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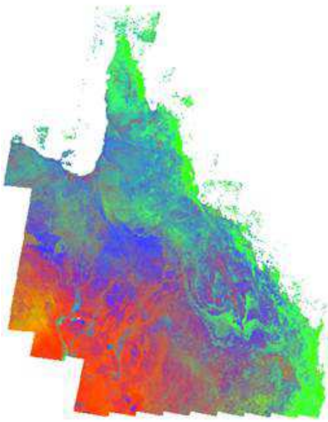

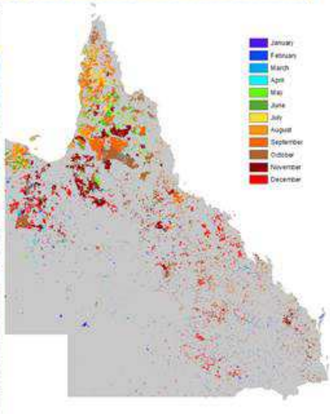

Ground cover and fire in the grazing lands

RP64G Synthesis Report

Reef Water Quality Science Program

Remote Sensing Centre

2014

Prepared by

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Cover images: Grazing (Future Beef), Fire (Rob Hassett), Other images (Remote Sensing Centre)

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1 Introduction

The purpose of this report is to describe the project to deliver fire scar mapping and improved ground cover mapping for Reef catchments, and other parts of the state. The Remote Sensing Centre, within the Department of Science, Information Technology, Innovation and the Arts (DSITIA), has produced ground cover mapping for some years to support a range of activities across Government. For example, it is used by the:

- Department of Agriculture, Fisheries and Forestry (DAFF) extension programs to help graziers understand ground cover levels on their property
- Reef Plan, Paddock to Reef Monitoring, Modelling and Reporting program (P2R) to analyse changes in ground cover and model sediment loss across grazing lands
- Research, development and extension into quantifying indicators of landscape condition for Reef stakeholders and other end-user requirements in conservation, vegetation management and pasture biomass monitoring

The Reef Water Quality Program (RWQ) funded this project to ensure continued delivery and improvement of ground cover mapping and support new developments in fire scar mapping from 2011 until 2014. Therefore, this report focuses on the delivery of data and maps to help inform grazing land management within the Great Barrier Reef (GBR) catchments. However, it is recognised that ground cover and fire scar data can be used for many purposes all across Queensland.

RWQ is a Queensland Government initiative that aims to improve the quality of water leaving grazing land, particularly in the Burdekin and Fitzroy catchments, the greatest contributors of sediment to the Reef receiving waters. It is expected that mapping products from this project will support water quality outcomes in the following ways:

- supply land managers with historical land monitoring data and help graziers make informed decisions about land management at a property level
- help government programs and Natural Resource Management groups identify target areas for extension and investment activities for land management and rehabilitation
- provision of cover data for catchment modelling
- capacity to report on ground cover targets in reef catchments for Reef Plan
- more informed evaluation of NRM funding applications
- provision of information for Water Quality Improvement planning
- identification of appropriate research, development and education/extension sites for research and demonstrations

2 Background

2.1 Ground cover and fire in the Great Barrier Reef catchments

Grazing of livestock in the GBR catchments relies on production of palatable pasture in the ground layer, also known as ‘ground cover’. Cattle graze pasture throughout the year and it is replenished after rain, predominantly in the wet season (i.e. typically November to April). Unsustainable removal or modification of ground layer vegetation can lead to a decline in grazing land condition through degradation of pasture composition (e.g. change from perennial to annual species) and growing capacity of soils. Reduced levels of ground layer vegetation can also increase overland flow, exacerbating hillslope and gully erosion processes and increasing sediment and nutrient delivery to waterways draining to the GBR lagoon (e.g. Bartley et al., 2010). Maintaining and improving the condition of ground layer vegetation has both production and water quality benefits.

Mapping of ground cover can provide information about productivity and erosion potential of grazing lands. A time-series of ground cover mapping also provides information about seasonal and management effects on ground cover in grazing lands. Through the decoupling of climate and management effects on ground cover, land managers can identify management triggers for ground cover response and implement appropriate strategies to improve productivity and water quality outcomes.

Fire is a key component of landscapes in Australia, where the complex interplay between fire and climate have played a critical role in the evolution of biodiversity (Keith et al., 2002). It continues to be an important tool for conservation and sustainable land management, and an ongoing resource management issue. Fire is used in broad scale grazing land management and can affect ground cover in a number of ways. It has a role in regenerating degraded pasture and managing woody thickening, but can expose soil to erosion, if not well managed (Russell-Smith et al., 2003).

Broad- scale historical mapping of fire in the GBR grazing lands shows that some areas are burned regularly and with the appropriate seasonal conditions, extensively (North Australian Fire Information: http://www.firenorth.org.au/nafi2/). An understanding of fire regimes (e.g. timing, frequency, seasonality, extent and patchiness) at regional and property scale is important for understanding and managing grazing land condition and erosion processes. Improved spatial and temporal information about fire scar location and frequency can be used to help identify the type of management applied across grazing lands, and adjust strategies as required and in response to a variable climate.

2.2 Remote sensing of ground cover

2.2.1 Definition of ground cover

Ground cover is the non-woody vegetation (forbs, grasses and herbs), litter, cryptogamic crusts and rock in contact with the soil surface. From a remote sensing perspective, ground cover is measured as the fractional cover of non-woody vegetation and litter near the soil surface (Muir et al., 2011).

2.2.2 Measuring ground cover using satellite imagery

DSITIA's Remote Sensing Centre (RSC), Science Division have produced annual, dry season ground cover data for some years. These data are produced by applying the Ground Cover Index (GCI) (Scarth et al., 2006) to Landsat TM/ETM+ imagery from 1986 to present.

The GCI is based on the spectral response of bare ground in the red and mid-infrared spectral bands of Landsat. The GCI predicts ground cover and bare ground for areas with low tree density (less than 15-20% foliage projective cover). GCI estimates of ground cover are generally reliable at high and low cover levels, with greater uncertainty in estimates at intermediate levels.

In recent years, RSC through the Joint Remote Sensing Research Program (JRSRP) have developed a new method for measuring and monitoring vegetation cover. The approach, termed *fractional cover*, measures land cover as percentages of green vegetation cover, non-green vegetation cover and bare ground. An additional empirical model has been developed as part of this project and applied to the fractional cover data to account for the woody vegetation in the over-storey and mid-storey to estimate levels of vegetation cover in the ground layer. This data derived from this method is termed *fractional ground cover* or simply *ground cover a*nd is providing improved ground cover measurements for a much greater land area and with greater accuracy than the GCI.

When combined with improved access to time-series of Landsat imagery from the United States Geological Survey, the information obtained from fractional ground cover will provide more regular and reliable information about ground cover dynamics. This is also facilitating the development of a range of education and extension products as well as data derivatives which are improving monitoring and reporting on ground cover and enhancing decision-support in the grazing land of the GBR.

2.3 Remote sensing of burnt area

Regional and continental scale maps of burnt area derived from MODIS imagery are available for various regions and time periods in the last decade. These have been largely provided by the Natural Resource Management (NRM) group, Cape York Sustainable Futures (CYSF) and published on the North Australian Fire Information (NAFI) website (www.firenorth.org.au/nafi). For other regions there is a paucity of spatial information. There are few regions within Queensland with detailed spatial maps describing longer term fire patterns.

The Landsat TM and ETM+ record of surface reflectance is unparalleled for its historical consistency, its spectral characteristics (sensitivity to change in many biophysical variables), spatial resolution (30 m), and revisit time of 16 days. It offers a rich source of information on biophysical trends and patterns of disturbance such as fire over the last two and a half decades. Earlier studies have demonstrated Landsat TM imagery can spectrally separate burnt area from surrounding land cover, as well as estimate fire intensity and evaluate post-fire vegetation recovery (Miller and Thode, 2007; Boer et al., 2008; Clemente et al., 2009; Harrison and Bradstock, 2010). The dense record of reflectance change stored in the Landsat archive also provides the opportunity to quantify trends in reflectance at both short and long time scales.

RSC has developed an automated method to detect fire-affected pixels on Landsat TM and ETM+ imagery (Goodwin and Collett, 2014). The method has been adapted to use the freely available dense time-series of Landsat imagery from the United States Geological Survey (USGS). However, Landsat data is frequently contaminated by cloud and cloud shadow. This can occlude the land surface, confound surface reflectance trajectories and reduce ground sampling frequency. Despite the 16 day revisit of Landsat, sometimes as few as 2 – 4 cloud free images are available for a given year and region within tropical and sub-tropical Queensland. This is particularly the case for northern coastal regions. To take full advantage of the complete record of Landsat, cloud affected imagery (up to 60%) is used in burnt area detection, and cloud affected pixels are screened out using a newly developed cloud and cloud shadow screening method (Goodwin et al., 2013). Therefore significant resources were allocated to the parallel developments of automated cloud and cloud shadow screening procedures. As such, these procedures form part of the operational framework to produce burnt area maps.

The cloud, cloud shadow and burnt area mapping framework is operational and processing of all RSC-held Landsat imagery over Queensland (1987 – 2013) has been completed. This means that there are time series based cloud and cloud shadow masks, and burnt area maps for every Landsat acquired over Queensland with < 60% cloud cover (>66,000 images).

Details of the methods and results for cloud, cloud shadow screening and the detection of fire affected pixels are presented in Sections 3.3 and 4.3.

2.4 Objectives

This project aimed to address the immediate and long-term goals of the RWQ Program and Reef Water Quality Protection Plan (Reef Plan) by providing spatial and temporal information on two key landscape attributes which affect the condition, resilience and sustainability of grazing lands in the GBR catchments: ground cover and burnt area (or fire scars). Improved access to time-series Landsat imagery from the USGS will provide users with more regular and reliable information about ground cover and fire dynamics in the GBR catchments.

The project has also provided information for the P2R program (under Reef Plan) to model or infer changes in pollutant loads delivered to the GBR. This information can be used to target and monitor rehabilitation and conservation activities in the GBR catchments.

The ground cover data produced by this project is used as a direct monitoring and reporting tool for the Reef Plan target of *a minimum of 70% late dry season ground cover on grazing lands*. It is also a key input for reporting on riparian areas.

The project objectives were to:

- implement new algorithms and obtain additional field data to improve the spatial and temporal reliability of remote sensed ground cover estimates
- develop a system to map and monitor burnt area and use of fire in grazing lands
- undertake reporting and interpretation of ground cover data for Reef Plan and RWQ policy and extension activities
- provide appropriate communication and training of the products to ensure successful uptake and use for policy, extension and science objectives

3 Methods

3.1 Ground cover product development

Research and development undertaken for this project has greatly improved ground cover monitoring in Reef catchments and across the state. This has included the development and improvement of fractional cover through the collection of additional field data, the development of fractional ground cover (also known as ‘cover under trees’). A range single-date and seasonal products have been developed including one which fills in gaps in the seasonal fractional ground cover data for the purposes of the catchment-scale water quality modelling under P2R. An approach has also been developed which compares cover levels for location of interest with the levels across a local region for similar land types. This approach has been incorporated in the FORAGE ground cover regional comparison report but also shows some promise as a mechanism for understanding spatial and temporal variability in ground cover due to grazing land management.

3.1.1 Fractional cover

This project has produced fractional vegetation cover mapping across Queensland using an algorithm from the linear spectral un-mixing model described in Scarth and Trevithick (in prep.). Spectral unmixing aims to quantify the sub-pixel components that contribute to the overall reflectance values of the satellite sensor. Sub-pixel components consist of surface cover fractions such as vegetation, soil, water etc. The unmixing approach applied here uses quantitative field information about cover fractions and statistical regression techniques to determine the corresponding reflectance signals in each pixel. These fractions are considered to represent the ‘pure’ composition of the cover type in each pixel, and are referred to technically as ‘end-members’. The fractions of each end-member are quantified per pixel and applied to the imagery with error terms. In the case of the fractional cover index algorithm, the fractions quantified are:

- green vegetation
- non-green vegetation (litter, dead vegetation, branches)
- bare ground (soil and rock)

'Primary' (or initial) fractional cover images have been produced by applying the fractional cover algorithm to Landsat imagery with no enhancement. These primary fractional cover images quantify and map total vegetation cover – they do not distinguish between over-storey ‘green’ vegetation (i.e. trees and shrubs) and ground layer ‘green’ vegetation (i.e. grasses, herbs, forbs). All higher order products, including ground cover, are derived from these primary images.

This process produces a four band Landsat-derived fractional cover index image. The first three bands correspond to the cover fractions (bare ground, green vegetation and non-green vegetation cover), and the remaining band quantifies the model 'error'. An example of a fractional cover image is shown in Figure 1.

Primary fractional cover images have been processed for the current archive of imagery, covering the entirety of Queensland and approximately 28 years. Additional imagery, as it is acquired from new Landsat overpasses or as older imagery becomes available, is processed during the overnight batch (along with other processing stages such as cloud, water etc.). The archive is therefore current at all times.

3.1.2 Field data

Fractional cover is calibrated/validated using data obtained from the star transect point intercept method outlined in Muir et al. (2011) and collected through this project, other RSC field campaigns and the National Ground Cover Monitoring Project (http://www.daff.gov.au/abares/aclump/pages/land-cover/ground-cover-monitoring-for-australia.aspx). 825 star transect sites exist across Queensland in a variety of biomes and 343 transects within the Reef Catchments. A further 724 sites collected from across Australia's rangelands have also been included in the calibration data set in an attempt to improve the model performance by representing the range of cover and bare ground reflectance values expected across the country. Certain areas in the Reef catchments are currently under sampled, most notably the Southern parts or the two larger inland catchments, the Burdekin and Fitzroy. A field trip was recently undertaken in October 2013 in the southern part of the Burdekin to help fill this data gap (Figure 2). These additional transect locations were targeted in higher foliage regions to provide field data for the development of the Fractional Ground Cover (Trevithick et al, 2014 and Section 3.1.4).

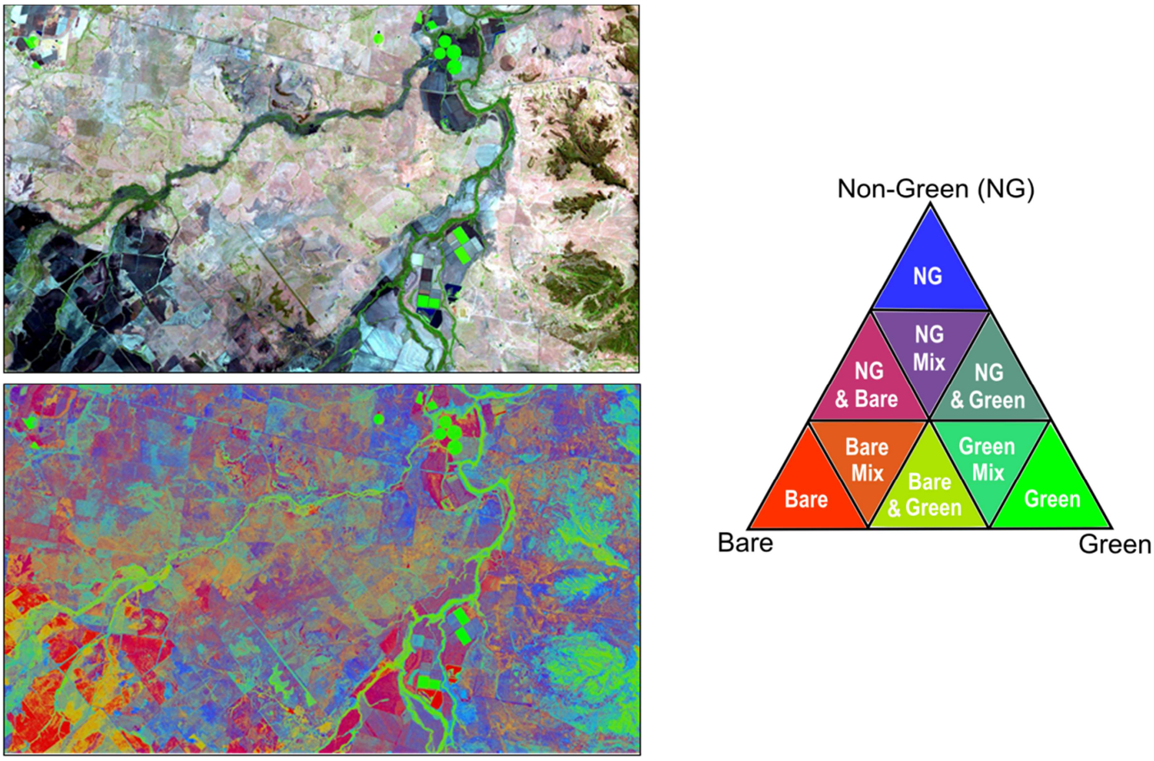


Figure 1 Example of a fractional cover index image. The top image shows the area in true colour. The fractional vegetation cover shows the photosynthetic ('green'), non-photosynthetic ('non-green') and bare ground fractions. For example, vigorously growing crops in centre pivots at the top right of the image are shown in green, and bare/fallow crops in the lower left are shown in red.

