Final Report – Volume 2

Estimating Pasture Total Standing Biomass (TSDM) from Landsat Fractional Cover.

Project code: ERM.0098

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Summary

We have found that it is not possible to estimate total standing dry matter (TSDM), at usable precision, from directly measured cover or Landsat based remote sensed cover using a generic function, as data from three grazing trials demonstrate different cover to mass relationships. Errors are not random and bias of 1000 kg/ha or more occur.

Calibration at the individual grazing trial scale (regional) leads to an improvement in prediction of TSDM by about 20%, as each grazing trial appears to have unique characteristics. Using both non-green (dry) and bare cover fractions in a log ratio provides a small improvement in prediction over ground cover. Inclusion of persistent green and average green cover for the last 365 days, as well as interaction terms provided the best prediction at grazing trial scale with potentially usable results for the Pigeon Hole trial site in the Northern Territory. At this scale, mean average error ranges from about 240 kg/ha (Pigeon Hole) to 526 kg/ha (Toorak) representing 14% and 31% of average TSDM respectively.

Calibrating models individually for each paddock independently decreased mean average errors in predicted TSDM at Pigeon Hole, with variable results at Toorak and Wambiana (Queensland).

Despite only modest success in the estimation of TSDM, it may still be useful to make available a "Landsat cover estimated dry season TSDM" to land managers, provided error estimates are supplied with the estimated mean value. This would provide robustly estimated upper and lower bounds for decision making and checks on other methods of biomass estimation at the paddock scale.

Calibration of data from a single paddock at each grazing trial and application of the function to the other paddocks lead to a significant increase in error (and instances of bias) relative to using data for all paddocks in the calibration. This is an indication that even the best function for a grazing trial may degrade significantly when applied to other nearby locations. Therefore, it is unlikely that "space" can be traded for "time", as the worst results occurred when the data from the last TSDM measurement was used to estimate TSDM as measured at previous times in each grazing trial.

Variation in TSDM to cover ratios and the amount of litter present, change the relationship between cover and TSDM between locations, on a paddock by paddock basis and with grazing pressure. Grazing appears to lower the TSDM required per unit cover ratio. Calibration by land type rather than by paddock appears to offer no benefit on average for the Wambiana trial (although estimates were slightly improved for 6 out of the 10 paddocks).

Grazing activity appears to impact on cover to mass relationships, as grazing occurs generally from the top of the sward downwards decreasing the mass per unit cover. In addition, removal of standing material by grazing both generates new litter via detachment and trampling, plus it exposes existing litter as standing material is removed.

Cover to mass relationships tend to poorest when there is little grazing (e.g. exclosures), where there is lower correlation between cover and TSDM than in similar grazed paddocks. At cover values above 90%, TSDM values can range from a 1,000 kg/ha to potentially more than 10,000 kg/ha as additional mass is added vertically to above existing material. Because of this non linearity, TSDM data requires transformation prior to further statistical modelling. Even with transformation the relationship with TSDM remains poor at high cover values, especially at the Wambiana grazing trial.

Introduction

The aim of this study was to investigate how well the components of Landsat fractional cover could be used to predict pasture total standing biomass at a range of scales using data from three well measured grazing trials in northern Australia.

Estimates of total standing dry matter (TSDM) at paddock scale or better are increasingly being requested by the grazing sector for: feed budgeting for animal production, mitigation of drought risk and maintenance of ground cover and ecosystem function. In northern Australian grazing lands, there are significant challenges in estimating TSDM by any method due to issues such as heterogeneity (soils, trees, species, topography), paddock size, accessibility of paddock to measurers, delays between estimation and use of data for feed budgeting. Furthermore, there are additional issues of palatability / selection by stock and stock distribution within a paddock even if TSDM is well quantified.

Remote sensing is a candidate methodology for solving some of these problems. Satellite platforms such as Landsat provide images potentially every 14 days at medium scale resolution (30m*30m pixels). This approach can provide a quite detailed view of typical paddocks. Other lower resolution sensor systems can provide a coarser view, 250-500 m up to several times per day (e.g. MODIS).

Landsat is operationally available and has had excellent radiometric and geometric corrections (Flood *et al.* 2013). In addition, there are well calibrated algorithms that use spectral data to produce direct estimates of green vegetation cover and non-green vegetation cover (fractional cover), as well as an estimate of a persistent green fraction (Denham and Watson 2015). In rangelands, the persistent green fraction corresponds to tree and shrub cover and this index is designed to show slowly varying (multi-year) changes in tree canopy dynamics. Adjustment of the cover fraction to account for persistent green and branches enables a more comprehensive estimate of ground cover fractions where there is tree cover. The current ground cover algorithm adjusts the overall fractional cover to a ground cover (no trees) view for areas with persistent green cover of up to 60%. This should allow for improved estimation of ground cover in grasslands, savannahs and open forests.

It is important to note that the non-green (dry) cover fraction includes cover from grass litter and tree litter as well as standing dry material. The mass of TSDM is commonly measured in grazing trials using the Botanal technique (Haydock and Shaw, 1975). However, the mass of the litter fractions are not accounted for in this measurement methodology and litter is almost never measured, creating a miss-match between the observation and the desired measurement.

Total ground cover measurements are also often made by staff who estimate pasture biomass. These cover estimates also do not distinguish “attached” from “detached” cover and in addition, these observations use a “quadrat” estimate based methodology, which gives significantly different values to the “point intercept” method used to calibrate satellite imagery (Murphy and Lodge 2002).

Availability of tree cover mapped at medium resolution helps account for tree-grass competition and cover hidden from satellite view. In an operational sense it would be ideal if biomass could be estimated from single date imagery using simple functions and maps of woody vegetation. If warranted, the precision of TSDM estimated could potentially be improved by calibrating at regional scale, land type scale or paddock scale perhaps with the inclusion of a range of other remote sensed indices, although measurement of TSDM for calibration purposes remains a challenge Mundava *et al.* 2015).

The broad scale availability of time series remotely sensed data makes possible the use of this data to calibrate and/or validate process models of the grazing system at paddock scales, in a similar manner to that used in AussieGRASS at a much coarser scale (Carter *et al*. 2003, 2010).

This report documents research and data collation as part of a cofounded Meat and Livestock Australia (MLA) and Cooperative Research Centre Spatial Information (CRCSI) with input from Queensland and Northern Territory governments.

Materials and Methods

Data sets and data extraction

Satellite data were obtained from Landsat TM 5, 7, and 8 via United States Geological Survey (USGS) and processed by Department of Science, Information technology and Innovation (DSITI) computing systems. The processing versions and documented at http://data.auscover.org.au/xwiki/bin/view/Product+pages/Landsat+Seasonal+Fractional+Cover. At time of extraction (Feb 2015) using the following product stages:

- Fractional cover version -“dil” (Guerschman *et al.* 2015)
- Cloud and masking products - “ddb” (Zhu and Woodcock 2012)
- Cast shadow mask - “ddc” (Zhu and Woodcock 2012)
- Incidence/exitance angle mask - “dgr”
- Single date water mask - “ddf” (Danaher and Collett 2006)
- Cloud shadow mask - “dgs”
- Snow mask - “dgt”
- Seasonal persistent green - “dja” (Denham and Watson 2015).

