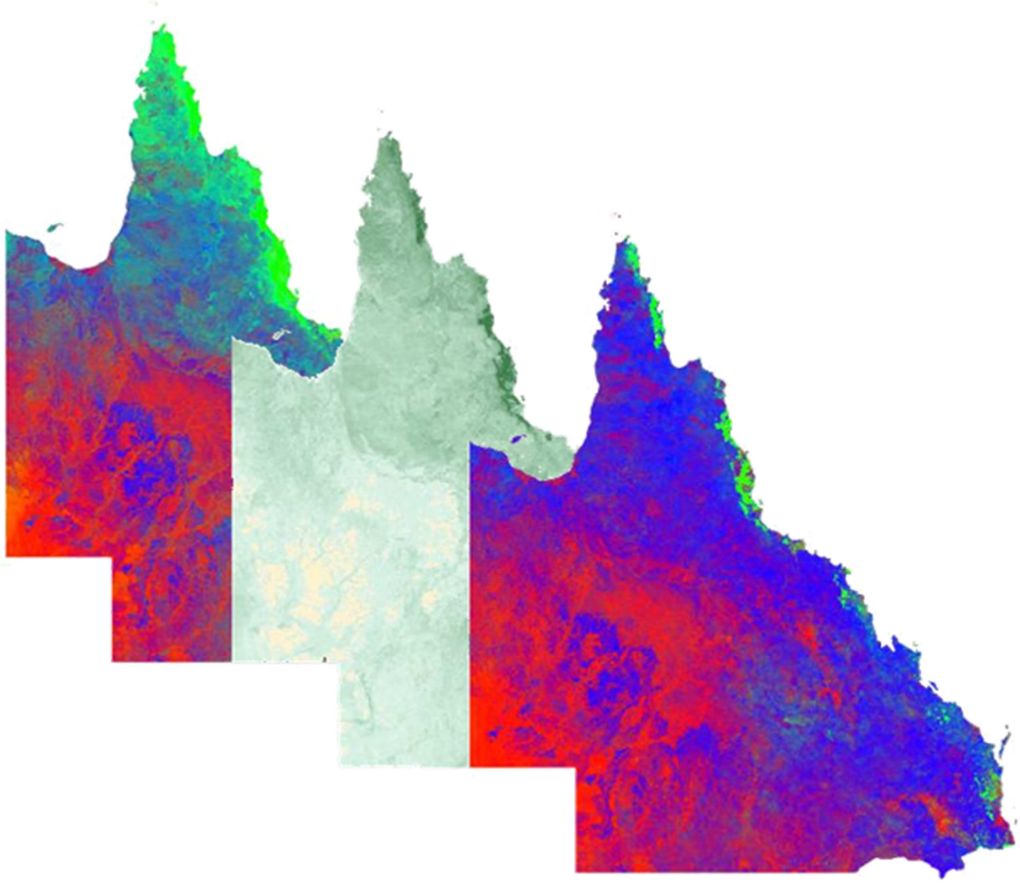
Department of Science, Information Technology and Innovation



Cover under trees

RP64G Synthesis Report

Reef Water Quality Science Program

Remote Sensing Centre

2014

Great state. Great opportunity.

Queensland Government

Prepared by

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Cover images: The three cover images represent the spring 2014 fractional cover, spring 2012 persistent green and the spring 2014 fractional ground cover products discussed within this publication.

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Introduction

Spatial and temporal information on ground cover is required to understand the condition, resilience and sustainability of catchments adjacent to the Great Barrier Reef (GBR). Unsustainable removal of ground layer vegetation can lead to a decline in grazing land condition though degradation of pasture composition and growing capacity of soils. Reduced levels of ground cover can also increase overland flow and the quantity of sediments and nutrients being delivered to waterways draining to the GBR lagoon. Maintaining and improving the condition of ground cover vegetation has both production and water quality benefits. Quantitative mapping of ground cover is required as a direct monitoring and reporting tool for the Reef Plan ground cover target and to model or infer reductions in GBR pollutant loads.

Estimates of ground cover derived from satellite imagery have historically been produced for Queensland using the Bare Ground Index (BGI) (Scarth et al. 2006). The BGI was subsequently replaced by its inverse, the Ground Cover Index (GCI). Both the BGI and GCI provide estimates of the level of 'total ground cover' (the sum of the green non-woody and non-green non-woody vegetation) from single date, dry-season Landsat satellite imagery. Recently, the GCI has been replaced by a new algorithm, fractional cover (fC). fC is based on a method developed by Scarth et al. (in prep.) that uses spectral unmixing techniques and field data collected across Australia's rangelands and coastal environments to report the per pixel fractions of green and non-green cover, and bare ground. In addition to the separation of the green and non-green cover, the fC improves upon the GCI as it has less error and bias across the range of ground cover levels.

The data used to derive the fC product is based on the extensive archive of Landsat imagery held by Department of Science, Information Technology, Innovation and the Arts' (DSITIA) Remote Sensing Centre (RSC), from 1986 to present. Following a recent announcement by the United States Geological Survey (USGS) and NASA, the Landsat archive has been made available and this has facilitated fC products being produced at a temporal frequency not previously available for the GCI. For any single (pixel) location in Queensland, there are now in excess of 600 dates of imagery over the 28 year time period. This increased temporal resolution provides additional information about the dynamics and composition of ground cover over time.

Both the fC and its predecessor the GCI are spatially explicit products, which predict cover at a medium spatial resolution (30 m) per-pixel scale. It is important to note that neither the GCI nor fC can distinguish overstorey and midstorey woody foliage cover from ground cover. As a result, in areas with even minimal tree cover, estimates of ground cover can become uncertain. To account for this uncertainty, previous versions of the ground cover products have been masked with a woody vegetation mask: Foliage Projective Cover (FPC). To date, this mask has been applied at a threshold of 15% and greater FPC (around 25-30% crown cover). This has significantly limited the area for which ground cover can be monitored in the grazing lands of Reef catchments, with only 38% of the total area being reported on when these masks are applied.

While the estimation of ground cover levels in areas of high foliage cover is challenging, the high temporal frequency fC products are facilitating the development of promising new methods for decoupling the woody vegetation and ground cover signals. The intention is to improve estimates of ground cover in areas of woody vegetation and also to improve the masking of the product when woody foliage levels are so high that the level of ground cover is not determinable from satellite imagery due to total occlusion.

With the development of the fC time-series, it has been possible to derive an estimate of ‘persistent green’ vegetation. The persistent green vegetation product provides an estimate of the vertically-projected green-vegetation fraction that is deemed to persist over time. These areas are nominally woody vegetation. The persistent green product is derived directly from the fC product and for the purposes of identifying woody vegetation cover, is generally considered to be equivalent to the Foliage Projective Cover (FPC) product, except in cases where persistent green vegetation is non-woody. The derivation of the 'persistent green' from the fC product allows for a correction or adjustment to be made to access the spectral signatures of the vegetation and ground cover underneath the overstorey. This was not possible using the previous BGI/GCI and FPC products as they were not derived from the same source algorithm and therefore were not complementary in terms of the overall contributions of cover spectral responses in the different vegetation strata.

This report outlines the details of the current research being undertaken to utilise the new fC and persistent green products to better quantify and map the levels and spatial arrangement of ground cover (and bare ground) in areas of higher midstorey and overstorey (woody) foliage cover (i.e. to map the “cover under trees”).

