses to better define sustainable ground cover thresholds in the study area. The first of these examined the relationship between catchment runoff and ground cover, in particularly testing whether the amount of ground cover in a catchment predicted the likelihood of surplus runoff events that might indicate a significant sediment loss event. The second analysis related DRCM data (Activity 2) to the land condition field data and ground cover to help identify levels of cover required to achieve a land condition outcome based on the ground cover state in the previous drought. These are discussed separately below.

Surplus runoff modeling

We used a novel two stage modeling process to investigate whether catchment wide levels of ground cover could be used to predict seasonal volumes of catchment runoff and therefore identify areas at higher risk of high sediment loss events.

The primary stage of the modeling process developed a predictive model of seasonal catchment runoff volume based on the physical and environmental attributes, but not seasonal ground cover, in a series of suitable catchments. From this primary model, the predicted seasonal runoff for any catchment in any season was then compared to the measured runoff and each season/catchment combination, and classified as either a runoff surplus or deficit depending on whether measured runoff was above of below the predicted values of the primary model (Figure 6). A secondary model was then developed by regressing these surplus/deficit classifications on mean catchment cover per season, with the idea that the secondary model would identify risk of surplus runoff events given the catchment’s seasonal ground cover (Figure 6).

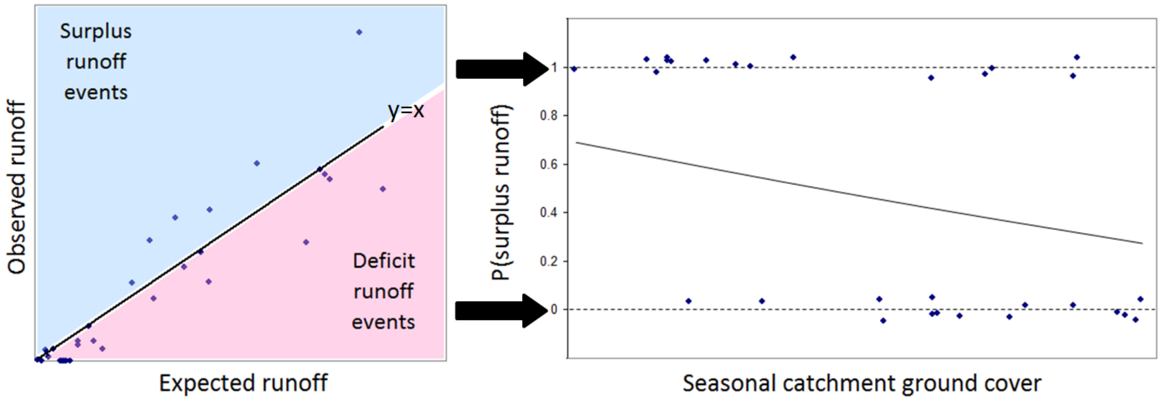

Figure 6. Two stage runoff modeling process (hypothetical data). The primary catchment model (left) provides seasonal estimates of catchment runoff (excluding influence of seasonal ground cover), and these estimates are used to define all seasonal runoffs as either surplus (blue zone) or deficit (red zone). These classifications are then used in the secondary model (surplus=1, deficit=0, values jittered for visual purposes in plot)(right), where they are modeled against seasonal catchment ground cover to provide an estimate of the probability of surplus runoff given catchment ground cover (fitted back line).

An initial pool of over 200 historically gauged catchments in and around the Fitzroy/Burdekin regions was examined to identify potential modeling catchments. This number was reduced in a selection process that eliminated catchments not meeting the following criteria

- relatively complete river flow volume data (2000-2012);
- predominantly used for grazing; with limited mining and cropping;
- >25% of area assessable for ground cover (i.e. grazing country with FPC<15%); and,
- not including another analysis catchment within its boundaries.

This selection resulted in 39 study catchments (Figure 7), for which there were between 3 and 44 seasonal observations of runoff volume and ground cover available between Autumn 2000 to Winter 2012. This provided a total of 905 observations, which were randomly assigned (2:1) to modeling and validation datasets.

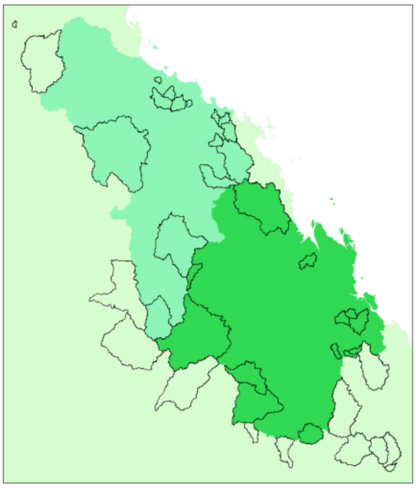

Figure 7. Distribution of modeling catchments in and around Burdekin and Fitzroy NRM regions.

The primary model predicted catchment runoff from a pool of predictors (Appendix 5). We used generalized linear models (McCullagh and Nelder 1996), in two separate modeling runs, one assuming normal errors and another Tweedie distributed errors (Smyth et al. 2012). Tweedie error structures have been successfully used for rainfall modeling (Hassan and Dunn 2011), and are suitable for dependent variables that are ≥0, typical of catchment runoff values. Normal error models, while more common may be violated by the dependent variable distribution in these data.

GLMs assume data are independently distributed, a condition unlikely to exist within catchments where runoff in one season can influence that in the next. To address this issue, primary models included predictors forced into the model to account for this serial correlation. In one set on runs this variable was *date*, and in another it was *prev.vol*.

We used a manual forward stepwise approach to identify better models. Beginning in each set of runs with two term models (forced variable plus alternately each other available predictor (Appendix 5)) we evaluated models based on AIC (Akieke 1974), deviance reduction, general significance of all terms, and residual diagnostic plots. With a 'best' two term model identified in each set of model runs, the best three term model that included the best two term model was similarly identified, and so on until no n term model could be identified that suitably addressed all assessment criteria.

The secondary modeling process was much simpler. The best primary model was used to classify seasonal catchment runoff volumes as either surplus or deficit depending on whether they were greater or less than predicted runoff. These classifications were then regressed on mean catchment ground cover in a logistic regression model.

Dynamic reference cover method and land condition modeling

The relationship between ΔGC in a dry period derived from the DRCM and ABCD grazing land condition was investigated. This relationship was then used to develop a model that predicts the probability of achieving a land condition class based on ΔGC and total cover, and also rainfall. A further preliminary model was developed to determine the cover level which would be required to achieve a land condition rating of B or better, given average annual rainfall. The following provides an overview of the steps of the model development.

1. Extract cover values ($CoverAvg_{t-3}$) for the ABCD land condition field data

The average cover in the three year period up to the year of assessment ($CoverAvg_{t-3}$) was extracted for a 1 ha area surrounding each site. This measure of cover was used to help account for variability in cover in the years preceding the field assessment of condition and to help adjust for climate differences between time of observation due to the use of data from a range of field campaigns.

2. Derive ΔGC_{2004}

The DRCM was applied to total cover imagery for the study area from the dry season of 2004 following Bastin et al. (2012) to derive ΔGC_{2004}.

3. Examine relationships between $CoverAvg_{t-3}$ and ΔGC and ABCD land condition classes

The relationship between $CoverAvg_{t-3}$ and ABCD land condition classes was examined by undertaking an ANOVA using a pairwise t-test and using a Bonferroni adjustment for multiple comparisons. The test was repeated using a quasi-binomial model to examine the relationship between ΔGC_{2004} and the ABCD land condition classes.

4. Develop a model to predict and map the probability of a land condition class

An ordinal logistic regression model was developed to predict the probability of achieving a land condition class given a ΔGC_{2004} value and a $CoverAvg_{t-3}$. The explanatory variables used in the model were therefore ΔGC_{2004} and $CoverAvg_{t-3}$. We also tested other explanatory variables including cover in year of assessment and ΔGC_{1995} but these were found to provide little additional explanatory information for model development. In the case of the ΔGC_{1995} this was because most locations showed little change in ΔGC between 1995 and 2004 and so provided essentially the same information. Although $CoverAvg_{t-3}$ had a weaker relationship to land condition class than ΔGC_{2004} we included it in the model to provide a recent estimate of the level of cover thereby accounting for any discrepancies between ΔGC_{2004} and the levels of cover just preceding, and at the time of field assessment.

An additional explanatory variable (mean annual rainfall) was added to the model to investigate the influence rainfall gradient has on the probability of achieving a land condition class given a ΔGC_{2004} value and $CoverAvg_{t-3}$. This was then mapped at both the pixel level and summarized (averaged) for sub-catchments, to show the cover threshold required to satisfy the following rule:

> *A location must have 50% or greater probability of at least B-condition land.*

This rule was chosen somewhat arbitrarily to test the preliminary model. However, it was considered a reasonable requirement to achieve outcomes for both minimizing erosion and maintaining productivity in the grazing system.

Activity 8

A variety of project materials were customized and provided to end users in this project. These included supplying and providing access to ground cover data and derivative products, regional ground cover comparison reports, packaging various ground cover products in VegMachine and ABCD land condition map products.

Ground cover data supply and delivery

The improved ground cover data developed as part of this project has been made publicly available through a range of mechanisms. This includes data requests, various access portals hosted by the Terrestrial Ecosystem Research Network, and in derivative forms such as maps and reports both online through FORAGE and in customized hard copy format or Google Earth compatible files. The data has been provided to a range of users. These include: extension officers and land managers in government, regional NRM groups and industry bodies; Australian and International agricultural and ecological research organizations;

private consultants; Paddock to Reef Program modelers; and, most importantly, individual landholders.

As Queensland Government improves data delivery mechanisms under its Open Data initiative, the ground cover data and derivative products will be made more widely available via a range of new mechanisms.

Regional ground cover comparison reports

As mentioned, a report has been developed by project partners in collaboration with the Reef Protection Program's project: RP68G – Enhancing FORAGE and PaddockGRASP. This report is a percentile-based comparison aimed at providing a non-interactive online tool for assessing local trends in cover for similar land types. To produce the report, per pixel levels of seasonal total ground cover are ranked into percentiles for the local region within a 50km radius of the centre of the selected lot on plan. Areas *not* included in the calculation of regional comparisons include:

- non-dominant land types (see below for explanation of a dominant land type).
- non-grazing land uses: based on Queensland Land Use Mapping Program data and including National Parks and other conservation areas, urban areas etc.
- travelling stock routes; and,
- areas with higher tree cover (i.e. FPC >15%).

The median ground cover for the selected lot on plan is derived by calculating the median ground cover for the dominant land types on the lot on plan for each seasonal ground cover image in the time series from 1986 to present. Dominant land types for the selected lot on plan is determined by selecting the least number of land types which constitute at least 80% of the area of the selected lot on plan.

The report will soon be available through FORAGE (www.longpaddock.qld.gov.au/forage) and is intended as a tool for extension and grazing land management and supported by online documentation.

VegMachine

VegMachine is stand alone PC software (Beutel et al. 2005) developed by a consortium of RD&E agencies to allow simple interrogation of vegetation time series like the fractional ground cover data developed in this project. The software has now been used on pastoral properties in most Australian states. A significant upgrade of the software and the development of a new training package (Beutel et al. 2010) saw the software focused more on extension personnel, and it has since become integral to property and project assessment work in the Fitzroy and later the Burdekin NRM regions.

All VegMachine data must be packaged and stored on the user's computer. This includes the ground cover time series, benchmark data and a variety of landscape images to aid user orientation. All three of these components have been improved and customized in the course of the current project, and the outcomes are detailed below.

One particular methodological advance worth note here was a change in data preparation for VegMachine. Previously, VegMachine cover time series have been prepared by individual DAFFQ staff on desktop computers from large sets of individual bare ground imagery sourced from DSITIA. These data have needed to be masked for tree and cloud cover, converted to ground cover format from bare ground format and mosaiced into annual regional images. This is a considerable task for one staff member, and even with sophisticated software takes about two weeks of dedicated work to generate a full working dataset for the Fitzroy or Burdekin NRM region. In this project DSITIA and DAFF moved to automate preparation of VegMachine datasets using DSITIAs high performance computing capacity. The result was that DAFFQ were provided with masked seasonal ground cover mosaics for the state, and their availability cut the preparation time of regional datasets by about 70%.

Fractional ground cover data time series

At the beginning of the project, VegMachine used the original ground cover data. This provided users with a single estimate of ground cover per year at the end of the dry season from 1988-2008. In the Fitzroy region, these VegMachine data were subset into the five Fitzroy NRM subregions, and in the Burdekin into three subregions based around the eight Burdekin NRM basins.

By project's end, a number of significant improvements were made to the way the ground cover time series was used in VegMachine.

1. The fractional ground cover data replaced the original bare ground algorithm. This provided more accurate assessment of ground cover values.
2. The fractional data were incorporated as seasonal images, and from a user perspective, the effect is in an increase from one to four assessments of ground cover over any calendar year.
3. The image time series was extended to winter 2012. The original objective was 2010 because of uncertainty around the future of Landsat 5, however that satellite performed longer and allowing extended data acquisition.
4. Data were bundled to regional level, so that each region (FBA and NQDT) now receives a single data set rather than a series of data subsets. This has eliminated the need to reconfigure the software between subregional datasets, a process which generated approximately one third of help requests from VegMachine users.

Percentile benchmarks

Historically, VegMachine has compared average cover within an area of interest to that within a comparable benchmark area over the same period (Beutel et al. 2010). This proved a useful approach to separating management and climatic effects on local ground cover. However, this approach does not indicate how much cover varies within the benchmark area, so limits user capacity to understand the scale of any difference between the time series for the area of interest and the benchmark area.

Percentile benchmarks were developed similar to the regional comparisons data above, though it should be noted that VegMachine benchmarks are based around subcatchment (Figure 4) and catchment/land type combinations (e.g. Upper Burdekin Red Basalt, Lower

Dawson Brigalow) rather than radii around the areas of interest. For each the 726 such strata in the Burdekin and Fitzroy NRM regions, 5th, 20th, 50th, 80th and 95th percentile of cover were estimated at each date in the cover time series, and these data packaged as standard .csv *averages* files for use in VegMachine. It should be noted here also that this considerable task was performed using code and facilities within DSITIA and developed under this project, which considerably reduced preparation time for these data.

Other image products

A number of incremental improvements were made to VegMachine imagery as well. Most notable was the development of a relative cover image for the period winter 2004 to winter 2012 (approximate bottom to top on most recent climate cycle). This image (Figure 8) takes average cover values (2004-2012) within major catchments, numerically transforms them to their respective percentiles of that population, then colour codes these transformed values on a colour ramp to spatially depict relative mean cover change across the landscape. The main purpose of the image is to locally highlight areas of unusually high or low cover such as scalds and fence line contrasts, and so allow better targeting of VegMachine analyses. It supersedes the previously used mean cover image that colour codes mean cover over the same period into one of five bands (<10, 10-30, 30-50, 50-70 and >70%).

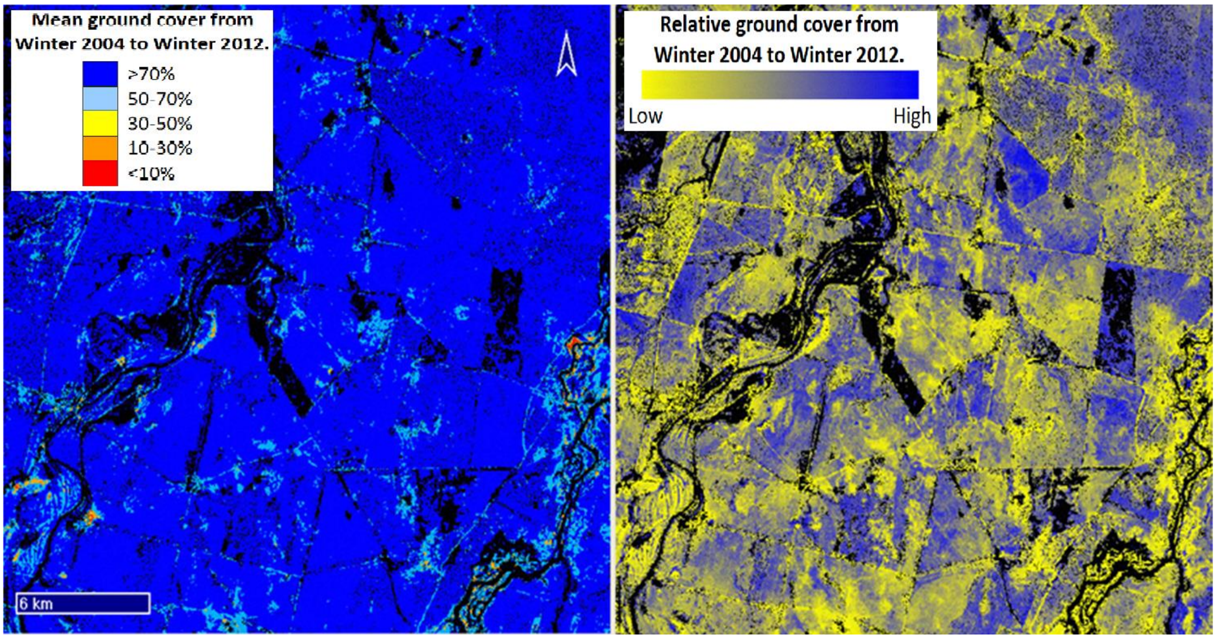

Figure 8. Mean (left) and relative cover (right) image examples from Burdekin NRM region. Both spatially describe mean ground cover (2004-2012), though the latter highlights areas such as fence line contrasts better. Black areas are masked by tree cover.