A semi-automated in-house python based system was developed to extract data for the nominated polygons in shape files provided by grazing trial operators. The system (Figure 1) intersects the polygon with the entire satellite archive and access the fractional cover, masks and seasonal persistent green for each date. Masks are applied to fractional cover to remove cloud, cloud shadow and other missing data. This process is especially important for the damaged Landsat 7. A count of valid pixels and pixels with no data is performed for each polygon (in this case, grazing trial paddocks). DSITI currently holds the full Landsat archive (1986 to current) with derivative products for Queensland and the Northern territory and increasing holdings for other states.

The ground cover fractions were estimated by making allowances for the persistent green fraction (assumed to be woody vegetation) and a non-green branch fraction and then the means and the spatial standard deviation of cover fractions were calculated. The data were extracted into a simple ASCII file for matching with on-ground data. Each row of data includes the recording of the main source file name, so that any issues with processing can be traced.

The system uses the USGS path row conventions to store and process imagery. Data on the same path (roughly north-south) are essentially continuous in time and therefore presents few problems for extraction. However, as cloud masks are generated on a “per scene” basis, the northern end of the scenes may have shadows from clouds that exist on the scene immediately to the north. Therefore, in all cases where data existed on a north-south scene overlap, the northern scene is used rather than the southern one. East-west overlaps are potentially much more difficult to deal with. In this study, trial sites were fortunately fully contained in a single path. Images made unusable due to cloud cover were included in the output data set with missing value flags.

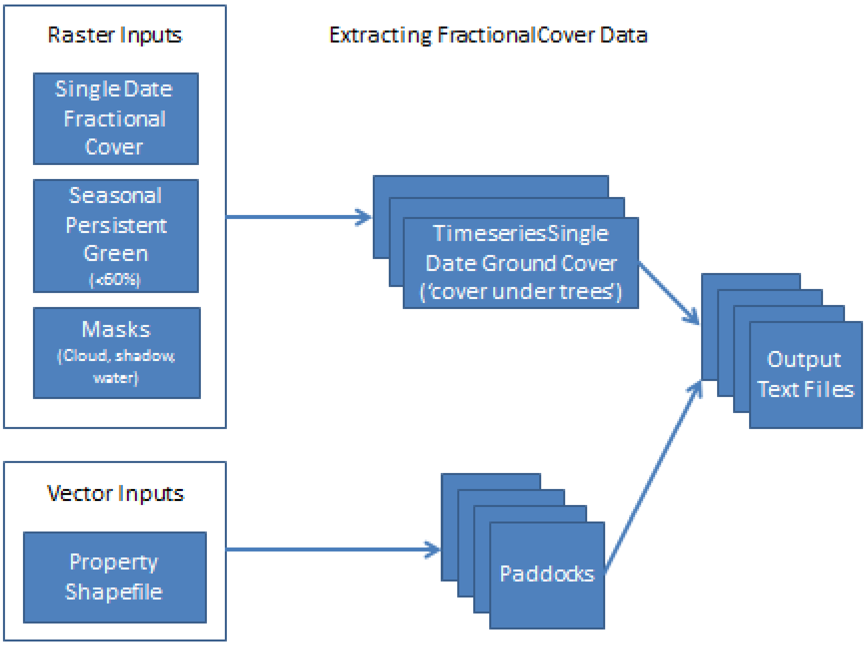

Figure 1. Data extraction process

Grazing Trial Data

A range of grazing trials were evaluated and ranked as tier 1, tier 2 or tier 3 on the basis of amount and quality of readily available data. Three tier 1 and four tier 2 sites were identified as suitable for this analysis.

TSDM data were assembled for each measurement period for each paddock in each of three tier 1 grazing trials: Pigeon Hole (Symes, 2007); Toorak (Orr & Phelps, 2014); and Wambiana (Reagain & Bushell, 2011; Appendices 1-3). At Wambiana, data were also assembled on a "land type" basis (Appendix 4).

For each observation, the day of measurement was recorded in order to match with the satellite data. Where available ancillary data such as field observed ground cover, standard deviations of TSDM and cover estimates were available, these were also collated for anlysis. Field observed "quadrat based" cover data, were transformed to "point intercept" cover, using the inverse of function derived by Murphy and Lodge (2002). While data for this project were collated at paddock scale, in the future it should be possible to analyse data at a finer resolution, as Wambiana has two well-established transect lines per paddock and TSDM sample sites/transects at Pigeon Hole are at least approximately known.

The average TSDM levels across all field data (that had corresponding satellite observations) were similar across the three trials: Pigeon Hole (1650 kg/ha); Toorak (1850 kg/ha); and Wambiana

(1950 kg/ha). Average ground cover across the trials was 77%, 61% and 83%; and persistent green cover was 5.5%, 1% and 18.5% respectively.

A number of other candidate tier 2 and tier 3 grazing trials were evaluated for further analysis and GIS boundaries were captured for tier 2 grazing (Appendix 5).

Analysis of data sets

Data analysis was staged from simple to more complex functions and analysed over a range of scales, using all data from all three trials together (to represent northern Australia), down to individual paddocks in each of the trials. A number of hypotheses (points 1-5 below) about the data and combinations of predictor variables were investigated using the "*R*" statistical package.

Comparison of Satellite and Field Observations of Cover.

(1) Simple linear and non-linear regression for each grazing trial using data from all paddocks and all recording times.
(2) Simple linear and non-linear analysis using green, non-green (dry) and total cover and 12 month average green.
(3) By paddock linear regression with total cover and other predictor variables.
(4) Comprehensive analysis to answer questions that would relate to any operational implementation.
    a. Data transformations: what is useful?
    b. How well can we estimate TSDM from Landsat total cover with optimum statistical procedures/transformations?
    c. Are statistical properties of data significantly different between grazing trials?
    d. How well can we estimate TSDM from Landsat fractional cover components with optimum statistical procedures?
    e. Are relationships different by paddock: is paddock scale calibration useful/ possible?
    f. Can calibration at one point in time be used for prediction for other times?
    g. Does calibration by land type level improve paddock level estimation of TSDM?
(5) Integrating remotely sensed estimates of cover and modelling.
    a. Model functions converting biomass to cover.
    b. Test of model green cover and remotely sensed green cover at Wambiana.

NB. Analyses 1-4 were carried out using a combination of Coplot, Tablecurve and FORTRAN, while section 4 was coded in R. In part 5a FORTRAN was used and 5b used the Cedar version of GRASP.

RMSE (residual mean squared error) was calculated on the square root transformed TSDM data sets and as such does not represent the RMSE of the un-transformed data (even if squared). However, it does allow a valid comparison between models. The median, and prediction limits were estimated for each model using perturbed model parameters to produce an ensemble of predictions, from which the 50^{th} (median), 2.5^{th} and 97.5^{th} percentile values were extracted. These plotted lines indicate that 95% of predictions for any given input data should be between the upper and lower bounds. Various models were accepted or rejected when an improvement was significant at the ($P < 0.05$) level (accounting for the number of terms in the model).