Cover under Trees Theoretical Model

The cover under trees theoretical model is based on field estimates of fractional cover. A description of the theoretical model for predicting cover under trees therefore requires an understanding of the three vertical vegetation structural strata that contribute to the satellite estimates of cover in the fractional cover method (fC). It also requires an understanding of how these strata are represented in field data measurements used to calibrate the fC. The three strata are: (i) the ground layer, which includes non-woody green and non-green vegetation and woody and non-woody litter; (ii) the midstorey woody vegetation stratum, which includes green and non-green vegetation less than 2 m in height; and (iii) the overstorey vegetation stratum, which includes green and non-green vegetation greater than 2 m in height. These strata are illustrated in Figure 1.

When viewed from above, as is done by the satellite, the midstorey and overstorey vegetation obscures the ground strata cover fractions (bare ground, green ground cover and non-green ground cover). In its standard format, the fC product estimates the cover fractions from all strata combined. A high estimate in the green or non-green fraction may be due to vegetation material in any of the vegetation strata.

The measurement of cover in the field for each of these strata is undertaken following Muir et al. (2011) and uses an upward-looking densitometer for overstorey measurements and a downward-facing laser pointer for point-intercept ground cover measurements. This field method provides quantitative measurements of downward and upward looking point intercepts of green and non-green foliage and vegetation cover, including branches, as well as overstorey gaps, bare ground and rock cover. It is important to note that the present field measurement of the overstorey only measures the overstorey from below, which is not the same view as the satellite. Any estimate of the overstorey using the field measurements needs to take this into consideration.

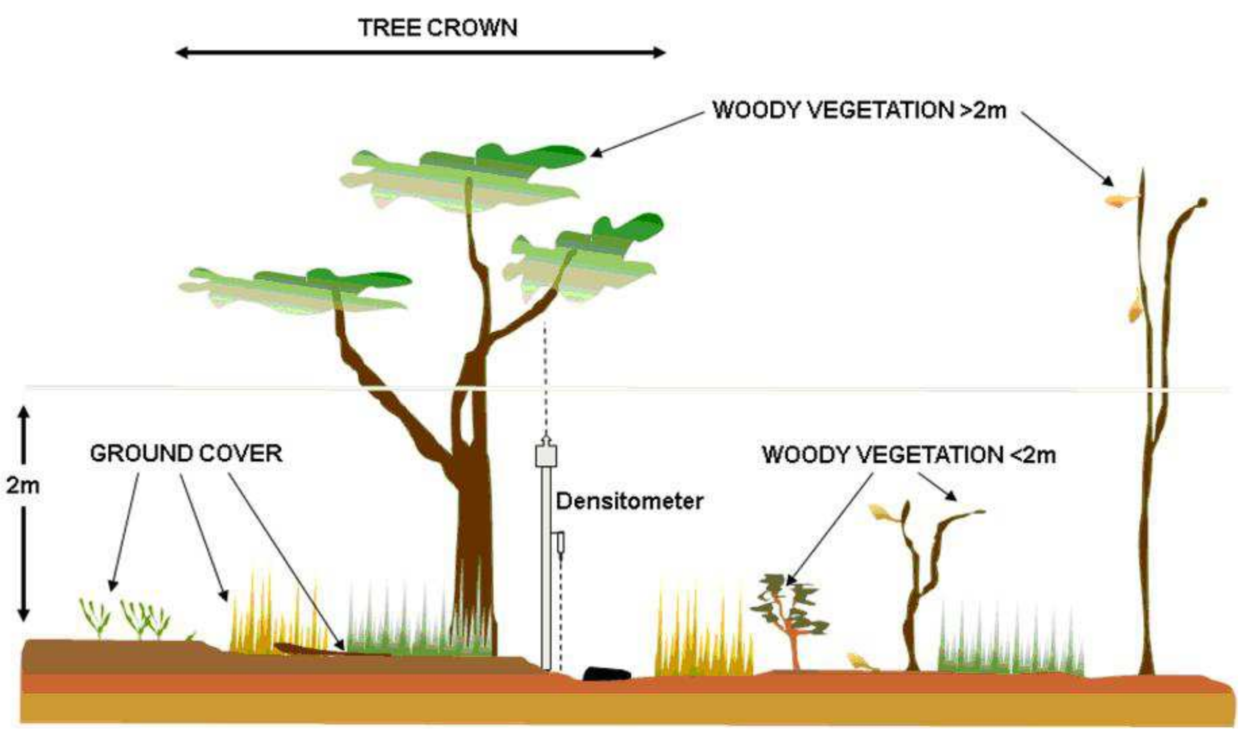


Figure 1: Schematic of ground, midstorey and overstorey vegetation strata which contribute to the fractional cover index (fC) product estimates of bare, green and non-green cover.

The cover under trees theoretical model aims to make an adjustment or correction to the fC product to account for the occlusion of the ground by midstorey and overstorey foliage when viewed from above by the satellite. The model aims to solve for, and effectively remove these strata from the estimates of cover. The final ground cover estimate is therefore based only on the proportion of ground that is visible by the satellite.

Overview of the Cover under Trees Model

The percentage of each cover fraction in the fC data (i.e. green cover, non-green cover) are comprised of the total of the each cover fraction in each of the three strata discussed above. However, not all of the ground and midstorey fractions are visible to the satellite due to occlusion by branches and foliage of the overlying strata. Therefore, the fC is the cumulative total of the visible portion of each cover fraction in each strata. Furthermore, the percentage of bare ground is only the visible portion of the ground surface that is not occluded by overlying vegetation in any strata. This visible region is often referred to as ‘gap fraction’ which is basically a measure of the spacing or gaps in the midstorey and overstorey and where the ground layer is visible when viewed from above. This is represented in the following equations (details of all this report’s equation’s nomenclature is given in the glossary):

$$\mathrm{Sat}_{\mathrm{tot\ green}} = \mathrm{visible\ \ Sat}_{\mathrm{Ground\ green}} + \mathrm{visible\ Sat}_{\mathrm{mid\ green}} + \mathrm{Sat}_{\mathrm{over\ green}}$$

$$\mathrm{Sat}_{\mathrm{tot\ non-green}} = \mathrm{visible\ \ Sat}_{\mathrm{ground\ non-green}} + \mathrm{visible\ Sat}_{\mathrm{mid\ non-green}} + \mathrm{Sat}_{\mathrm{over\ non-green}}$$

$$\mathrm{Sat}_{\mathrm{tot\ bare}} = \mathrm{visible\ \ Sat}_{\mathrm{ground\ bare}}$$

In order to solve for the above components, an estimate of the green and non-green vegetation in the midstorey and overstorey is required. This vegetation is assumed to be the woody vegetation and associated foliage (trees and shrubs). It is assumed to be less variable than the ground layer in terms of changes due to seasonal effects and vegetation phenology. To estimate the less variable green fraction we use an existing approach termed the ‘persistent green’. The persistent green derives estimates of the less variable vegetation fractions by analysing the green fraction of the fC data over a long time-series (e.g. 10 or more years). The minimum of the time-series is considered to represent the less variable fractions. For the persistent non-green fraction, a method did not exist and an approach has been developed as part of this study, which is based on field data representing the non-green cover fractions. This is described in detail in the following section.