VegMachine training

This project saw the rollout of continued VegMachine training for staff in multiple agencies. Three different types of training were provided on request. Most training was provision of the standard VegMachine training program, a four hour applied training event where users learn to run the software and interpret results from local data analyses. However advice and training were provided through a number of other fora, listed in the results section.

Land condition mapping

The original post 1995 ABCD land condition mapping was used as a mapping product in several regional exercises. Most notably, it has been used through two planning cycles for field work by DAFFQ's Burdekin extension team to target properties and regions potentially contributing to sediment loads in the GBR catchment. It was also used in regional analyses linking economics, productivity and land condition across regional, land types (Star et al. 2012, Timms et al. 2013). Digital copies of the validated imagery have been provided to NQDT and FBA for internal planning and evaluation purposes also.

Results

Activity 1

Activity 1 greatly exceeded the stated goals for extending the ground cover time series in the Burdekin and Fitzroy. All image dates of Landsat 5 and 7 imagery available in DSITIA's archive have been processed to produce fractional cover and seasonal fractional cover. Furthermore, Landsat 8 has recently been launched and this new imagery is now being acquired, as of June 2013. Testing has shown that the fractional cover algorithm, which was developed for Landsat 5 and 7 data, performs similarly for Landsat 8 imagery, therefore assuring ongoing production of data. Figure 9 shows an example of fractional cover data for an area of the central highlands near Emerald in the Fitzroy catchment.

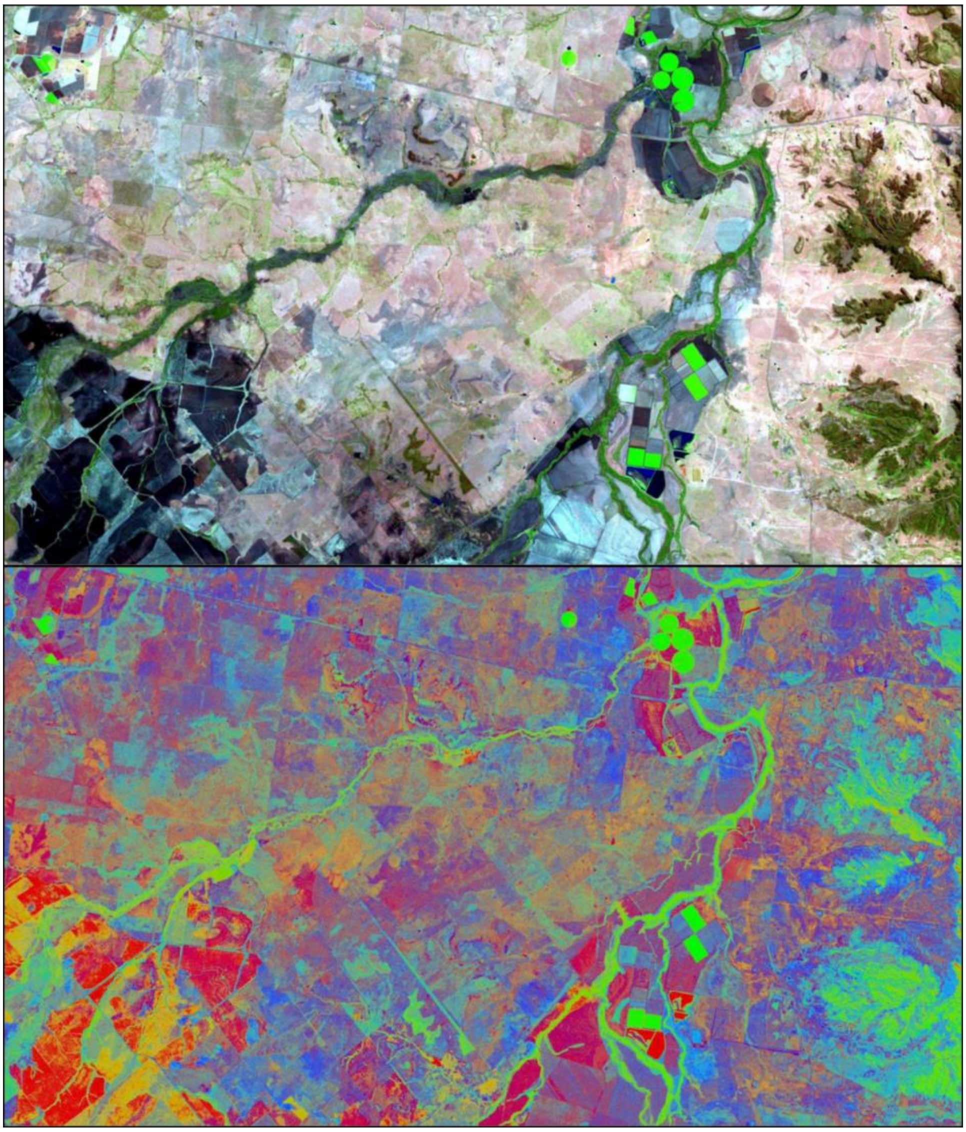

Figure 9. An example of fractional cover near Emerald in the Fitzroy catchment. The top image is a true colour image of the area showing a mix of light and dark soils and areas of cropping and grazing land uses. The bottom image is the corresponding fractional cover image for the same area. Areas of bare ground are apparent in the south-west and central parts of the image (bright red areas), green cover is apparent on the riparian areas, forested hills, and centre pivot cropping areas (bright green), and a mixture of green, non-green and bare ground can be seen as various shades of blue, green and red for the grazing lands.

The fractional ground cover model estimates, per pixel, the proportion of green and non-green vegetation and bare ground. Also produced is an estimate, per pixel, of the model error and the sum-to-one value of the three fractions. The root-mean-square-error (RMSE of the model for all of Queensland is 11% for the green fraction, 14% for the non-green fraction and 11% for the bare ground fraction. The model fit across the range of cover levels has improved from the GCI (RMSE=13% (Scarth et al. 2006)), which had greatest error in the mid-range cover levels (Figure 10).

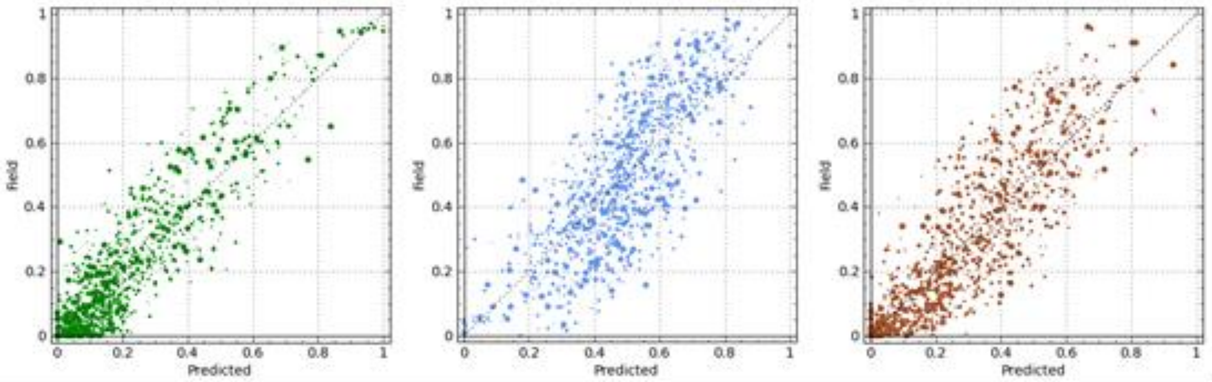

Figure 10. Fractional cover scatter plots. Predicted green (left), non-green (centre) and bare ground (right) cover fractions compared to the field measurements of cover fractions.

Seasonal fractional cover composites have been produced for the four calendar seasons (summer, autumn, winter, spring) from 1986 to present. Some gaps or ‘no data’ areas still occur in the seasonal composites due to an insufficient number of valid measurements across the season resulting from cloud cover or gaps in the Landsat 5 or 7 data (e.g. due to SLC-off issues with Landsat 7). Figure 11 shows the time-series of single-date fractional cover for a single pixel. The green dots show the selected medoid for each season within the time-series. The medoid is less affected by short-term fluctuations and outliers in the time-series and is considered to be more representative of cover levels over a season.

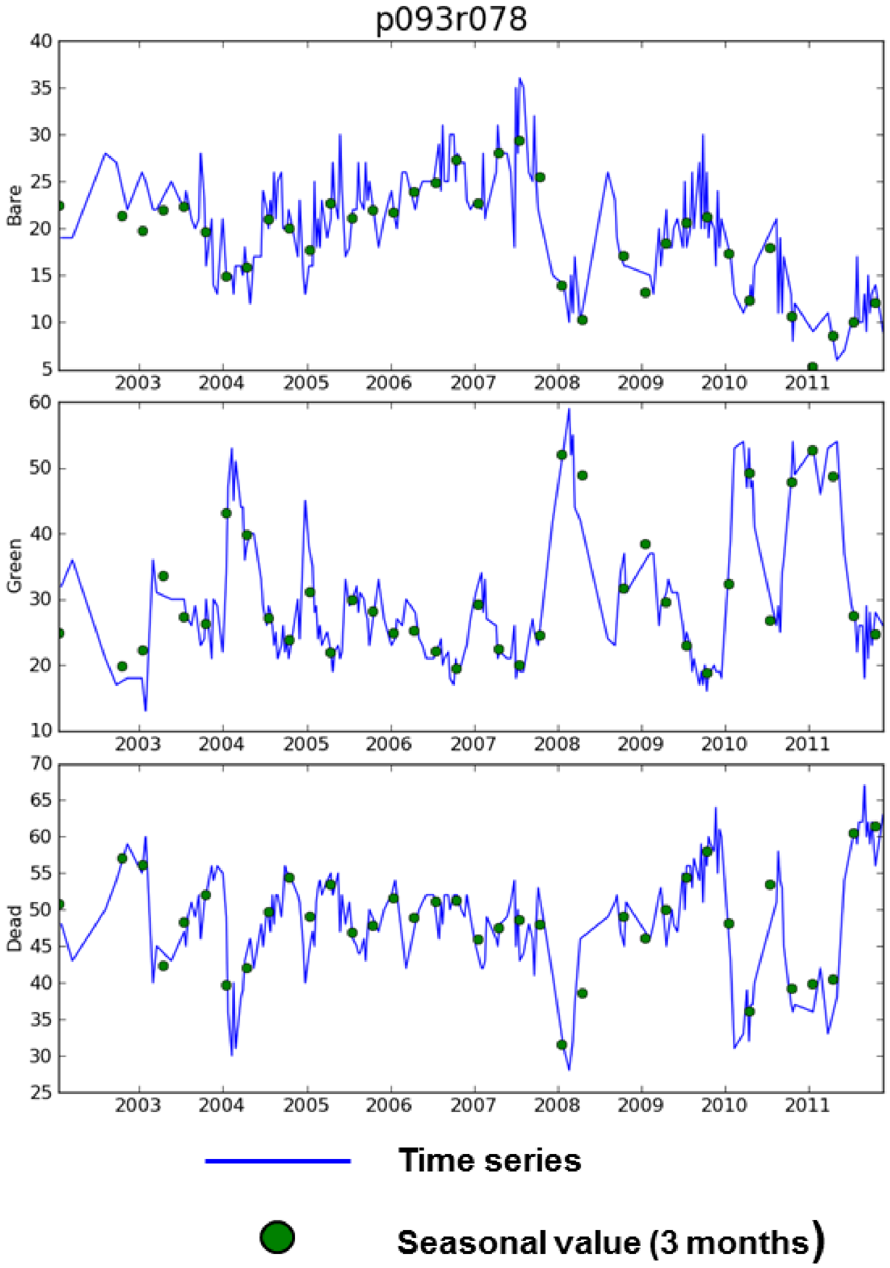

Figure 11. Fractional cover (%) time-series for a single pixel (Landsat Path/Row 93/78). The blue line shows the time-series cover levels derived from the single-date Landsat scenes. The green dots show the seasonal 'medoid' chosen to represent the median value of cover for each. The graphs show that the seasonal value is less sensitive to short-term fluctuations and is considered to represent the cover levels over that season.

Figure 12 compares a single date fractional cover mosaic with a seasonal fractional cover mosaic for Queensland. The example shows that the seasonal mosaic is less affected by scene to scene 'edge' effects thus making comparisons over large areas more consistent. Figure 13 shows seasonal fractional cover over three seasons for a grazing area in the Burdekin catchment. The transition between seasons clearly shows the dynamics of the green and non-green cover and bare ground as the dry season approaches from autumn to winter and then extends into spring. The senescence of the green pasture cover of the late wet season (autumn) imagery is especially apparent by the increase in the non-green (blue colours) and bare ground (red colours) in the early and late dry season images of winter and spring, respectively.

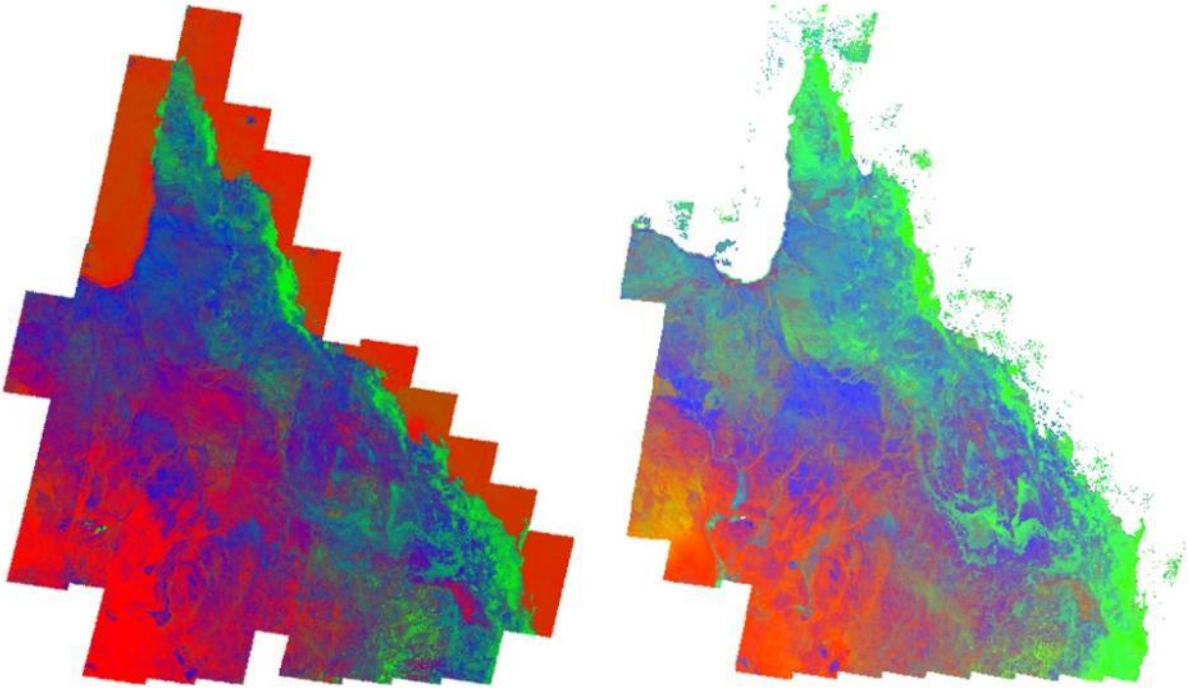

Figure 12. Example Fractional cover mosaics for Queensland. Left image shows a mosaic of single-date imagery. Note the scene to scene boundary effects. Right image shows a mosaic of seasonal fractional cover. Note the relatively seamless mosaic.