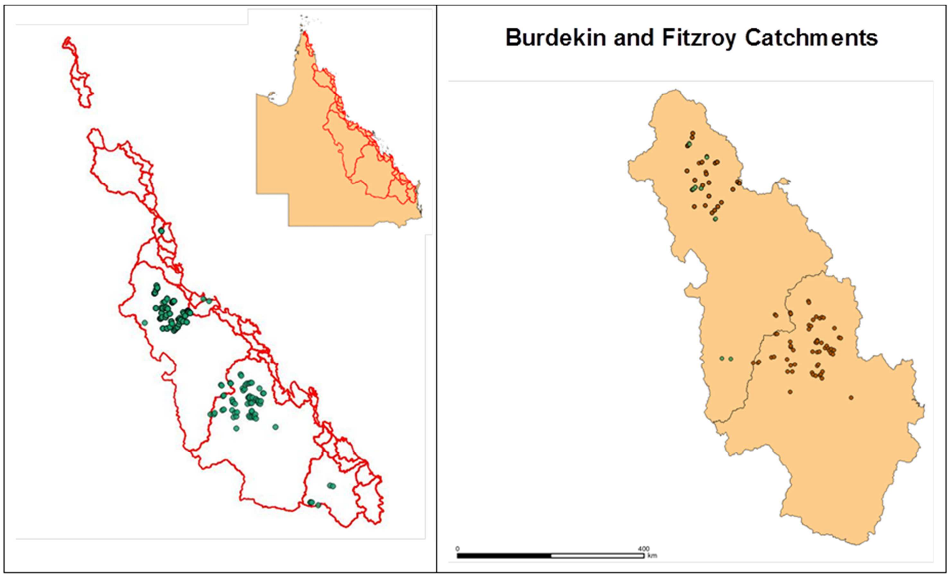


Figure 2 Left: Location of field calibration/validation sites within the GBR catchments. Right: Location of field calibration/validation sites within the Burdekin catchments. New sites acquired in October 2013 are shown in green.

3.1.3 Masking of satellite imagery

Fractional cover is not able to be derived in areas partially or totally obscured by cloud or cloud shadow, and open water. Prior to the development of the fractional ground cover algorithm, fractional cover, like its predecessor the GCI, has been restricted to generally open landscapes where tree cover is relatively low for the purposes of measuring ground cover. This meant masking the imagery at 15% woody foliage cover based on the foliage projective cover (FPC) product produced from Landsat imagery by RSC. FPC measures the wooded vegetation extent and cover and is produced for all of Queensland on an annual basis. The development of the fractional ground cover algorithm in this project has facilitated estimates of ground cover in areas of much higher woody vegetation cover, as much as 60%. Above this threshold, woody vegetation cover is so high that a reliable model of the ground layer is not able to be derived. Therefore, for the production of fractional ground cover data, the Landsat imagery and fractional cover is masked with appropriate cloud, cloud shadow, open water and woody vegetation cover masks. Further details of these masks are provided below.

3.1.3.1 Cloud, cloud shadow and water masking

RSC implements three levels of cloud and cloud shadow mask which can be applied to Landsat imagery and the fractional cover products. These are, in increasing order of accuracy and preference:

i. Automated masks produced from single date imagery (the ‘fmask’ method). The fmask method was developed by Zhu and Woodcock (2012) and adapted for application by Neil Flood, who is based in RSC and works for the JRSRP. Although the original method was not developed for Australian conditions, the quality of initial masks being produced are extremely promising, with high levels of accuracy observed (>90%) (N. Flood pers. comm.). A major benefit of this method is that it produces both cloud and cloud shadow masks from a single Landsat image. As such, this method can be automatically applied to all available imagery in the archive.
ii. Automated masks produced by a time-series method developed by RSC as part of the fire scar mapping program. The accuracy of this mask generally exceeds 95% (Goodwin et al., 2013). The methods used to produce automated masks are discussed in Sections 3.3.3 and 3.3.4.

iii. Masks created by manual thresholding and editing. These masks have been quality checked by an experienced image interpreter and are considered to be the highest quality cloud/cloud shadow masks available. Production of these masks is highly labour intensive and is therefore limited to only those scenes which have been selected for the Statewide Landcover and Trees Study, also known as SLATS (i.e. one scene per year).

iv. Water masking follows Danaher and Collett (2006). Areas of open water are masked from the imagery to minimise the effects of inundation on surface reflectance values, therefore minimising error on fractional cover and fire scar mapping outputs due to the influence of water. This is particularly important for areas where infrequent periodic inundation can affect soil moisture levels and areas can appear dark in the imagery and be misclassified, particularly in the fire scar data.

RSC processing systems use an automated function to apply cloud and cloud shadow masks preferentially, depending on which mask is available for a particular scene in the image archive.

3.1.3.2 Woody vegetation cover masking

Estimating ground cover levels becomes increasingly inaccurate at Foliage Projective Cover (FPC) levels of 15% or greater (i.e. areas of woody vegetation cover). This is due to the influence on reflectance from the various strata of vegetation present at any location. To create a fractional ground cover layer from the fractional cover images, it is necessary to mask out pixels that are obscured, or partially obscured, by over-storey foliage.

As mentioned above, until recently, higher foliage cover areas were masked using the latest available, single-date FPC data produced by RSC, with a threshold of 15% for the purposes of estimating ground cover. This product has some limitations that may affect fractional ground cover estimates, particularly when different years are compared. Work has been undertaken to develop an improved woody vegetation mask, the ‘persistent green’, derived directly from the fractional cover index using time-series analysis techniques. The persistent green product estimates the less variable component of the time-series of the green fraction. This less variable component is assumed to be the woody vegetation component - the ground cover and herbaceous vegetation demonstrate greater variability due to seasonal effects. As the persistent green product is derived directly from the fractional cover index, it is more integrated with fractional ground cover and therefore provides a more consistent and complementary masking product. The work for the development of the persistent green product was undertaken through this project and a project funded by the Terrestrial Ecosystem Research Network’s (TERN) AusCover program and the first version of the product is now available (Johansen, 2012).

3.1.4 Fractional ground cover

As previously discussed, *fractional ground cover* or *ground cover* is the name that has been applied to the outcome of the research and development task referred to as ‘cover under trees’. The full details of this approach are detailed in a separate report (Trevithick et al., 2014) and briefly described below.

As previously discussed in Sections 2.2.2 and 3.1.3.2, estimating ground cover levels becomes increasingly inaccurate at Foliage Projective Cover (FPC) levels of 15% or greater (i.e. in areas of higher woody vegetation cover). As no distinction is made between the photosynthetic (green) ground cover fraction and photosynthetic (green) over-storey foliage, high values in the green fraction could be due to either tree/woody shrub cover or green leaf ground layer cover. However, in areas of FPC above 15%, there may still be sufficient reflectance from the ground cover layer through the tree canopy layer to be able to predict ground cover in these areas. This would greatly extend the spatial extent of the ground cover product; and improve our understanding of tree-grass dynamics and the influence of cover under trees on runoff and erosion rates.

As detailed in the report prepared by Trevithick et al. (2014), for this project, the authors have developed a method for using the fractional cover algorithm to improve ground cover estimates in areas of greater than 15% FPC. The method also estimates the over-storey green fractional component, thus providing an integrated product for ground cover and over-storey (woody) vegetation. This has not been the case in the past where FPC and GCI were separate products, derived from different algorithms and methods.

The method uses time-series approaches to 'track' the minimum green fraction and linear statistical fitting to identify this less variable vegetation fraction. The assumption is that the proportion of green fraction present through time (the minimum), regardless of seasonal variations, is assumed to represent the perennial woody vegetation. This is termed the 'persistent green', and is a separate product. A model is then applied which has been based on field measurements of fractional cover in the upper, mid and ground layers of the vegetation. In the model, the total green cover estimate is adjusted down by using the persistent green cover amount. The non-green and bare ground cover fractions are also readjusted, so total cover adds up to 100%. These adjustments result in a reduced residual error in the ground layer for all three cover fractions.

The method is now being applied operationally for single-date and seasonal imagery. Validation has been somewhat limited to those field sites where fractional cover has been measured in areas of higher tree canopy cover. Further validation using new field data is proposed to better understand the model's limitations in different environments and at different levels of tree foliage/canopy cover.

3.1.5 Understanding and quantifying error in field data

The collection of field calibration and validation data used in the calibration of fractional cover and fractional ground cover can result in measurement errors. For example, errors associated with sampling method, operator variability and heterogeneous sites can contribute to inaccuracies in estimating cover at a field site and increase the error and uncertainty in the model.

To quantify the field measurement errors associated with operator biases, an experiment was conducted to compare different levels of experience and interpretation. The experiment compared measurements undertaken by four experienced operators and four inexperienced operators for 10 transects, covering the full range of ground cover fraction distributions. All measurements were taken over two consecutive days to ensure no change in ground cover fraction distributions. From the results of the experiment, it was possible to statistically assess the repeatability of measurements both between and amongst experienced and inexperienced operators, using a logistic regression, over a variety of fractional cover distributions and highlight areas of discrepancy. Results of the experiment are described in Section 0.

3.1.6 Derived Products

3.1.6.1 Seasonal fractional cover and fractional ground cover

Access to the entire Landsat archive has provided an opportunity to composite imagery into representative seasonal images. The benefits of compositing in this manner are the creation of a regular time-series capturing seasonal variability while minimising missing data and contamination present in single date imagery (Flood, 2014).

The method of compositing used in the creation of the seasonal fractional cover product is the selection of representative pixels through the determination of the medoid. The medoid is a multidimensional median, suitable for use with multidimensional data, such as satellite imagery with numerous reflective bands. It operates in a similar manner to the median, which is the medoid equivalent for univariate data. The principle is the minimisation of the total distance between the selected data point and all other data points (in this case pixel values over the season of interest) by the selection of the point which results in the least total distance. Like the median, the value selected is an actual valid data point and not an averaged or blended value made up of different image layers. The pixel selected is therefore a true representative pixel. In addition, because it selects the centrally located point in the multi-dimensional space, it is robust against extreme values, inherently avoiding the selection of outliers, such as occurs when cloud, cloud shadow or other artefacts go undetected.

The images used in the creation of the seasonal product are masked for cloud, cloud shadow and water, as described in section 3.1.3.1. This masking results in areas of ‘no-data’. The calculation of the medoid requires that for each pixel in the representative image generated, at least three valid measurements from the time-series of imagery for the season must be available. Due to the high level of cloud cover in the reef catchments during the wet season, three cloud free measurements are sometimes not available, resulting in data gaps in the resulting seasonal fractional cover image. However, one or two cloud free measurements may exist in these gaps, which can be used as ‘patches’ for the seasonal fractional imagery to create more complete images for applications which require more continuous data, such as the catchment-scale water quality modelling for P2R. The development of these patches is discussed in Section 3.1.7.

3.1.6.2 Fractional Cover Deciles

The fractional cover decile products compare, per-pixel, the level of cover for the season of interest against the long term cover for that same season. For each pixel, all cover values over the entire time-series of seasonal images are classified into deciles. The cover value for the pixel in the season of interest is then classified according to the decile in which it falls. This is an effective way of identifying areas of low or high cover in a relative, rather than absolute, way. Two fractional cover decile products are currently produced: green cover and total cover (i.e. the sum of the green and non-green fractions),. Figure 3 illustrates the total cover decile product for the Burdekin in Spring 2013. Large areas of red indicate that the cover levels for that season are ranked in the lower deciles compared to the long term (~28 years) levels of cover measured for the same season.

3.1.7 Seasonal fractional (ground) cover ‘patches’

The method for developing the seasonal fractional cover product produces a robust and ‘clean’ or more complete product, less influenced by the contamination of cloud and cloud shadow. Due to the requirement for at least 3 valid pixels at any given location for each season, in some areas of frequent high cloud cover there may remain some gaps in the seasonal data. This includes some parts of the GBR catchments, where there is often high cloud cover, particularly in the north during the wetter seasons. However, in these areas there often exist one or two images for each season with cloud free data. Data from these single date images can be used to increase the coverage of the seasonal product in the areas of ‘no-data’, effectively acting as a data ‘patch’. These ‘patches’ would not be as robust as the primary seasonal fractional cover images, given the potential presence of undetected cloud and cloud shadow or unseasonably high or low cover values which still occurs in single date imagery, but would allow for the creation of a more continuous coverage, which for certain applications is more desirable than highly robust product with data gaps. At the time of writing, these data are only provided to P2R modellers as they have a requirement for more complete and continuous data. They also have parameterisation approaches which can account for outliers in the data.

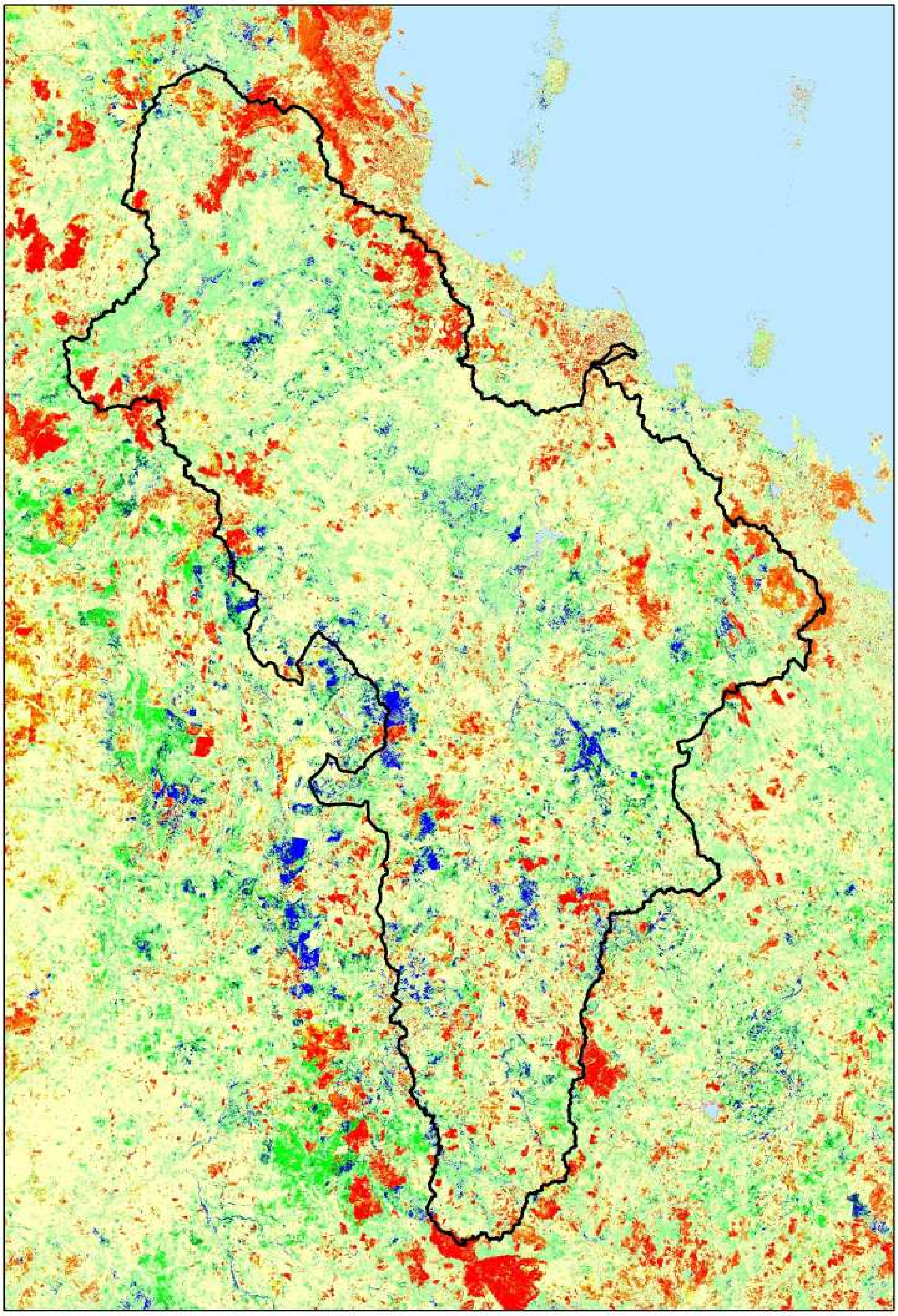


Figure 3 Example of a fractional cover decile image, showing the total cover decile product for the Burdekin catchment in Spring 2013.

3.1.8 Spatial averaging and benchmarking

Both the fractional ground cover and its predecessor the GCI are spatially explicit products that predict ground cover at the pixel level. Both products are optimised for the whole of Queensland and therefore over- and under-estimation of cover can occur in certain locations. The extent of this error is quantified by the RMSE for the model which provides an estimate of the uncertainty of the cover prediction for any given location, based on the field calibration data. While both the GCI and fractional ground cover model's performance at the pixel scale is quantified, its performance at a catchment or regional scale is not well understood. The products are used to average predicted ground cover levels for a single annual (dry season) date across large areas, such as land types or catchments. In some cases, these averages are used for benchmarking purposes to compare ground cover level of a paddock or property to the 'regional average'. However, the influence of averaging on errors and understanding spatial variability in cover is not well quantified, although it is expected that averaging reduces errors by accounting for over- and under-estimation, assuming no bias in the model. However, the use of the product in this way is not very informative as it reduces the available information on spatial variability and is not representative of ground cover variations in time and space.

The additional time-series information available from the USGS Landsat archive can improve temporal estimates of cover variability. Approaches such as the Dynamic Reference Cover Method developed by Bastin et al. (2012) and the regional ground cover comparison report developed for FORAGE and VegMachine have established a foundation for future research and development of metrics which better quantity spatial and temporal ground cover dynamics, particularly the influence of climate and management on cover levels. These two similar approaches use local benchmarking to compare an area of interest to cover values in the local region. By using local benchmarking it is assumed that local climate effects have been accounted for, therefore any difference in cover is likely to be due to the management effects on that location. The approaches differ slightly in the way that they calculate or compare local areas with regional cover values. The approach of Bastin et al. (2012) calculates a cover deficit value based on the difference between a focal pixel and a nearby reference pixel: a pixel with persistently high cover. The trend in these cover deficit values is then compared over time to identify improving, declining or stable ground cover management. The regional comparison provides a graphic summary of an area compared with the local region for similar land types to identify the level of cover and general rank of a location compared with the range of cover for similar areas in the local region. Further work is planned to investigate the development of this approach into a spatial image product.