‘Persistent green’ vegetation is the visible green fraction which is not seasonal. That is, the visible green fraction present in the midstorey and overstorey. Persistent green can be represented by the following equation:

$$\mathrm{persistent\ green} = \mathrm{visible\ mid\ green} + \mathrm{visible\ over\ green}$$

Similarly, ‘persistent non-green’ vegetation is the visible non-green fraction present in the midstorey and overstorey, which is not seasonal, and can be represented by:

$$\mathrm{persistent\ non} - \mathrm{green} = \mathrm{visible\ mid\ non} - \mathrm{green} + \mathrm{over\ non} - \mathrm{green}$$

Therefore, the initial equations can be rewritten as:

$$\mathrm{Sat}_{\mathrm{tot\ green}} = \mathrm{visible\ \ Sat}_{\mathrm{ground\ green}} + \mathrm{persistent\ green}$$

$$\mathrm{Sat}_{\mathrm{tot\ non-green}} = \mathrm{visible\ \ Sat}_{\mathrm{ground\ non-green}} + \mathrm{persistent\ non} - \mathrm{green}$$

$$\mathrm{Sat}_{\mathrm{tot\ bare}} = \mathrm{visible\ Sat}_{\mathrm{ground\ bare}}$$

The amount of each fraction visible at the ground layer is the area not occluded by the combined persistent green and persistent non-green cover in the midstorey and overstorey.

$$\text{Proportion of ground occluded} = \text{persistent green} + \text{persistent non} - \text{green}$$

The proportion of the ground visible (i.e. the “total gap” or gap fraction in the midstorey and overstorey) is therefore:

$$\text{total gap} = 1 - (\text{persistent green} + \text{persistent non} - \text{green})$$

Assuming that cover fractions in each vegetation strata are independent, ground cover fractions can be estimated by the following equation:

$$\mathrm{visible\ Sat}_{\mathrm{ground\ fraction}} = \text{ ground fraction} \times \text{total gap}$$

By substituting and rearranging our original equations we can estimate actual ground cover fractions, with the influence of midstorey and overstorey occlusion accounted for:

$$\mathrm{Sat}_{\mathrm{tot\ green}} = (\text{ground green } \times \text{total gap}) + \text{persistent green}$$

$$\boxed{\xrightarrow{\text{yields}} \qquad \text{ground green} = \frac{\mathrm{Sat}_{\mathrm{tot\ green}} - \text{persistent green}}{\text{total gap}}}$$

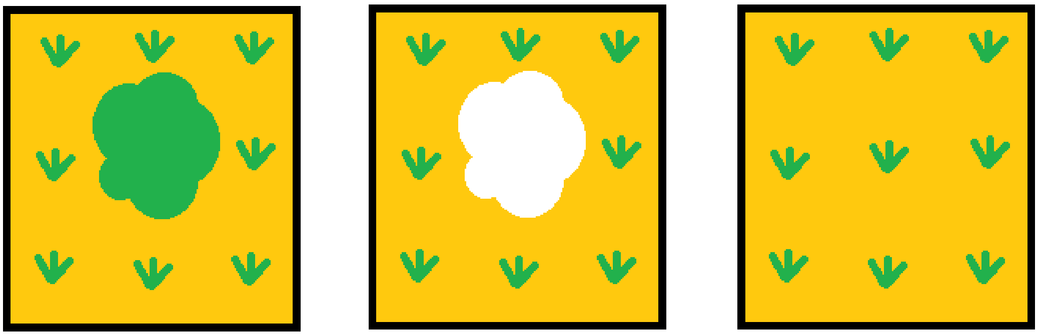
$$\mathrm{Sat}_{\mathrm{tot\ non-green}} = (\text{ground non} - \text{green} \times \text{total gap}) + \text{ persistent nongreen}$$

$$\boxed{\xrightarrow{\text{yields}} \qquad \text{ground non} - \text{green } = \frac{\mathrm{Sat}_{\mathrm{tot\ non-green}} - \text{persistent nongreen}}{\text{total gap}}}$$

$$\mathrm{Sat}_{\mathrm{tot\ bare}} = \text{ground bare} \times \text{total gap}$$

$$\boxed{\xrightarrow{\text{yields}} \qquad \text{ground bare} = \frac{\mathrm{Sat}_{\mathrm{tot\ bare}}}{\text{total gap}}}$$

A schematic example of the correction for the green cover fraction is presented in Figure 2. Firstly the proportion of persistent green for the image pixel is estimated (Figure 2a). Next, the persistent green is removed from the total green estimate for the pixel (Figure 2b). Finally, an estimate of the final proportion of cover in the pixel is estimated by dividing by the area of the pixel visible (i.e. the ‘total gap’), and this is used to effectively estimate or fill in the portion of the ground layer in the pixel which was occluded by the persistent green vegetation.



a) Persistent green portion of pixel estimated.

b) Persistent green portion of the pixel is removed from the total green estimate for the pixel.

c) Cover for the entire pixel is estimated by adjusting the remaining green estimate by accounting for occlusion (i.e. adjusting for the gap fraction).

Figure 2: Schematic example of how the cover under trees model corrects for tree cover using estimates of persistent green and gap fraction. Note that the model does not discriminate spatially within the pixel, all corrections are done across the entire pixel.

Derivation of the Cover under Trees Model using Field Data

As previously discussed, obtaining an estimate of the ground layer requires an understanding of the amount of ground visible to the satellite sensor, and knowledge of the actual levels of cover in those areas not visible to the satellite sensor.

Developing a model that is based on field data to predict persistent non-green vegetation in the same way as would be measured by the satellite sensor requires some adjustment to be made to the field measurements. This is because overstorey measurements in the field are collected from underneath the overstorey (i.e looking up), while satellite-based estimates are calculated from data collected from above the overstorey (i.e. looking down).

Solving for the green fraction

The field overstorey green fraction ($\mathrm{Field}_{\mathrm{over\ green}}$) is the proportion of the site covered by overstorey foliage, observed vertically above in the field. It is determined by summing the total number of green overstorey observations and dividing this by the total number of observations at the site. An adjustment is also made to account for the interception of a branch (looking up), preventing an overstorey observation. We remove these observations from the calculation of $\mathrm{Field}_{\mathrm{over\ green}}$. We do this as we do not know what the overstorey observation is above the branch. Thus, the calculation of $\mathrm{Field}_{\mathrm{over\ green}}$ is as follows:

$$\mathrm{Field}_{\mathrm{over\ green}} = \frac{\mathrm{nField}_{\mathrm{over\ green}}}{(\mathrm{nField}_{\mathrm{tot}} - \mathrm{nField}_{\mathrm{over\ branch}})}$$

We can also calculate an estimate of the gap fraction for the overstorey ($\mathrm{Field}_{\mathrm{over\ gap}}$) as this influences the amount of midstorey and ground stratum that is visible from above. The $\mathrm{Field}_{\mathrm{over\ gap}}$ measurement is the total number of observations for all cover fractions in the overstorey divided by the total number of observations taken at the site.

$$\mathrm{Field}_{\mathrm{over\ gap}} = \left(1 - \frac{\mathrm{nField}_{\mathrm{over\ tot}}}{\mathrm{nField}_{\mathrm{tot}}}\right)$$

Adjustment of the field measurements for branches is not required for the midstorey and ground layer measurements as these are directly measured in the field in the same way that they would be viewed from the satellite sensor (i.e. effectively viewing downward). However, as previously discussed, both of these strata require adjustment to account for occlusion by the overstorey vegetation.