Terminology

There are various terminologies used for cover measurements. The traditional users of cover data (modelling and pasture ecology) have historically use somewhat different terminology to the remote sensing products now coming into common usage. These products have cover estimates that often include the woody component and use international terminology. Units for cover are usually in % and range from 0-100, with use internally within GRASP model code, in units 0.0-1.0. In this report the following definitions are used:

- *Bare ground:* The corollary of ground cover, (i.e. 100 - ground cover), also called bare soil (BS).
- *Fractional cover:* Satellite derived estimates of three cover components: green vegetation (PV) (comprising the persistent green and green grass); non-green or non-photosynthetic vegetation (NPV) typically dry standing grass and litter; and bare ground (including rock cover).
- *Green ground cover:* Green ground cover, green grass as used in pasture ecology (excludes over-storey), photosynthetic vegetation (PV)
- *Total ground cover:* Cover that does not include a tree component. Ground cover is derived from satellite green + non-green fractional cover, after adjusting for persistent green and a branch fraction (persistent dry). No estimate of ground cover is made where persistent green exceeds 60% (e.g. rainforests).
- *Litter cover*: cover (dry/dead) from grass and trees (may be only partially visible due to standing grass).
- *Persistent green cover:* highly damped estimate of green cover from near permanent green (e.g. trees and shrubs, nominally no contribution from green pasture).
- *Non-Green:* Cover from dead grass, grass litter and tree litter – sometimes called dry or dead, or non-photosynthetic vegetation (NPV) cover. (In fractional also includes a tree branch component).
- *Total (ground) cover:* as used in pasture ecology, excludes over-storey (100 - % bare ground).

Results

Comparison of Satellite and Ground-based Observations of Cover

Field measurements of ground cover (taken along with TSDM) were available at each grazing trial. Satellite cover estimates were compared to the field estimates, as a check on data issues for both field and satellite values.

Time series data plots (Appendix 6) reveal that field observed total ground cover was in all cases less than the satellite estimate. When the field cover data were corrected to a "point intercept" basis, the cover values for Toorak and Pigeon Hole were quite close, while Wambiana satellite average cover estimates appeared to be higher than field estimates by about 14% (Table 1, Figure 2), which could be from bias in field or satellite estimates. The "dil" ground cover version"dj4" appears to overestimate the non-green (dry) cover fraction on highly reflective soils. While the mean cover values at Toorak were close to the satellite estimates, the correlation (r^2 = 0.31) and slope (0.59) were poor, with the poorest fit in the 10% paddock. The reasons for this poor fit are not understood.

Table 1. Mean total cover across all paddocks and measurements for three grazing trials and linear correlation between corrected field observations and total cover from Landsat.

Trial	Mean Satellite total Cover (%)	Mean Corrected Field Total Cover (%)	Mean Field total cover (uncorrected) (%)	r^2	Intercept	Slope	N
Pigeon Hole	78.4	79.5	66.4	0.691	5.91	0.912	118
Toorak	54.4	51.6	32.7	0.312	23.67	0.596	45
Wambiana	83.3	69.6	53.4	0.637	30.65	0.757	251

Predicting TSDM from field cover observations

Estimating TSDM from field cover estimates provides a point of comparison for TSDM estimates from remote sensing. The linear correlation between field observed cover and TSDM was slightly lower when the cover correction was applied to field observations, suggesting that this correction is correctly adjusting for observer problems in estimating the litter component of total cover.

Satellite estimated cover was a more useful predictor (using simple linear analysis) of TSDM than cover from field observations at only one of the three grazing trials. Correlation at Pigeon Hole averaged over 13 individual paddock equations was (r^2 0.53 and 0.81) for field and satellite respectively. At Toorak, the field observed cover (6 paddocks) gave a better estimate of TSDM (r^2 0.36 and 0.33), with the caveat that there were many fewer seasons with observations for field cover than at the other two sites. At Wambiana, correlation of TSDM with field and satellite cover (10 paddocks) was similar (r^2 0.52 and 0.52). The trends were not consistent at the paddock level, with some paddocks at each grazing trial being different from the general trend.

Simple linear and non-linear regression for each grazing trial using data from all paddocks and all recording times.

Untransformed data from each paddock for all occasions were used to establish simple equations for the three grazing trials (Appendix 7) Summary statistics are shown in Table 1; data were analysed using Tablecurve 3D.

Cover to mass (Linear approximations)

If simple linear fits are applied to cover vs TSDM for each trial, the slope of each line is in proportional units (i.e. kg/ha TSDM for a 1% change in cover) and the residual cover estimate for zero TSDM can be estimated from slope and intercept values. The mean and standard deviation for each parameter was calculated for each grazing trial using data from each paddock.

The mass needed for 1% change in cover varied with grazing trial (Figure 3), with the caveat that the Wambiana satellite based ground cover seems to be biased high by about 14% (Table 1), which if corrected for, makes it similar to values for Pigeon Hole (60 kg/ha TSDM / 1% cover). Toorak data suggests about 30 kg/ha of TSDM / 1% cover, possibly due to the presence of annual grasses and broad-leafed forbs.

The estimate of cover at zero biomass involves litter cover from grass and trees. It is not surprising that Wambiana has the greatest residual cover (Figure 4), as it had the highest tree cover, compared to Pigeon Hole and Toorak. Pigeon Hole has a considerable litter cover that is likely derived from grass with a minor tree litter component. However, if the 14% cover bias at Wambiana is considered, then Pigeon Hole and Wambiana residual cover levels are quite similar. This closeness after bias adjustment may reflect that tree litter is mainly below the tree canopy and not fully detected in the satellite data.

Data from individual paddocks at Toorak fitted independently suggests that once TSDM is removed, there is between 0% (at 10% utilisation) and 30% (at 80% utilisation) (Figure 5). There was considerable “between paddock” variability in mass per unit cover at Toorak and Pigeon Hole, as, demonstrated by relatively large standard deviations. While linear fits have some diagnostic value for biological parameters, it is clear from the data that they provide a less useful fit to the data than other functions. Data (un-transformed) plotted with fitted equations (Appendix 7) show that the 95% prediction interval for linear fits to individual grazing trial data are large; Pigeon Hole was about 500 kg/ha, while Toorak and Wambiana about 1500 kg/ha.

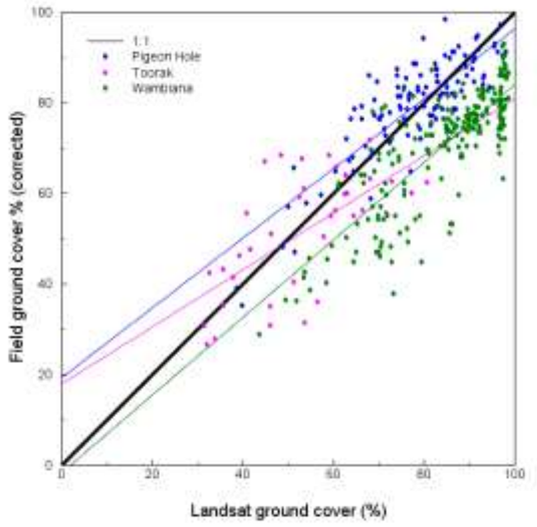

Figure 2. Satellite and field estimates of ground cover (corrected) for three grazing trials showing lines of best fit for each trial. For all data field ground cover = 14.56 + 0.717 * satellite ground cover, $r^2 = 0.568$.