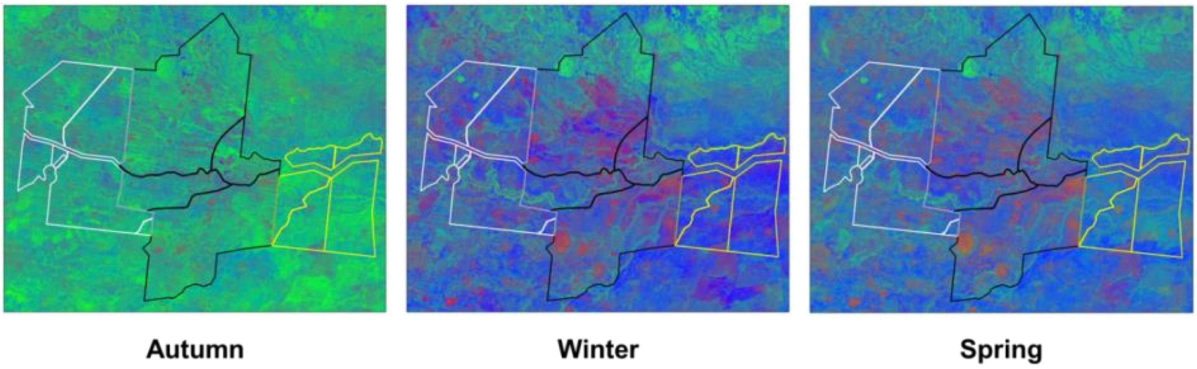

Figure 13. Fractional cover example for grazing lands in the Burdekin catchment over three seasons. The transition of high green cover to high non-green cover and bare ground from the wet season (Autumn) to the early and late dry season (Winter and Spring images, respectively) is clearly apparent. These seasonal data have been produced for all of Queensland from 1986 to present.

Activity 2

The model used to estimate cover under trees adjusts for the influence of mid- and upper-strata green and non-green vegetation, and canopy gap fraction within those strata, on the level of expected ground cover fractions. The model is based on field data from across Australia.

The theoretical model was applied to Landsat fractional cover imagery at the locations corresponding with existing fractional cover field sites. The residual errors between the fractional cover product estimates of *ground cove*r and actual measurements taken in the field were determined for both the original (unadjusted) fractional cover product and the adjusted fractional cover product for each of the cover fractions as follows:

Residual error = satellite prediction of cover fraction – field measurement of cover fraction
Therefore a positive residual represents an overestimate by the fractional cover product for a given fraction and a negative residual represents an underestimate for a given fraction.
Figure 14 presents the residuals from the comparison of the unadjusted (top) and adjusted (bottom) fractional cover products with the field data for the ground layer. The x-axis represents increasing persistent green cover, where 1 = 100% persistent green cover. The black line shows the bias of the model fit to the field data over the range of persistent green cover. For all three fractions there is an increase in accuracy with the correction, but reduced precision at higher levels of tree foliage cover (i.e. as persistent green increases).This is due to the influence of the persistent green canopy of the over storey on estimates of ground cover in areas with higher tree cover – a limitation of past ground cover products. The increase in accuracy is particularly evident in the green fraction, with slope of the regression line for the residual errors reducing from 0.81 to 0.13. While there is a visible reduction in precision for the field sites with higher levels of tree foliage cover after correction, the actual RMSE is typically less because, particularly for the green fraction, the unadjusted image-based estimates at these sites were consistently incorrect. After applying the adjustment, the majority of estimates improved. Interestingly, there is very little bias in the bare fraction, regardless of whether it has been adjusted for trees or not. The model to correct for tree foliage cover reduces the bias in the dry and green fractions, but does not entirely remove it.

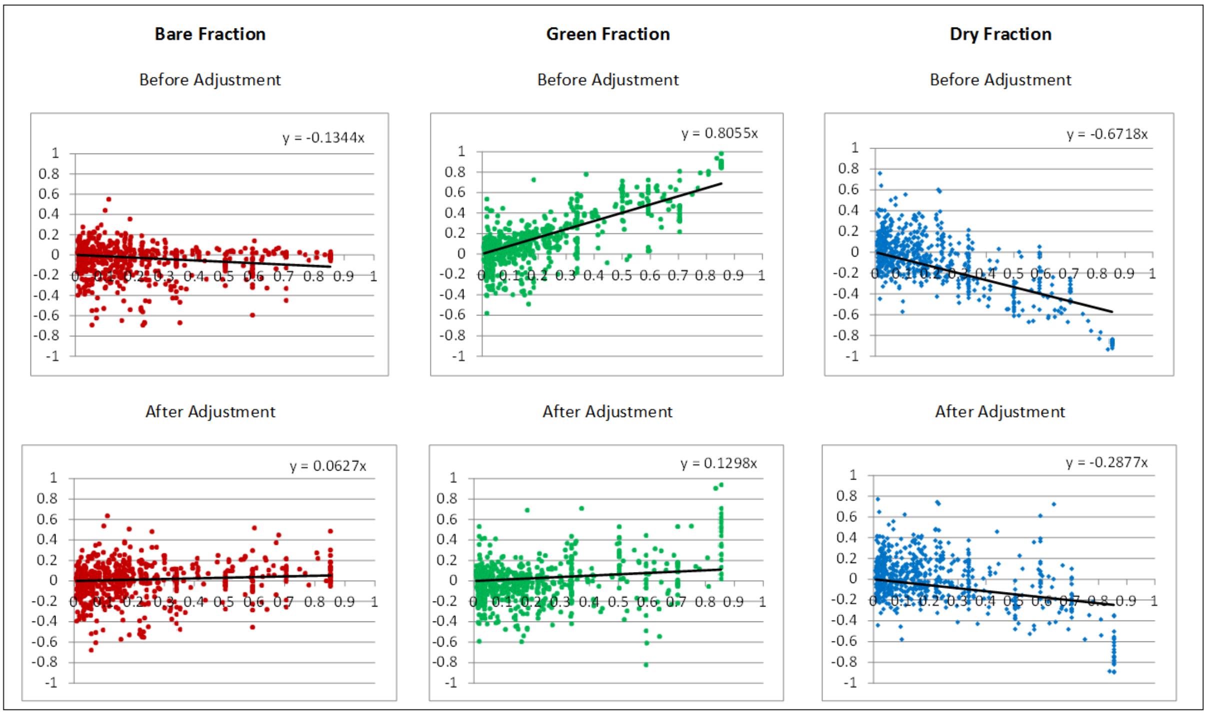

Figure 14. Field data plots for tree cover corrections. Uncorrected (top) and corrected (bottom) residuals (vertical axis) for each cover fraction versus observed field values (horizontal axis).

An example of a preliminary fractional cover product corrected for ground cover under trees is shown below (Figure 15). Further development and validation of these preliminary products is still required, but visual inspection suggests the theoretical model applied to imagery is performing well. The left image in Figure 15 shows the uncorrected fractional cover product. The centre image shows the persistent green product used as part of the approach. This product is derived from the time-series of the green fraction. The right image shows the fractional cover after the correction for the mid- and upper strata has been applied. It shows the influence of a fire under the forest canopy in the centre of the image and a greater proportion of non-green vegetation in the ground stratum, particularly at the top right of the image.

Separating climate from management

Dynamic reference cover method

The DRCM was applied to imagery from 1995 and 2004 following Bastin et al. (2012). These dates were chosen as they were particularly dry times in the study area and provided the greatest range in cover. Figure 16 below shows an example of ΔGC_{1995} and ΔGC_{2004} for an area in the Burdekin grazing lands. Darker areas indicate where the cover level had greater difference to a local benchmark or reference location. There is generally an improvement between 1995 and 2004, highlighting the severity of the drought in the mid-1990's. The area highlighted by the red rectangle has shown a considerable improvement in cover between 1995 and 2004. This might highlight a successful management intervention aimed at improving cover and resilience during drought.

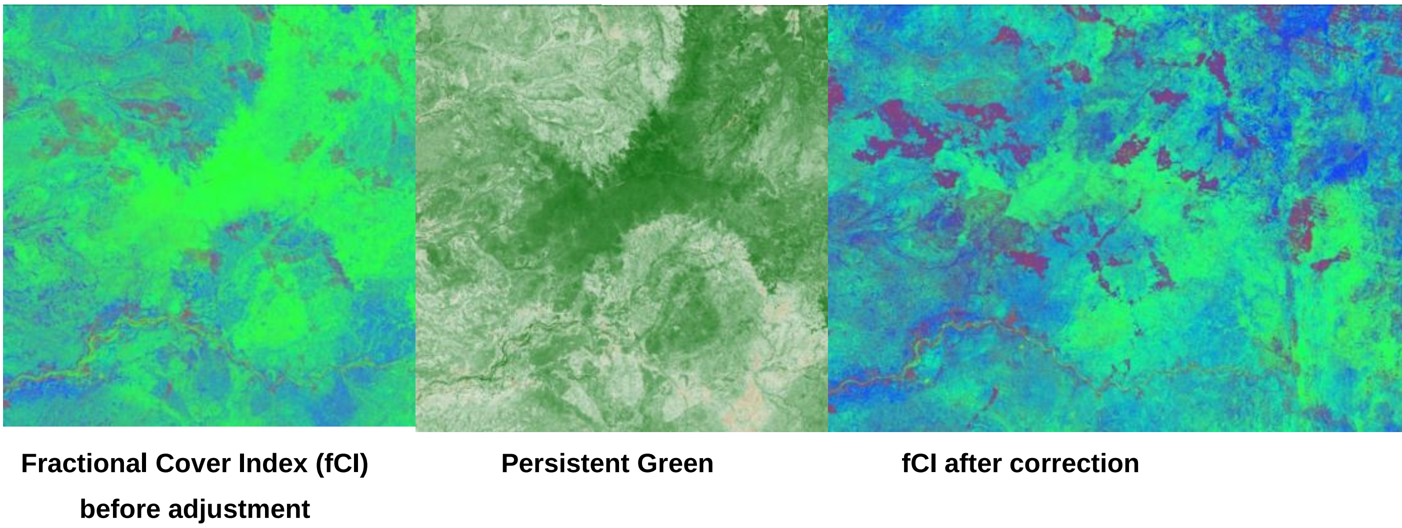

Figure 15. Corrected fractional cover product for mid and upper strata vegetation. Left image shows the uncorrected fractional cover image. The centre image shows the persistent green – this is indicative of tree cover. The right image shows the corrected fractional cover image.

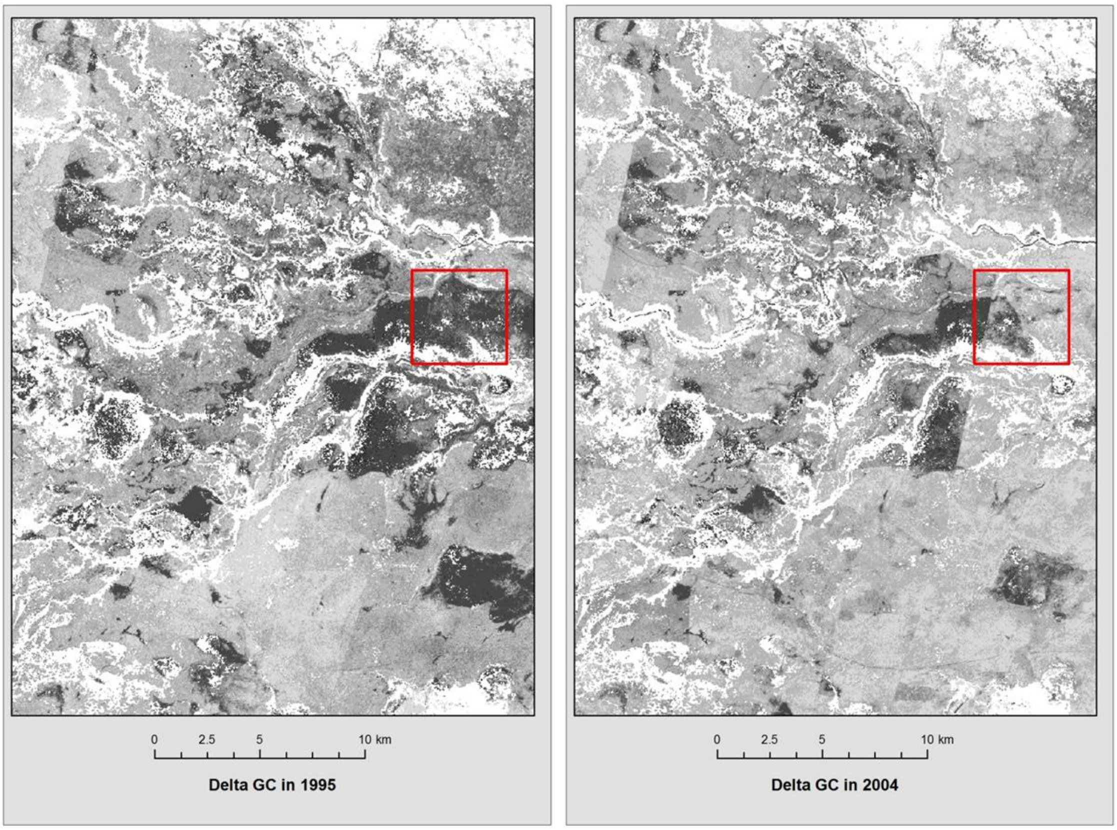

Figure 16. ΔGC_{1995} and ΔGC_{2004} for an area in the Burdekin grazing lands. Darker areas indicate where the cover level had greater difference to a local benchmark or reference location. White areas are those areas masked out due to high tree cover. The red rectangle highlights an area which has shown considerable improvement in cover between droughts.

Regional ground cover comparison

Figures 17 and 18 shows an example of how cover percentiles and comparisons made for the same local conditions have been used to generate graphs which help rank and compare a location to its local region. This example is derived from a FORAGE report but the same principles have been applied in VegMachine (see Figure 31). Figure 17 shows the dominant land types for the property and their distribution within a 50km radius. Figure 18 shows ongoing cover levels within the property and its component land types compared to the regional percentiles.

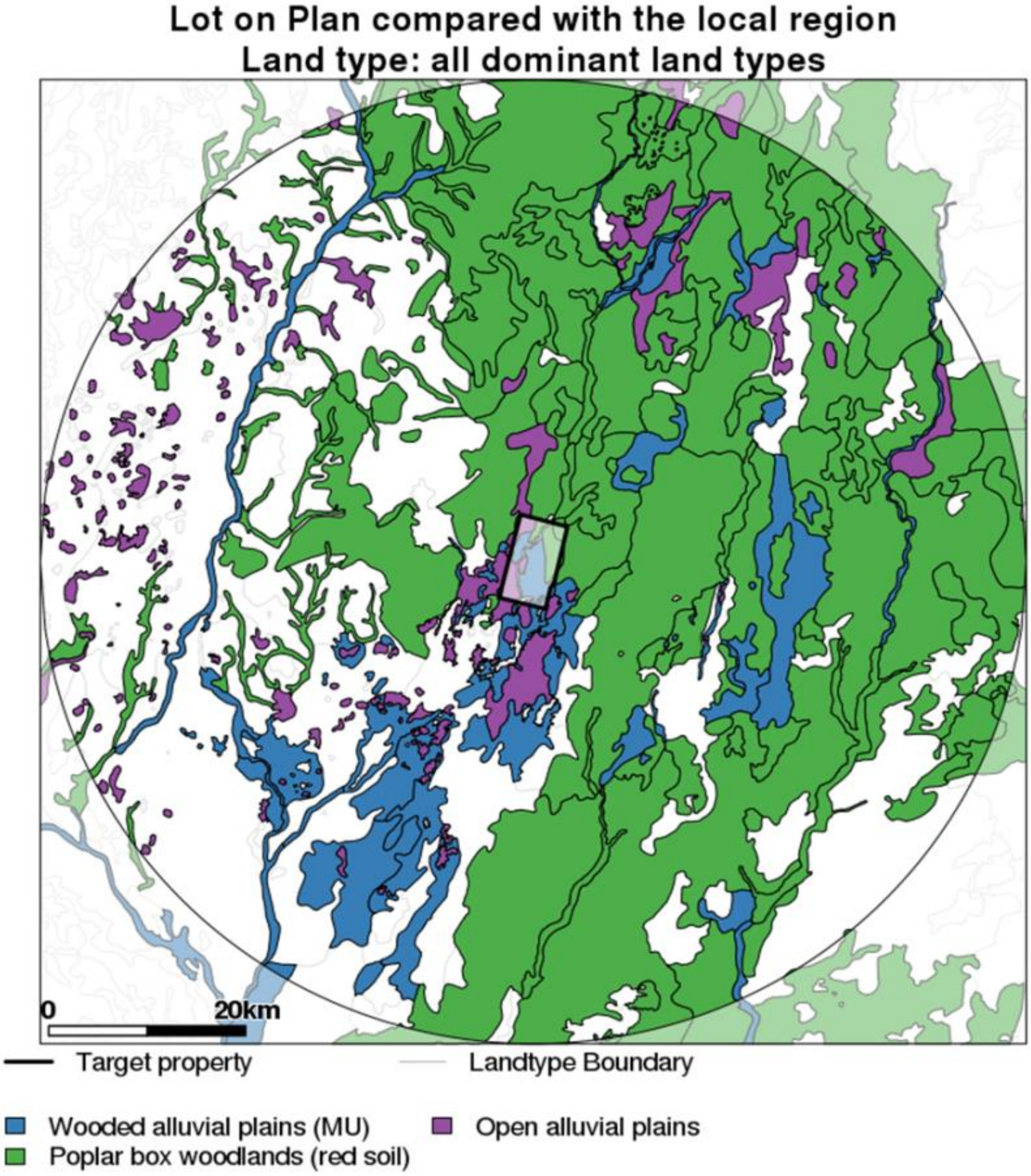

Figure 17. Example from regional comparison report. This part of the report shows the dominant land types for the chosen lot on plan (black rectangle) and within a 50km radius of the lot on plan. This is the area included in the comparison.