The visible midstorey green fraction ($\mathrm{visible\ Field}_{\mathrm{mid\ green}}$) is the proportion of total midstorey green (i.e. foliage) measurements ($\mathrm{Field}_{\mathrm{mid\ green}}$) multiplied by the proportion of the site that is visible from above – the overstorey gap fraction ($\mathrm{Field}_{\mathrm{over\ gap}}$). $\mathrm{Field}_{\mathrm{mid\ green}}$ is the total number of observations in the midstorey green fraction divided by the total number of observations at the site.

$$\mathrm{visible\ Field}_{\mathrm{mid\ green}} = \mathrm{Field}_{\mathrm{mid\ green}} \times \mathrm{Field}_{\mathrm{over\ gap}}$$

$$\mathrm{Field}_{\mathrm{mid\ green}} = \frac{\mathrm{nField}_{\mathrm{mid\ green}}}{\mathrm{nField}_{\mathrm{tot}}}$$

Similarly, we can estimate the gap fraction for the midstorey as follows:

$$\mathrm{Field}_{\mathrm{mid\ gap}} = \left(1 - \frac{\mathrm{nField}_{\mathrm{mid\ total}}}{\mathrm{nField}_{\mathrm{tot}}}\right)$$

Now that we have estimates of the gap fractions in the midstorey and overstorey, we can estimate the visible green fraction for the ground stratum ($\mathrm{visible\ Field}_{\mathrm{ground\ green}}$). This is given by the proportion of ground stratum green cover multiplied by the proportion of the ground visible from above (i.e. is not occluded by overstorey or midstorey vegetation). $\mathrm{Field}_{\mathrm{ground\ green}}$ is the total number of observations of the ground strata green fraction divided by the total number of observations at the site.

$$\mathrm{visible\ Field}_{\mathrm{ground\ green}} = \mathrm{Field}_{\mathrm{ground\ green}} \times \mathrm{Field}_{\mathrm{mid\ gap}} \times \mathrm{Field}_{\mathrm{over\ gap}}$$

$$\mathrm{Field}_{\mathrm{ground\ green}} = \frac{\mathrm{nField}_{\mathrm{\ ground\ green}}}{\mathrm{nField}_{\mathrm{tot}}}$$

By substituting these formulas into our original equation for fC green, we have an estimate of the satellite fC green fraction ($\mathrm{Est_{tot\ green}}$):

$$\mathrm{Est_{tot\ green}} = \mathrm{visible\ \ Field_{ground\ green}} + \mathrm{visible\ Field_{mid\ green}} + \mathrm{Field_{over\ green}}$$

$$\mathrm{Est_{tot\ green}} = \frac{\mathrm{nField_{ground\ green}}}{\mathrm{nTot}} \times \left(1 - \frac{\mathrm{nField_{mid\ tot}}}{\mathrm{nTot}}\right) \times \left(1 - \frac{\mathrm{nField_{over\ tot}}}{\mathrm{nTot}}\right) + \frac{\mathrm{nField_{mid\ green}}}{\mathrm{nTot}} \times \left(1 - \frac{\mathrm{nField_{over\ tot}}}{\mathrm{nTot}}\right) + \frac{\mathrm{nField_{over\ green}}}{(\mathrm{nTot} - \ \mathrm{nField_{over\ non-green}})}$$

Solving for the non-green fraction

In a similar fashion, we can calculate an estimate of the fC non-green fraction from the field data.

$$\mathrm{Est_{tot\ non-green}} = \mathrm{visible\ Field_{ground\ non-green}} + \mathrm{visible\ Field_{mid\ non-green}} + \mathrm{Field_{over\ non-green}}$$

However the non-green fraction for the midstorey and overstorey is made up of both branch and dead material, so some adjustment is required to model the non-green viewable to the satellite.

$$\mathrm{Field_{over\ non-green}} = \mathrm{Field_{over\ dead}} + \mathrm{Field_{over\ branch}}$$

$$\mathrm{Field_{over\ dead}} = \frac{\mathrm{nField_{over\ non-green}}}{(\mathrm{nField_{tot}} - \ \mathrm{nField_{over\ branch}})}$$

$$\mathrm{Field_{over\ branch}} = \frac{\mathrm{nField_{over\ branch}}}{\mathrm{nField_{tot}} \times (\mathrm{Field_{over\ green}} - \mathrm{Field_{over\ dead}})}$$

This is the proportion of overstorey branch viewable, but an adjustment is made to account for our estimates of the area of leaves and non-green vegetation that is viewable by the satellite in the midstorey due to occlusion by the overstorey vegetation.

$$\mathrm{visible\ Field_{mid\ non-green}} = (\mathrm{Field_{mid\ branch}} + \mathrm{Field_{mid\ dead}}) \times \mathrm{Field_{over\ gap}}$$

$$\mathrm{visible\ Field_{mid\ non-green}} = \left(\frac{\mathrm{nField_{mid\ branch}}}{\mathrm{nField_{tot}}} + \frac{\mathrm{nField_{mid\ dead}}}{\mathrm{nField_{tot}}}\right) \times \left(1 - \frac{\mathrm{nField_{over\ tot}}}{\mathrm{nField_{tot}}}\right)$$

Where visible midstorey non-green is the proportion of midstorey non-green foliage and branch cover. This is multiplied by the proportion of the site visible to the satellite in the midstorey because it is not occluded by overstorey leaves, branches and dead vegetation.

$$\text{visible Field}_{\text{ground dry}} = \text{Field}_{\text{ground dry}} \times \text{Field}_{\text{mid gap}} \times \text{Field}_{\text{over gap}}$$

$$\text{visible Field}_{\text{ground dry}} = \frac{\text{nField}_{\text{ground dry}}}{\text{nField}_{\text{tot}}} \times (1 - \frac{\text{nField}_{\text{mid tot}}}{\text{nField}_{\text{tot}}}) \times (1 - \frac{\text{nField}_{\text{over tot}}}{\text{nField}_{\text{tot}}})$$

Where visible ground non-green is the proportion of ground level non-green cover multiplied by the proportion of the ground visible to the satellite is not excluded by overstorey or mid leaves, branches and dead vegetation.

$$\text{Est}_{\text{tot non green}} = \frac{\text{nField}_{\text{ground dry}}}{\text{nField}_{\text{tot}}} \times (1 - \frac{\text{nField}_{\text{mid tot}}}{\text{nField}_{\text{tot}}}) \times (1 - \frac{\text{nField}_{\text{over tot}}}{\text{nField}_{\text{tot}}}) + (\frac{\text{nField}_{\text{mid branch}}}{\text{nField}_{\text{tot}}} + \frac{\text{nField}_{\text{mid dry}}}{\text{nField}_{\text{tot}}}) \times (1 - \frac{\text{nField}_{\text{over tot}}}{\text{nField}_{\text{tot}}}) + \frac{\text{nField}_{\text{over dry}}}{(\text{nField}_{\text{tot}} - \text{nField}_{\text{over dry}})}$$

$$\text{Field}_{\text{persistent green}} = \text{visible Field}_{\text{mid green}} + \text{Field}_{\text{over green}}$$

$$\text{Field}_{\text{persistent green}} = \frac{\text{nField}_{\text{mid green}}}{\text{nField}_{\text{tot}}} \times \left(1 - \frac{\text{nField}_{\text{over tot}}}{\text{nField}_{\text{tot}}}\right) + \frac{\text{nField}_{\text{over green}}}{(\text{nField}_{\text{tot}} - \text{nField}_{\text{over dry}})}$$

Similarly, with an additional adjustment for dead branches.

$$\text{Field}_{\text{persistent dry}} = \text{visible Field}_{\text{mid dry}} + \text{Field}_{\text{over dry}}$$

$$\text{Field}_{\text{persistent dry}} = \frac{\text{nField}_{\text{mid dry}}}{\text{nField}_{\text{tot}}} \times \left(1 - \frac{\text{nField}_{\text{over tot}}}{\text{nField}_{\text{tot}}}\right) + \frac{\text{nField}_{\text{over dry}}}{(\text{nField}_{\text{tot}} - \text{nField}_{\text{over green}} - \text{nField}_{\text{over dead}})}$$

With these inputs we can derive an equation, using multivariate fitting techniques, to fit our estimate of persistent dry from our estimates of persistent green and fC green as would be observed at our field sites by the satellite (Figure 3).

$$\text{Est}_{\text{persistent non-green}} = 0.58 \text{ x } \text{Field}_{\text{persistent green}} - 0.6282 \text{ x } \text{Est}_{\text{tot green}} \text{ x } \text{Field}_{\text{persistent green}}$$

This equation is then used in the final model, with the substitution of $\text{Field}_{\text{persistent green}}$ with $\text{Sat}_{\text{persistent green}}$ and $\text{Est}_{\text{tot green}}$ with $\text{Sat}_{\text{green}}$.