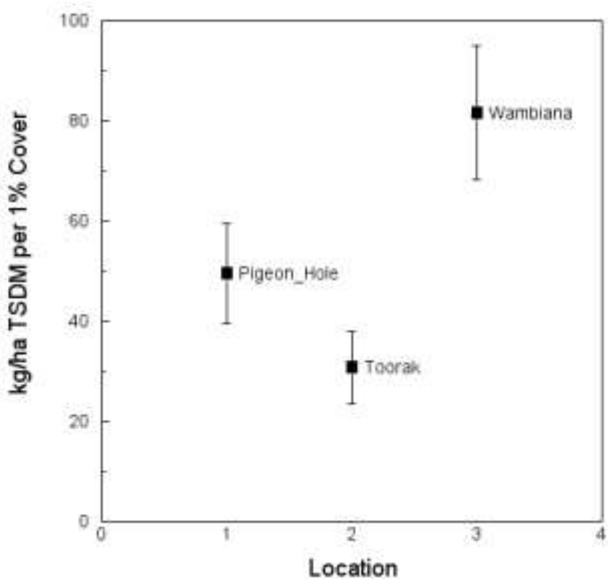

Figure 3. Mass of TSDM (kg/ha) needed to produce 1.0 percent ground cover at three grazing trials based on a simple linear fit. Error bars show one standard deviation reflecting "between paddock" level variability and temporal variability at each grazing trial.

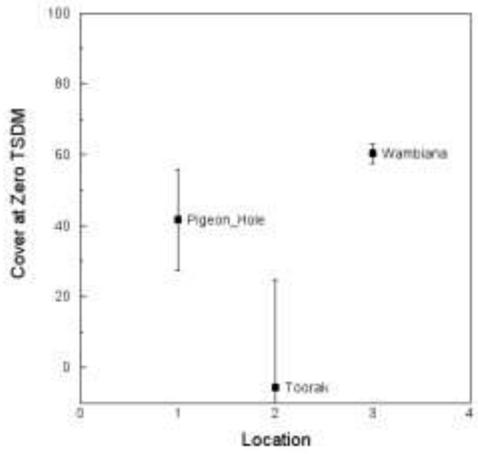

Figure 4. Estimate of cover when TSDM is zero estimated from linear fits to data. Error bars show one standard deviation reflecting between paddock variability at each grazing trial.

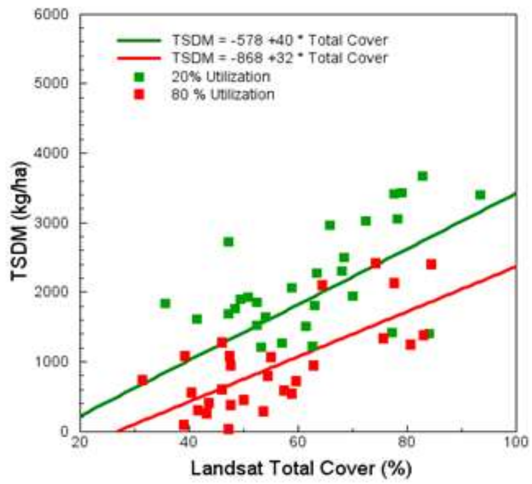

Figure 5. Change in slope and intercept with pasture utilisation in two treatments for the Toorak grazing trial.

Simple linear and non-linear analysis using green, non-green (dry) and total cover and 12 month average green by grazing trial.

The data for all paddocks at each grazing trial show that relationships between cover and mass are approximately linear at lower cover values, but become strongly nonlinear at higher cover values (Figure 6), with clear differences between grazing trials. Toorak shows much more variability than the other two grazing trials.

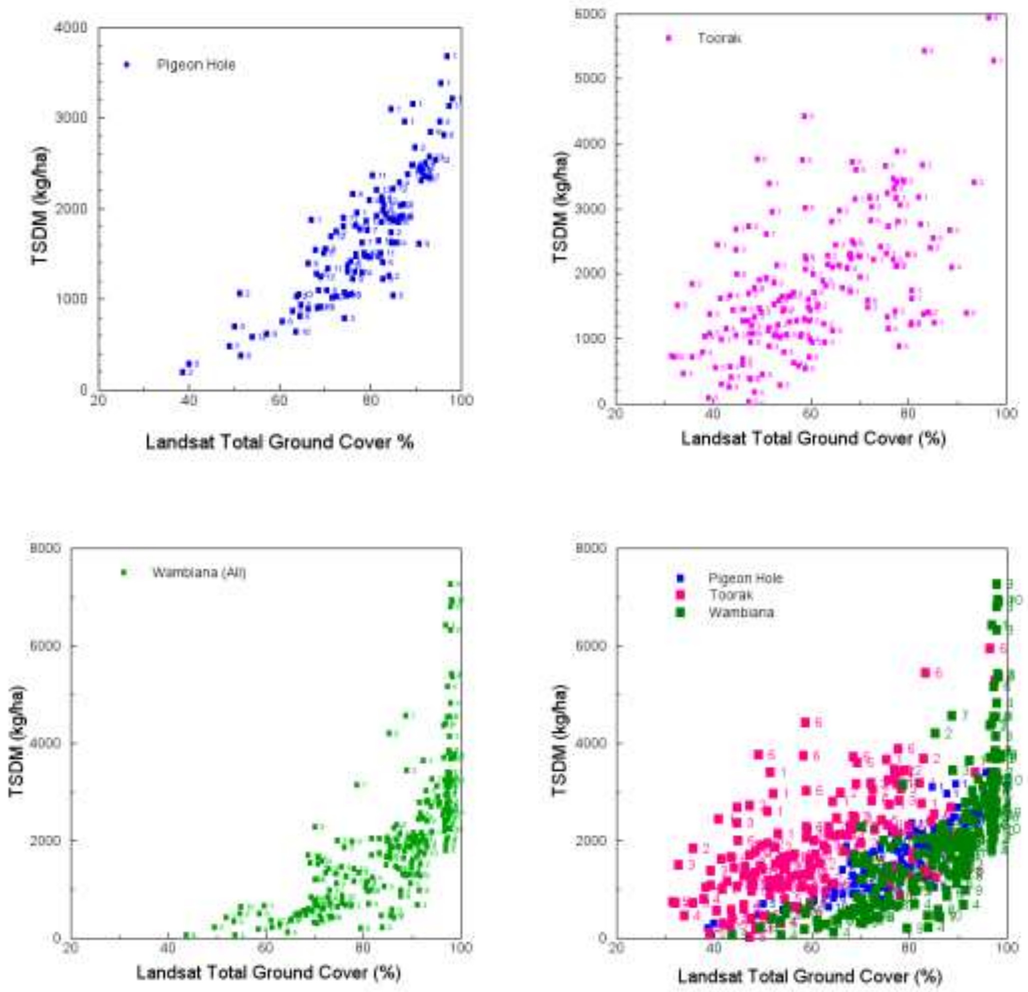

Figure 6. Data from Pigeon Hole (top LHS), Toorak (top RHS) and Wambiana (bottom rhs) spell as individual grazing trials and combined (bottom RHS). Numbers are for paddocks within each trial.