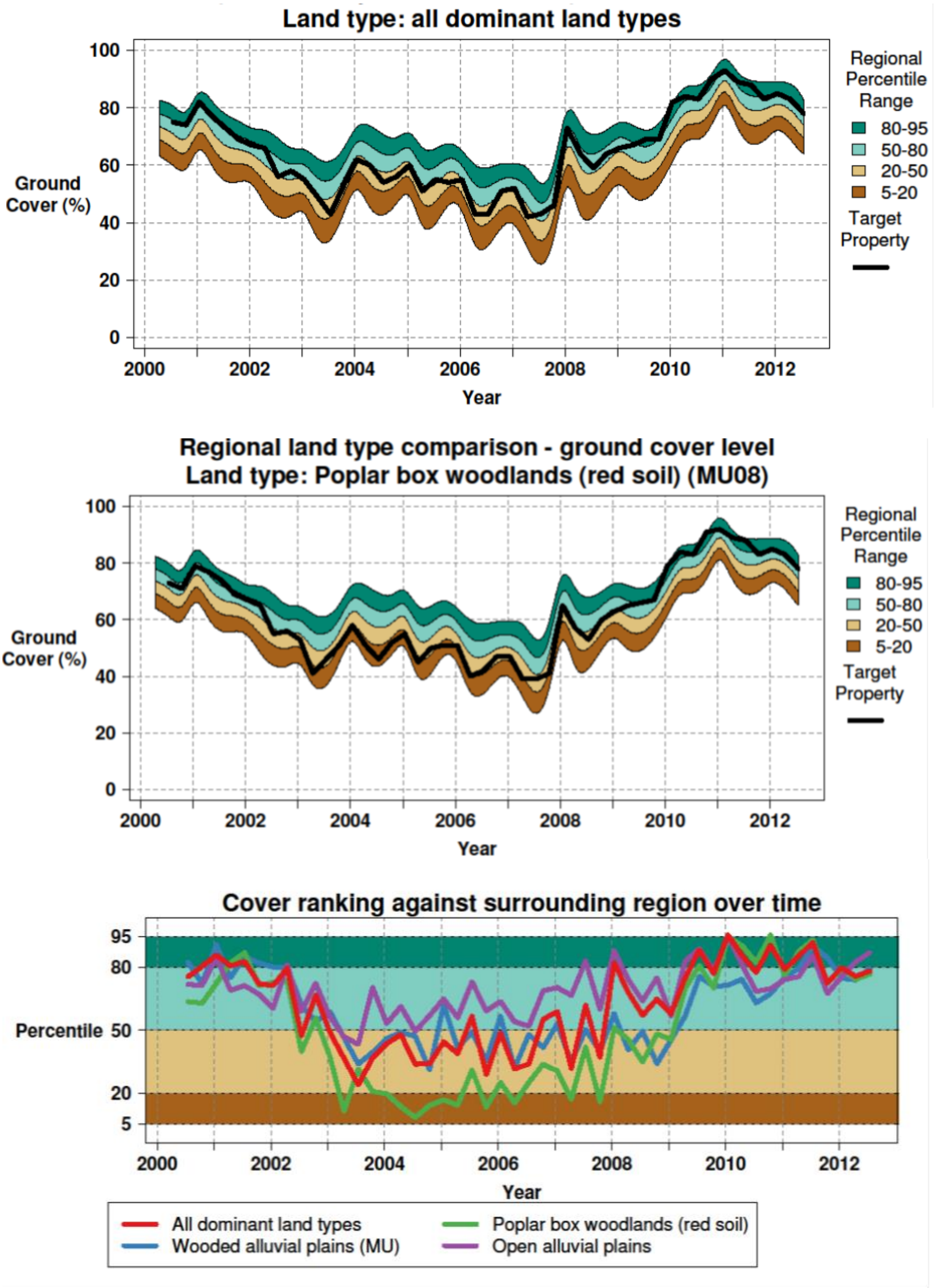

Figure 18. Example of regional comparison report. The graphs show the median cover for the target property (black line) plotted against the range of cover levels for the same land types within the 50km radius. The graph at top shows the result for all dominant land types and the graph at centre is an example for a particular land type (Poplar Box Woodlands). The graph at bottom shows the percentile ranking for the property.

The example graphs above show the general inter-annual variability in cover levels over time, with a steady increase evident in the recent, wetter years. The top and bottom graphs also show that, for all land types, the target property has generally been in the upper 50th percentile for cover levels over time. An exception was the dry years of the early 2000's. The graph in the centre for the land type 'Poplar Box Woodlands (red soil)' shows that for that land type, the cover levels in the drought years of the early 2000's were in the lower percentiles for the local region for that land type. This is further evidenced in the cover ranking graph at bottom which shows that for the target property, that particular land type had much lower cover levels relative to the local region than the other land types.

Graphs such as those above can be generated using FORAGE for any lot on plan or other selected area (as can be done in VegMachine) in Queensland. The reports can assist extension officers and land managers to identify land management issues and highlight areas where cover levels are improving or declining.

Activity 3

Figure 19 shows an example of the four land condition class probability layers developed through our work. Analyses of these data (Figure 20) showed a number of patterns in regional land condition. Firstly, the Burdekin NRM region has lower levels of grazing land condition in both examined time periods than the Fitzroy region. Both regions also improved post 1995, though improvements in the Fitzroy were largely in terms of increased A condition and decreased C condition area, whereas changes in the Burdekin region were spread across condition classes with more A and B condition, and less C and D condition areas post 1995. Table 4 shows the estimated proportion of each sub catchment in A, B, C and D condition, before and after late 1995. These sub catchment data closely align with regional patterns.

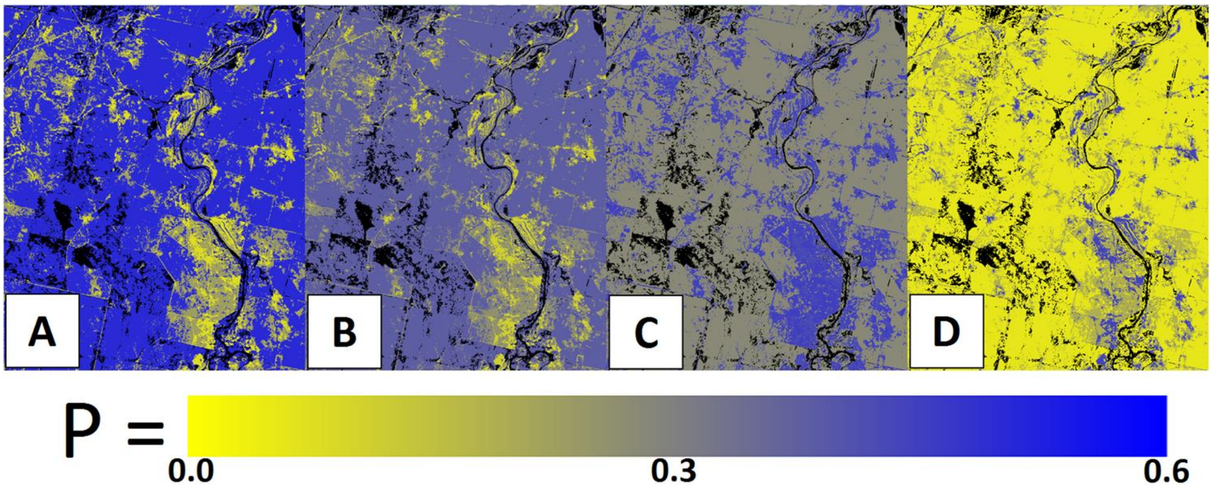

Figure 19. An example of the validated ABCD mapping in the Fitzroy Basin. Images show the same area and map probability of A to D (left to right) in that area. Darker blues indicate a higher likelihood that a location is in the indicated land condition class, and yellows indicate lower likelihood that a location is in the indicated land condition class.

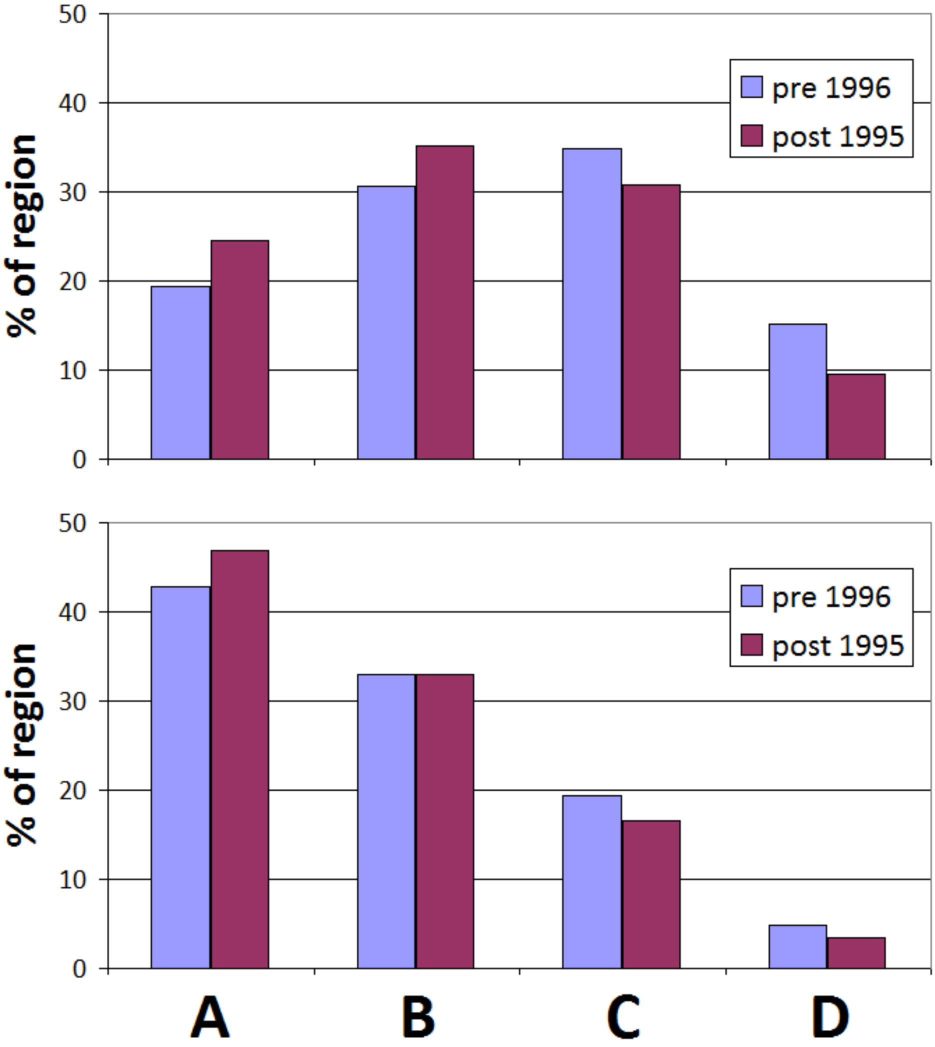

Figure 20. Proportions of region in each land condition class before and after late 1995. Burdekin (top) and Fitzroy (bottom).

It is unclear if management has contributed to this broad change, since there are no real data to compare management change between periods. However it seems likely climate did play some role in the observed improvement. This is likely because the 1990s drought was more severe than the 2000s drought across the study area (Figure 21), and average rainfall 1996-2010 was higher than in 1988-1995 (Figure 22). Consequently, the latter period represents climatically better conditions, and so should better allow for higher ground cover and ultimately better land condition, all other factors being equal.

Table 3. Estimated ABCD coverages (% of catchment) in Burdekin and Fitzroy NRM region sub catchments.

Region	Catchment	Period	A	B	C	D
Fitzroy	Boyne Calliope	Pre 1996	47.4	33.1	16.2	3.3
		Post 1995	47.6	33.1	16.0	3.2
Fitzroy	Comet	Pre 1996	42.2	32.7	20.0	5.1
		Post 1995	46.7	33.0	16.7	3.6
Fitzroy	Fitzroy Coastal	Pre 1996	42.3	32.9	19.8	5.0
		Post 1995	47.3	33.0	16.3	3.4
Fitzroy	Fitzroy River	Pre 1996	45.0	32.9	17.9	4.2
		Post 1995	47.9	33.0	15.9	3.3
Fitzroy	Isaac	Pre 1996	44.5	33.1	18.2	4.2
		Post 1995	47.8	33.1	15.9	3.2
Fitzroy	Lower Dawson	Pre 1996	43.7	33.0	18.8	4.5
		Post 1995	48.9	33.0	15.2	3.0
Fitzroy	Mackenzie	Pre 1996	40.0	32.8	21.4	5.7
		Post 1995	45.9	32.9	17.3	3.9
Fitzroy	Nogoa	Pre 1996	39.4	32.4	22.0	6.2
		Post 1995	43.7	32.9	18.9	4.6
Fitzroy	Upper Dawson	Pre 1996	44.8	33.2	18.0	4.0
		Post 1995	47.7	33.2	16.0	3.2
Burdekin	Bowen Broken Bogie	Pre 1996	23.9	34.7	31.5	10.0
		Post 1995	26.6	36.9	29.2	7.4
Burdekin	Bowen Coastal	Pre 1996	23.4	34.3	31.8	10.5
		Post 1995	26.2	36.6	29.5	7.7
Burdekin	Cape Campaspe	Pre 1996	16.6	28.0	36.9	18.5
		Post 1995	25.0	35.6	30.5	8.9
Burdekin	Lower Belyando	Pre 1996	29.5	29.5	36	16.5
		Post 1995	23.4	34.2	31.8	10.6
Burdekin	Lower Burdekin	Pre 1996	22.6	33.5	32.4	11.5
		Post 1995	26.5	36.8	29.2	7.5
Burdekin	Suttor	Pre 1996	18.2	29.2	35.5	17.1
		Post 1995	22.9	33.7	32.1	11.3
Burdekin	Townsville coastal	Pre 1996	23.1	33.8	31.9	11.2
		Post 1995	26.5	36.8	29.3	7.5
Burdekin	Upper Belyando	Pre 1996	18.7	29.8	35.2	16.3
		Post 1995	21.0	32.0	33.5	13.5
Burdekin	Upper Burdekin	Pre 1996	18.7	30.1	35.6	15.6
		Post 1995	26.5	36.8	29.3	7.4

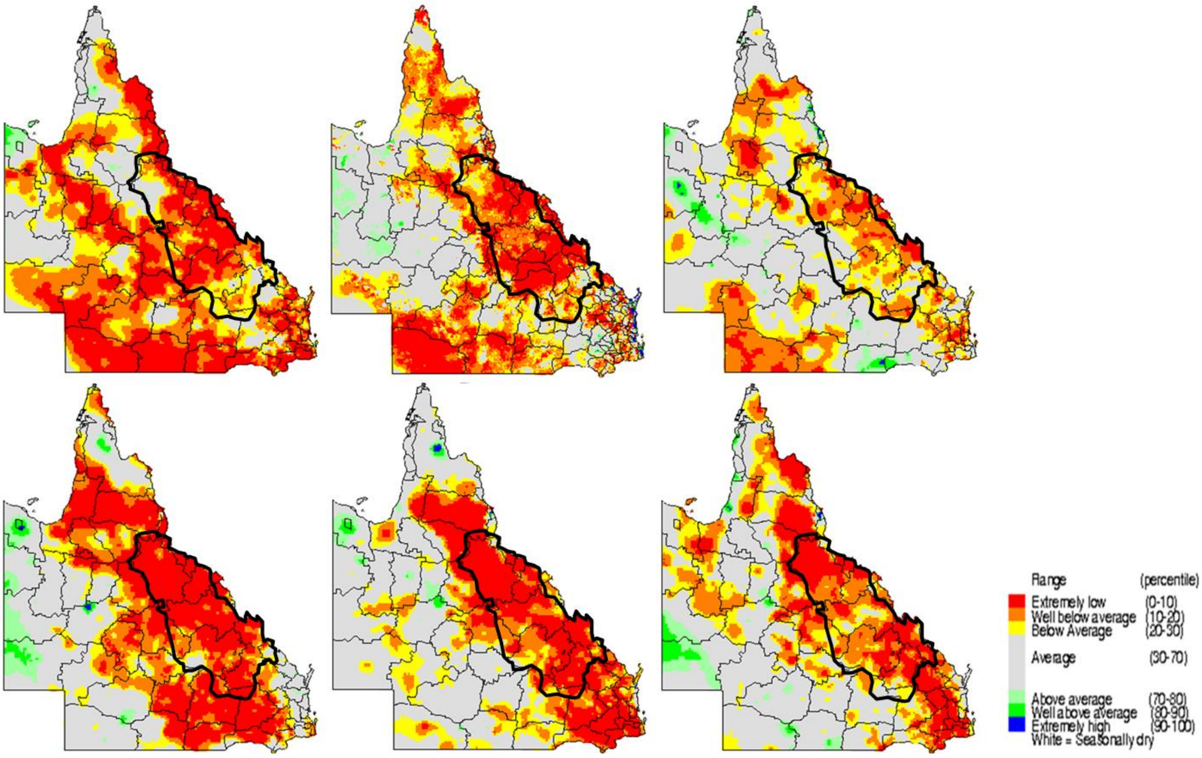

Figure 21. The three driest years of the 2000s and 1990s droughts in Fitzroy/Burdekin. Images show the deciles of 24 month rainfall anomaly to August in the years 2002, 2003 and 2004 (top, left-right) and 1993, 1994 and 1995 (bottom, left to right) (Adapted from www.longpaddock.qld.gov.au).