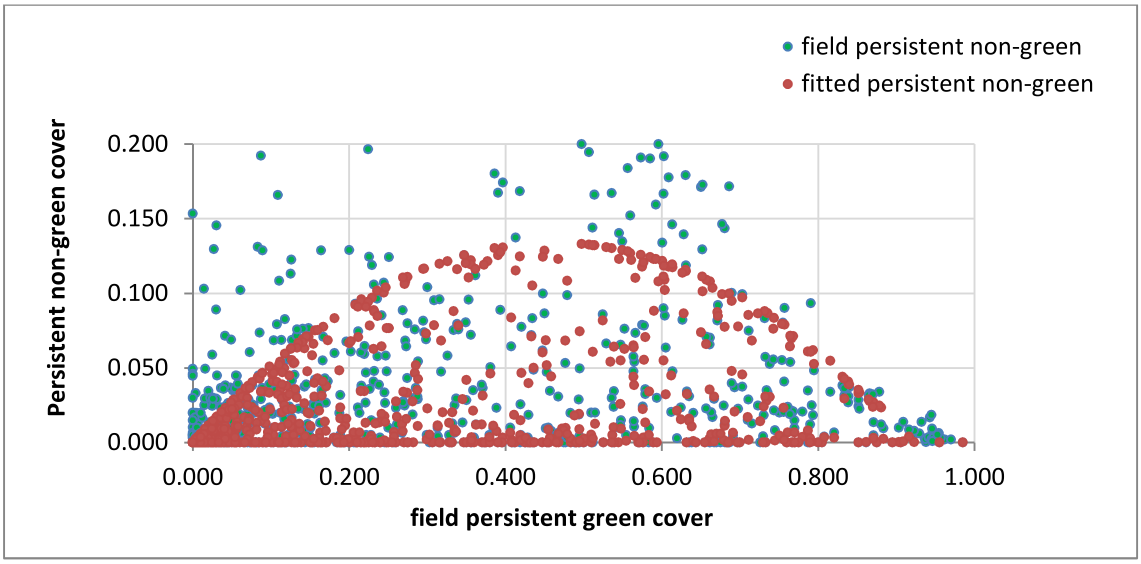


Figure 3: Persistent non-green cover as a function of persistent green cover, total non-photosynthetic vegetation and total not photosynthetic vegetation. All measurements are from field data point intercept measurements. Results plotted here against persistent green alone.

Testing the Theoretical Model with Fractional Cover Field Data

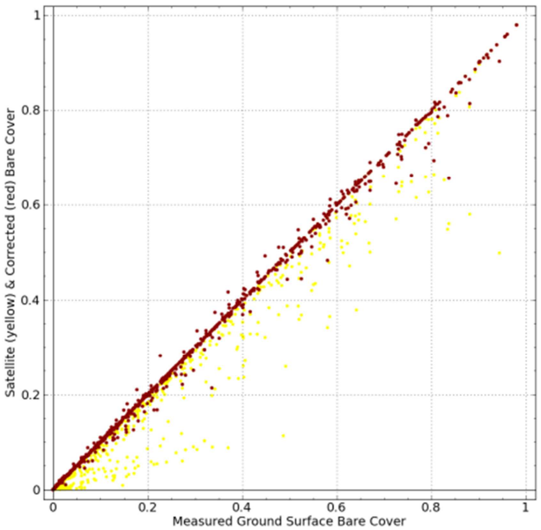
With an estimate of persistent green and non-green from the field data, we can also use the satellite estimates, which are calibrated by the field data, to test the model. To do this requires an estimate from the field data for bare ground. As there is no bare fraction in the midstorey and overstorey, we only need to correct to account for the proportion of ground occluded by the midstorey and overstorey vegetation.

$$\mathrm{Est}_{\mathrm{tot\ bare}} = \text{ visible } \mathrm{Field}_{\mathrm{ground\ bare}} = \mathrm{Field}_{\mathrm{ground\ bare}} \times \mathrm{Field}_{\mathrm{mid\ gap}} \times \mathrm{Field}_{\mathrm{over\ gap}}$$

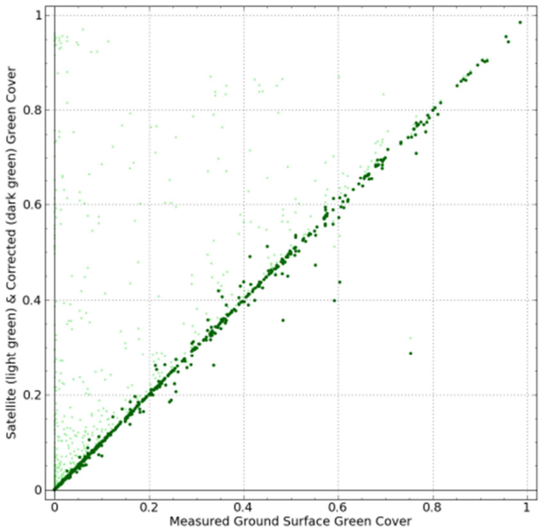
$$\text{visible } \mathrm{Field}_{\mathrm{ground\ bare}} = \frac{\mathrm{nField}_{\mathrm{ground\ bare}}}{\mathrm{nField}_{\mathrm{tot}}} \times \left(1 - \frac{\mathrm{nField}_{\mathrm{mid\ tot}}}{\mathrm{nField}_{\mathrm{tot}}}\right) \times \left(1 - \frac{\mathrm{nField}_{\mathrm{over\ tot}}}{\mathrm{nField}_{\mathrm{tot}}}\right)$$

We can then substitute our field values into our original three equations to get the corrected cover values.

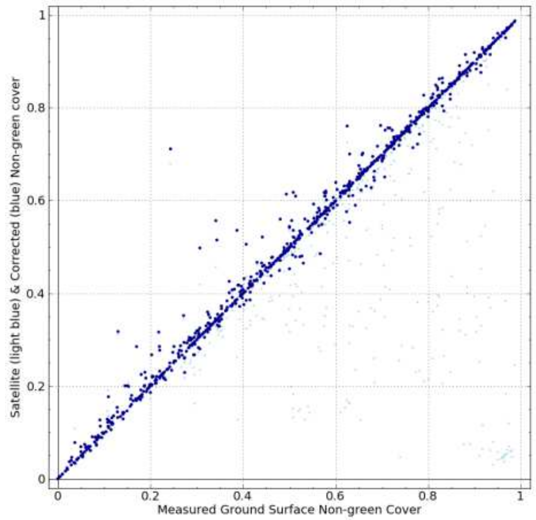
The results from this analysis (Figure 4) demonstrate the major effect overstorey vegetation has on the predicted levels of the ground cover fractions and how, in theory, this impact could be considerably mitigated by the adjustments proposed. The theoretical model has some limitations which, when applied to the satellite imagery, reduce its effectiveness. These limitations are discussed in the section on model limitations.



2 a) Measured bare ground at field sites vs estimates of satellite predicted bare ground from field data. (Uncorrected data – yellow points, corrected data – red points)



2 b) Measured green ground cover at field sites vs estimates of satellite predicted green ground cover from field data. (Uncorrected data – light green points, corrected data – dark green points)



2 c) Measured non-green ground cover at field sites vs estimates of satellite predicted non-green ground cover from field data. (Uncorrected data – light blue points, corrected data – dark blue points)

Figure 4: Field data summaries corrected for tree cover and uncorrected field data measurements for each ground cover fraction.