Non-linear fits to the untransformed data slightly improve correlation (Table 2). The 95% prediction limit (Appendix 7) shows some narrowing at higher cover levels for Pigeon Hole and Wambiana for non-linear vs linear fits.

Table 2. Correlation of satellite derived cover variables with TSDM (Adjusted r^2) for each grazing trial using various functions for data for all paddocks and times, (Av_green is a 12 month rolling average green cover).

Trial	Total (linear)	Total (non-linear)	Green, non-green (dry) (linear)	Green, non-green (dry) (non-linear)	Total, Av_green (linear)	Total, Av_green (non-linear)
Pigeon Hole	0.716	0.767	0.715	0.766	0.860	0.999
Toorak	0.312	0.325	0.309	0.322	0.311	0.372
Wambiana	0.504	0.602	0.553	0.559	0.571	0.649

By paddock linear regression with total cover and other predictor variables

Data for paddock -by- paddock correlations (as opposed to whole grazing trials) indicate that individual paddocks (treatments) may have different mass-to-cover relationships (Appendix 8), suggesting that calibration at this scale will be better. Out of 29 paddocks, 23 had improved simple liner correlation between satellite cover and TSDM, compared to whole grazing trial level. This suggests that calibration at paddock scale is likely to be of value if improved precision is required.

In the case of Toorak where the statistical fit was poor, incorporation of percentage utilisation (Appendix 2) improved the fit to data (r^2 improved from 0.312 to 0.446 linear and from 0.325 to 0.471 non-linear) indicating a significant grazing effect (Figure 5).

Comprehensive analysis to answer questions that would relate to any operational implementation

(a) Data transformations.

Data combined from the grazing trials were plotted as histograms (Figure 7) and transformation was investigated. Data was made more suitable for linear analysis and several transforms were eventually applied. For TSDM, a square-root transform was chosen, as a log transform was too severe. For cover variables where the unit is percentage, a logit transformation (Figure 8) was applied. In the case where there were two cover predictor variables, a variation of this approach was used which accounted for the correlation between cover variables and used a log (to base e) ratio transformation. These transformations do much to stabilise the statistical properties of the data set (Figure 9).

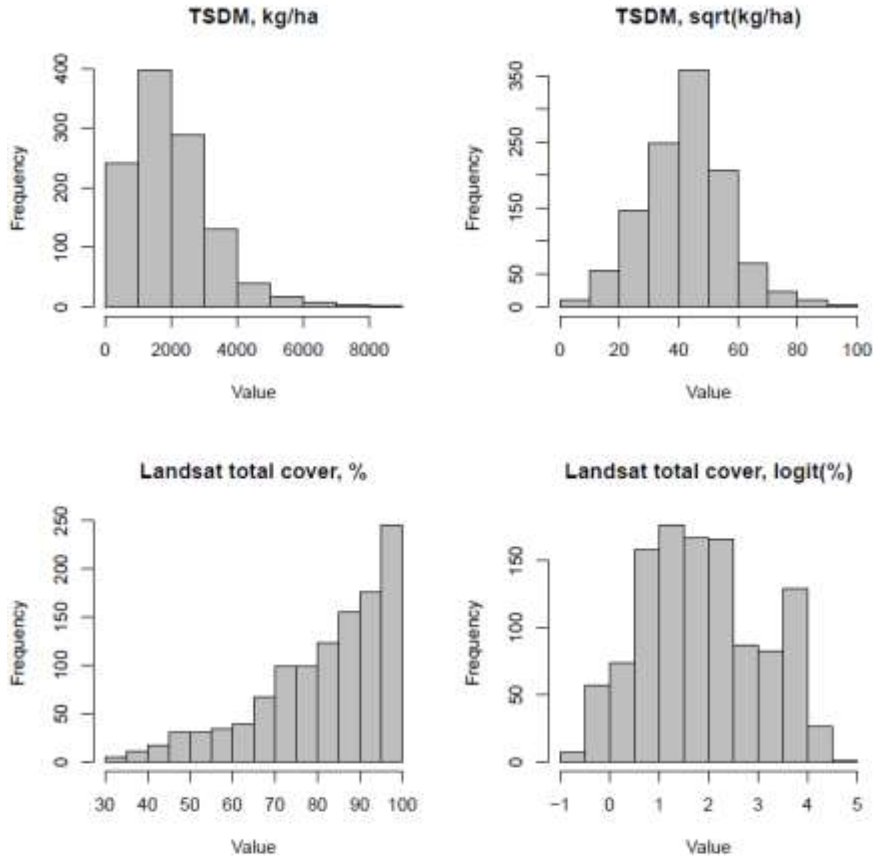

Figure 7. Raw (left) and transformed (right) variables for TSDM and Landsat total cover. Data from all three trials combined.

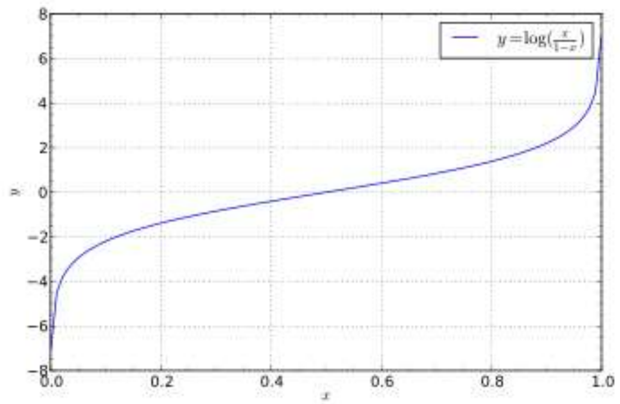

Figure 8. Form of logit transformation applied to percentage cover.

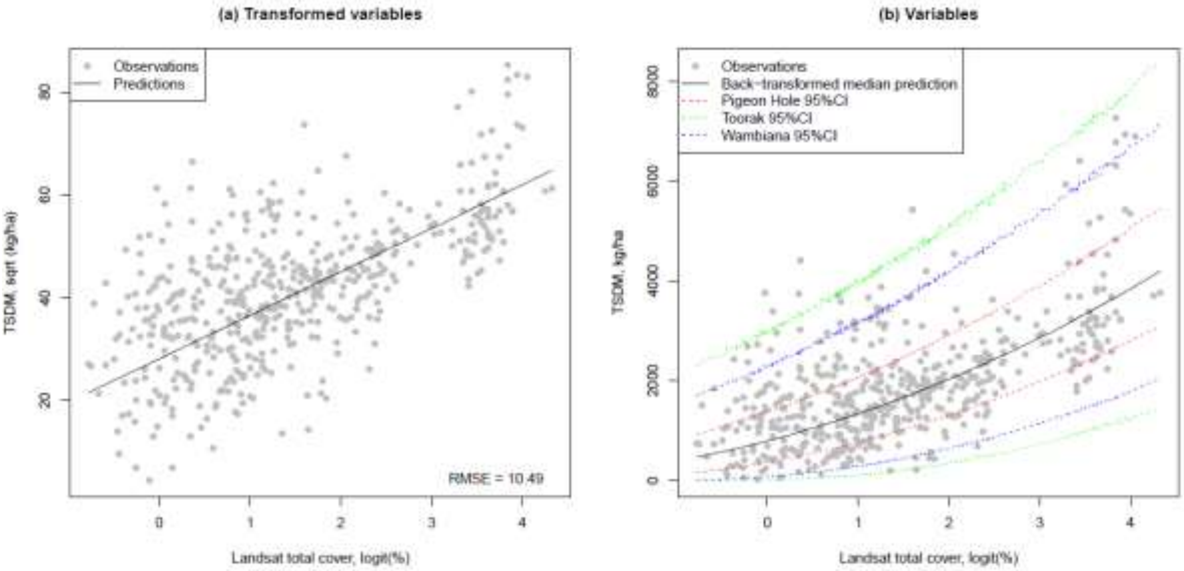

Figure 9. Transformed data with fit across all grazing trial data for (a) transformed and (b) back transformed cases.