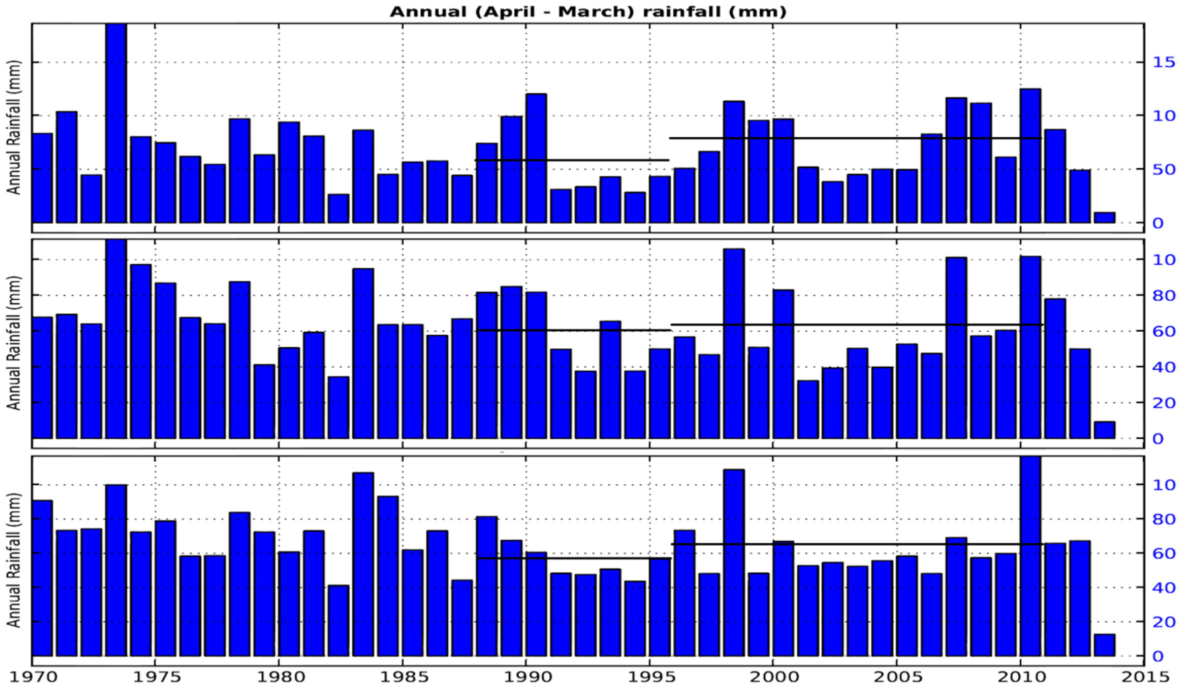

Figure 22. Annual rainfall in Fitzroy/Burdekin. Charters Towers (top), Clermont (middle) and Theodore (bottom). Horizontal lines show mean annual rainfall over the two periods (1988-1995 and 1996-2010) (Adapted from www.longpaddock.qld.gov.au).

The land condition change analysis provides a reasonable amount of detail about where and how much land condition has changed from one period to the next. A few points are worth note though about how to interpret these data.

- Firstly, both images were by necessity recalibrated using data collected only post 2003. Such a calibration assumes that the corrections identified in our validation model are appropriate to both periods, though this assumption cannot be tested.
- The validation model (Appendix 4) identified an effect for the type of ABCD assessment used during validation. Sites assessed using the GLM land condition framework had significantly higher likelihoods of A and B condition, and corresponding lower likelihoods of C and D than those assessed using the Patchkey methodology. The proportions analyzed here are those for GLM style assessments, largely because the bulk of the validation data were collected in that metric.
- Both the validation site data (2004-2012) and the image data (1988-1995, 1996-2010) were collected over multiple years. We know that land condition can change over time, both with local management and with broader wet/dry seasonal cycles.
- As per Karfs et al. (2009a), this approach will not identify poor condition areas with heavy coverage of weeds.

Activities 4, 5 and 6

Table 4 shows the predicted proportions of A, B, C and D condition country in each region according to both the unvalidated and validated post 1995 land condition mapping. The validated mapping was recalibrated according to the best identified model (Appendix 4), and this model suggests the original mapping substantially overestimates the proportion of B condition country in each region. It also suggests land condition classes are very differently distributed in the two regions – B and C condition is most common the Burdekin while A and B are more common in the Fitzroy region.

Table 4. Predicted percentages of A, B, C and D condition country in Fitzroy and Burdekin NRM regions. Estimates are derived from the original post 1995 ABCD mapping and validation model (Appendix 4).

Model	Region	A	B	C	D
Unvalidated mapping	Burdekin	13.5	70.2	11.2	5.1
Validated mapping	Burdekin	24.4	35.0	30.9	9.7
Unvalidated mapping	Fitzroy	12.4	76.1	8.5	3.0
Validated mapping	Fitzroy	46.8	33.0	16.6	3.6

The reality check exercise that asked experienced land condition assessors to compare these proportions within regions and qualitatively rank their likelihood did not suggest a clear difference between the two maps within either region, though the validated mapping did have a higher mean ranking in both regions. Consequently the validation model was adopted and mapping adjusted accordingly. Validated mapping was used for the Activity 3 work, and mapping was also generated for distribution to end users (see Activity 8).

Activity 7

Surplus runoff modeling

Multiple primary models were investigated under two potential error structures trialed in this work. The final model selected (Appendix 6) was a normal error model based on catchment runoff in the previous season, amount and timing of rainfall in the current season, and catchment size, and accounted for 63% of the variance in seasonal catchment runoffs over the 615 catchment/season observations in the modeling data subset. This is a simpler model than the best Tweedie error model, with a higher proportion of variance explained, and (subjectively) an equal or better set of diagnostic residual plots. Figure 23 shows the plot of observed versus expected runoff values for this model.

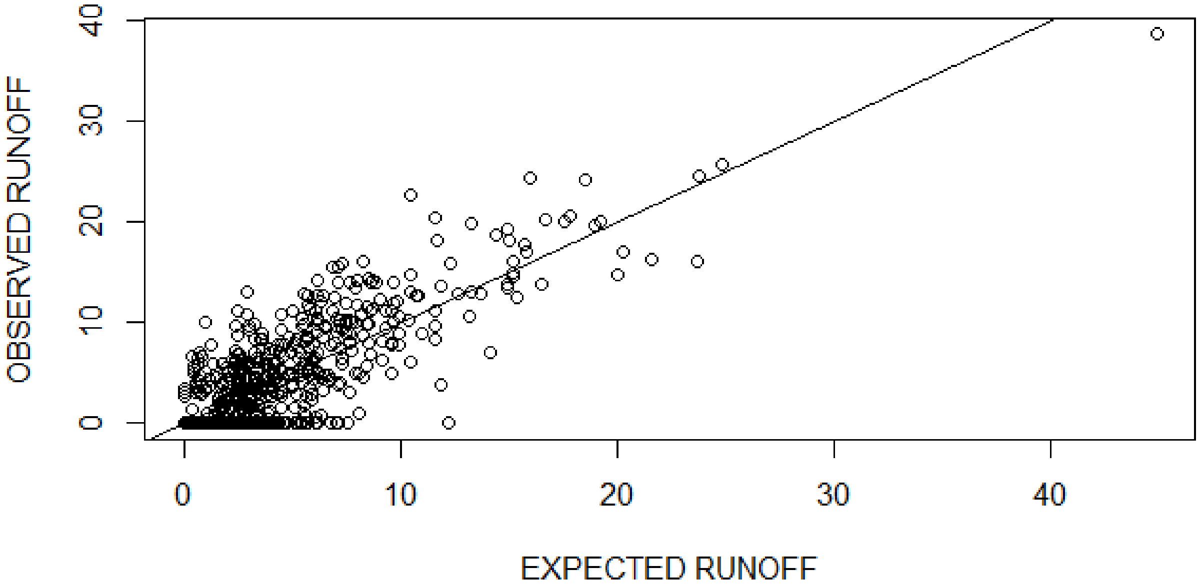

Figure 23. Primary runoff model observed versus expected runoff values. Data modeling data subset for primary model (Appendix 6). Units are square root of summed mean daily m^3s^{-1} runoff for a season.

The secondary model did not perform as expected, with a slight but significant positive relationship identified between catchment ground cover and likelihood of surplus runoff (Figure 24). This is a counterintuitive outcome, suggesting risk of surplus runoff *increases* with ground cover levels, however it seems much more likely that this outcome is a statistical artifact of the data and the analysis rather than an insight into runoff – ground cover relationships. A number of issues may have contributed. At this point in time, it is unclear which might be responsible, but they include the following.

- Failure to fully account for serial correlated errors in the data.
- Measuring ground cover and runoff in the same season. While ground cover in a season should affect runoff, it is possible that rainfall could also have influenced ground cover, and thus fueled the positive association between runoff and ground cover.
- Inclusion of catchments where as little as 25% of areas was assessed for ground cover levels.
- Significant variation in catchment sizes which would have complicated the task of relating rainfall and runoff due to varying temporal lags.

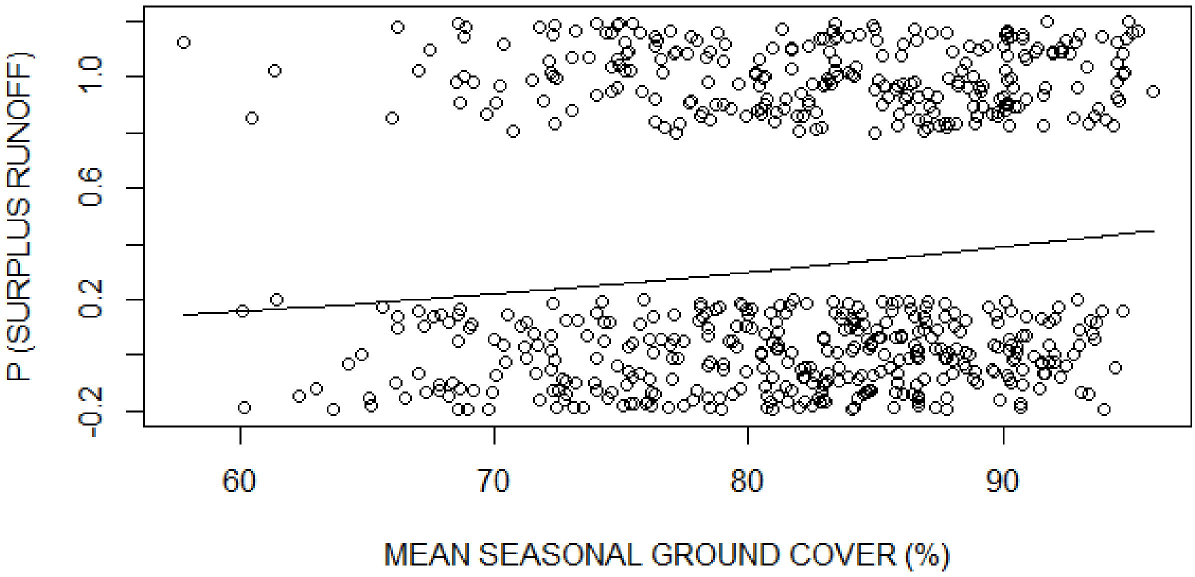

Figure 24. Secondary catchment runoff model. Surplus (y=1) and deficit (y=0) events plotted against mean seasonal ground cover values (y axis values are jittered vertically to improve visibility). The sloped line shows the fitted probability of a surplus runoff event given ground cover levels.

Dynamic reference cover method and land condition modeling

Figure 25 shows the relationship between $CoverAvg_{t-3}$ and the ABCD land condition field data. This shows that land condition classes A, B and C do not differ greatly in median levels of cover although the range (variance) of cover in each class does become less as land condition state improves. Land condition class D clearly has a lower median cover and much greater range with little overlap with the other classes, however there were few field sites assessed in this class compared to the other classes.

The relationship between ΔGC_{2004} and ABCD land condition class is much clearer than for $CoverAvg_{t-3}$ (Figure 26). While there remains significant overlap in the range of ΔGC_{2004} values between condition classes, there is a clear relationship which shows that as ΔGC_{2004} becomes more negative (i.e. the cover has a greater difference to the local reference cover level), land condition declines.

A predictive model for the probability of a land condition class based on $CoverAvg_{t-3}$, ΔGC_{2004} and mean annual rainfall was developed for the study area. All three explanatory variables were found to be significant predictors ($P<0.001$). Figure 27 shows the probability of B or better land condition for a given average annual rainfall, $CoverAvg_{t-3}$ and ΔGC_{2004}. In general, it shows that if ΔGC_{2004} is strongly negative, much more ground cover is required to achieve a given level of land condition (e.g. ≥B condition). It also shows that lower rainfall areas require lower levels of ground cover than more mesic areas to achieve the similar levels of grazing land condition. This confirms the value of maintaining ground cover levels, particularly during, but also outside drought events. More importantly though, it quantifies these relationships and provides specific ground cover targets to maintain and/or improve land condition post drought.

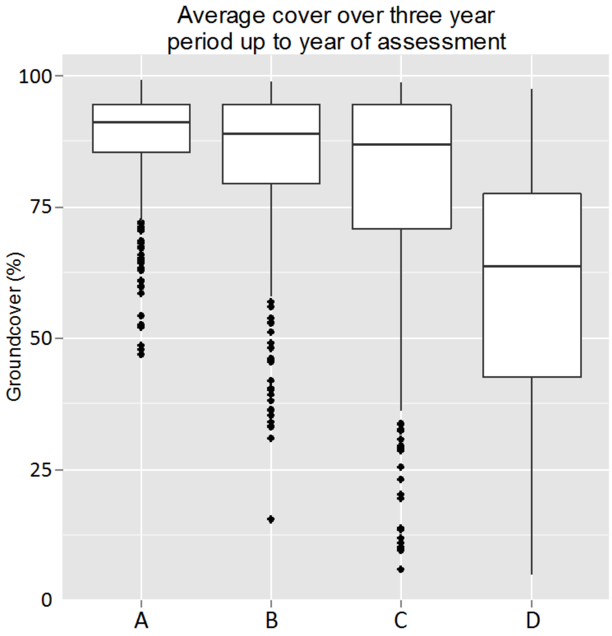

Figure 25. Box plots of relationship between *CoverAvg*$_{t-3}$ and land condition class.