Applying the Theoretical Model to Satellite Imagery

An example of the results from the current model are presented in Figure 5.

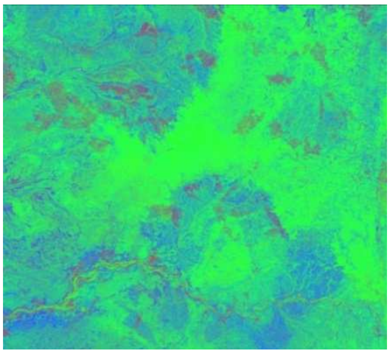
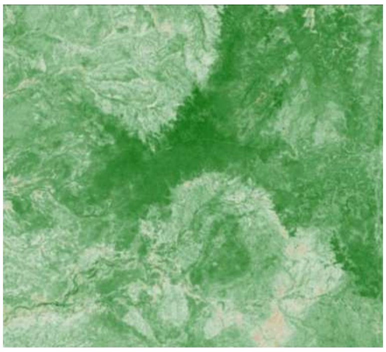
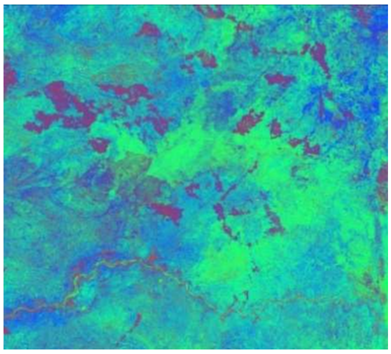
Fractional Cover (fC) before correction	Persistent Green	Fractional Cover (fC) after correction
		

Figure 5: An example of the fractional cover (fC) product prior to correction for trees, the persistent green image used for the correction and the fractional cover product after correction for trees. The corrected image shows that most of the ground cover at this image date is non-green vegetation (as indicated by the relatively high amount of blue in the image). Interestingly, a fire scar is revealed under the tree cover just left of the centre of the image (as indicated by the red area which indicates a high amount of bare ground).

The theoretical model was then applied to Landsat fC imagery at the locations corresponding with the field sites. The imagery was selected using two criteria: a lack of 'contamination' or occlusion of at the site location in the imagery, due to cloud or cloud shadow, and the proximity of the image date to the date of field acquisition. A 3x3 pixel window around each field site in the imagery was corrected using the model. This is the approximate size of the field site extents. Results for each band (i.e. cover fraction) at each site for these 3x3 pixel windows were then averaged for both the fC imagery and the corrected fC imagery. The residual errors between the image data results and the actual measurements in the field were determined for both the original fC product and the corrected fC for each fraction. Results were only reported for sites with < 60% persistent green as this is the threshold which is applied to the cover under trees product.

$$\text{Residual error} = \text{satellite prediction of cover fraction} - \text{field estimate of cover fraction}$$

Therefore a positive residual represents an overestimate by the satellite prediction for a given fraction and a negative residual represents an underestimate by the satellite prediction.

Results from the analysis for both the fC product and the corrected product are presented in Figure 6.

For all the fractions there is an increase in accuracy with the correction. This is particularly evident in the green fraction, with slope of the regression line for the residual errors reducing from -0.83 to -0.33. The actual root mean square error (RMSE) is typically less because, particularly for the green fraction, estimates at these sites were consistently incorrect prior to adjustment due to the contribution of overstorey vegetation to the estimates of green cover. After correction, the majority of estimates at these sites' locations improved. There is very little bias in the bare fraction, regardless of whether it has been corrected for trees or not. The model to correct for tree foliage cover reduces the bias in the non-green and green fractions, but does not entirely remove it.

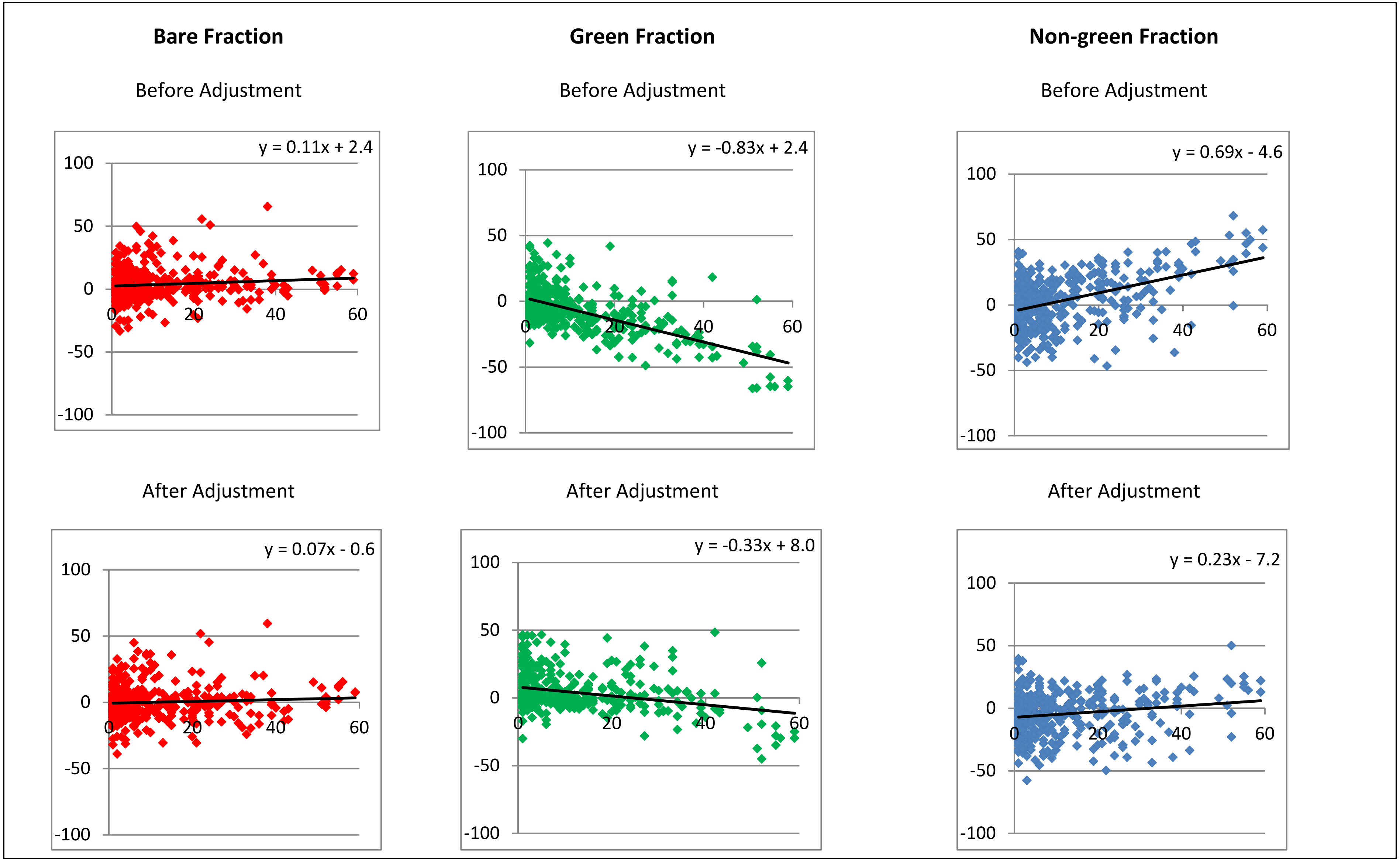


Figure 6: Residual errors (satellite estimates of cover– field data measurements of cover) for corrected and uncorrected fractional cover index (fC) estimates of each ground cover fraction, restricted to <60% persistent green.