3.1.9 Statistical summary products

Long term minimum, median, maximum and standard deviation products were developed for the preceding GCI and have now been developed for fractional ground cover. These products provide information about the long term behaviour of ground cover and are potentially useful in the development of other ground cover products. For example, the minimum ground cover product was used by Bastin et al. (2012) in the development of the Dynamic Reference Cover Method. The long-term persistent or maximum bare ground product will also be used by staff mapping gullies at the catchment-scale to help identify gully-affected areas. These products will be released as open data in late 2014.

3.2 Ground cover products

An initial user group meeting was held in March 2012 to develop a list of potential standard products based on fractional cover and Landsat imagery. Details of products are provided in Appendix 1.

Since this workshop further research and development has resulted in the creation of the seasonal product and fractional ground cover. The completeness, increased ability to monitor ground cover over larger areas on a regular time step and accuracy these data, means it is now the basis for most of the standard products currently being delivered, as listed below and described in Appendix 1.

- Seasonal Fractional Cover and fractional ground cover
- Total cover deciles (based on seasonal fractional ground cover)
- Green cover deciles (based on seasonal fractional ground cover)
- Single date Fractional Cover and fractional ground cover.
- Time-series summary products

3.2.1 Data delivery

Standard products are being delivered through the Queensland Government's Open Data initiative and in a range of derived formats including FORAGE reports and VegMachine. Open Data delivery uses TERN AusCover infrastructure with products discoverable through the Open Data Portal.

3.3 Burnt area mapping

3.3.1 Overview of burnt area mapping

This project has mapped burnt areas across Queensland using the dense time series based change detection methods described in Goodwin and Collett (2014). The method identifies significant peaks and troughs (i.e. changes) in image pixels, which stand out from the normal variation in reflectance over time. Further contextual and spectral information is then used to fully map the spatial extent of the 'change feature'. The change feature is then attributed using the spectral characteristics of the whole feature (i.e. contiguous clump of changed pixels) rather than the individual pixel. This multi-stage time series approach has been adopted for cloud, shadow and burnt area detection. It works over four passes through the time series to: initially identify and screen clouds (2 passes) and shadows from the Landsat time-series; and finally to identify and map burnt areas.

Cloud, cloud shadow and burnt area algorithms were calibrated and validated using a strategically selected set of path/rows across Queensland (Goodwin et al*.,* 2013; Goodwin and Collett, 2014). This requires, within each path/row, a series of randomly selected points to be interpreted 'on-screen' by an image analyst to determine whether the pixel contains: cloud, shadow, burnt area or background (cloud/shadow-free).

3.3.2 Study location

One of the aims of this project was to develop and optimise burnt area mapping procedures for the state of Queensland. Twenty regions, represented in each case by a Landsat World Reference (WRS) Path/Row, were selected to capture the diversity in fire regime, landuse, biogeographic and climatic variation (Figure 4). For each region, a Landsat TM and ETM+ time-series were acquired.

This incorporated between 5 and 41 images per year (TM and ETM+), while the total number per Path/Row ranged between 428 and 608 image dates.

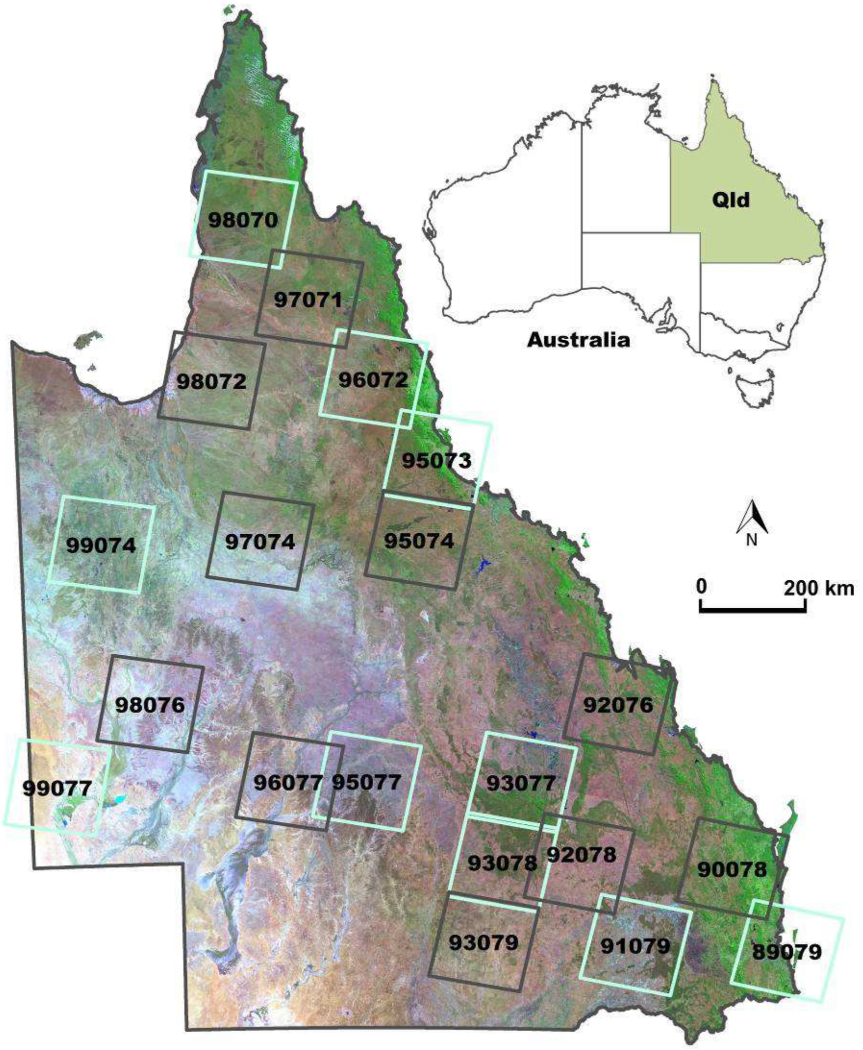


Figure 4 The location of Landsat dense time-series stacks used in the calibration and validation of burnt area mapping.

3.3.3 Cloud masking

The method for cloud detection is fully described in Goodwin et al. (2013). The approach for classifying cloud involves identifying positive outliers in Landsat TM band 1 reflectance values (visible blue, *B1*) over time, and then applying a region grow filter to map a greater proportion of cloud extent. Figure 5 shows the discrimination of cloudy pixels as positive outliers in the *B1* reflectance over time.

Cloud affected pixels are identified on a running minimum difference of *B1*. That is, each pixel in the *B1* time sequence is compared with a 'no change' *B1* reference pixel, where the reference is the minimum of the seven *B1* pixel values from the preceding and following dates. At the start and end of the time-series, where fewer observations are available, sampling is limited as necessary. A running minimum difference requires that only one cloud-free observation be present in the 7 dates preceding and following the date of interest. In addition to *B1*, the ratio of Landsat TM bands 1 and 7 (mid infrared) is used as a mask to discriminate land surfaces with elevated *B1* values from cloud. This ratio, known as *B17*, reduces the number of false positives in pixels identified as change.

The process to mask clouds is as follows: first, a set of cloud ‘seeds’ are identified for a given image in the time-series stack by applying thresholds to the *B1* minimum difference and the *B17* ratio. Next, a watershed region grow filter is used to more fully map the cloud extent. In this way, the initial thresholds for change ‘seeds’ can be quite conservative, thus reducing commission errors (‘false cloud’), but the region growing thresholds can be more liberal as region growing only considers pixels as candidate cloud pixels if they are in proximity to a cloud seed. Two passes through the time series of cloud detection are applied, where cloudy pixels identified in the first pass are screened from the time series. Cloud detection is then applied a second time to enable detection of more subtle, optically thinner clouds such as cirrus. Finally, a buffer of 5 pixels is applied to the final cloud masks to ensure all cloud-affected pixels are masked.

A single set of optimised thresholds have been derived for Queensland based on the *B1* seed and region grow lower limit, and the *B17* ratio thresholds. All pixels identified as cloud are subsequently screened from the Landsat time-series to enable further change detection of cloud shadow and then fire.

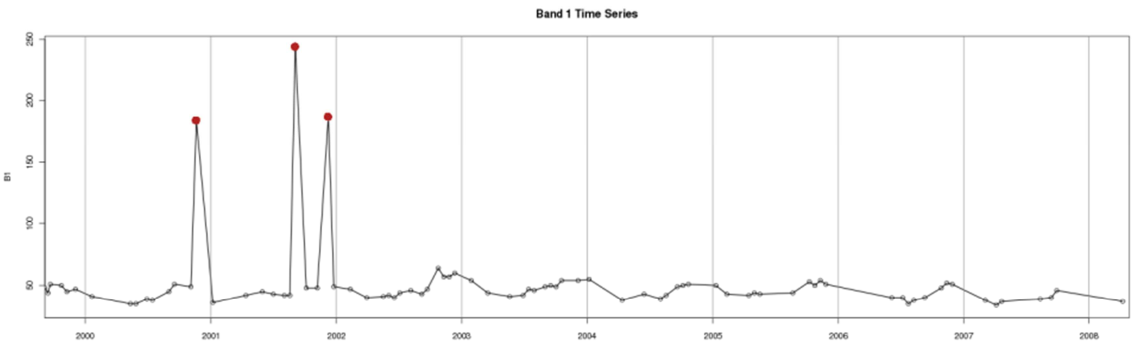


Figure 5 An illustration of Landsat TM band 1 (visible blue) reflectance over time. Note the red dots correspond to cloud affected pixels.

3.3.4 Cloud shadow masking

The method for cloud shadow detection is also fully described in Goodwin et al. (2013). Similarly to clouds, cloud shadows are classified using time-series based change detection followed by region growing. However, rather than locating positive outliers, significant negative outliers in reflectance are identified. As cloud shadows are spectrally and morphologically similar to other types of change, an additional attribution step is required to separate cloud shadow from other ‘dark change’ that may occur as a result of fire, inundation, crop etc.

The sum of Landsat TM bands 4 (near infrared) and 5 (mid-infrared) (*B45*) was found to be the most sensitive reflectance metric for detecting cloud shadow. In contrast to the cloud detection procedures, cloud shadow detection requires a stratification step to reduce the confounding influences of long-term non-seasonal and short-term seasonal trends on change detection. Long-term non-seasonal trends in reflectance can be related to variable rainfall patterns, vegetation regrowth/dieback and land management practices whereas highly periodic, short-term seasonal trends are influenced by seasonal rainfall, growth cycle, and changing illumination conditions (e.g. pixels in locations with steep topography). To capture these trends and enable cloud shadow detection, two median smoothed curves are produced from the time sequence of *B45*: a running median of *B45* ($B45_{RM}$); and a median of *B45* derived from pixels captured under comparable sun-sensor-earth geometry and growing conditions, i.e. seasonal *B45* ($B45_{SM}$). In both cases, clouds are screened out prior to median smoothing. Due to frequent cloud cover, particularly in mountainous areas along the coast, a second pass of $B45_{SM}$ is applied to reduce the impact of gaps in the time-series or spurious results.

The most suitable reference ($B45_{RM}$ or $B45_{SM}$) for estimating change for a given pixel is then determined by comparing the residuals between the median smoothed and unsmoothed reflectance curves. Visual interpretation of the residual data shows that the distribution of residuals is not random with particular image features recording high residual values. Spatial clusters of high residuals principally correspond to cropping areas, edges of water bodies that are periodically inundated and other highly dynamic features. Given that pixels with very high residuals are likely to result in mapping errors, these pixels are identified and screened from the analysis by applying a threshold and subsequent region growing to the positive residuals data layer. For these highly dynamic features, which make up only a small fraction of most Landsat scenes (1-6%), the current time-series approach is not appropriate. A higher frequency of observations would be required to capture trends and detect changes in these features.

Once the data has been stratified, screened to remove highly dynamic features, and a suitable reference pixel for change detection found, the median difference per pixel is computed – using either the $B45_{RM}$ or $B45_{SM}$ as reference. Seeds of change are identified by applying a conservative threshold to the median difference layer and subsequently applying a watershed region growing filter to complete the change mapping. Thresholds required for both the detection of outliers and region growing were determined through optimisation. The resulting ‘dark change’ maps may contain changes due to cloud shadow, fire, inundation and other sources of reflectance decline. A change classification is then applied. Cloud shadows are identified by matching each cluster of contiguous ‘dark change’ pixels to an associated cloud given the satellite-solar-earth geometry. Finally as with the cloud masks, a buffer of 5 pixels is applied to the cloud shadow masks.

3.3.5 Burnt area classification

The method for burnt area mapping is documented in Goodwin and Collett (2014). Burnt pixels have similar spectral and temporal characteristics to cloud shadow and are detected using the approach described in section 3.3.4 but with some variations. Burnt areas are also detected using the sum of Landsat TM bands 4 (near infrared) and 5 (mid-infrared), *B45*, as this was found to be the most sensitive metric over the range of vegetation types in Queensland. Landsat TM band 5 reflectance is sensitive to burnt area due to changes in vegetation structure and moisture content. Typically, a burn event will result in a decline in band 5. Savannas however, are highly dynamic environments, characterised by high fractions of senescent grass and soil during the dry season, which then green up during peak rainfall periods. A decline in *B45* can also result from these changes in vegetation water content and vigour. As a result, the behaviour of band 4, *B4*, over time is assessed to separate changes relating to ‘green up’ and increased moisture from those changes which are due to fire. Outliers are located relative to two median filters – a running median (using only the 7 preceding observations) and the seasonal median described in Section 3.3.4. Clouds and shadows are screened from the surface reflectance imagery prior to median smoothing. Outlier identification and region growing then proceeds as described in section 3.3.4. The temporal behaviour of B4 and B45 in response to fire is shown in Figure 6. Figure 7 shows the steps involved in locating negative outliers for burnt area mapping using *B45*.

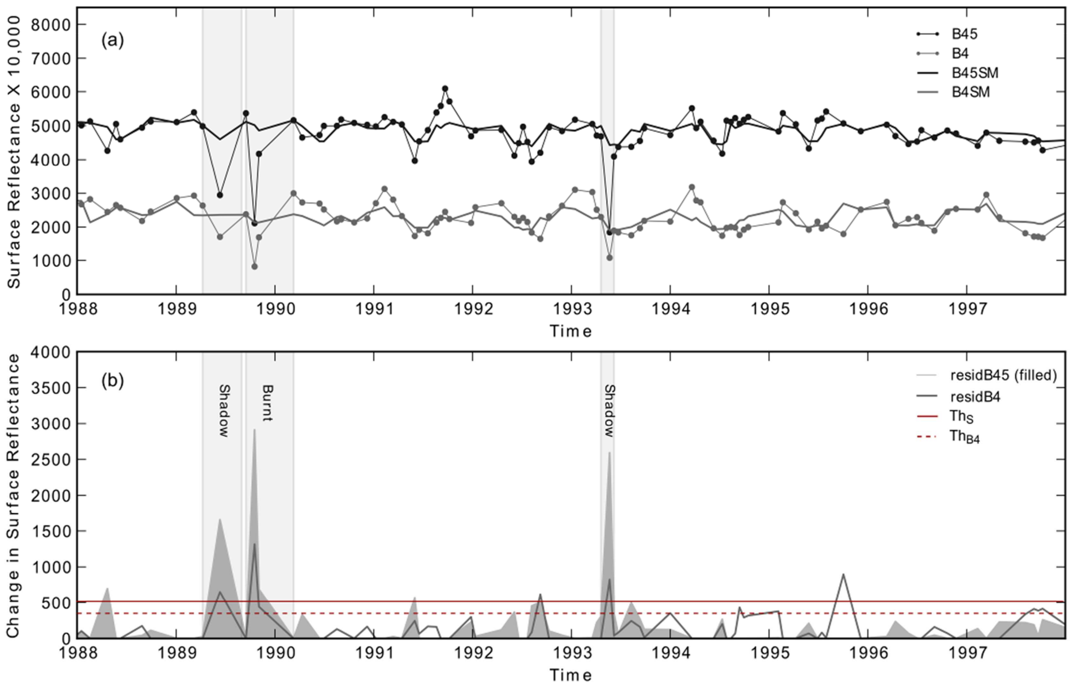


Figure 6 Example of B4 and B45 reflectance curve behaviour in response to burn events and shadows.

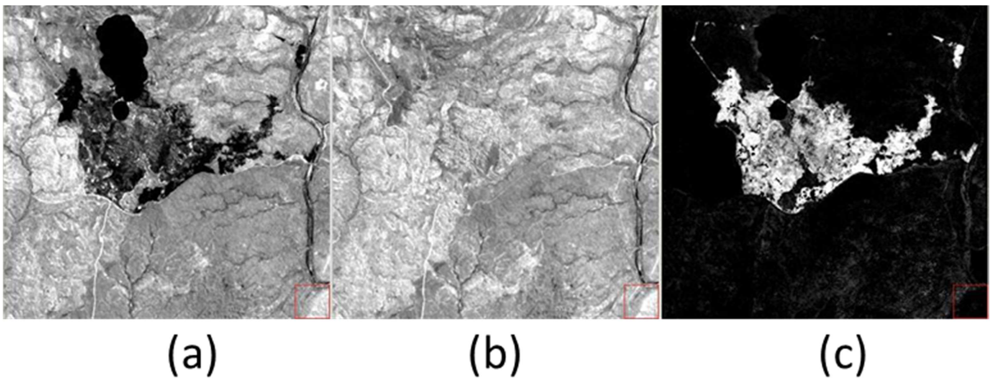


Figure 7 Dark object classification: (a) actual B45 image; (b) reference of 'no change' derived from the time-series; and (c) difference layer used to classify dark objects.