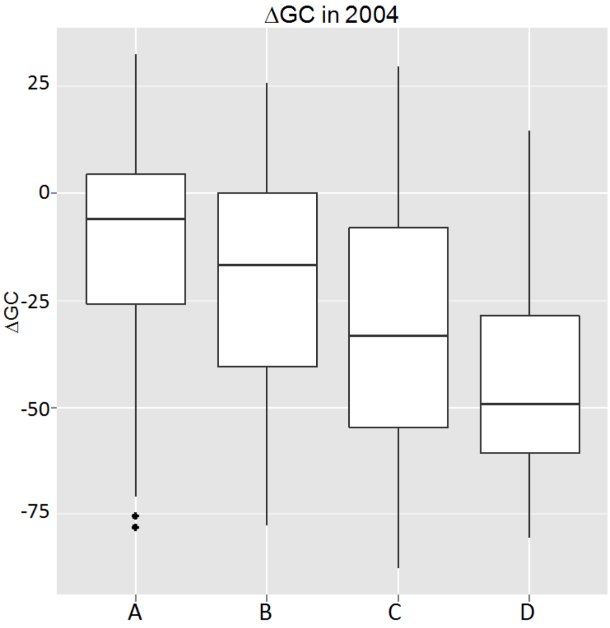

Figure 26. Box plots of relationship between ΔGC_{2004} and land condition class.

Figure 28 provides another perspective on the above model, showing the threshold of cover required to meet the criterion of ≥ 50% probability of achieving B condition or better, given ΔGC_{2004} and average rainfall. Similar to Figure 27, this quantifies important relationships between ground cover, condition, rainfall and ΔGC_{2004}.

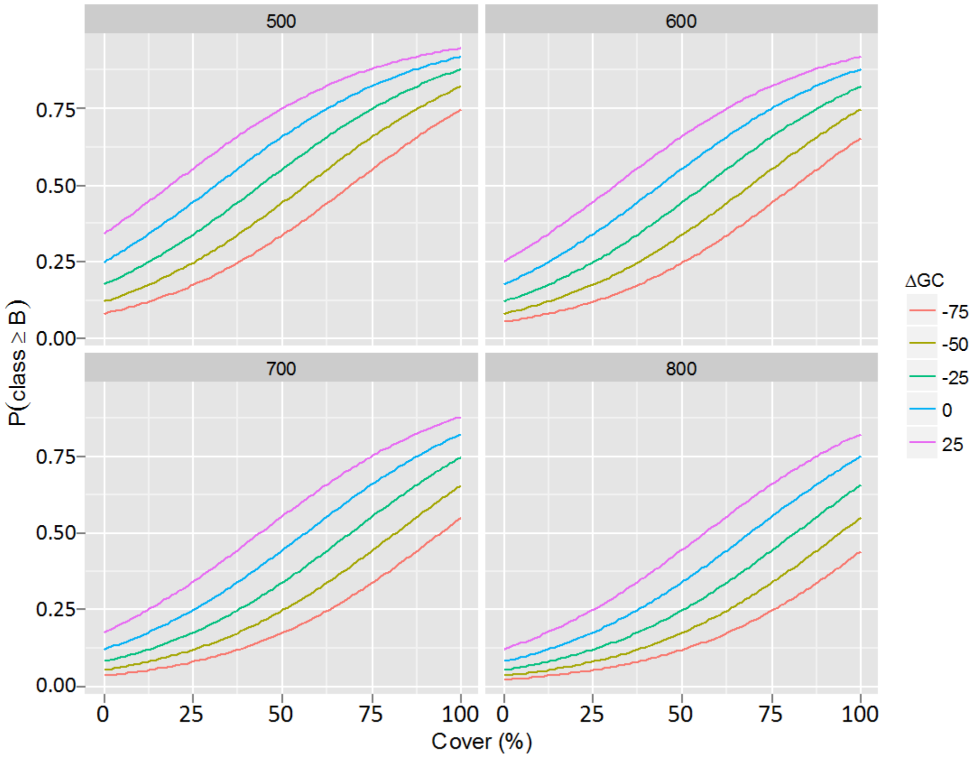

Figure 27. Modelling likelihood of B condition and better. The model uses ΔGC_{2004}, ground cover, and rainfall to predict the likelihood that sites are in B condition or better. For example, sites on the 500mm average annual rainfall isohyet (top left) with a ΔGC_{2004} of -25 require about 45% ground cover to achieve a 50% likelihood of being in B condition or better. On the 800mm isohyet (bottom right), and with the same ΔGC_{2004} value of -25, the level of cover required for a 50% probability of B condition or better, increases to around 80%.

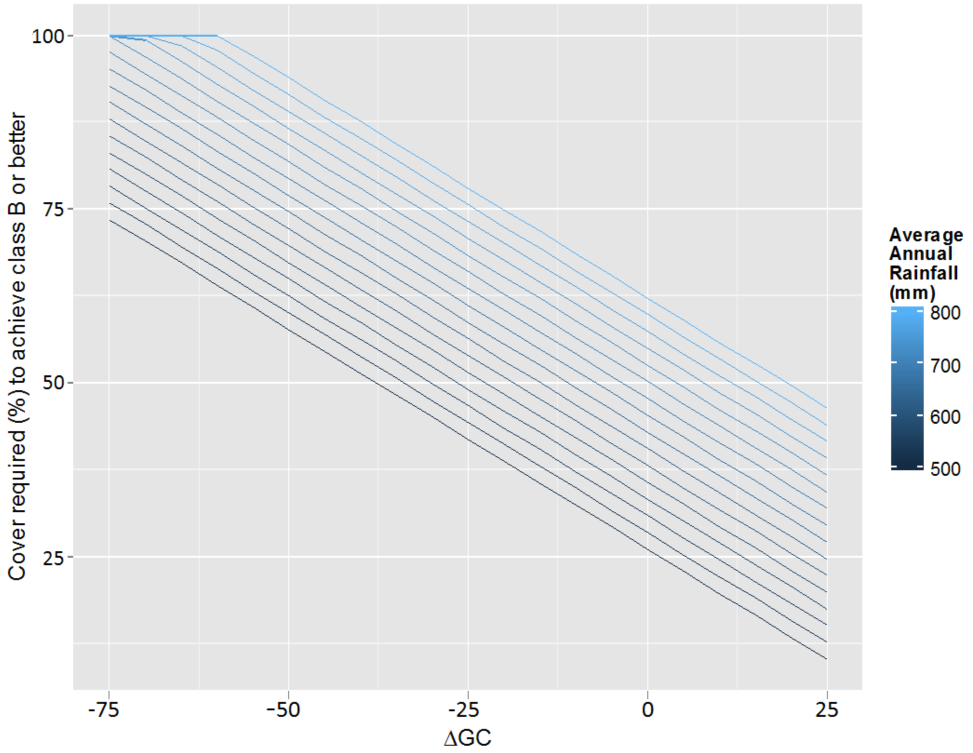

Figure 28. Cover threshold required for ≥50% probability of at least B-condition. Predictors are ΔGC_{2004} and average annual rainfall. For example, locations on the 500mm annual rainfall isohyet with ΔGC_{2004} value of -25, require about 45% ground cover to have a 50% probability of B condition or better. By contrast, sites on the 800mm rainfall isohyet with the same ΔGC_{2004} value of -25, about 80% cover is required for a 50% probability that the site is in B-condition or better.

Two maps were generated for the study area to provide a spatial representation of the model output. The first map provided a pixel scale (i.e. 30m x 30m) representation of the cover threshold required to achieve a 50% probability of B condition or better (Figure 29). This example shows marked spatial variation in terms of cover required, with darker areas indicating locations with a higher ground cover target. Particularly noticeable are fence-line effects where some areas require much higher levels of cover than adjacent areas. At this scale the mapping should assist land managers and NRM bodies to target on ground activities.

The second map product averages the same ground cover targets as Figure 27 across catchments (Figure 30). This map more clearly shows the influence of long term average rainfall on the cover levels required to achieve a given level of condition. Nearer to the coast, higher rainfall catchments (e.g. Bowen, Isaac, and Fitzroy) require higher levels of cover than those drier catchments further west to achieve the same level of condition. The map has obvious applications to the setting of regional targets for ground cover.

Activity 8

Ground cover data delivery

As mentioned, ground cover and related fractional data products are available via a number of channels. Improved mechanisms are also being investigated to ensure accessibility and usability. Some existing mechanisms for accessing ground cover data and information such as the regional comparison report include:

- VegMachine (http://futurebeef.com.au/resources/vegmachine/)
- FORAGE (http://www.longpaddock.qld.gov.au/forage/groundcoverreport.php)
- TERN Auscover Data Portal (http://data.auscover.org.au/Portal2/)
- Data request to DSITIA’s Remote Sensing Centre (http://www.nrm.qld.gov.au/science/remote-sensing/)

Future developments include developing Google Earth files for easy viewing and distribution via the Queensland Globe (https://data.qld.gov.au/maps-geospatial/qld-globe) and TERN’s facilities. Other online mapping tools are also being investigated subject to funding.

VegMachine

Data improvements

Figure 31 provides a graphic example of many of the packaged improvements in the VegMachine datasets created in this project. The two screenshots show analysis of the grazing exclosure at the Wambiana near Charters Towers. Figure 31A approximates the sort of analysis that was possible prior to the project, while 31B shows the depth of analysis possible today. Four main improvements created in this project are worth note.

1. The cover time series extended from 2009 to winter 2012.
2. Use of the fractional cover rather than the GCI (not obvious in this image), providing more accurate assessment of ground cover.

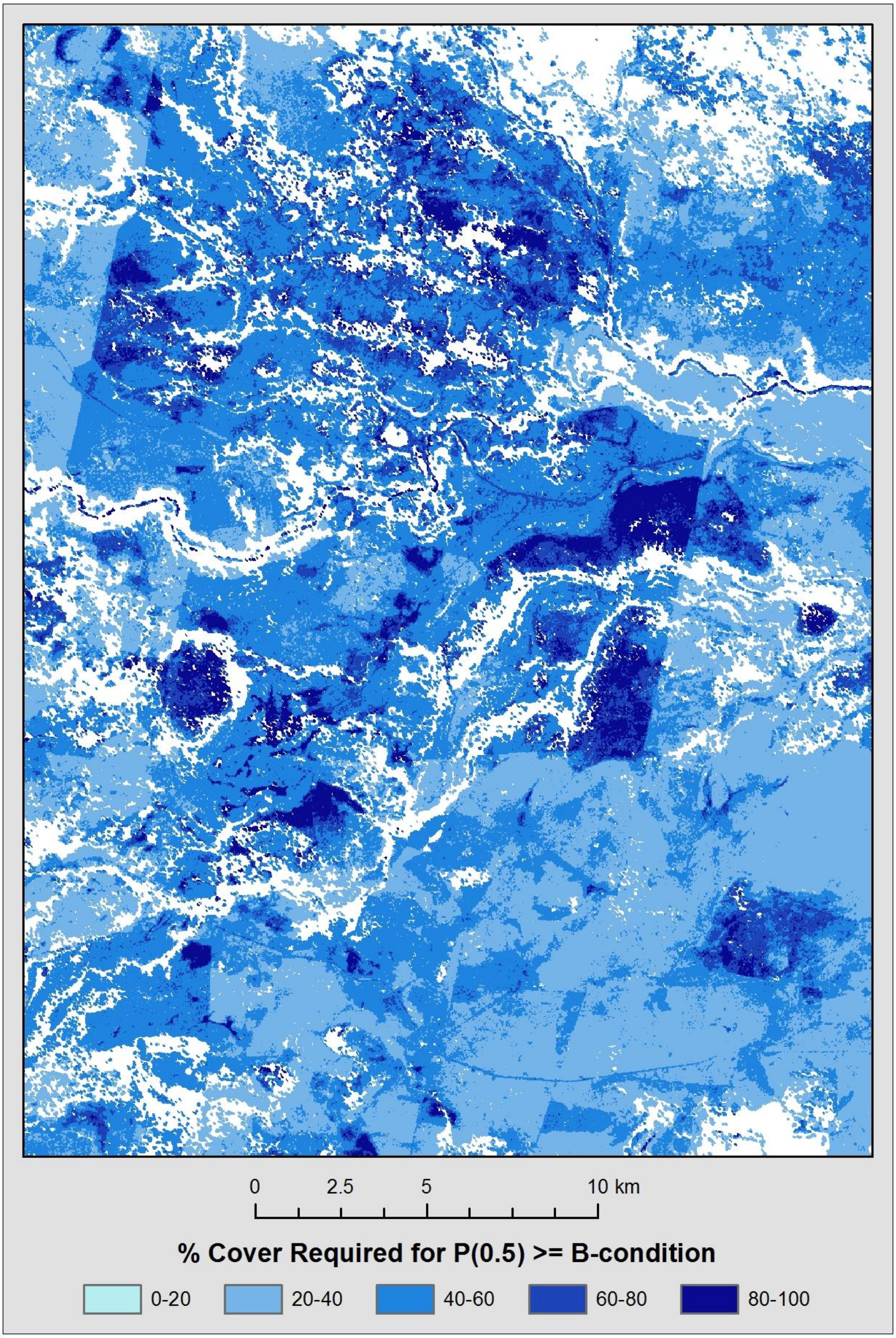

Figure 29. Mapped cover thresholds to achieve B condition of better. This example in the Burdekin grazing lands shows the level of ground cover required to achieve a 50% probability of B condition or better given ΔGC2004, current levels of cover, and average annual rainfall. Darker areas require greater cover to achieve the same level of land condition. White areas on the map are areas masked out due to high tree cover.

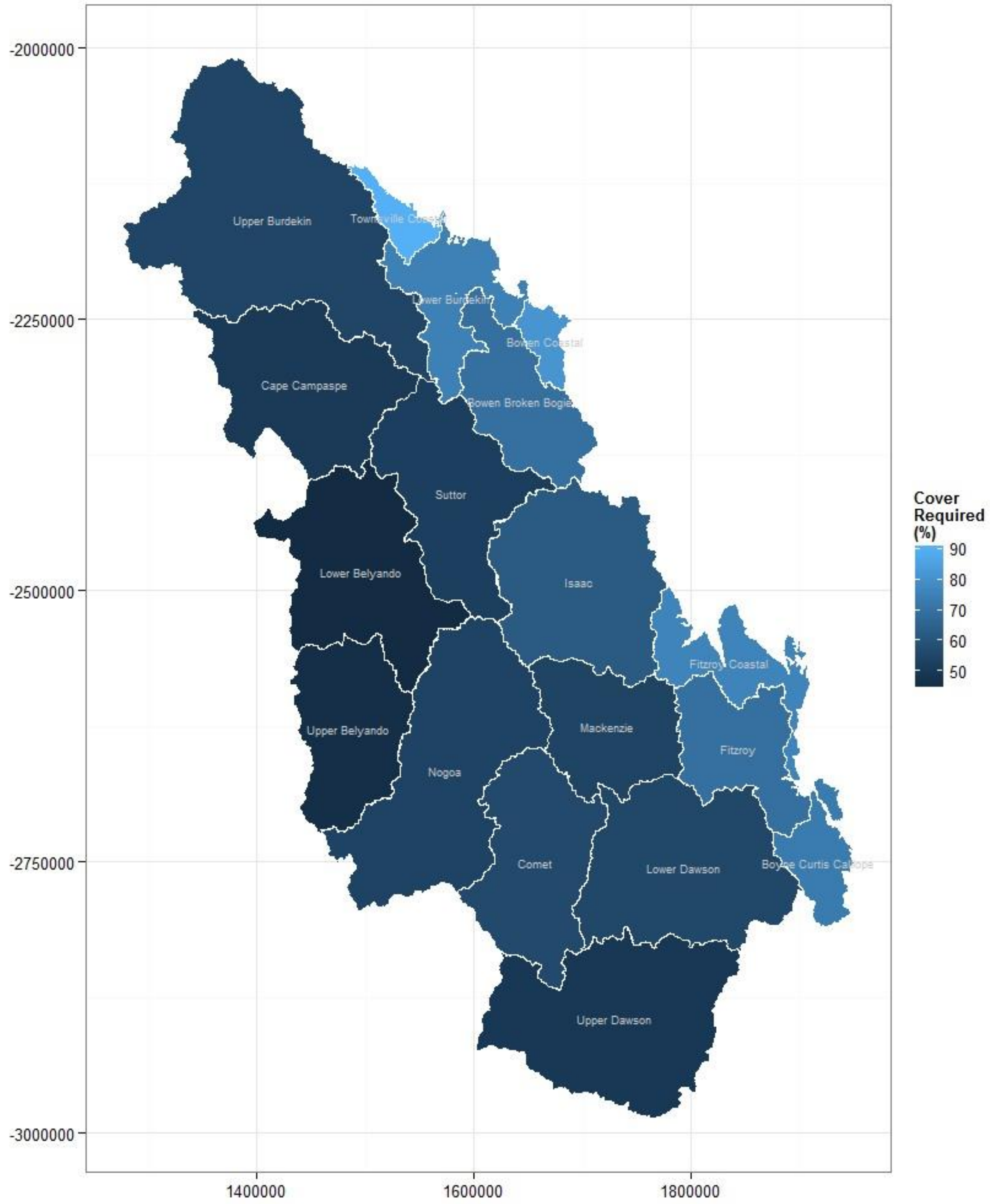

Figure 30. Sub catchment scale ground cover targets. The mapped thresholds indicate the approximate level of ground cover required to achieve a 50% probability of B condition or better in each catchment.