Model Limitations

There are two major dependencies of the theoretical cover under trees model which reduce its effectiveness when applied to the satellite products:

i. The reliance of the model on persistent green estimates; and
ii. The random distribution of ground cover fractions.

These limitations are discussed below and further research is proposed in these two areas.

Reliance of Model on Persistent Green Estimates from Satellite Data

The model relies on the persistent green product, not only for the estimation of persistent green, but also persistent non-green and the gap fraction.

The persistent green model estimates persistent green by investigating the long term green fraction of the fC product and determining the minimum green that is present regardless of seasonality. The underlying premise of the persistent green product is the separation of the fC green fraction into variable and non-variable trend components. The non-variable trend component is the green fraction which is always present regardless of seasonal influences and is therefore assumed to be associated with perennial vegetation and therefore assumed to be ‘persistent’.

The cover under trees model has recently been updated to use a dynamic persistent green product. This should improve the model compared with earlier versions, as the estimate of overstorey and midstorey green and non-green cover will be coincident with the date of the imagery being processed, thus being more representative of the cover at that time. The ‘dynamic’ persistent green is derived by fitting smoothed splines to the minimum of the time-series of the green fraction. This means that the persistent green can be estimated for any season in the time-series and is therefore aligned with the ground cover estimation for the same season. Where the persistent green has not been updated for more recent seasons due to the compute time required, the most recent available persistent green has been used for calculating the cover under trees model and the data is distributed as an interim data set, which is replaced by the final version over time. By aligning the estimates of persistent green and non-green vegetation with the date (i.e. season) that the ground cover is being estimated, the adjustment for the non-ground vegetation strata should be more robust and considerate of the seasonal influences on reflectance and the vegetation dynamics. Further work will focus on quantifying the improvement to the model by using coincident seasonal information about the persistent green vegetation.

Assumption of Distribution of Ground Cover Fractions

Improvements in the management of the field point intercept data has allowed for analysis of the field data at the point level, rather than site level, allowing for determination of the actual distribution of ground cover fractions. A major assumption of the theoretical model is that the distribution of cover fractions in each vegetation layer is independent of the other layers within the vertical profile. For the ground cover fractions this can be interpreted as that the presence of shrubs or trees in the midstorey and overstorey will not affect the likelihood of whether bare ground, non-green vegetation or green vegetation is found on the ground for any random point at the site.

To test this assumption, the distribution of cover for all field sites where any trees were recorded was investigated. Point intercept data points were separated into those points occurring under midstorey and overstorey and those with no overstorey of any kind (ground cover only). The proportion of each fraction was then determined for each decile level of tree cover.

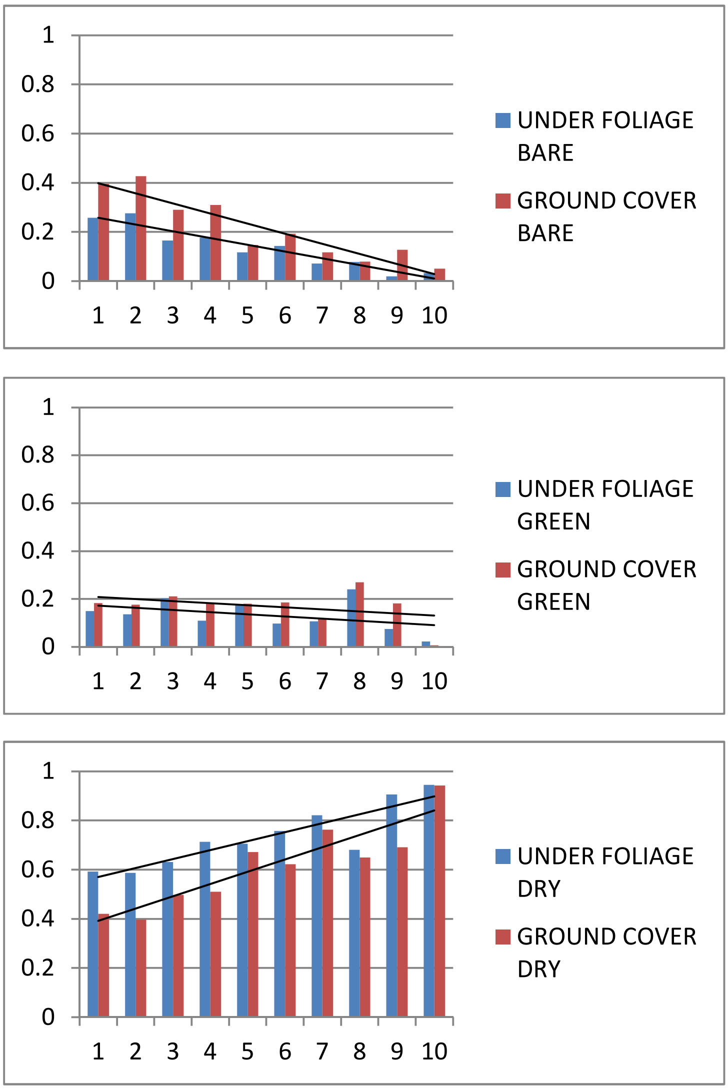


Figure 7: Proportion of ground cover fractions, for various levels of site persistent green (each bin represents a decile of persistent green, e.g. bin 1 represents sites with 0-10% persistent green, while bin 10 represents sites with 90-100% persistent green).

From these histogram results, there are two clear patterns, one occurring across the deciles, as tree cover increases, and the other between the ground cover levels at each individual decile:

- Across the deciles, it can be seen that as tree cover increases, the overall proportion of non-green ground cover increases while the proportion of bare ground decreases. The proportion of green ground cover also decreases, but to a lesser degree.
- For each individual decile, regardless of the level of tree cover, there is a greater proportion of non-green cover occurring under foliage and a lesser proportion of bare ground. Again, a similar pattern is observed in the green fraction, but also to a lesser degree. However, as tree cover increases this effect appears to diminish.

Both these results are attributed to litter accumulation under trees, covering bare ground and, to a lesser degree, green ground cover. As tree cover increases, entire sites become dominated by litter and bare ground becomes is considerably reduced. The green fraction is the least affected by the presence of a midstorey or overstorey, presumably because green grass is less likely to be covered entirely by litter than bare ground and a relatively low proportion of green cover actually grows under foliage due to shading effects and tree-grass competition for water and nutrients.

Discussion

The initial results for the fC product, corrected for cover under trees, appear promising. The testing of the methodology, using the field site data, demonstrates the high degree of effectiveness of the model under ideal circumstances. While there are some limitations to the model that reduce its effectiveness for satellite imagery, even the results for the correction of the imagery at the field site improved the bias of the product for every fraction. The fractions that benefit the most from an adjustment for tree cover are the non-green and green fractions.

The green fraction was most notably improved fraction for the results from the satellite imagery. The non-green fraction was the next most improved fraction, followed by the bare fraction, which was the least improved. Before correction, the green fraction of the fC is a considerable over estimate for areas with higher tree cover (due to the green contribution to the signature from foliage). Conversely, the non-green fraction is considerably underestimated (due to the obscuration of litter that exists underneath the foliage). The lack of improvement in the bare fraction, is not due poor performance of the model, but because at high levels of tree cover, there is almost no bare ground present under the foliage. As a result, the uncorrected prediction of bare cover is largely accurate and adjustment of this fraction makes little difference to the results.