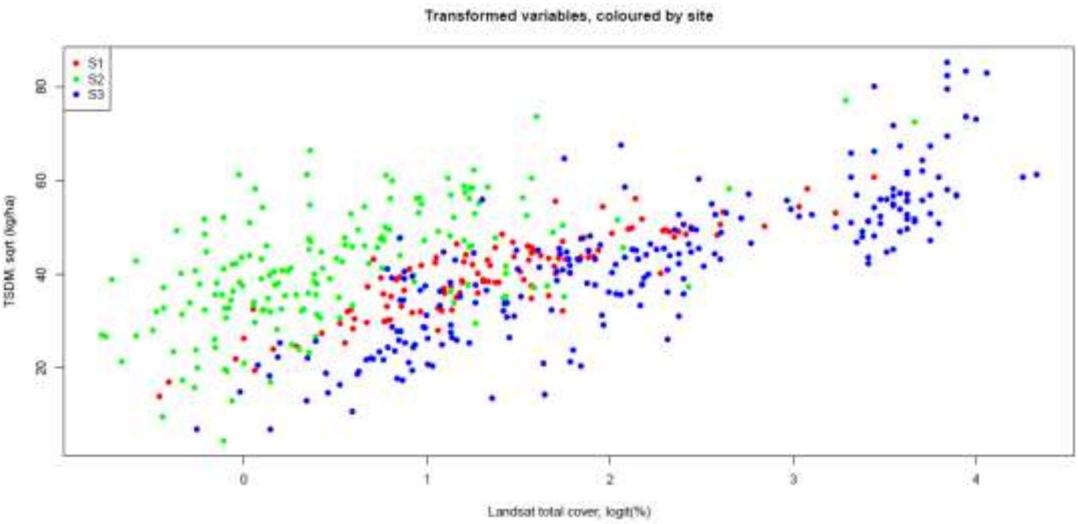

Figure 10. Data from all three grazing trials in transformed format (S1/red = Pigeon Hole, S2/green = Toorak, S3/blue = Wambiana).

How well can we estimate TSDM from Landsat total cover with optimum statistical procedures/transformations?

If a global function integrating data from all three grazing trials is fitted to transformed satellite ground cover and TSDM, a modest fit is obtained (Figure 9). The errors are large, with (an average RMSE 10.49 on transformed data) predictions often 500–1000 kg/ha too high, or 500–2000 kg/ha low on average indicating considerable bias, with the Toorak grazing trial having the poorest results (with poor predictions for most paddocks).

Are statistical properties of data significantly different between grazing trials?

If grazing trails are treated independently, then three statistically different functions emerge (Figures 10 and 11). Prediction limits are still large with only Pigeon Hole having the 95% prediction interval of less than 1000 kg/ha (Figure 11, individual paddocks Appendix 10).

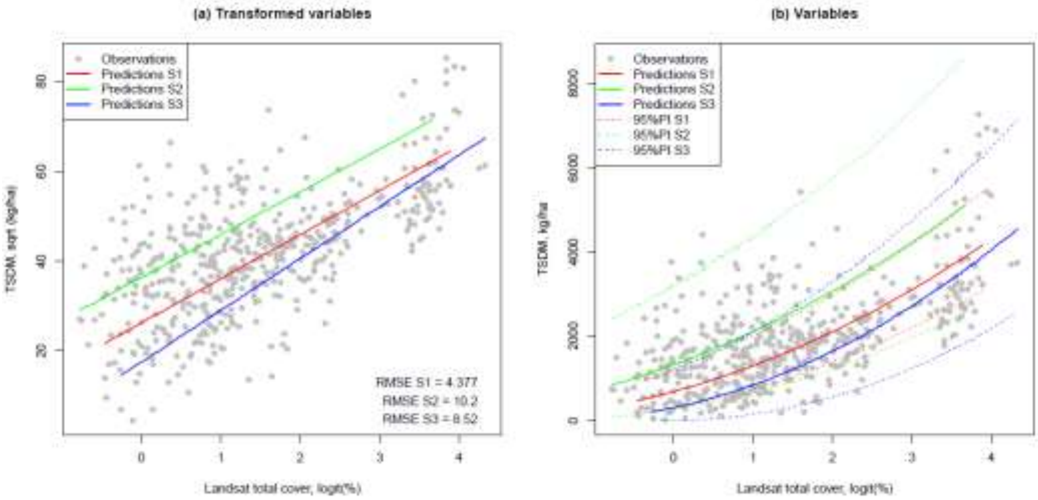

Figure 11. (a) Function fitted to transformed data and **(b)** back-transformed function with raw data with confidence limits for prediction at each of the three grazing trials.

(b) How well can we estimate TSDM from Landsat fractional cover components with optimum statistical procedures?

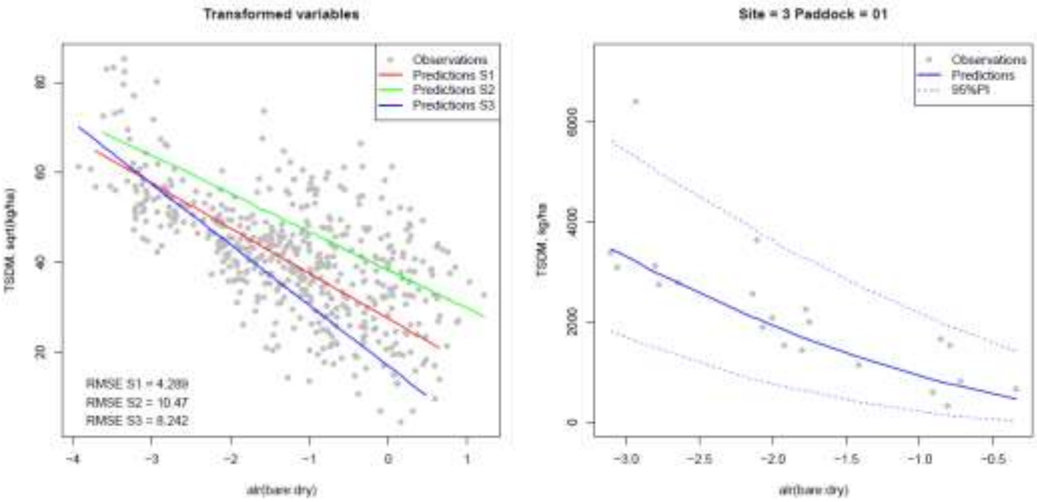

Figure 12. (a, LHS) transformed TSDM as a function of log (bare/dry) ratio for S1, Pigeon Hole, S2, Toorak and S3 Wambiana and **(b**, RHS**)** function applied to Wambiana paddock 1, showing overall error limits for Wambiana.