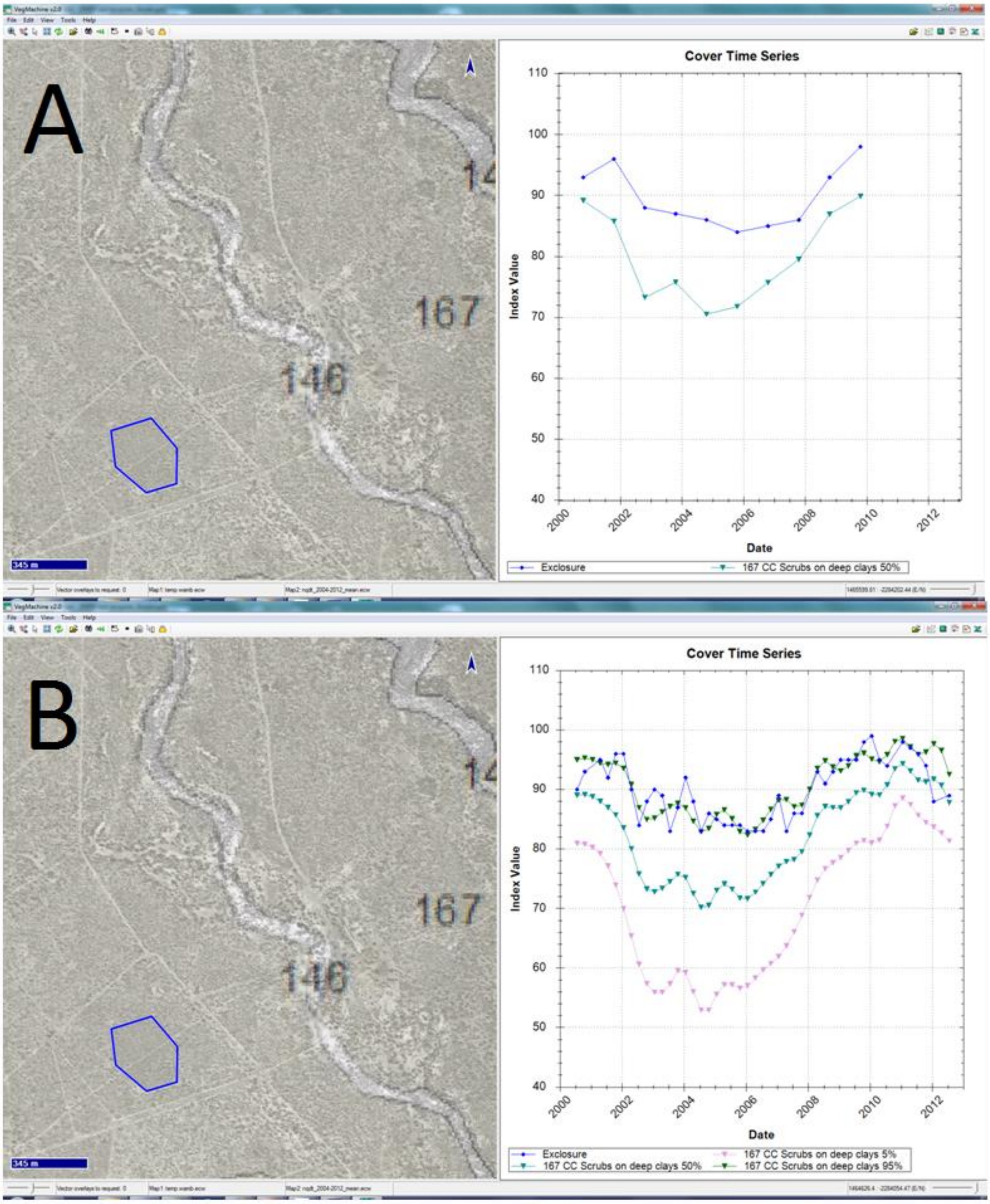

Figure 31. VegMachine analysis of Wambiana exclosure. Prior to (A) and after (B) project outputs have been customized for use in VegMachine.

3. A higher density of data points through the time series due to the incorporation of seasonal imagery rather than annual imagery as occurred prior to the project.
4. Change from a single land type average benchmark to percentile benchmarks to better represent cover variability in the benchmark area (5th, 50th and 95th percentiles are used here, but 20th and 80th were also available).

This is a good example of how the team has packaged the project outputs into customized monitoring tools. Other examples discussed above are the regional comparisons (Activity 1 and 2) and the ABCD land condition mapping (Activity 4, 5 and 6).

Training activities

32 RD&E staff in 6 separate agencies participated in standard VegMachine training at five different venues (Table 5). In addition a number of other training activities and products were developed and provided to end users over the course of the project and these are listed below.

- Five NQDT staff completed an advanced three hour workshop that covered better VegMachine report preparation. This was requested and designed to help NQDT staff prepare more consistent reports for project evaluation.
- Nine staff in DAFF, NQDT and FBA have attended three presentations on the new fractional data, percentile benchmarks and other features of the 2013 data. More are planned as the NRM groups move back into project evaluation later this year.
- Approximately 20 phone requests for help with the software have been answered.
- Two instructional videos on VegMachine have been developed and posted on the VegMachine's Futurebeef website (futurebeef.com.au/resources/vegmachine/).
- Project staff have participated in RP68G 'Enhancing FORAGE' working group on the redevelopment of the FORAGE ground cover report, including drafting comparison documents to help align the FORAGE and VegMachine outputs.

Table 5. Training details for standard VegMachine training activities.

Location	Date	AgForce	FBA	NQDT	DSITIA	DNRM	DAFF	Total
Brisbane	09.03.12				4	4		**8**
Emerald	28.02.12		2				3	**5**
Rockhampton	28.10.11		2					**2**
	01.11.11						1	**1**
	27.01.12			1				**1**
	08.07.12						1	**1**
Theodore	20.08.12		2					**2**
Townsville	01.11.11	1		6				**7**
	21.11.11						3	**3**
	16.08.12			2				**2**
Total		**1**	**6**	**9**	**4**	**4**	**8**	**32**

Activity 9

The project has produced a number of scientific and plain English written reports, interviews and training materials. These include;

- Star, M., Rolfe J., Donaghy P., Beutel T., Whish G., Abbott B. (2012) Targeting resource investments to achieve sediment reduction and improved Great Barrier Reef health. *Agriculture, Ecosystems & Environment.* http://dx.doi.org/10.1016/j.agee.2012.03.016 (See Appendix 1)
- Bastin G, P Scarth, V Chewings, A Sparrow, R Denham, M Schmidt, P O'Reagain, R Shepherd and B Abbott. (2012) Separating grazing and rainfall effects at regional scale using remote sensing imagery: A dynamic reference-cover method. *Remote Sensing of Environment*, **121**, 443–457. doi:10.1016/j.rse.2012.02.021 (See Appendix 1)
- Dan Tindall's Interview with Regional ABCD regarding ground cover work (10/10/12).
- Terry Beutel's interview with Ecos magazine VegMachine (01/05/13) (http://www.ecosmagazine.com/?paper=EC13112).
- Advanced VegMachine user training presentation.
- VegMachine data update presentation.
- Updated VegMachine page of Futurebeef website (http://futurebeef.com.au/resources/vegmachine/)
- VegMachine instructional videos on the FutureBeef website.

Discussion

Benefits and application

A key point to note about the work described here is the extent of its impact. The ground cover data, its derivative products and associated activities have had a major impact of RD&E in the GBR catchments and beyond. Our products and services have helped inform the following activities in the Burdekin and Fitzroy regions.

- Catchment modeling
- Reporting for ground cover targets
- Evaluation of NRM funding applications (FBA and NQDT)
- Informing Water Quality Improvement planning (FBA)
- Identification of extension target areas (DAFFQ in the Burdekin)
- Economic assessment of land rehabilitation (FBA and NQDT)
- Identification of suitable RD&E sites for research (FBA and NQDT)
- Generation of fire history data mapping
- Development of novel landscape assessment tools (e.g. DCRM).

This is a sizeable list of activities that have benefitted from the derivatives and data funded under this project, and it is clear that the work has demonstrated value to a wide range of end users.

Improved ground cover data and products

This project has facilitated the development of an improved ground cover algorithm which provides long-term, seasonal information about the dynamics of green and non-green cover and bare ground. The approach has improved the accuracy of ground cover estimation using satellite imagery and provides discrimination between the green and non-green ground cover fractions – this was not possible with previous approaches. The combination of the new approach and the improved time-series of satellite imagery as a result of the opening up of the Landsat archive has provided project partners with data and information required to investigate relationships between ground cover, grazing land condition and runoff to better inform targets. Importantly, the improved information is providing land managers, water quality modelers and policy-makers with an objective and comprehensive tools for decision-making.

The seasonal fractional cover data will be critical to water quality modeling as part of the Paddock to Reef program by providing data at a spatial and temporal resolution better suited to representing the seasonal dynamics in vegetation cover, a key element of the universal soil loss equation (USLE) approach. The Paddock to Reef catchment modeling is reliant on the ground cover data for the cover factor. The fractional cover data is enabling a more accurate and robust cover factor adjustment to be developed than is currently used therefore improving the parameterization of the water quality models. The development of an approach for cover under trees also has the potential to greatly increase the area which can be accounted for in water quality modeling and reporting, thus also improving parameterization of the models. Furthermore, the fractional cover data also includes a per pixel estimate of error which could be used to quantify uncertainty in the cover parameters used in the water quality modeling.

The improved data are also potentially valuable extension and grazing land management tools. Products developed from these data such as the regional comparison report and VegMachine provide extension officers with useful information at an appropriate spatial and temporal resolution to assist producers with managing for appropriate levels of ground cover in different seasons to ensure productive grazing systems are maintained and to minimize erosion risk. As producers become more aware of the uses of these tools for grazing land management, the data and derived products may be used directly for property and paddock-scale decision-making. This uptake of products by producers will be enhanced by the development of data delivery systems that provide timely and efficient delivery of the data and products in formats that are manageable and easily understood.

The improved ground cover data and derivative products are greatly enhancing reporting on Reef Plan targets and objectives, and facilitating improvements in regional NRM monitoring and evaluation. The improved understanding of spatial and temporal dynamics of ground cover, and the de-coupling of climate and management effects on ground cover are enabling more meaningful reporting on ground cover targets. It is now possible to identify and quantify, spatially and temporally, deficits in ground cover that present risk to water quality. With products like the DRCM, VegMachine and regional comparison reports we have improved ability to report on where and by how much ground cover has changed and what the drivers for those changes may be. As previously mentioned, the cover under trees approach also has the potential to expand the areas which are monitored and reported for ground cover. Not only can this help with reporting on the effectiveness of management practice change in improving ground cover, but it can also assist with prioritizing and targeting investment for extension or management practice improvement programs.

There remain some limitations with the improved ground cover data. The data is calibrated by field estimates of fractional ground cover. The accuracy of these field methods may vary between operators. In addition, there may be some undersampled cover types, on soils or landscapes which have specific reflectance characteristics. This could influence the predictive capability of the fractional cover algorithm in some areas. However, the field methodology has been developed such that quantitative measurements of fractional cover are simple and subjectivity is minimized, and enough estimates are made at the site scale to ensure representative sampling of the cover fractions over an area large enough to calibrate the satellite based estimates. Observer influences are therefore considered to be negligible and with the recent acquisition of additional sites in a range of landscapes through the National Ground Cover Monitoring Program, the range of cover types which have been adequately sampled has been greatly improved. The present levels of error observed in the fractional cover model are considered to be approaching the lowest that could be expected for most areas, and acceptable for most applications given the resolution of the data to which the model is applied. One possible limitation of the field data is limited temporal sampling of the range of seasonal and longer term climatic conditions which influence ground cover and the range of regimes under which ground cover is managed. Additional analyses are required to assess this and future field campaigns should also be designed with this in mind.

The improved fractional cover data has also facilitated development of a preliminary approach to estimate cover under trees. Whilst this approach requires further validation and development (see further discussion below), the potential for these data to expand the areas which can be reliably monitored for ground cover is encouraging. The results from this preliminary analysis demonstrate the major effect mid- and upper-strata vegetation has on the predicted levels of the ground cover fractions derived from satellite imagery. The results suggest, this impact could be considerably mitigated by the adjustments proposed which correct for these effects.

The arrangement of cover across a paddock, property or catchment can have a significant effect on infiltration and runoff, both key drivers of erosion. It can vary according to climate, management and land type. Further work is proposed (subject to resources) which will focus on use of the seasonal fractional cover data to better quantify the spatial arrangement of ground cover. With recent advances in de-coupling the climate and management, and the greater temporal sampling with the Landsat archive, this remains one of the more important ground cover factors to resolve.

Continuity of the ground cover data

On February 13, 2013 the next satellite in the 40+ years of Landsat missions was launched. Landsat 8, has now finalized orbital parameters and sensor calibration exercises and the first image acquisitions for Queensland are complete. The data will be free and readily accessible within days of acquisition via the web. The specifications of the Landsat 8 sensor are designed such that cross-calibration of pre-processing streams and algorithms such as for fractional cover are relatively straightforward. This will assure ground cover data and derivative products and facilitate continuous improvements to these data and products for years to come. With Landsat 7 remaining functional until around 2014/15 (in SLC-off mode), and the 25+ year history of Landsat 5 and 7 imagery already available on DSITIA's archive, the continuity of the Landsat program is critical to ongoing long-term monitoring of land cover features in GBR catchments, including ground cover. The long-term history of ground cover data available provides an invaluable time-series of information at a spatial scale suitable for property and regional planning.

In addition to Landsat 8, a number of medium and high resolution satellite-based sensors are planned by a number of space agencies around the world in the coming years. In order to ensure redundancy in the production of ground cover data, further work is required to cross-calibrate ground cover algorithms, or develop new approaches, for application with some of these new sensors. This is a significant research and development task and would require appropriate levels of resourcing and the continuation of partnerships between space agencies and remote sensing experts.

Land condition mapping

This work showed that ground cover data have capacity to help us map grazing land condition. This has been done previously in the reef catchments (Karfs et al. 2009a) but our work represents the most concerted effort to validate the mapping across all land condition classes in the Burdekin and Fitzroy regions to date.

Historically the ABCD mapping in the Fitzroy and Burdekin regions has been presented as a single layer, four value (A, B, C or D) image. It specifies condition classes as present or absent, so that a pixel is only mapped as one of the four possible grazing land condition classes, and this is a common approach to the presentation of classification models. What has often not been understood by users though is that those classifications have always been based on probabilities, and that where, say, D condition is mapped, the modeling does not suggest a 100% likelihood that the country at that point is in D condition. This has been especially difficult to explain in the absence of appropriate validation data, and has led to confusion at times when the mapping appears “wrong” in the field. With the validation process used here, we now have a clearer idea of the likelihood of any condition class at any location.

The presentation of the mapping as four probability layers capitalizes on the validation work, but it also presents some challenges for both the creators and consumers of these data. Firstly, while the presentation of probabilities is a more informative than simply mapping the presence/absence of a condition class, it is also more complex to explain, and this should shape the end use of the map product. In particular it should *only* be used for internal planning/institutional purposes, or in well supported one-on-one extension activities. It is unsuitable for general, unsupported distribution.

A second challenge is the likely ‘shelf life’ of the ABCD product. Land condition changes, and while much of the validation data was collected in 2011 and 2012, without ongoing modeling and validation, the product will lose some of its value as conditions change. We note here though that the validation data will maintain its currency much longer because it can be used by future studies to retrospectively validate other spatially explicit land condition products. A good example of this is the work of Activity 7 which shows considerable promise as an avenue to improve land condition mapping (discussed below), but there are likely to be other approaches that will need testing, and these too will benefit from the availability of this substantial data set.

As an exercise in documenting land condition change between periods, the interdecadal analysis of Activity 3 successfully demonstrated that change can be documented at a range of scales. Two aspects of the work though highlight important issues around these types of analysis. Firstly, it seems likely that the changes detected were in part driven by climatic conditions, but it is unclear if management also had a role, since there were no long term data about management practices in the region. Conclusions about land condition change at broader scales will require longitudinal management practice data at the same scales, and this underlines the importance of current efforts to compile these types of data in the GBR catchments (www.reefplan.qld.gov.au/measuring-success/report-cards.aspx). A second (and lesser) issue is the lack of ABCD validation data for the 1988-1995 period. This meant that period’s ABCD image was calibrated with data collected between 2004 and 2012. This was an issue beyond control of our project, but it does highlight once more the future value of the current validation data as a tool to retrospectively validate future iterations and variations of land condition mapping.