The resulting 'dark change' maps may include changes due to fire, but also any previously undetected cloud shadow, inundation and land use change. As such, post-change classification is required to identify fire-affected pixels. A classification tree using the thermal and spectral characteristics of each change object is used to attribute the change to fire or non-fire related causes. Burnt vegetation exhibits spectrally and morphologically similar behaviour to many of these other change features in time and space. However, at thermal wavelengths (e.g. band 6 on Landsat), burnt vegetation appears 'hotter' than surrounding unburnt vegetation. This means that the burnt vegetation has greater thermal emissivity than unburnt vegetation. 'Predictors' based on at-satellite brightness temperature, derived from Landsat TM and ETM+ thermal band 6, were found to be the most important in the classification tree. The median brightness temperature (in degrees Kelvin) of a contiguous clump of change pixels is compared to that of a sample of neighbouring pixels to determine whether the cluster is significantly hotter than the surrounding unchanged pixels (Figure 8c). Initial assessment of burnt area maps is described in Section 4.3.2.

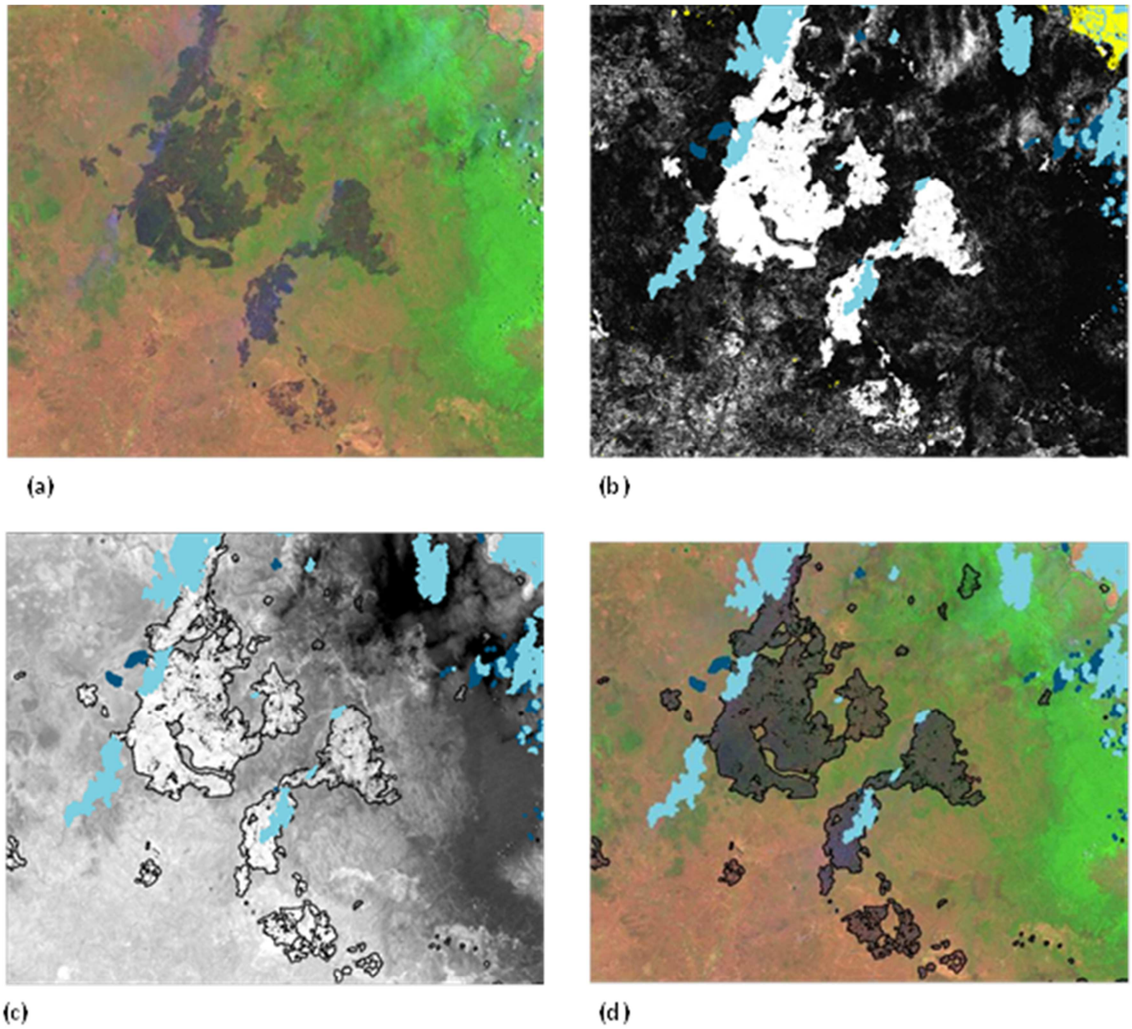


Figure 8 Classification of fire: (a) Landsat image (path/row: 93/75) with some very large active fires west of the range; (b) median difference B45, where bright areas indicate "dark change", and cloud and cloud shadow masks are overlaid in light and dark blue respectively, with "high residual" features masked in yellow; (c) brightness temperature, where the "hotter" regions are bright and cooler regions are dark, with cloud and shadow mask overlaid in light and dark blue; and (d) resulting burnt area classification (outlined in black) overlaid on the Landsat image. NOTE: the cloud mask has detected the smoke plumes as cloud.

3.3.6 Calibration/optimisation and validation

Image classifications generate both commission (false positives) and omission (missed features) errors with the desired outcome usually dependent on a trade-off between the two, determined by the requirements of a particular application. In this analysis, omission errors may result from missed or under-mapped change or incorrect attribution. Similarly, the commission rate is influenced by both over-mapping and misclassified change.

Algorithm optimisation required a representative sample of 'change' (*e.g.* cloud, cloud shadow and burnt area) and 'no change' pixels across Queensland. This involved generating a series of random points for images from strategically selected Landsat path/rows. An example is shown in Figure 9. At each random location, an image analyst then visually interpreted and recorded whether the pixel contained: cloud, shadow, fire or background (cloud/shadow/fire-free). This information was then used to balance the commission and omission errors as well as validate the derived products.

For cloud and shadow detection 180,000 points were sampled across 6 path/rows (and 10 dates per path/row). Thirty percent of these were withheld from optimisation to be used in validation. The burnt area mapping also used an extensive set of random points (500,000) across 20 path/rows for optimisation and validation.

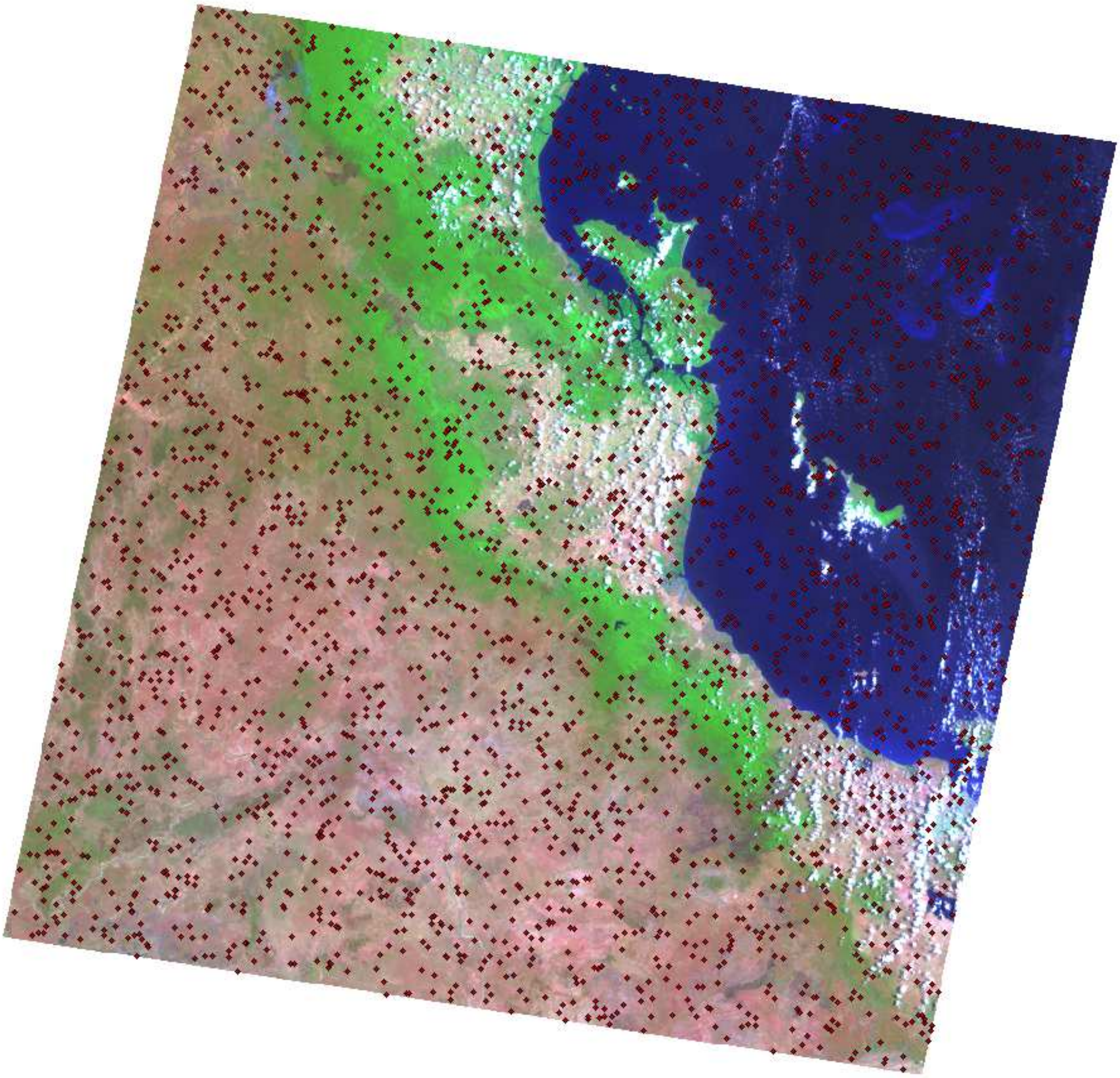


Figure 9 Random points (red dots) overlaid on a Landsat TM image. Note: the spectral bands used were RGB: 5,4,2, WRS Landsat Path/Row 95/73.

4 Results

4.1 Fractional cover

The overall accuracy of the fractional vegetation cover algorithm is quantified using the root mean square error (RMSE). This statistical measure indicates the likely range of observed cover for a given reflectance. The RMSE for the fractional cover model is 11.8%. This compares with the RMSE of the preceding GCI, which is 12.9%. While this seems only a modest improvement, the fractional vegetation cover model also has an improved statistical fit, reduced bias and is based on a much greater amount of field data than the GCI. This means that, in general, it can be expected that estimates of cover will be accurate regardless of the level of cover. This is a marked improvement over the GCI which could be as great as 20% in error, particularly in the mid-range of cover (i.e. ~50% cover), despite the overall model error being similar to fractional cover.

All Landsat 5, 7 and 8 images available and stored on the RSC archive have been processed to surface reflectance, with cloud, cloud shadow and water masks applied. Single-date and seasonal fractional cover images have also been generated (Figure 10). This equates to in excess of 66,000 individual images, and ~100 seasons between 1986 and present for all of Queensland. The generation of these images is now an automated stage within the RSC processing stream and any newly acquired images will be processed on arrival, with seasons updated 1 month after the conclusion of any given season.

Appendix 1 lists the standard fractional cover products and where they can be accessed.

It should also be noted that through the National Ground Cover Monitoring Project, the fractional cover algorithm has also been cross-calibrated to the MODIS satellite image archive. National data sets are being generated at 500m pixel resolution using 16-day composites. Recent work undertaken as part of TERN’s AusCover has also applied the medoid approach of Flood (2013) to produce monthly composites of the MODIS fractional cover. These data are available through the AusCover Product Pages (see Appendix 1 for details).

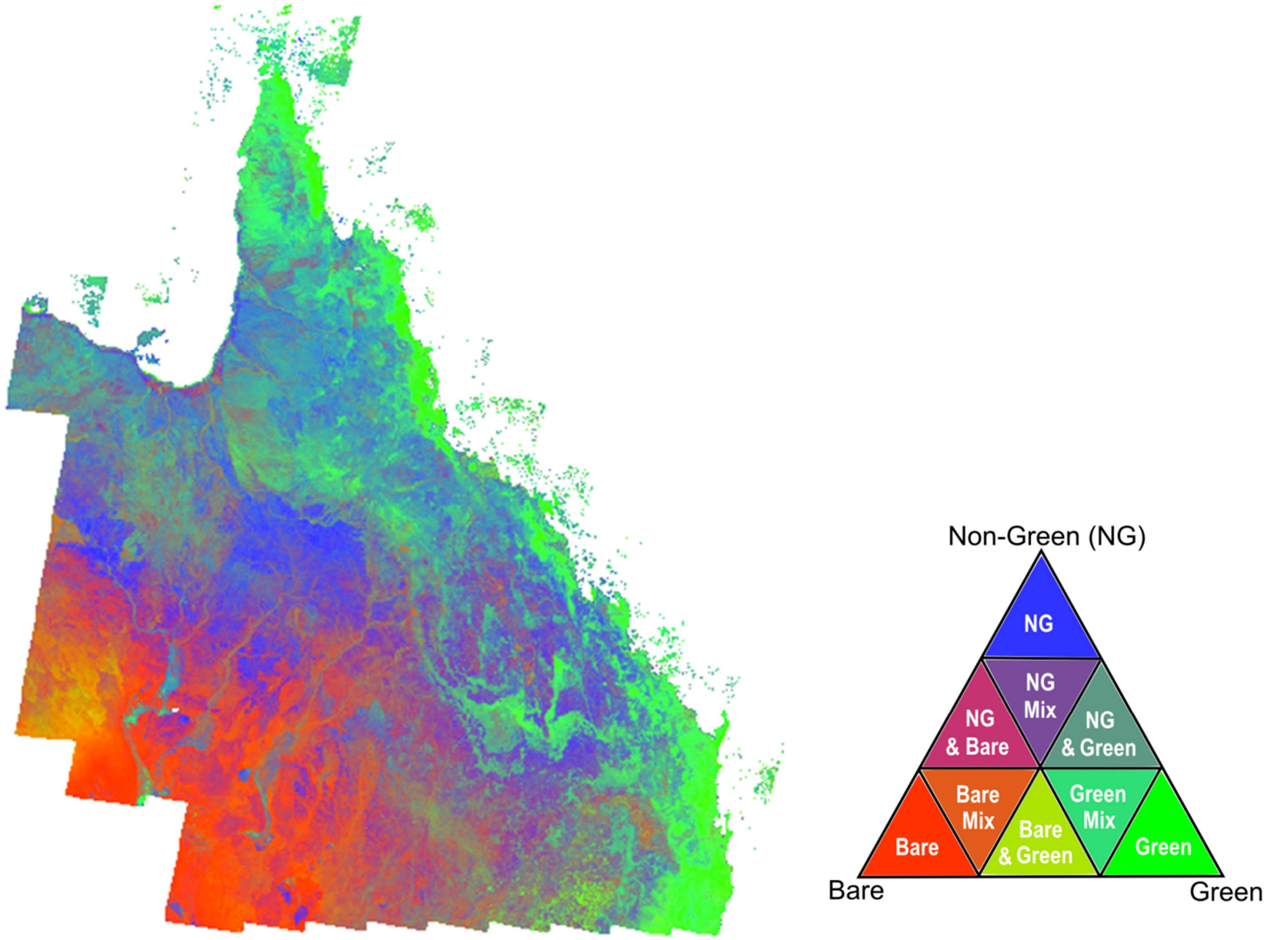


Figure 10 Example of seasonal fractional cover index product for Queensland. Seasonal summaries are produced by compositing a range of dates and presenting the median cover for that period.

4.2 Fractional ground cover

To test the accuracy of the fractional ground cover theoretical model, the model was applied to seasonal ground cover imagery at locations corresponding with field sites. A 3x3 pixel window located around each field site was corrected (i.e. adjusted) using the theoretical model. Results for each cover fraction at each site for these 3x3 windows were then averaged for both the fractional cover imagery and the corrected fractional ground cover imagery. The residual errors between the image data results and the actual measurements in the field were determined for each cover fraction (green, non-green and bare ground) for the fractional cover and the fractional ground cover as follows:

$$Residual\ error = satellite\ prediction\ of\ cover\ fraction - field\ measurement\ of\ cover\ fraction$$

Therefore a positive residual represents an overestimate by the satellite for a given fraction.

Results from the analysis for both the fractional cover product and the corrected product (i.e.fractional ground cover) are presented in Figure 11.For all three cover fractions there is an increase in accuracy with the correction.

Interestingly, there is very little bias in the bare fraction, regardless of whether it has been corrected for trees or not. This suggests that bare ground measurements are not strongly influenced by higher tree canopy cover, possibly due to the high levels of tree litter (non-green cover) that occurs in these areas. The bias in the green and non-green fraction is reduced by the adjustment, but it does not entirely remove it.