Using only total ground cover (or its inverse “bare ground”) does not use the full power of the fractional cover data set. Investigation into using the green component an additional covariate suggests there is little improvement to be gained, possibly because most data are from the dry season. This leaves bare and non-green (dry) as fractions that could be used as predictors. In combining percentage type variables that are co-constrained, it is necessary to transform the data to improve statistical properties. The index log(bare/dry) with square root TSDM was slightly better than using total ground cover on its own (Figure 12a). RMSE on transformed data for Wambiana was reduced (from 8.52 to 8.24). However some data points are still poorly predicted (see 95% prediction limits for Wambiana paddock 3, Figure 12b) and plots for all other paddocks (Appendix 10).

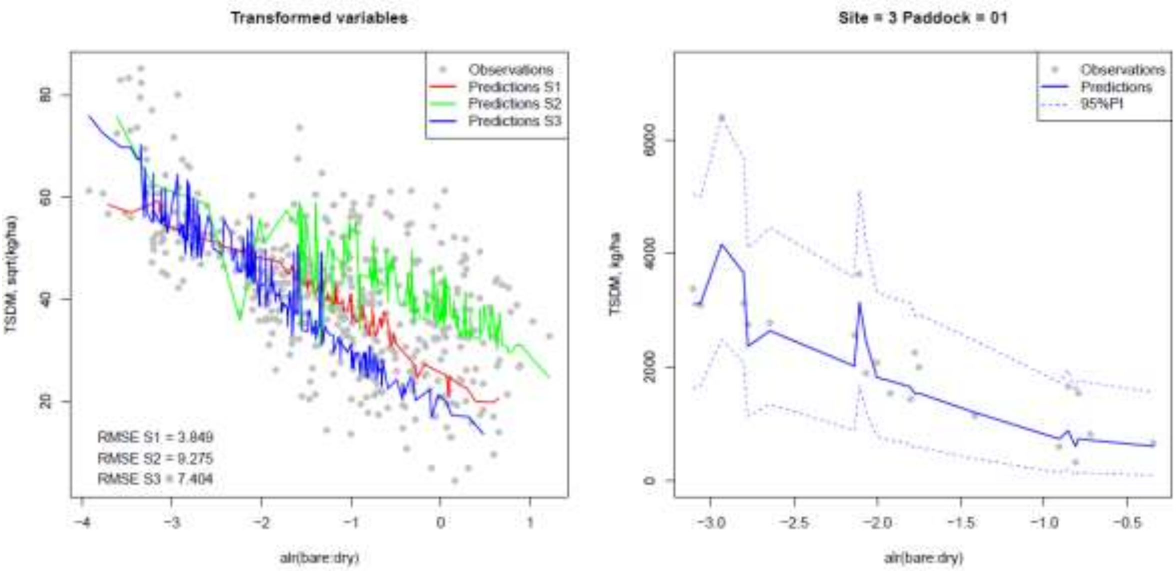

Figure 13. (a, LHS**)** transformed TSDM as a function of log (bare/dry) ratio with inclusion of average rolling 365 day green cover, persistent green and interaction terms and **(b**, RHS**)** function applied to paddock 1 at Wambiana, showing overall error limits.

Adding variables such as persistent green and index of pasture growth (rolling 365 day mean green ground cover), along with interaction terms (Table 3) significantly improves the estimates of TSDM at each grazing trial (see RMSE values Figure 12a and 13a) and appears to reduce error limits some of the time at individual grazing trials and paddocks (Appendix 11). The approach, however, uses many more variables, requiring a large data set for robust calibration with the risk that new unique combinations of input variables may generate spurious results. The range of persistent green values are small (Appendices 1-3), making it risky to apply these functions to more woody situations than in the calibration data set. The inclusion of persistent green may also reflect varying tree grass competition in different paddocks or trend in persistent green over time, as seen at Wambiana reflecting increases in currant bush (*Carissa ovata*) (Appendix 6).

Table 3. Terms included in the best function generated to describe TSDM .

Coefficient	Variable	Term
X[1]	= 1	intercept
X[2]	= zSub$bd_alr	Log(bare/dry)
X[3]	= zSub$AV_GC	% Av green (365 days)
X[4]	= zSub$PG	% Persistent green
X[5]	= zSub$bd_alr * zSub$AV_GC	Interaction 1
X[6]	= zSub$bd_alr * zSub$PG	Interaction 2
X[7]	= zSub$AV_GC * zSub$PG	Interaction 3
X[8]	= zSub$bd_alr * zSub$AV_GC * zSub$PG	Interaction 4

Are statistical properties of data significantly different between paddocks?

The 8 parameter function was inappropriate for use at the paddock scale due to lack of data. Simple linear regression on transformed and untransformed variables showed quite variable correlations, slopes and intercepts on a paddock by paddock basis.

A test of the model is to evaluate how a function developed on just one paddock (using all data collected over time) at a grazing trial will work on the other paddocks in that grazing trial. A representative paddock from each grazing trial (TSDM close to grazing trial average (paddock 3, “Bauhinia” Pigeon Hole; paddock 2, 20% Utilisation Toorak; and paddock 2, Wambiana) was used to calibrate the model (in this case log(bare/dry)) with evaluation on the other paddocks (Appendix 12). RMSE values for transformed data indicates a modest but significant decline in skill when just using one paddock relative to using the data from all paddocks at each grazing trial data (see Figure 11a) for Wambiana and Pigeon Hole. Toorak was only a little worse on average using a single paddock for calibration, with a few paddocks improved relative to the case where all paddocks were used in the calibration.. Increases in error were not random and quite a few of the independently tested paddocks were biased high or low by up to 500 kg/ha or more. This test is probably a reasonable assessment of field performance on “independent” data, as one would expect a decline in predictive skill, even when the best equations (Figure 12) are used at new un-calibrated locations.

Can calibration at one point in time be used for prediction for other times?

Calibrating a statistical model at a single point in time is risky due to the low number of data points available, for example one for each paddock, and in the case of Toorak, just six observations in total.

Climate tends to have an overriding effect, which can be much larger than paddock to paddock differences (Appendix 6). A test was conducted using data from the last set measurements taken at each grazing trial and fitting the log(bare/dry) function, then evaluating the function for all other samplings at each grazing trial. As expected, RMSE values became large by a factor of 2-3 times from using all data for each grazing trial as per example paddocks (Figure 14).