Ground cover thresholds

The development of improved ground cover products and quantitative measures for separating climate from management has enabled models to be developed to investigate the levels of cover required in dry times to ensure maintenance of sustainable ground cover levels. We were also able to investigate the relationship between cover and grazing land condition, mainly due to the additional ABCD land condition field data that has been collected during this project.

The results of the modeling show that short term ground cover levels do relate to land condition class, though the ability of cover to discriminate condition classes is limited at the higher end of the condition spectrum. This is consistent with the ABCD land condition framework (Chilcott et al. 2003), since higher condition is more dependent on composition than absolute cover. The approach used by Bastin et al. (2012) provides a method to quantitatively compare ground cover in local areas during the driest times when variance in cover levels is expected to be at its greatest. The approach assumes that the climate signal in the cover has been removed, and therefore what remains are the effects of management. This is a reasonable assumption although the approach does not account for local variability due to soil/land type, tree-grass dynamics, hydrology, spatial arrangement, species composition, topographic position – all factors which can influence cover levels. Despite this, the approach does provide a robust and spatially comprehensive relative measure of cover for the study area. The ΔGC values obtained by applying the method showed a very good relationship with land condition classes based on the field data. As ΔGC declines, so too does land condition. This suggests that ΔGC is a potentially useful surrogate for grazing land condition.

The inclusion of ΔGC, $CoverAvg_{t-3}$ and rainfall in a model to predict a land condition class has provided a useful tool for identifying ground cover targets above which desirable levels of both sediment reduction and grazing land productivity are likely. Given that ΔGC and ground cover are able to be calculated and analyzed spatially and temporally for every 30m x 30m (pixel) location in the GBR catchments, we are now able to provide a spatially explicit estimate of the existing cover level and grazing land condition and what is required for any particular location to achieve a desired cover level and condition state. By including rainfall in the model, we have also shown that different locations on the rainfall gradient require different levels of cover to achieve the same land condition outcome. This suggests that region- or catchment-specific ground cover targets which account for factors such as rainfall and land type would be more appropriate. Some regions or catchments have naturally lower cover and may also present lower erosion risk due to soil type or topographic features. Conversely, they may have naturally high levels of erosion where management interventions are ineffective and cost-prohibitive.

The modeling work undertaken as part of this project has made an effort to relate ground cover estimates from remote sensing to GLM land condition classes derived from field estimates. Whilst a reasonable relationship has been established, it could be argued that future work focus only on the ground cover and relative levels of cover as represented by approaches such as the DRCM, rather than GLM land condition classes. However, GLM land condition is a well-understood, simple conceptual framework that underpins many grazing land management initiatives, including Best Management Practice (BMP). The advantages of relating cover and cover derivatives to the GLM land condition framework is that it provides a useful mechanism for easily summarizing and communicating the results of relatively complex analyses to a range of end users.

Further advances to the modeling presented here could account for ground cover recovery times post-drought. In addition, improving the temporal sampling across seasons and years of the land condition field data would assist in better understanding the shifts between land condition states that occur as a result of climate and management. The GLM land condition framework is based on a number of factors: cover; composition; woody thickening; soil condition; and time. The advent of a range of new remote sensing data sets which either directly or indirectly measure these factors, including those developed as part of this project, presents an opportunity to model and monitor land condition more comprehensively, and future work could focus on the development of these models.

The substantial effort here to relate catchment runoffs to ground cover levels unfortunately failed to produce a useful result. At smaller scales there is a clear relationship between ground cover and runoff in rangelands (Tongway and Hindley 1995), however it seems likely in this case that both temporal and spatial scale issues confounded our analysis, and it is unclear whether alternative approaches at this scale would evade these issues using the same data. The existing river gauge data in Queensland are however a remarkable data asset, and it seems likely, given the right approach, that they can contribute further to our understanding of rangeland health in the reef catchments.

VegMachine

The packaging of the ground cover data for VegMachine, and aligned work to train and support VegMachine users in the project area have been critical to the uptake of the ground cover data in Fitzroy and Burdekin regions. VegMachine analyses were required components of grant application assessments in both the FBA and NQDT organisations by the conclusion of this project. This was a major driver of the VegMachine training work in the two regions, and in excess of 300 properties had been subject to VegMachine analyses by the conclusion of the project. Both organizations intend to continue to use the software beyond the life of this project, and this is a strong endorsement of the software as a tool for accessing the ground cover data set.

This use of the software has predominantly been for internal agency purposes; regional staff consulted with land managers, but VegMachine analyses were more often focused on informing internal assessment processes, rather than feeding information back to graziers. There is evidence however that VegMachine can engage land managers. Early work with VegMachine if the Fitzroy region (pre 2011) focused more on grazier access to VegMachine analyses than on institutional use of the software. This has since changed as described above, but in that period ABS data (ABS 2011) indicates graziers in the Fitzroy region were about 16 times more likely than the national average to monitor ground cover by remote sensing. Specific methods were not canvassed by the survey, but there are no obvious alternative explanations for this uptake, and it hints strongly at the likely impact of

VegMachine in a concerted program to connect graziers to ground cover monitoring across the state, or even nationally using VegMachine.

One of the more pleasing outcomes of the work from an institutional standpoint has been DSITIA's greater role in preparation of VegMachine datasets. The process of developing the codes and methods has been a significant advance that has multiple benefits including; reduced preparation time for DAFFQ staff, lower risk of preparation errors through increased automation, greater capacity to update time series, and greater capacity to serve VegMachine data to other regions using codes and methods developed in this work. It also highlights the feasibility of developing statewide or even national time series datasets, which would be an essential ingredient in a broader VegMachine program connecting graziers to ground cover monitoring data.

Conclusions

Fractional ground cover matters.
The fractional cover archive is the most temporally and spatially detailed dataset that we have of physical change in the GBR catchments. Moreover, it is an archive of actual measurements rather than modeled values, and its value is demonstrated by the wide uptake of the data by multiple RD&E users with a range of needs and motivations. This project has provided significant advances in the way ground cover data are produced, how they are delivered, and how they are used. In doing so, it has demonstrated not just the value of the data but also the potential for value adding where the data are available for new approaches.

Land condition mapping will evolve.
The project produced a set of regional ABCD grazing land condition maps. These were based on long term mean and trend in ground cover values, and demonstrated useful capacity to map condition across the landscape. The thresholds work provided a valuable insight into how we might develop the next generation of land condition mapping using the ΔGC product. That approach would bring with it a number of challenges, not least of all explaining ΔGC to end users, but the results to date suggest it has clear potential to help us map land condition better. There is also potential to incorporate other datasets such as fire history and woody trend into new land condition products, and of course, field validation remains necessary for any new products. But looking forward, it seems likely we will find improved ways to map the health of the grazing landscape using remotely sensed imagery.

We have clearer ground cover targets now
One of the most promising outcomes of the project has been the work around ground cover thresholds and the ΔGC product. This modeling is in its early days, but it has provided valuable insight into grazing landscape responses after drought, in terms of both ground cover and land condition, and for the first time has provided quantitative estimates of the time it takes to achieve a given level of recovery. Such information has many obvious potential applications, including the land condition mapping discussed above. Further work should focus on the ΔGC, as well as continued field validation including possibly repeat sampling of existing assessment sites, since these seem likely to produce high value outcomes.

The ground cover data is only as good as its delivery systems
The project has demonstrated a number of effective delivery channels for the ground cover data, and this has been a real key to the project's success. While the ground data cover is a significant asset, without effective access for a range of users, it is of limited real value. VegMachine is an excellent example of packaging the data to meet end user needs, and we recommend further development below, but other avenues, such as FORAGE ground cover reports and land condition mapping have been demonstrated also. It would be counterproductive to think that all needs can be served by one delivery mechanism, and looking forward it may be that as much value will be generated from delivering the data better as from improving the accuracy of the data itself.

Future Directions

Secure the future for the ground cover work

It is abundantly clear that the ground cover data produced by the Queensland Ground Cover Monitoring Program is a critical element in the RD&E space of the Reef Rescue Program and beyond. Without these data, there is minimal capacity to report on ground cover targets for the reef or other outcomes, to estimate cover for water quality modeling, or to populate datasets for tools like VegMachine and FORAGE. This is a considerable set of limitations, and it would impact substantially on future RD&E, including that within Reef Rescue 3. Despite this, the ground cover work is not fully funded beyond June 2013. We continue to seek funding for the work, but suggest that funding for the work under Reef Rescue 3 would represent a worthwhile investment.

Improve data delivery through VegMachine online

VegMachine has demonstrated its value in this project. It has been used across agencies, to provide benchmarked assessments of ground cover change on more than 300 grazing properties. A range of technological advances in data delivery mechanisms are providing potential for wider uptake of ground cover products by grazing land managers. These include cloud computing, national infrastructure developed through TERN and the NBN, and web-delivery mechanisms developed by Queensland Government and Google. We believe that there is enormous scope to capitalize on these technologies, and provide land managers with easy access to ground cover data by moving VegMachine online. This would be a substantial collaborative undertaking. It would require integration of all processes from image acquisition to end user training and support. However its benefits would be world leading. It would give thousands of land managers immediate access to 25+ years of state-of-the-art monitoring data, which they could use to understand the outcomes of their past actions and better shape their future directions.

Improve the index and connect the components

Finally, we see benefit in continuing R&D to both improve the ground cover dataset itself, and to better understand how it relates to other system components like land condition, management and economics. There are number of pathways to potentially improve the cover index. These include improved evaluation of cover under trees and integration of cover spatial arrangement into cover assessments. As far as ground cover's relationship to other variables, we do not have 25 years of catchment wide seasonal observations of economic outcomes, land condition or management practice. However, we do have that for ground cover, and we can leverage the size of that dataset to improve other datasets if we can find how they relate to ground cover. If we can do this, we will have a much better range of options for managing the GBR catchments and lagoon sustainably.

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Appendices

Appendix 1. Project publications

Two scientific publications have been co-generated by project partners through this project. Full citation details are listed below. The papers are available by contacting Terry Beutel, Terry.Beutel@daff.qld.gov.au.

Bastin G, P Scarth, V Chewings, A Sparrow, R Denham, M Schmidt, P O'Reagain, R Shepherd and B Abbott. (2012) Separating grazing and rainfall effects at regional scale using remote sensing imagery: A dynamic reference-cover method. *Remote Sensing of Environment*, **121**, 443–457.

Star M, J Rolfe, P Donaghy, T Beutel, G Whish and B Abbott. (2012) Targeting resource investments to achieve sediment reduction and improved Great Barrier Reef health. *Agriculture, Ecosystems & Environment, 180, 148-156.*

Appendix 2. ABCD site assessment variables

This is a full list of variables noted during site inspections for DAFFQ validation work. Variables collected as per McDonald et al. (1990) are marked(*).

Variable	Description
DATE	Date of data collection
EASTING	Easting coordinate of site (EPSG 3577)
NORTHING	Northing coordinate of site (EPSG 3577)
PASTURE TYPE*.	Dominant/subdominant pasture species. Possible values are • Perennial • Perennial/annual • Annual/perennial • Annual • Litter
TREE COVER*	Tree (>5m tall) crown cover. Possible values are • No trees • Cleared Land • Isolated clumps (Clump of 2-5 plants >200m apart) • Isolated plants (Trees > 100m apart) • Very Sparse (<10% cov: Crowns well-separated) • Sparse (10-30% cov: Crowns clearly separated) • Mid-dense (30-70% cov: Crowns touch or slight sep) • Dense forest (>70% cover: Crowns overlap)
WEED ABUNDANCE*	Cover of exotic weed species. Possible values are • None • Slight (<5% of site) • Moderate (5-50% of site) • Abundant (>50% of site)
MID STOREY*	Mid storey (1-5m) woody crown cover. • No under storey • Sparse (Isolated plants) • Open (Crowns well-separated) • Medium (Crowns slightly separated to separated) • Dense (Crowns touch)
CONDITION	Four point grazing land condition rating. Possible values are • A • B • C • D
GRAZING	Subjective perception of medium term grazing pressure. • No Grazing • Light Grazing • Moderate Grazing • Heavy grazing • Very heavy grazing

Variable	Description
EROSION TYPE*	Main type of erosion. - Gully - Sheet - Terracette - Rill - Scald - Unknown
EROSION AMOUNT*	Area of site affected by erosion - Slight (<5% of site) - Moderate (5-50% of site) - Abundant (>50% of site)
FIRE*	Time since last fire at site - Unknown - Present (<1 year) - Relic (1-3 years)
GROUND COVER*	Ground cover - Bare Cover (<5%) - Low Cover (5-20%) - Moderate Cover (20-50%) - High Cover (50-80%) - Very High Cover (>80%)
NOTES	Any relevant ancillary remarks about site including position of assessment relative to photo point.

Appendix 3. Validation model variables

Variable	Description
Year	Year of site inspection
FPC	Foliage projected cover of site
Patchkey	Patchkey site assessment (1), GLM ABCD assessment (0)
Image%A	Percent of site mapped in A condition in original mapping
Image%B	Percent of site mapped in B condition in original mapping
Image%C	Percent of site mapped in C condition in original mapping
Image%D	Percent of site mapped in D condition in original mapping
Region	Fitzroy or Burdekin
ImageAB	Image%A + Image%B
ImageCD	Image%C + Image%D
ImageCD2	Image%C + 2*Image%D
ImageCD3	Image%C + 3*Image%D

Appendix 4. Final ABCD validation model.

```
> summary(polr(data=dat3,ABCD~Region+ImageCD2+Patchkey))

Call: polr(formula = ABCD ~ Region + ImageCD2 + Patchkey, data = dat3)

Coefficients:
                      Value     Std. Error      t value
RegionFitzroy       -0.9775       0.09554       -10.232
ImageCD2             1.2111       0.07162        16.909
Patchkey             0.6494       0.14947         4.345


Intercepts:
          Value       Std. Error    t value
A|B       0.9633      0.0835        11.5423
B|C       0.6314      0.0802        7.8747
C|D       2.6758      0.1094        24.4699

Residual Deviance: 4141.171
AIC: 4153.171
```

Appendix 5. Catchment runoff modelling variables

Variable	Definition
sqrt.vol	Square root of total daily $m^3.s^{-1}$ of runoff for 3 month season.
date	Median decimal date of season (e.g. 1987.29).
$date^2$	**$date^2$**
rain.a	total mm of rain for m_1, m_2 and m_3 of season (m=month).
rain.b	total mm of rain for m_{-1}, m_1 and m_{-2} of season.
rain.c	weighted rain $(3*m_1 +2*m_2 + m_3)/2$.
rain.d	**rain.a** from previous season.
rain.e	Weighted rain of previous season $(m_{-3} +2*m_{-2} + 3*m_{-1})/2$.
prev.vol	**sqrt.vol** of previous season.
lt.gci	Long term (2000-2012) mean ground cover of catchment.
sqkm	Area of catchment (km^2).
rainvol.a	**rain.a*****sqkm***1000***sqrt.vol**^{2}.
rainvol.b	**rain.b*****sqkm***1000***sqrt.vol**^{2}.
rainvol.c	**rain.c*sqkm***1000***sqrt.vol**^{2}.
rainvol.d	**rain.d*sqkm***1000***sqrt.vol**^{2}.
rainvol.e	**rain.e*sqkm***1000***sqrt.vol**^{2}.
summer	If season=summer then 1 else 0.
spring	If season=spring then 1 else 0.
winter	If season=winter then 1 else 0.

Appendix 6. Final catchment runoff primary model.

```
> summary(primary.model)

Call: glm(formula = dat3sqrt.vol ~ prev.vol + rain.a + rainvol.a + rain.b)

Deviance Residuals:
     Min          1Q        Median        3Q          Max
  12.2178      2.0479      0.4117      2.2149      12.2843


Coefficients:
                Estimate    Std. Error  t value  Pr(>|t|)
(Intercept)   -7.558e-02   2.101e-01   -0.360   0.719
prev.vol       6.622e-06   8.762e-07    7.557   1.51e-13 ***
rain.a         1.389e-02   1.901e-03    7.305   8.62e-13 ***
rainvol.a      2.869e-09   1.998e-10   14.357    < 2e-16 ***
rain.b         1.136e-02   1.505e-03    7.547   1.61e-13 ***
(Dispersion parameter for gaussian family taken to be 10.72297)

Null deviance:        17861.6  on 618  degrees of freedom
Residual deviance:    6583.9  on 614  degrees of freedom
AIC: 3232.1
```