The fractional ground cover has also now been generated for all available Landsat imagery up to winter 2014. The generation of the single-date and seasonal ground cover has been operationalised and incorporated into RSC's automated Landsat data processing stream.

4.2.1 Field calibration/validation data

An experimental trial was completed in early April 2012 to better understand the influence of field measurements on fractional cover products. The trial was conducted over ten sites around Brisbane and compared four inexperienced operators and four experienced operators. Results showed that in general, the field method used for estimating fractional cover is robust and repeatable. However, the experiment did reveal some inconsistencies between inexperienced operators and good agreement between experienced operators. This suggests regular calibration is required between operators to ensure consistency. This information will help RSC and collaborating partners develop field training programs for the future.

4.2.2 Spatial averaging and benchmarking

The availability of robust estimates of seasonal fractional cover over long time periods has facilitated the development of approaches which aim to compare and quantify local differences in cover to assist with benchmarking and monitoring of cover management in grazing systems. This includes the dynamic reference cover method described in Bastin et al. (2012) and the regional ground cover comparison report. It is also planned to undertake further research to improve metrics for understanding local and regional spatial variability in cover and grazing land condition and these two approaches will be investigated as potential methods for progressing this research.

4.2.2.1 Dynamic reference cover method

Figure 13 shows an example of output from the dynamic referencing method (Bastin et al., 2012). This approach helps to highlight areas which are improving or declining in cover based on comparison of time-series derived minimum ground cover level in dry times. It can be applied at a range of scales and is particularly useful for regional-scale reporting of trends in cover.

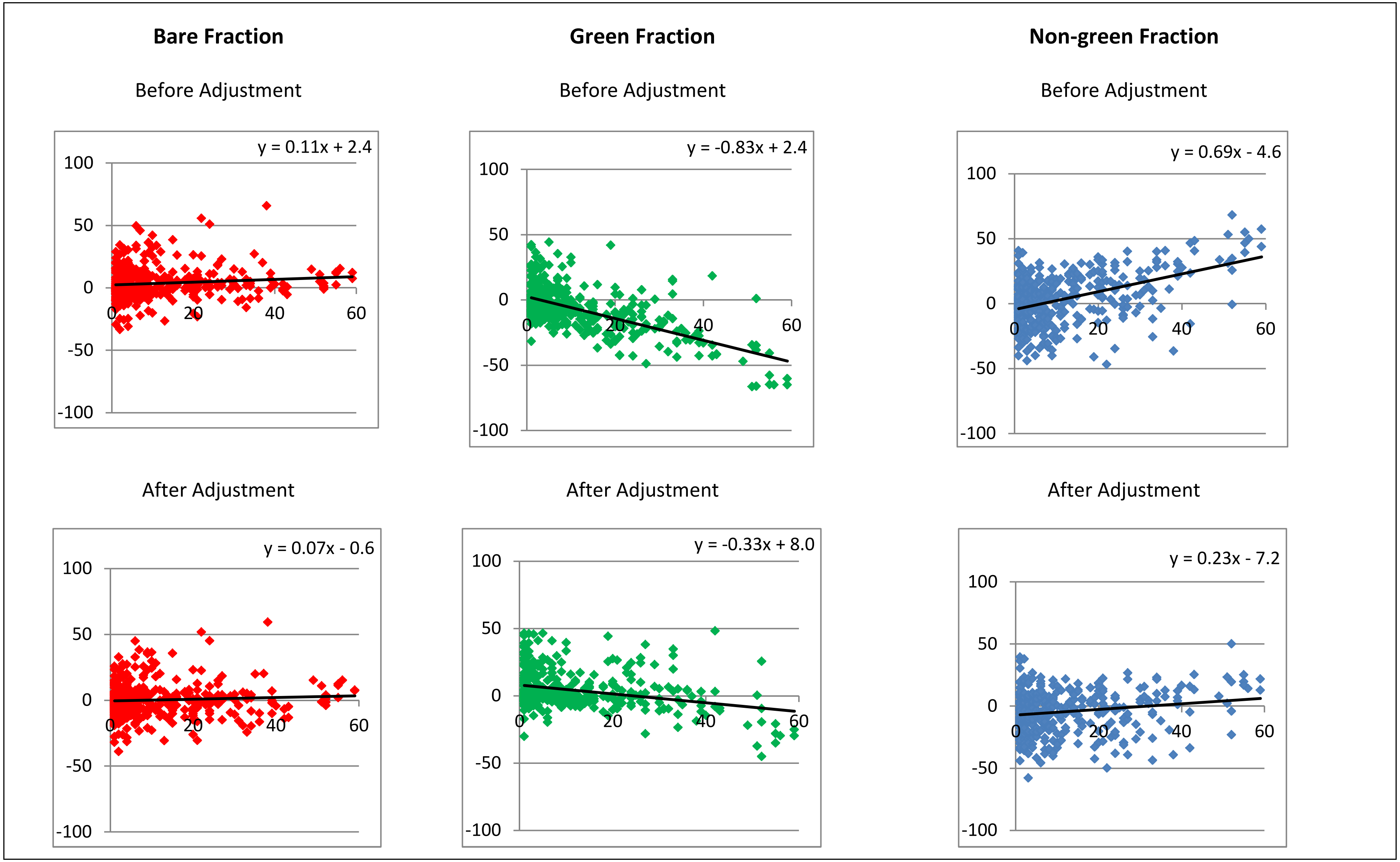


Figure 11 Residual errors (satellite estimates of cover– field data measurements of cover) for corrected and uncorrected fractional cover index (fC) estimates of each ground cover fraction, restricted to <60% persistent green.

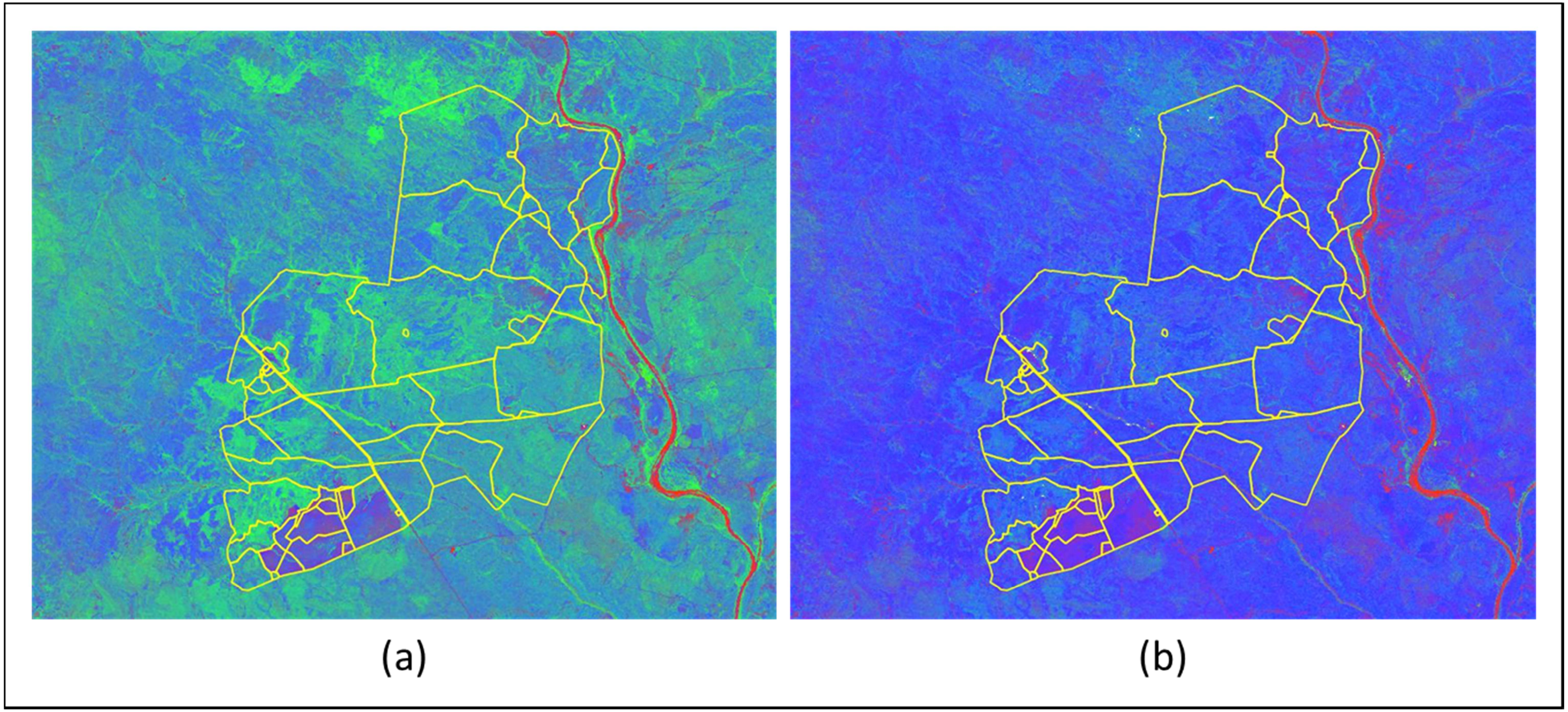


Figure 12 Example of the cover under trees model applied to winter 2013 imagery for Spyglass Beef Research Station (a) Fractional cover image (b) Fractional ground cover image. There is an apparent increase in the non-green fraction in the fractional ground cover image. This indicates that most of the green cover seen in the fractional cover image is in fact tree and shrub cover and that the ground cover during this season is dominated by non-green vegetation (e.g. senescent grasses and litter).

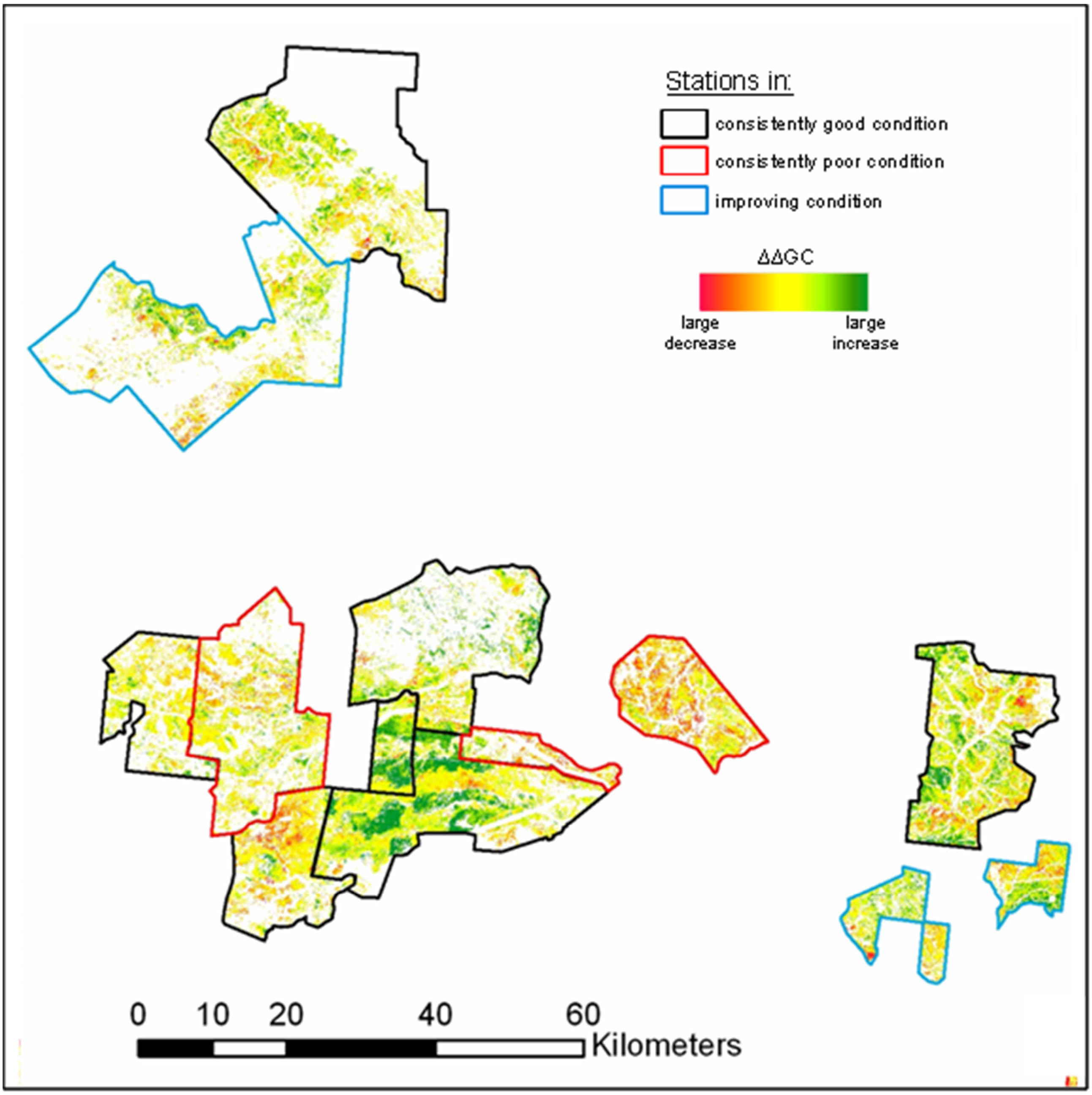


Figure 13 Example of output from the dynamic referencing method described by Bastin et al. (2012). The map highlights properties which have remained in either good or poor land condition, or improved in condition based on GCI change assessment. White areas within property boundaries have FPC of 20% or greater and have been masked out (source: Bastin et al, 2012).

4.2.2.2 Regional ground cover comparison

The ground cover regional comparison approach has been incorporated into a FORAGE report. The report is designed to enable users to accurately compare the ground cover levels on their selected lot on plan with the levels of ground cover for their local region, both for current levels and historically.

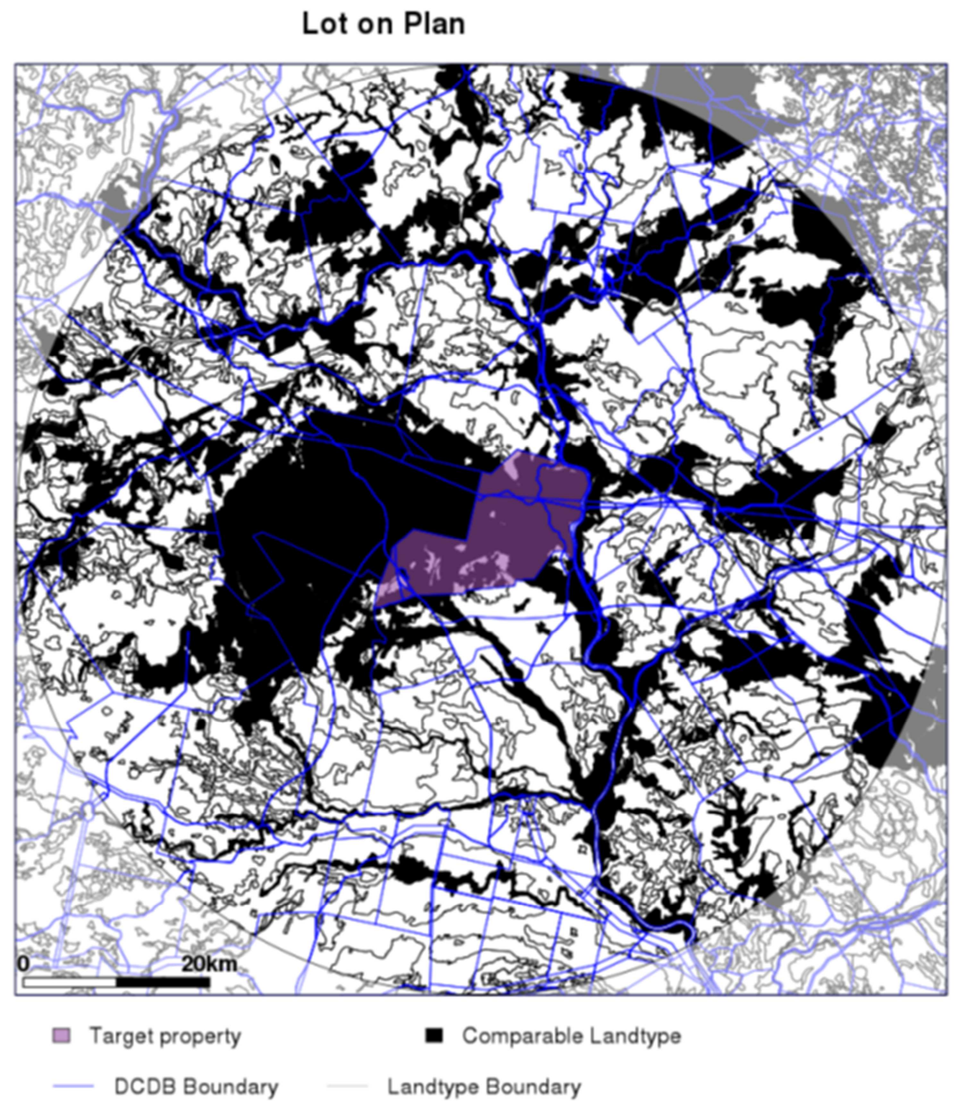
The report only focuses on ground cover for the dominant land types present for a given lot on plan. Dominant land types are determined by selecting the major land types, present on the lot on plan, which combined constitute greater than 80% of the area.

Ground cover levels for each dominant land type identified are then compared with ground cover levels for the same land types within the local region. The local region is defined by a 50 km radius around the selected lot on plan (Figure 14). The use of this localised radius is intended to reduce the influence of regional climate variability on any comparisons. Differences between the ground cover levels on the selected lot on plan and the local region are therefore assumed to be due to management.