While the model to correct for tree foliage cover reduces the bias in the non-green and green fractions, it does not entirely remove it. The results from the analysis of the point intercept data can help to explain the remaining bias after correction. A primary assumption of the model is that the distribution of the ground cover fractions in random. This assumption allows the effective removal of the portion of the pixel in which the ground is obscured and the estimation of the pixel's cover based on the remaining unobscured portion. However, from the analysis of the field data at the point level, the actual distribution is not random. The presence of midstorey and overstorey foliage results in an increase of non-green ground cover in the form of litter. At a site with high foliage, the estimation of the site based on the unobscured portion of the pixel ground cover signal will result in an underestimate of the non-green fraction and a subsequent over estimate of primarily the green fraction (as there is typically little bare ground at high foliage sites).

Another factor that impacts on the results of the model is that it relies heavily on the persistent green product for the estimation of persistent green, persistent non-green and the gap fraction. Any errors in the persistent green product will result in errors in the correction for tree cover. Improvement of the persistent green product, and provision of a dynamic product which can produce single date images to match the fC product, will directly improve the corrected cover under trees fC product.

Finally, it should be noted that all these analyses rely on accurate field data measurements. While point intercept data is largely considered one of the most robust and reliable field data collection methods, results are still of variable quality (Trevithick et al., 2012) There now exists a national standard for ground cover data collection (Muir et al., 2012), however not all sites were collected using this standard. Additionally, at present the fractional cover field data set is heavily dominated by sites with low tree cover, so we can be less confident in the results presented here for the higher deciles of tree cover, than for the lower deciles.

Therefore, although the initial results for the correction are promising, there are three clear areas in which further research would improve the corrected product. These are:

- improvement to the existing persistent green product;
- development of an adjustment to the model to account for the actual distribution of ground cover fractions relative to tree cover; and
- additional collection of field sites following the national standard in areas with variable levels of tree cover.

References

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Scarth, P., Byrne, M., Danaher, T., Henry, B., Hassett, R., Carter, J., and Timmers, P. (2006) State of the paddock: monitoring condition and trend in groundcover across Queensland. In: Proceedings of the 13th Australasian Remote Sensing and Photogrammetry Conference, Canberra, Australia, November 2006.

Trevithick, R., Muir, J. and Denham R. (2012) The effect of observer experience levels on the variability of fractional ground cover reference data. In: Proceedings of the XXII Congress of the International Photogrammetry and Remote Sensing Society 2012, Melbourne, Australia, 25 Aug – 1 Sept 2012.

Glossary

This glossary describes the nomenclature of all equation symbology which occurs throughout this report.

Portion of any observation visible from above, as by the satellite.	visible
Theoretical ground cover bare fraction proportion	ground bare
Theoretical ground cover green fraction proportion	ground green
Theoretical ground cover non-green fraction proportion	ground non-green
Theoretical midstorey and overstorey gap.	total gap
Theoretical proportion of persistent green	persistent green
Theoretical proportion of persistent non-green (branch and dry)	persistent non-green
Theoretical proportion of overstorey green measurements	over green
Theoretical proportion of overstorey non-green measurements	over non-green
Theoretical proportion of midstorey green measurements	mid green
Theoretical proportion of midstorey non-green measurements	mid non-green
The proportion of any ground fraction visible by the satellite	$\mathrm{Sat}_{\mathrm{ground\ fraction}}$
Green cover fraction from fractional cover product	$\mathrm{Sat}_{\mathrm{tot\ green}.}$
Bare cover fraction from fractional cover product	$\mathrm{Sat}_{\mathrm{tot\ bare}.}$
Non-green fraction from fractional cover product	$\mathrm{Sat}_{\mathrm{tot\ non-green}.}$
Green cover fraction from fractional cover product adjusted for persistent cover (cover under trees)	$\mathrm{Sat}_{\mathrm{ground\ green}.}$
Bare cover fraction from fractional cover product adjusted for persistent cover (cover under trees)	$\mathrm{Sat}_{\mathrm{ground\ bare}.}$
Non-green fraction from fractional cover product adjusted for persistent cover (cover under trees)	$\mathrm{Sat}_{\mathrm{ground\ non-green}.}$
Persistent green derived from fC product	$\mathrm{Sat}_{\mathrm{persistent\ green}}$
Persistent non-green estimated from fC product using equation derived from field data	$\mathrm{Est}_{\mathrm{persistent\ non-green}}$
Estimate of total green fraction as would be seen by satellite derived from field data	$\mathrm{Est}_{\mathrm{tot\ green}}$
Estimate of total non-green fraction as would be seen by satellite derived from field data	$\mathrm{Est}_{\mathrm{tot\ non-green}}$
Estimate of total bare fraction as would be seen by satellite derived from field data	$\mathrm{Est}_{\mathrm{tot\ bare}}$

Persistent green derived from field data (proportion)	$\mathrm{Field}_{\mathrm{persistent\ green}}$
Persistent non-green derived from field data (proportion)	$\mathrm{Field}_{\mathrm{persistent\ non-green}}$
Total number of overstory observations at a field site	$\mathrm{nField}_{\mathrm{over\ tot}}$
Number of green overstory observations at a field site	$\mathrm{nField}_{\mathrm{over\ green}}$
Total number of midstory observations at a field site	$\mathrm{nField}_{\mathrm{mid\ tot}}$
Total number of observation points at a field site (typically 300)	$\mathrm{nField}_{\mathrm{tot}}$
Number of bare ground observations at a field site	$\mathrm{nField}_{\mathrm{ground\ bare}}$
Number of dry ground observations at a field site	$\mathrm{nField}_{\mathrm{ground\ dry}}$
Number of green ground observations at a field site	$\mathrm{nField}_{\mathrm{ground\ green}}$
Number of branch overstorey observations at a field site	$\mathrm{nField}_{\mathrm{over\ branch}}$
Number of midstorey branch observations at a field site	$\mathrm{nField}_{\mathrm{mid\ branch}}$
Number of overstorey dry observations at a field site	$\mathrm{nField}_{\mathrm{over\ dry}}$
Number of midstorey dry observations at a field site	$\mathrm{nField}_{\mathrm{mid\ dry}}$
Number of overstorey green observations at a field site	$\mathrm{nField}_{\mathrm{over\ green}}$
Number of midstorey green observations at a field site	$\mathrm{nField}_{\mathrm{mid\ green}}$
Proportion of green overstorey observations at a field site	$\mathrm{Field}_{\mathrm{over\ green}}$
Proportion of bare ground observations at a field site	$\mathrm{Field}_{\mathrm{ground\ bare}}$
Proportion of over branch observations at a field site	$\mathrm{Field}_{\mathrm{over\ branch}}$
Proportion of mid branch observations at a field site	$\mathrm{Field}_{\mathrm{mid\ branch}}$
The combined number of overstorey dry and overstorey branch observations	$\mathrm{nField}_{\mathrm{over\ non-green}}$
The combined proportion of overstorey dry and overstorey branch observations	$\mathrm{Field}_{\mathrm{over\ non-green}}$
The proportion of overstorey dry for a given site derived from the field data	$\mathrm{Field}_{\mathrm{over\ dry}}$
The proportion of midstorey dry for a given site derived from the field data	$\mathrm{Field}_{\mathrm{mid\ dry}}$
The proportion of overstorey green for a given site derived from the field data	$\mathrm{Field}_{\mathrm{over\ green}}$
The proportion of midstorey green for a given site derived from the field data	$\mathrm{Field}_{\mathrm{mid\ green}}$
The proportion of overstorey gap for a given site derived from the field data	$\mathrm{Field}_{\mathrm{over\ gap}}$
The proportion of midstorey gap for a given site derived from the field data	$\mathrm{Field}_{\mathrm{mid\ gap}}$