To undertake the comparison, the levels of seasonal ground cover, for each season on record (1986 to present), within the local region are ranked into percentiles and graphed (Figure 14). The seasonal cover, for the same period, for the lot on plan is then plotted on the same graph. This enables the direct comparison of the trend and the level of ground cover for the selected lot on plan to the range of ground cover levels for the region over time.

The information contained in the ground cover regional comparison report can be useful for:

- Indicating the level of ground cover which is possible for particular land types during a particular season or climate period
- Setting regional benchmarks or targets for particular land types and management practices
- Indicating land types which have ground cover which may be more resilient in dry times and those that are more susceptible to lower levels of cover or greater variability
- Monitoring the effect of different management practices (e.g. stocking rates, wet season spelling, use of fire etc) on the ground cover levels on different land types.



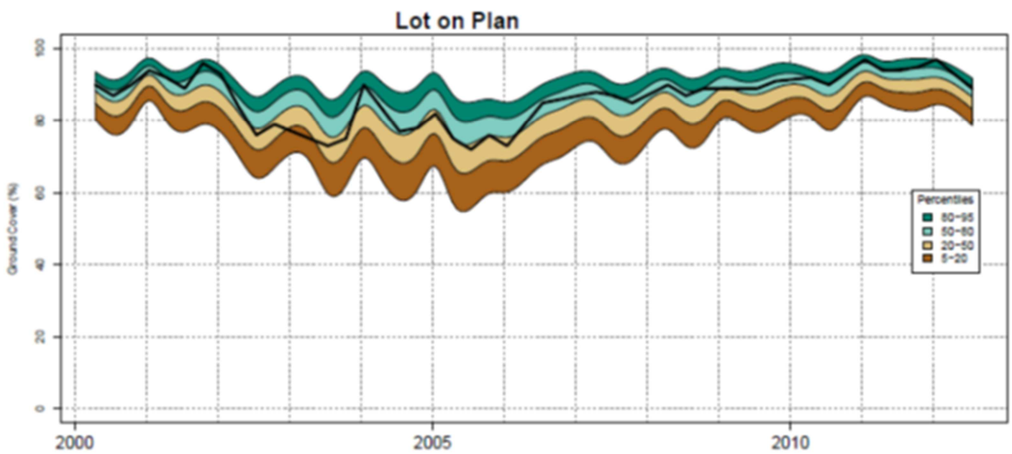


Figure 14 Example from the regional comparison report. The top graphic shows the comparable land types for the chosen lot on plan (purple polygon) and within a 50 km radius. This is the area included in the comparison. The bottom graph shows the median cover for the target property (black line) plotted against the range of cover levels for the comparable land types within the 50 km radius.

4.3 Burnt area mapping

4.3.1 Classification of cloud and cloud shadow

The cloud and cloud shadow detection approaches are now implemented as an operational part of the RSC Landsat image processing stream. Validation and calibration of cloud and cloud shadow masks has been completed (see Goodwin et al., 2013). The cross-validation of cloud and cloud shadow indicated consistent thresholds with minimal variation from producers and users accuracies across Landsat path/rows. This demonstrates the results are robust and can be applied to different regions of Queensland with varying climates and vegetation. The following seed and region growing thresholds were chosen for cloud detection:

i. *B17* of 1.1 (*B17 is the* ratio of Landsat TM bands 1 and 7)
ii. *B1* change of 47 (*B1* is visible blue)
iii. *B1* region grow of 25.

An example of cloud classification based on these thresholds is shown in Figure 15.

Significantly, the producers and users accuracies for cloud detection were greater than 98 and 87%, respectively. The producers and users accuracies for clear areas (i.e. areas not affected by cloud or other change) were higher, with values greater than 99 and 98%, respectively. The overall classification accuracy (averaged across all regions) was 97%. The application of a 5 pixel buffer resulted in a reduction in overall accuracy of about 2%. It was determined, however, that for many applications the significant reduction in cloud omissions achieved by application of a buffer is more important than the resulting increase in false cloud and therefore overall error.

The dominant metric used to detect cloud shadow across all WRS footprints was $B45_{sm}$, with over 65% of the pixels using $B45_{sm}$ to estimate change (note: $B45_{sm}$ is the seasonal median of Landsat bands 4 and 5). Visual inspection of the positive average residual layer shows higher values correspond to landscape patterns, primarily due to agriculture (Figure 16). The 89/79 WRS footprint had the highest proportion of pixels (6%) considered to be too temporally variable for cloud shadow detection. This was due to extensive agriculture and urban areas (Brisbane and the Gold Coast) contained in this footprint

Table 1 shows the validation results for the combined operational cloud and shadow masks. This table shows total accuracies (averaged across regions) of 98% and 97% for buffered and unbuffered masks, respectively, and the relative effects on omission (missed cloud) and commission (false cloud) errors. Most of the relatively high commission error is associated with cloud and shadow buffering, which is a necessary cost to reduce the rate of missed cloud and shadow. Probably the largest sources of false cloud were changes in bright soil or urban areas.

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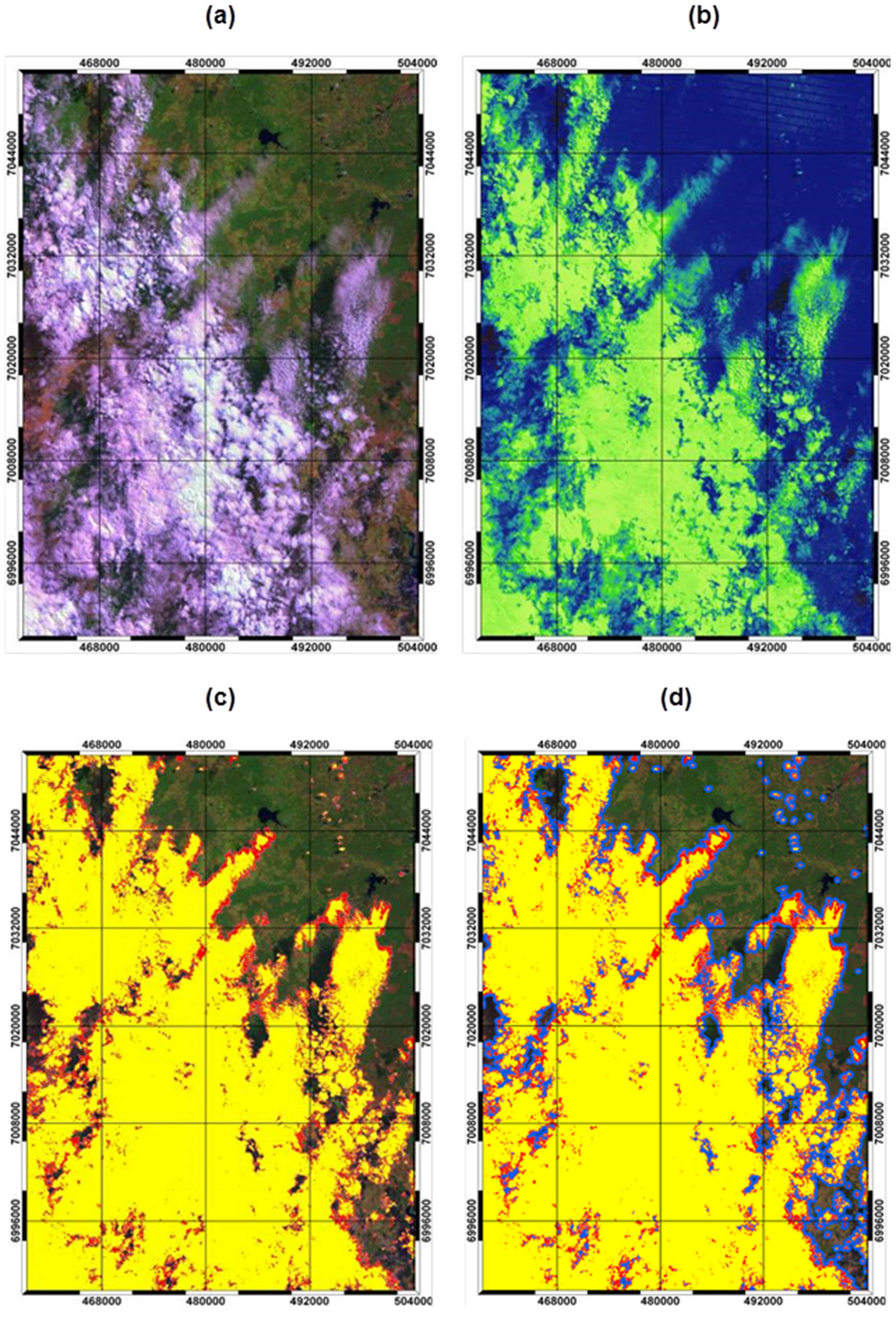

Figure 15 Illustration of cloud classification sequence: (a) Landsat TM image; (b) running B1 minimum difference with brighter green indicating large positive change and darker blue low change; (c) cloud classification overlaid upon the Landsat TM image with yellow indicating cloud seeds and red pixels that were region grown; (d) cloud buffer (blue) of five pixels added to (c). Note: the spectral bands used were RGB: 5, 4,2, WRS 89/79, 20050928.

(a) (b)

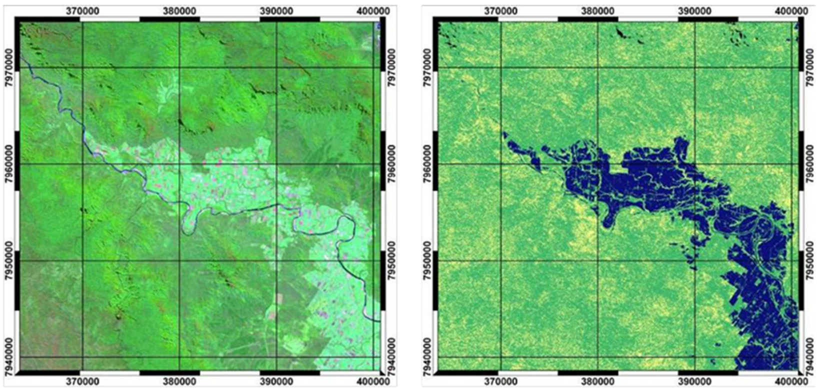

Figure 16 Map showing distribution of optimal reference median derived from residual errors: (a) Landsat TM image using the spectral bands (RGB: 5, 4, 2, 20030521, WRS 95/73); (b) the stratified reference medians where green = $B45_{sm}$, yellow = $B45_{RM}$ and blue denotes unclassified regions, due to high residuals.

Table 1 Contingency table showing all classes in the combined time series cloud and shadow classification for all land-based observations. Producer's and user's accuracies are presented for final buffered (•) and unbuffered (†) cloud, shadow and clear classifications. Bracketed results/totals include the ambiguous observations. These are not included in the user's and producer's statistics.

	Reference data				
Classes	**Cloud**	**Shadow**	**Clear**	**Ambiguous***	**Total**
Cloud: Pass 1	8717 †●	28 †●	395	Excluded (175)	9140 (9315)
Cloud Buffer: Pass 1	134 ●	93 †●	670 †	Excluded (42)	897 (939)
Cloud: Pass 2	6 †●	0 †●	92	Excluded (1)	98 (99)
Cloud Buffer: Pass 2	5 ●	1 †●	64 †	Excluded (1)	70 (71)
Shadow	18	1639 †●	138	Excluded (61)	1795 (1856)
Shadow Buffer	28	183 ●	935 †	Excluded (21)	1146 (1167)
Clear	143	136	39380 †●	Excluded (67)	39659 (39726)
Unclass.	2	84	331 †●	Excluded (36)	417 (453)
Total	**9053**	**2164**	**42005**	**- (404)**	**53222 (53626)**

Producer's Accuracy			
Final Product (●):	97.89%	**89.83%	94.54%
Unbuffered Product (†):	96.35%	**81.38%	98.51%
User's Accuracy			
Final Product (●)	86.84%	61.95%	99.09%
Unbuffered Product (†)	94.43%	91.31%	98.08%
Total Accuracy			
Final Product (●)	97.12%	97.48%	
Unbuffered Product (†)	98.41%	98.90%	

*Ambiguous observations which include observations of smoke, haze, shaded cloud, etc. are presented here (in brackets) for interest, and are included in the bracketed totals. However they have been excluded from the user's and producer's statistics.

**Shadow observations classified as cloud, because of order of precedence have been counted as correct in the shadow producer's statistics.

4.3.2 Burnt area accuracy assessment

The validation data consists of 100 images sampled from 10 locations across Queensland. This included a range of burnt area fractions with 5000 random points sampled per image (total *n*=500,000). The validation results for our automated time series approach are encouraging and shown in Table 2 These demonstrate a high proportion of burnt area observations were correctly classified with only moderate commission errors (producer's and user's accuracy of 85 and 71%, respectively). Although, the background and total classification accuracy approached 100%, these results are largely driven by the background class as the burnt area represents a small fraction of total area sampled (<1%) and only have a small influence on the total accuracy assessment. The producer's accuracy increases by 4% while the user's accuracy declines by 8% when a morphological dilation or buffer of 1 pixel is applied to the burnt class for pixels exhibiting a B45 decline. The use of a pixel buffer was also found to be effective at infilling gaps in burnt areas.

An example of a burnt area classification sequence is shown in Figure 17. This demonstrates that burnt areas are generally well delineated in the *B45* difference layer, $resid_{B45t}$, relative to unburnt vegetation. The spatial variability in the magnitude of $resid_{B45t}$, which most likely relates to both fire intensity and the relative timing of fire and image acquisition, is also evident.

Table 2 Contingency table showing the results with (and without) a pixel buffer.

	Burnt (reference)	Background (reference)	Total
Burnt (classified)	2424 (2545*)	986 (1515*)	3410 (4060*)
Background (classified)	444 (323*)	488129 (487600*)	488573 (487923*)
Total	2868 (2868*)	489115 (489115*)	491983 (491983*)
Producer's accuracy	85 (89*)	100 (100*)	
User's accuracy	71 (63*)	100 (100*)	
Total accuracy	100 (100*)		

* Pixel buffer of 1 pixel where *B45* change exceeded 0.

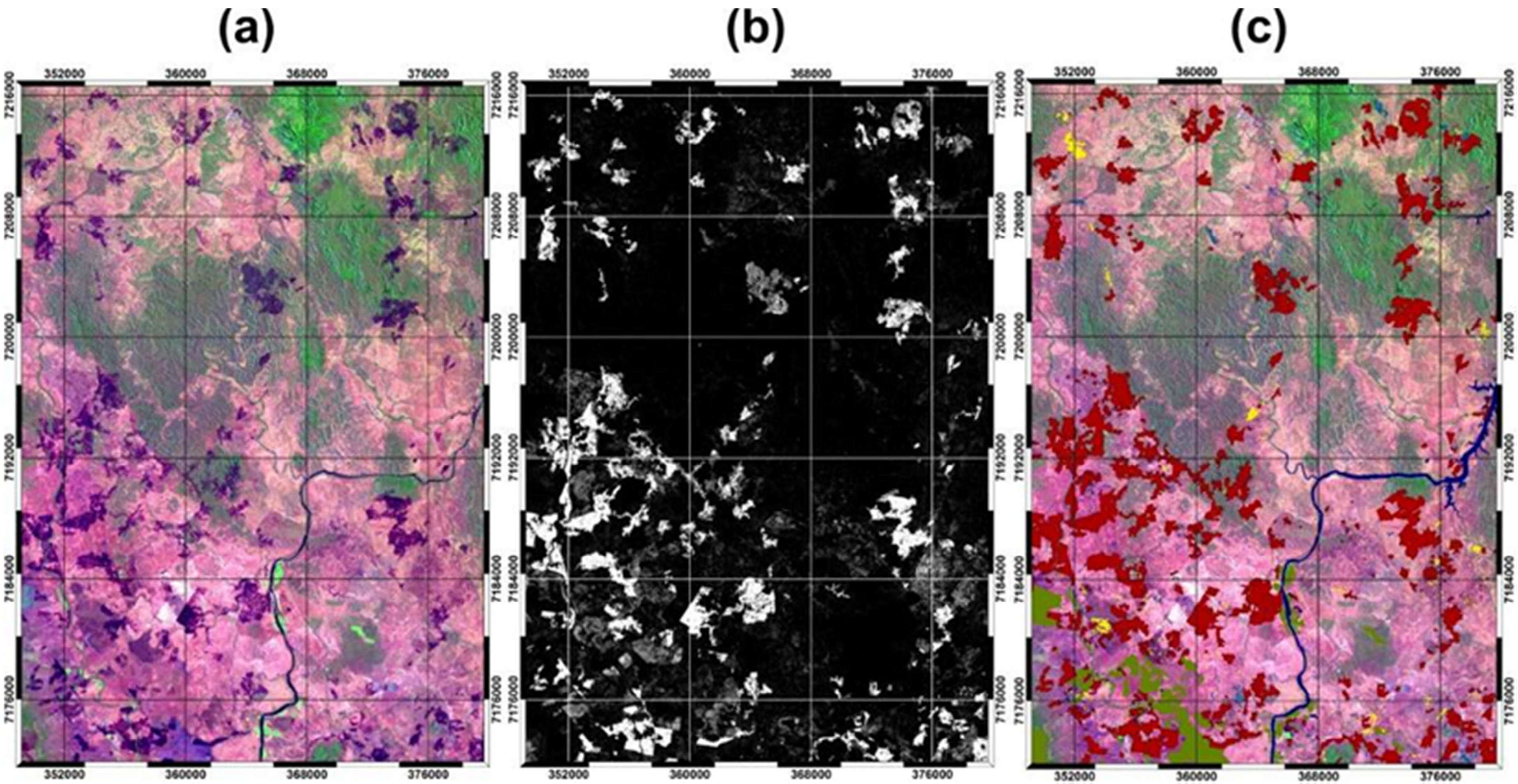

Figure 17 Illustration of a burnt area classification and intermediate change layer. (a) Landsat image: RGB: 542, Path/Row: 90/78, and date: 19960929 (b) B45 median residual (residB45t) where black indicated no or negative change and brighter colours indicates larger magnitudes of change and (c) Landsat image with burnt area classification overlaid (red=fire, green=crop mask, yellow=unburnt change).

5 Discussion

This project aimed to deliver ground cover information and burnt area mapping at spatial and temporal resolutions that have previously not been available. This was achieved through extensive research and development, facilitated by a range of collaborative partnerships. The advent of freely available Landsat satellite imagery archive has enabled the development of improved or new algorithms for fractional ground cover measurement, cloud and cloud shadow masking and classification of burnt areas across Queensland. These products will provide fundamental information to RWQ and Reef Plan for extension, modelling and monitoring activities.

5.1 Ground cover

5.1.1 Landsat imagery

Over 66,000 individual Landsat images between about 1988 and present across all of Queensland are stored in the RSC archive on the high performance computing facility at the EcoSciences Precinct in Brisbane (Figure 18). The acquisition of these data has been made possible by the opening up of the Landsat archive by the United States Geological Survey and NASA, with assistance for the Australian archive provided by Geoscience Australia. The Landsat imagery has been automatically processed and corrected using the process stream developed and implemented by Flood et al. (2013). The processing stream includes automated steps for download of imagery and correction of for atmospheric and land surface effects, cloud and cloud shadow and topographic effects. The production of these data has been facilitated by the development of cloud and cloud shadow masking as part of the fire scar work undertaken as part of this project. The archive includes imagery from Landsat 5, 7 and 8 satellites. Each satellite has a return interval of 16 days and up to 8 days where two satellites are operating in tandem. This is enabling development of a range of land cover products, including fractional cover and fractional ground cover, which can be compared and analysed to understand land cover dynamics over reasonably long periods of time. It also establishes a reliable and efficient platform for future acquisition and processing of Landsat imagery and imagery from other planned satellite missions (e.g. European Space Agency's Sentinel-2 mission) assuring data and information delivery for Reef extension, monitoring and reporting programs. Other states and territories are also using the archive for their own purposes, establishing consistent information across jurisdictions which are enabling grazing extension, in particular, to be operating from a common monitoring base.

5.1.2 Fractional cover and fractional ground cover

The development and application of the fractional cover and fractional ground cover ('cover under trees') algorithms described in this report is providing medium-resolution (~30 m pixel resolution) seasonal (or more regular) information about the levels of green and non-green cover and bare ground for the past ~26 years. These methods and the products derived from them have replaced the Ground Cover Index (GCI). The data provides additional information to the GCI, with greater temporal frequency informing the understanding of the dynamics and composition of ground cover, and with greater accuracy and less bias across the range of ground cover levels.

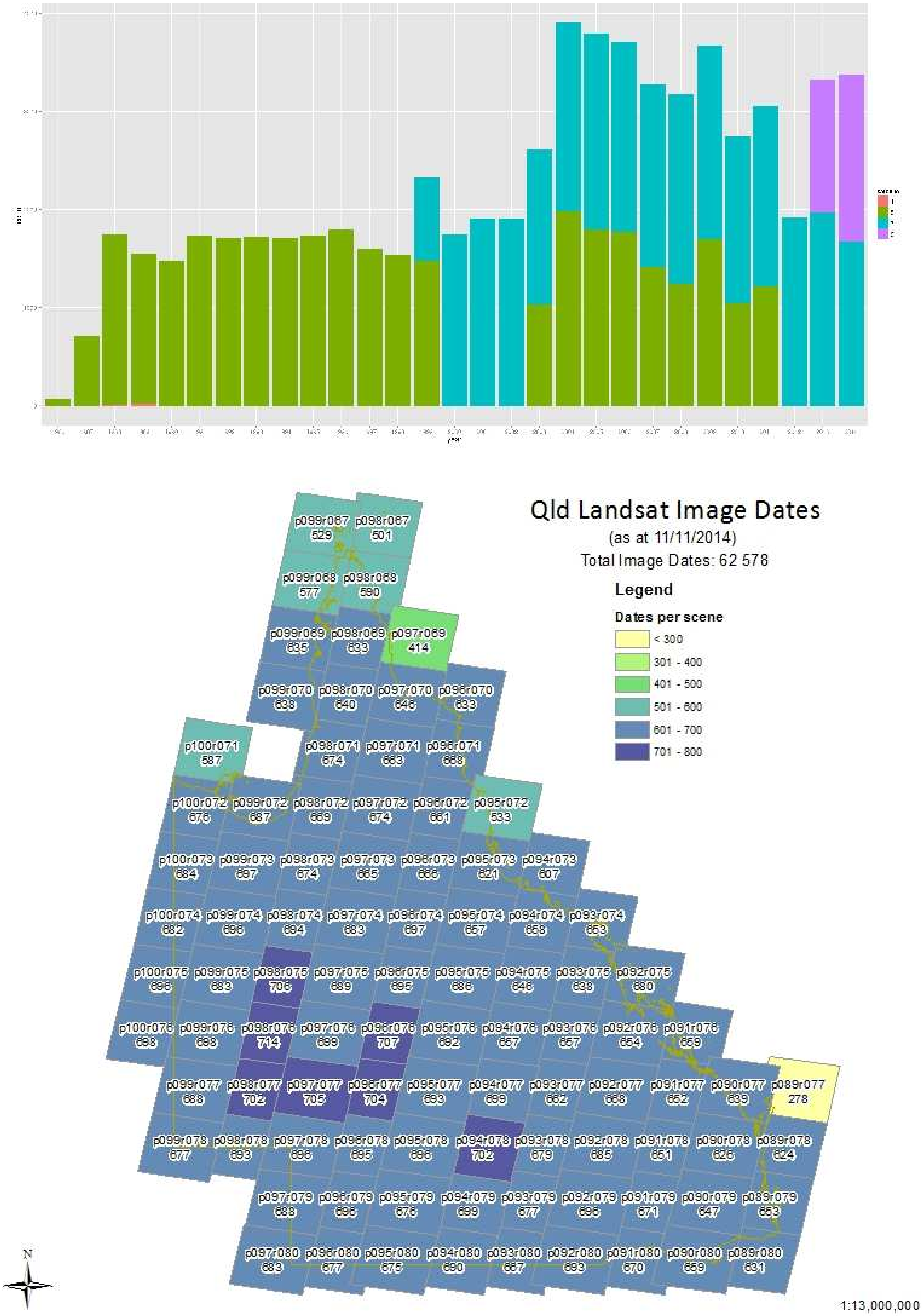

Figure 18 Current DSITIA archive of Landsat 5, 7 and 8 satellite imagery (as at November 2014). For some periods of the archive, two satellites were operating in tandem providing greater temporal frequency.

The fractional cover product has facilitated a number of developments, The green cover fraction can be used to map persistent green cover in the landscape (assumed to be the woody component of vegetation), thus improving woody vegetation mapping and helping to understand woody vegetation trends and processes such as encroachment and thickening which affect the grazing industry and can influence management actions, and have impacts on water quality, This improved understanding of the persistent green vegetation has also led to what is the perhaps the most significant development in ground cover measurement to date – the fractional ground cover or ‘cover under trees’ algorithm. This product is now accounting for the influence of trees and shrubs on the reflective signal measured by the satellite sensor. This is enhancing the ability to resolve what the composition of cover and bare ground is in the ground layer, particularly in areas with higher tree cover which we previously masked out in the GCI and earlier fractional cover data.

Based on the fractional ground cover data (and field calibration data), there is an increase in non-green cover and bare ground as tree cover increases. Further work is required to validate this relationship and further test the upper threshold of tree cover at which the fractional ground cover model can be applied. Understanding the limitations of the fractional ground cover will be critical to its implementation in the water quality models for Reef and also for grazing land management activities. Ideally, any further validation exercise will target the range of land types and levels of tree cover which are present in Reef catchments. This work could be stratified, taking into account existing field data, seasonality and preferably different management regimes. As such, grazing trials such as Wambiana and Spyglass are critical to any validation exercises.

5.1.3 Seasonal fractional ground cover

The free availability of the Landsat archive has enabled the development of consistent seasonal products of the Landsat imagery itself, and also of the fractional cover and fractional ground cover which are derived from the Landsat data. These products are providing representative measures of vegetation cover on a regular time step and minimising the influence of outliers and missing data due to cloud, cloud shadow, sensor malfunction or other artefacts in the imagery. Additional ‘patches’ can be introduced to fill in any gaps which result from limited valid measurements, providing spatially comprehensive data to those users who require continuous information, such as the P2R modellers.

The regular time step of the seasonal data has also facilitated improvements in statistical analysis of changes in cover. Statistical approaches can be applied to the data which do not require methods to account for gaps or outliers, meaning that analysis of trends and fluctuations in cover can be investigated. The benefit of this has been demonstrated in the Regional Ground Cover Comparison approach now being delivered to the Burdekin in report format from FORAGE. It is anticipated that as the data becomes more accessible through web interfaces, Google Earth (Globe) technology and FORAGE reports, that this seasonal data will form the basis of range of monitoring, reporting and land management activities. However, this will require ongoing extension and education which will need to involve the range of end users to ensure products are presented and developed in ways which are understandable and usable, depending on the required application.

5.1.4 Product delivery and use

Fractional ground cover products can be used in a range of ways. For RWQ and Reef Plan, the products may be used to support extension, monitoring and reporting activities. A range of products have been or are currently being developed from the fractional ground cover. This includes the seasonal products, but also products which provide summaries of the time-series of data such as the long-term the maximum, minimum, median and mean. The products are being distributed and made available in various formats via a range of mechanisms (refer to Appendix 1 for details). These include Forage, VegMachine, VegCover.com, Queensland Government Information Service (QGIS), the government's internal Spatial Information Repository (SIR), and the geoportal of TERN's AusCover program, thus enabling access for all clients, stakeholders and the general public. The introduction of the fractional ground cover has extending the reporting region for Reef Plan from 38% of the grazing lands of Reef catchments, to over 94% of the grazing lands. Improvements are also planned for the reporting for Reef Plan 2013-18 which include the use of cover deciles and improved time-series data from the seasonal products.

The extensive time-series information can be used to monitor and report changes in ground cover levels and dynamics across a number of years, as well as short and long-term seasonal fluctuations. These data may be used to identify areas of persistently low or high cover and areas at risk of elevated erosion and sediment transportation. By comparing the data with climate information, benchmarks or reference data, we can improve our understanding of the long-term effects of management. However, with respect to some land cover dynamics, the extent of time-series available (~27 years) is relatively limited, which restricts the ability to assess land management impacts post-European settlement. Pasture modelling packages such as AussieGRASS and inferred changes in sediment regimes derived from sediment tracing and dating studies may help augment the historical record of ground cover changes due to management and climate. It may be possible to extend the time-series of fractional cover as far back as 1972 using earlier imagery captured by the Landsat program. However, this would require extensive research and development to pre-process the imagery and undertake cross-calibration of the fractional cover algorithm. In terms of looking forward, the work undertaken as part of this project and other research and development undertaken by RSC and its partners, has ensured a successful transition of the fractional ground cover algorithm from Landsat 5 and 7, to Landsat 8, paving the way for application to other similar sensors in the future. The time-series that is now available is unparalleled in terms of repeat measurements over such a long period of time. As users become more familiar with the data, greater reliance on the data is expected, particularly as producers start to use it more regularly for planning seasonal stocking rates and other land management activities.

In an extension setting, fractional ground cover products can be used to demonstrate to land managers the impact of practices on ground cover levels at a range of scales. As previously mentioned, the regional ground cover report has been presented as an example of this and VegMachine has been used for a number of years in this way. Land managers may use the information to adjust their practices (e.g. stocking and utilisation rates) and thus improve ground cover, pasture production and land condition. Planned projects such as the NRM Spatial Hub and the complementary VegMachine Online, will only improve the land managers access to these data in readily accessible, easily understood formats, improving uptake and use, and product improvements.

The time-series fractional ground cover data is currently being used to improve modelling of sediment and nutrient runoff and loads undertaken as part of the P2R modelling program. The information will improve the cover factor parameter used in the Universal Soil Loss Equation, which is the basis for P2R models. The data can also be used to validate parameters in the GRASP model, thus improving paddock runoff and pasture predictions obtained from AussieGRASS. There are a range of uses for the fractional ground cover data which extend to Reef-related activities and other land management and planning activities in Reef catchments. These uses include:

- quantifying biomass and fuel loads and assessing post-fire recovery, for example as part of the state-wide fire hazard and risk mapping undertake by the Public Safety Business Agency

- biodiversity and land condition assessments
- natural disaster recovery monitoring
- linking with economic and social information for improved grazing practices
- monitoring cropping practices and cover management in cropping areas

5.1.5 Further research

A number of research tasks to improve field measurement of fractional ground cover are being identified and undertaken, where time and resources permit. The method used by RSC to measure fractional cover in the field has been adopted as a national standard (Muir et al., 2011). However, the repeatability and consistency of the method among field officers requires further testing in a range of environments and land cover types. Recent research has indicated that for relatively experienced operators, the method is consistent and repeatable, less so for inexperienced operators. This has highlighted a need for appropriate training and regular calibration of field officers to ensure data is consistent and accurate.

The accuracy of field data in representing actual cover fractions at any one location and point in time is fundamental to how well the derived products represent reality. Further research in this area will check accuracy of field data by:

- testing and analysing how representative the current sample is of land cover types across Queensland and Australia
- collecting additional data, where required, particularly in high foliage areas
- testing and possibly improving current methods for accuracy
- investigating new technologies, such as unmanned aerial vehicles, terrestrial laser scanning and hemispherical photography, for more objective and efficient monitoring and collection of calibration and validation data.

The fractional ground cover is providing spatial and temporal information that may be used to compare different areas (e.g. paddocks or properties) and better understand ground cover patterns due to climate and management. Despite this new information, the spatial arrangement of cover and how it varies with time is still not well understood. Further work is required to develop metrics which quantify spatial variability in cover and to present these in formats which are of value to the range of end users. Some work has been undertaken by Bastin et al. (2012) and also by RSC to develop ways of quantifying local variability in cover, thus de-coupling management from climate and to analyse what this may mean in terms of trend in cover over time. However, further work is required to be able to apply these metrics at a property level so that it can be reliably used for grazing land management, helping to understand grazing preferences, natural and management-induced patchiness, and seasonal variability. It may be that other remote sensing technologies can assist with this work, such as those active sensors such as radar and LiDAR, which can help distinguish vegetation structure. These metrics have the potential to be used as surrogates for monitoring grazing land condition, particularly when combined with other land cover and management information.

From a productivity perspective, a significant enhancement to fractional ground cover data would be to relate the cover estimates to pasture biomass or feed-on-offer. Work has commenced through an MLA-funded sub-project of the NRM Spatial Hub which aims to link the fractional ground cover with modelled estimates of pasture biomass. It is expected that improvements can be made to modelled pasture biomass estimates by effectively using the fractional ground cover data as a cross-calibration mechanism for the cover factor which is included in the pasture biomass models. This project is also investigating the benefits of other remote sensing and modelling approaches from across Australia in an effort to establish a consistent and collaborative framework for ongoing interaction between remotely sensed cover and biomass estimates and modelled biomass.

5.2 Burnt area mapping

5.2.1 Cloud and cloud shadow masking

Removal of the effects of cloud and cloud shadow is a fundamental requirement in the development of algorithms to map attributes such as burnt area and ground cover. As discussed in Section 4.3.1, RSC has developed three operational mask products: (i) the *fmask* algorithm (Zhu and Woodcock, 2012) which can be applied to single-date imagery; (ii) a time-series approach which can be used for large archives of imagery; and, (iii) a manual editing approach which can be used for highly accurate masking of single-date imagery.

All products have achieved accuracies exceeding 90% for cloud and cloud shadow. This is sometimes achieved at the expense of information in pixels that are not cloud- or cloud shadow-affected. Conservative thresholds and buffering are necessary for algorithms applied across the range of environments in Queensland and Australia. However, with the time-series of Landsat imagery now available, it is be possible to have a Landsat image every 16 days, or as often as 8 days when two satellites are operational. It is therefore likely that a pixel masked in one image will not be masked in the preceding or subsequent image. This may still lead to loss of information where a land cover attribute changes rapidly (e.g. ‘green-up’ post-fire), but to reduced effect.

The development of these masks has placed the Queensland Government in a unique position to be able to monitor and report on a range of land cover attributes. Few organisations in the world have developed such capacity.

5.2.2 Burnt area product

We found a time series framework is well suited for automated mapping of burnt areas. In particular, the ability to characterise temporal trends was effective at separating fire related change from seasonal and non-seasonal influences on vegetation, and sources of noise or contamination. These benefits have been demonstrated in earlier two-date change detection studies (Boer et al., 2008; Miller and Thode, 2007). Notably, in the present study, a time series approach using median filters to smooth the time series was able to provide a reference of ‘no change’ that accounts for seasonal/non-seasonal trends and noise/contamination present in individual image dates allowing automated detection of burnt areas using an archive of over 66,000 images.

Our results showed that over 80% of burnt areas were detected with less than 30% commission error. Given the diversity of land surfaces and burn characteristics as well as the inclusion of cloud contaminated imagery, we believe this to be an acceptable result for mapping burnt areas over large areas. Manual editing can be undertaken to improve the data and RSC has developed a method for doing this as efficiently as possible. The recently released 2013 data has been manually edited, significantly improving the product for end users. The historical archive is currently being assessed for the level of resourcing and time that would be required to remove errors and misclassification in the data.

5.2.3 Product delivery and use

The burnt area mapping is currently available through the Queensland Government Information Service and the TERN AusCover data portal (refer to Appendix 1). Other potential delivery mechanisms include FORAGE and the North Australian Fire Information (NAFI) service. NAFI has an established community user base that includes graziers, land managers and government fire management agencies. The data is currently being formatted to facilitate its upload to the NAFI website.

The project has also developed a number of preliminary products which are yet to be formally released. These include historical summaries of the frequency or number of times burnt and the time since burnt (e.g. see Figure 19 and Figure 20). This information will help to highlight areas with exposed soil and potentially increased susceptibility to erosion and generation of sediment and nutrients. It may also be used to monitor land condition and identify changes to pasture or vegetation ecology. Inappropriate fire regimes may reduce production capacity and initiate or accelerate processes such as vegetation thickening and encroachment. The products are also effective tools for fire management authorities and graziers in planning for use of fire and also for incident management.

Burnt area products may also be used by P2R and other programs (e.g. AussieGRASS) to re-initialise models of cover or pasture where a fire has been detected and mapped. The data can improve our understanding of erosion levels post-fire and capacity to account for this in models (i.e. parameterisation). As with the ground cover data, there are many other uses for the information including: biodiversity and land condition assessment; fire management planning; and carbon and CO_2 monitoring.

5.2.4 Further research

A range of issues exist with the burnt area mapping, which will be prioritised and addressed through further research, where time and resources permit. These include:

- incorporating knowledge of vegetation dynamics into the algorithm for better regionalisation of the model
- accounting for the time interval between burn event and image capture, possibly using more frequent image sources such as MODIS
- understanding the rate of ash disappearance
- modelling fuel loads and burn intensity to understand severity and potential risk of erosion
- relating the timing of fires to rainfall events to identify erosion risk
- linking fire regimes with ground cover dynamics
- improvements to burnt area method:
  - the assumption that burnt areas decline in reflectance over time may not always be true
  - missed cloud/shadow in the pre-processing has been found to impact the detection of burnt area.

Furthermore, the validation approach used to assess accuracy of products can be improved. Field data or another source of non-Landsat derived data would be beneficial to assess the impact of time-series gaps on fire history accuracy. This work is ongoing and some data has been sourced from the Queensland Rural Fire Service, Queensland Parks and Wildlife Service, and some individuals from around the state to assist with the assessment.

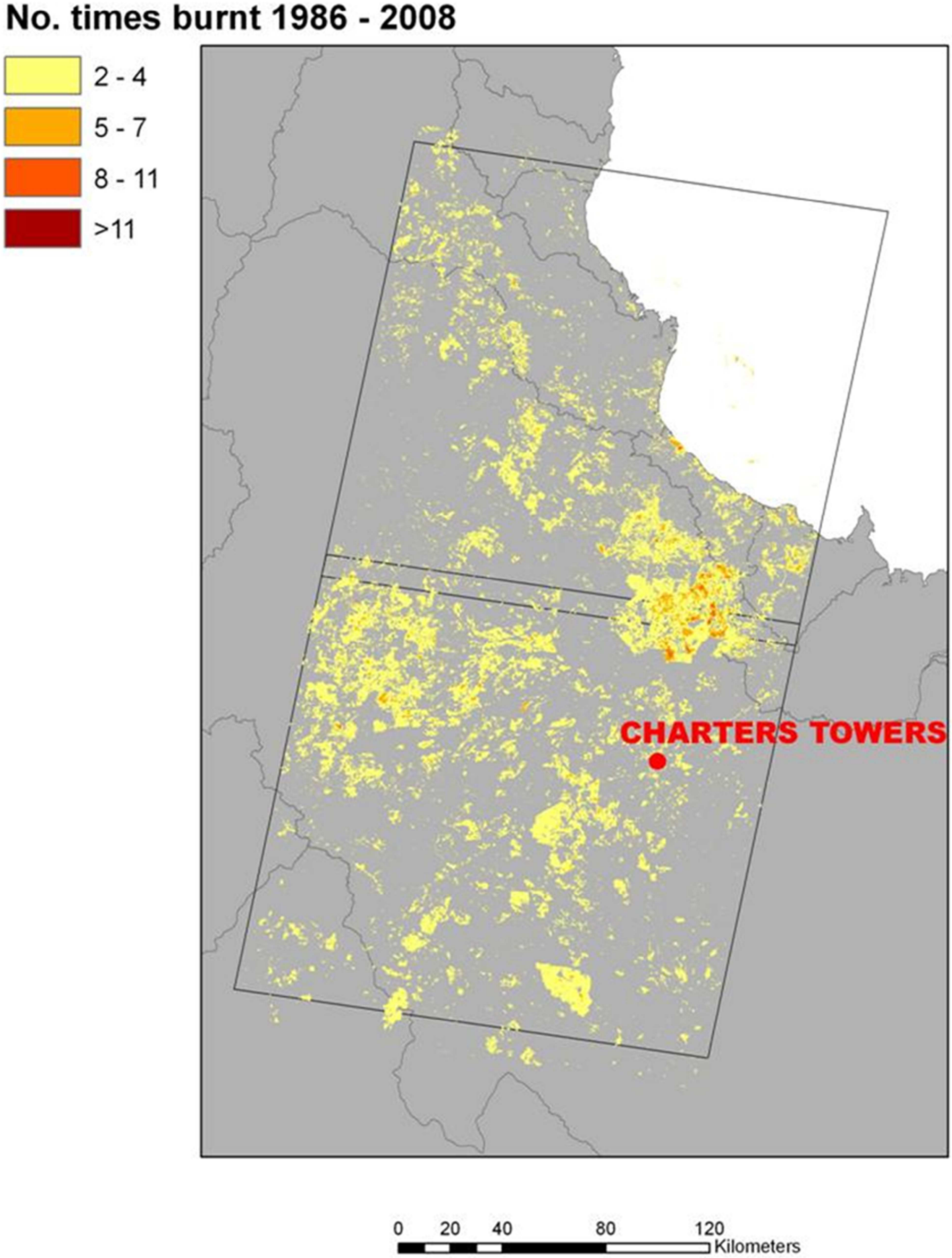

Figure 19 Example burnt area summary product for two Landsat scene areas near Charters Towers. This example shows the number of times an area has burnt in a 22 year period.

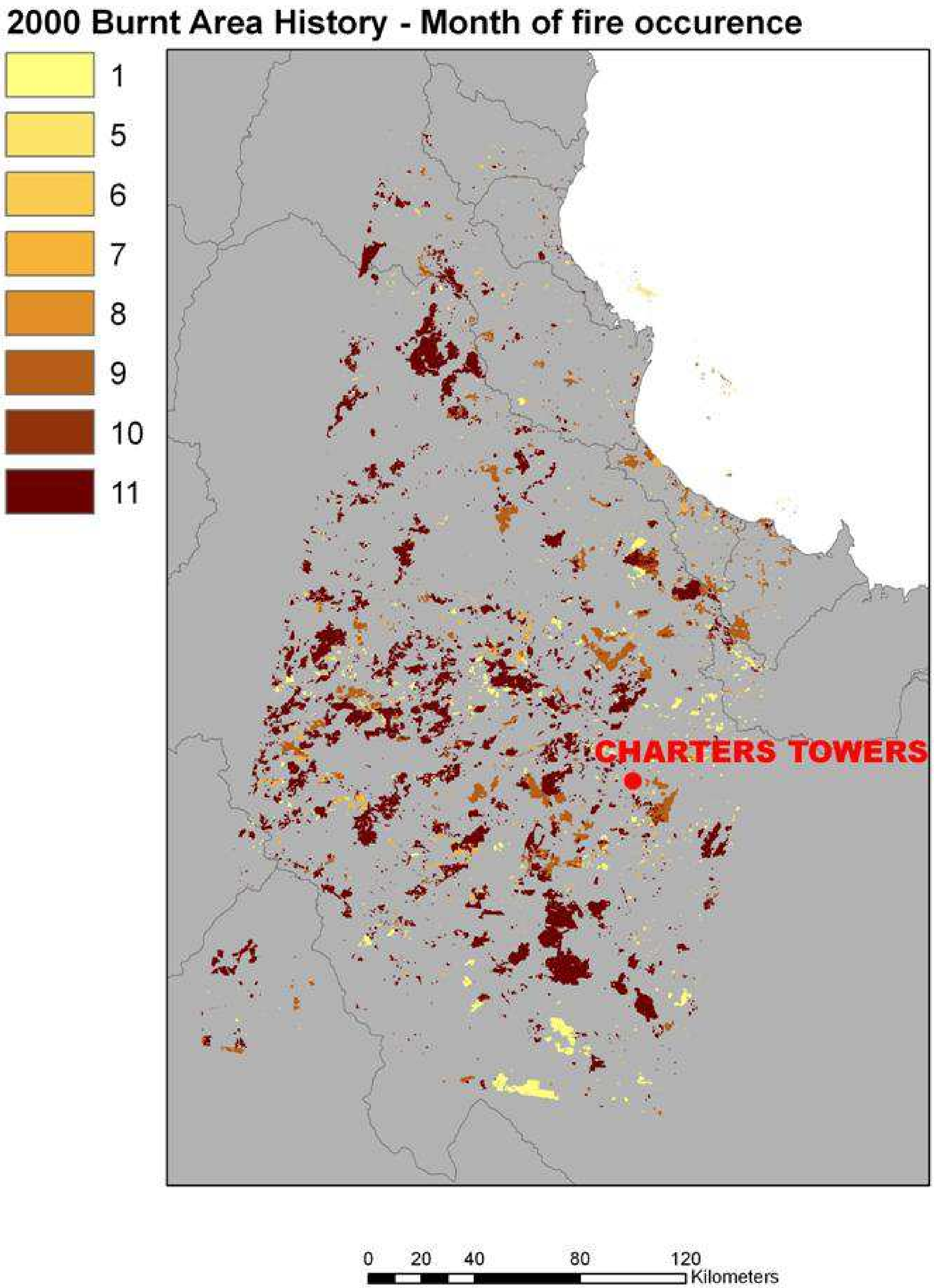

Figure 20 Example burnt area summary product for two Landsat scene areas near Charters Towers. This example shows the month of the year that fire occurred during the year 2000.

6 Recommendations for future work

Future research activities for ground cover should focus on development of metrics which better quantify the spatio-temporal patterns in ground cover. This can improve understanding of pasture dynamics, grazing preferences, and land condition and runoff and sediment transport pathways. Other research which links cover data with pasture biomass has commenced but requires extensive field validation. New technologies such as radar and LiDAR and UAV also show some promise for capture of structural information about cover, potentially assisting with biomass estimates and calibration of spatial metrics. The development of a range of surrogates and proxies for grazing land condition using remote sensing and digital soil mapping approaches has paved the way for the potential to develop grazing land condition monitoring tools. This would require some effort and additional calibration and validation data and testing with landholders and extension staff. New technologies such as web mapping services and the Queensland (Google) Globe offer opportunities to deliver these data and the information derived from them in easily understood and accessible formats.

For burnt area mapping, future efforts should focus on augmenting the Landsat time-series with higher temporal frequency data such as that from MODIS, and also editing and improving the current historical mapping. The development of a near real-time burnt area mapping approach would also be of interest to some end users, especially fire managers. For grazing land management, product development should focus on summary products such as burn frequency and time since burnt. These will be developed once the historical data has been edited. These products can potentially inform land condition issues and also provide information to assist with development of appropriate burning regimes to promote pasture regeneration and for managing woody weeds.

Finally, ongoing support and development is required to ensure that cover and burnt area algorithms can continue to be produced using Landsat imagery and data from existing or planned new satellite missions. This remains a significant challenge as there are a range of missions planned for the next 5-10 years all of which have the potential to complement the Landsat time-series and provide higher temporal and spatial resolution data for a range of applications. These future work programs will leverage national and international agreements and collaborations. However, it is critical that Queensland Government maintains its position as leaders in this area to ensure Reef programs and other state initiatives are supported by world-leading remote sensing science and applications.

7 Conclusions

Landsat satellite imagery processing streams and automated algorithms for mapping fractional ground cover and burnt areas have been developed and implemented, and additional field calibration data collected in the Burdekin catchment grazing lands. This project has produced operational, long-term time-series data and information products about fractional vegetation and ground cover and burnt area at temporal (seasonal) and spatial scales not previously available. This has resulted in additional information on ground cover components and increased confidence in the accuracy of predictions compared with the previously used GCI, as well as long-term fire histories. Both outcomes have a range of applications in grazing land management, water quality modelling and monitoring, reporting and evaluation. The list of standard products developed and now available as Open Data is listed in Appendix 1.

The products developed by this project will provide RWQ and Reef Plan with key information to support extension, monitoring and reporting activities. Methods for spatial benchmarking and averaging have also been developed to support reporting and interpretation of ground cover data, including for the Reef Plan and RWQ BMP and extension activities.

The data and information from this project is being delivered through a range of Open data mechanisms including data visualisation, download and reporting portals, and through hard copy maps and information (refer to Appendix 1 for specific details). Additional work is required to educate extension officers about how to access the information and then once they have access, how to interpret the data and convert that into a meaningful message for landholders. There is also a need to educate Regional NRM Groups, modellers and others involved in reef management and reporting about how best to use the data for Reef Plan reporting, catchment modelling, and water quality improvement plan activities.

With a range of new medium and high-resolution satellite sensors planned for launch in the coming years, the research and development undertaken as part of this project will ensure continued production of land cover change products to support land management, BMP and policy-making. Communication of the products and training with end-users is also ongoing to ensure successful uptake and use for policy and science objectives. This has placed the Queensland Government at the forefront of organisations around the world for monitoring land cover change and will ensure decisions are based on a detailed and comprehensive evidence-base.

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Appendix 1 Standard products

The following table summarises standard ground cover and fire scar mapping products and their current delivery mechanisms.

Note: Seasonal products are based on standard calendar seasons (summer, autumn, winter, spring)

Product	Format	Spatial extent	Frequency	Delivery Platform(s)	Links
Fractional cover	Digital data (raster image format) KML (Google Earth) Reports (VegCover PaST)	State-wide	Every 16 days (individual dates) and seasonal composites (1986 to present)	Queensland Spatial Catalogue TERN Auscover VegMachine VegCover (PaST & Chopper)	https://data.qld.gov.au/dataset/fractional-vegetation-cover-products-for-queensland http://www.auscover.org.au/xwiki/bin/view/Product+pages/Landsat+Seasonal+Fractional+Cover http://futurebeef.com.au/resources/vegmachine/ http://vegcover.com/past/ http://vegcover.com/chopper/
Fractional ground cover	Digital data (raster image format) Reports (VegCover PaST)	State-wide	Every 16 days (individual dates) and seasonal composites (1986 to present)	Queensland Spatial Catalogue TERN Auscover VegCover (PaST & Chopper)	https://data.qld.gov.au/dataset/fractional-vegetation-cover-products-for-queensland http://www.auscover.org.au/xwiki/bin/view/Product+pages/Seasonal+Ground+Cover http://vegcover.com/past/ http://vegcover.com/chopper/
Fractional cover (total cover deciles)	Digital data (raster image format) KML (Google Earth) Reports (VegCover PaST)	State-wide	Seasonal (1986 to present)	Queensland Spatial Catalogue TERN Auscover VegCover (PaST & Chopper)	https://data.qld.gov.au/dataset/fractional-vegetation-cover-products-for-queensland http://www.auscover.org.au/xwiki/bin/view/Product+pages/Seasonal+Cover+Deciles http://vegcover.com/past/ http://vegcover.com/chopper/
Fractional cover (green cover deciles)	Digital data (raster image format) KML (Google Earth)	State-wide	Seasonal composites (1986 to present)	Queensland Spatial Catalogue TERN Auscover Vegcover (PaST & Chopper)	https://data.qld.gov.au/dataset/fractional-vegetation-cover-products-for-queensland http://www.auscover.org.au/xwiki/bin/view/Product+pages/Landsat+Seasonal+Fractional+Cover http://vegcover.com/past/ http://vegcover.com/chopper/
Fractional cover (long-term time series	Digital data (raster image	State-wide	Based on complete Landsat	To be released late 2014	

Product	Format	Spatial extent	Frequency	Delivery Platform(s)	Links
statistics: 5th percentile, 95th percentile, mean, median, standard deviation, no. of obs.)	format)		time-series (1986 to 2013)		
Ground cover report	Report (pdf)	State-wide	Based on complete Landsat time-series (1986 to 2013)	FORAGE	https://www.longpaddock.qld.gov.au/forage/groundcover.php
Ground cover – minimum threshold report	Report (pdf)	State-wide	Based on complete Landsat time-series (1986 to 2013)	FORAGE	https://www.longpaddock.qld.gov.au/forage/groundcover.php
Ground cover - regional comparison report	Report (pdf)	Burdekin only (other areas by request)	Based on seasonal fractional data (soon to be updated to seasonal fractional ground cover)	FORAGE	https://www.longpaddock.qld.gov.au/forage/groundcover.php
Annual fire scars	Digital data (raster)	State-wide	Annual composites of monthly burn data (1987 to 2013)	Queensland Spatial Catalogue	https://data.qld.gov.au/dataset/landsat-fire-scars-queensland-series