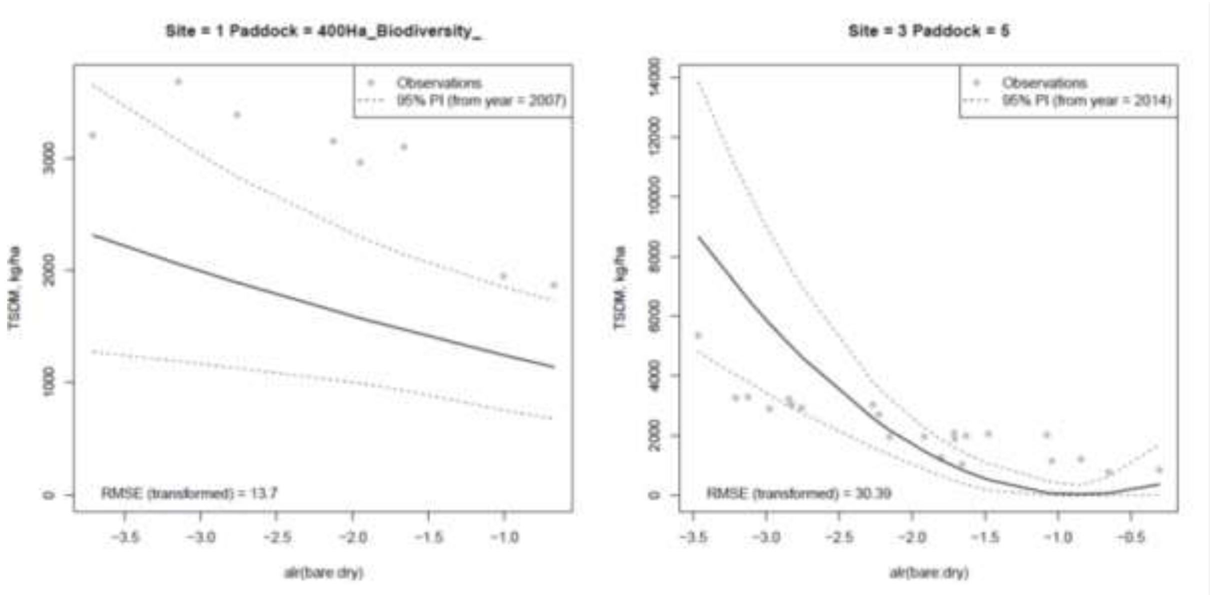

Figure 14. Paddock TSDM and calculated RMSE, using only data from the last data collection from each grazing trial, showing the Biodiversity paddock from Pigeon Hole (LHS) and paddock 5 from Wambiana (RHS) (2 of 29 paddocks shown as an example).

Does calibration by land type level improve paddock level estimation of TSDM?

The Wambiana grazing trial (Appendix 4 and 5) provides an opportunity to test if calibration could be improved when more detail was provided. TSDM was collected for three land types, which occurred in each of the ten paddocks in about the same proportion. A statistical model (Table 3) was constructed for each land type, based on TSDM data combined at the paddock level. The TSDM was then predicted for each land type by paddock combination and added for each paddock with correct area weighting (Appendix 13) for comparison with Site 3 (Wambiana) paddocks in Appendix (11). While prediction was improved in some paddocks, there was no improvement overall at this location. In locations with larger variations in pasture sward and soil type it may still be worthwhile to calibrate at the land type scale.

Cover and process modelling.

While remotely-sensed cover estimates are not directly used in point to paddock scale modelling of TSDM, these data do, however, provide a potential mechanism for model calibration and validation (Figure 15).

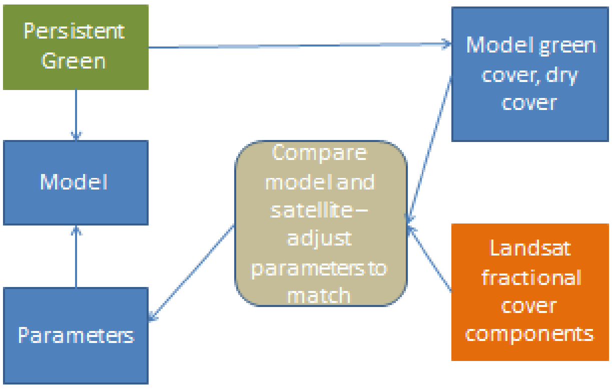

Figure 15. Conceptual diagram showing integration of remote sensed cover data with modelling.

For historical reasons the GRASP model has used two different functions for ground cover.

1. $Total\_cover = TSDM^{**0.95} / (TSDM^{**0.95} + yield\_totcov50^{**0.95})$

   Total ground cover; cover scaled 0.0-1.0. TSDM, total standing dry matter (kg/ha) yield_totcov50; A parameter typically 300-3000 kg/ha for mass at 50% total cover.

In the case of green (ground) cover, cover is estimated from the green pool using the function:

2. $Green\_cover = 1.0\text{-}EXP^{(TSDM*(LN(0.5)/yield\_grncov50))}$

   Green cover scaled 0.0-1.0, yield_grncov50, a parameter typically 300-3000 kg/ha mass at 50% green ground cover.

Both of these cover functions can be parameterised from field data, as mass at 50% cover can be potentially estimated from field measurements. The GRASP green cover function is used to calculate green cover for transpiration and interception of solar radiation and the total cover function is used to calculate ground cover for erosion. The use of different function forms has not been fully reconciled, although in AussieGRASS (as opposed to point versions of the GRASP model), the green cover function is used for both green and total cover with different mass at 50% cover parameters (but based on limited data).

The grazing trial TSDM data and the satellite ground cover data provided an opportunity to test the efficiency of the two model formulations. The analysis suggests that the current green cover function is marginally better (less than 1%) than the total cover function for estimating total cover. The use of the same function for both purposes allows direct comparison of parameters and simplifies the model and documentation. However, the TSDM required for 50% ground cover would need to be modified (reduced by 5-10%) in existing parameter files. When comparing model output to satellite data, model parameters or output should be adjusted to "point intercept" form and ideally use a ground cover model that explicitly accounts for the litter layer.

An additive cover algorithm which builds total cover from grass basal area, tree litter, grass litter and TSDM with default parameters for the linear litter mass-to cover (tree litter 100 kg/ha / 1% cover and grass litter 12 kg/ha / 1% cover) is available. The data from the grazing trials clearly indicate that litter is an important cover component (Figure 3) if modelling is to match satellite based measurement.

Integrating remote sensed data and modelling at Wambiana

The green ground cover fraction from the model was compared to green ground cover from GRASP (version GVT89C25) for a number of paddocks at Wambiana. In prior work these paddocks the GRASP model had been well calibrated to the field measurements of TSDM. Green ground cover is likely to provide greater insight into model performance and be of greater use in parameter adjustment (Figure 14) than non-green (dry) cover as it is closely connected with pasture growth. While total and non-green cover are the result of growth plus the additional processes of: death, detachment, eating, litter formation, and litter decay.

Un-calibrated model runs suggest that GRASP produced too much green cover especially in better years (upper graphs in Figures 16a and 16b). After calibration, the apparent fit of satellite and GRASP-predicted green cover improved (Figure 16a lower graph), but this resulted in very little actual improvement in the overall correlation between the satellite- and GRASP-derived estimates of green cover (Figure 16b). However, there was less of a curvilinear relation after the re-calibration. Reasons for remain variation between model and satellite remain to be investigated.

Even after calibration, it is evident that GRASP shows a decline in green cover which is much faster than is observed in the satellite data. Spatial variability that is captured by the satellite is not captured in the GRASP model and this would be a part of the reason for this difference. This requires further work to determine what the major contributors to this difference are: it may well require some adjustment to GRASP parameters or indeed to GRASP equations. Also, the regression shows a positive intercept, suggesting that low simulated cover underestimates that seen by the satellite. There is a whole raft of possible causes of this. In the current point version of GRASP, it is unlikely that these differences will be accounted for.

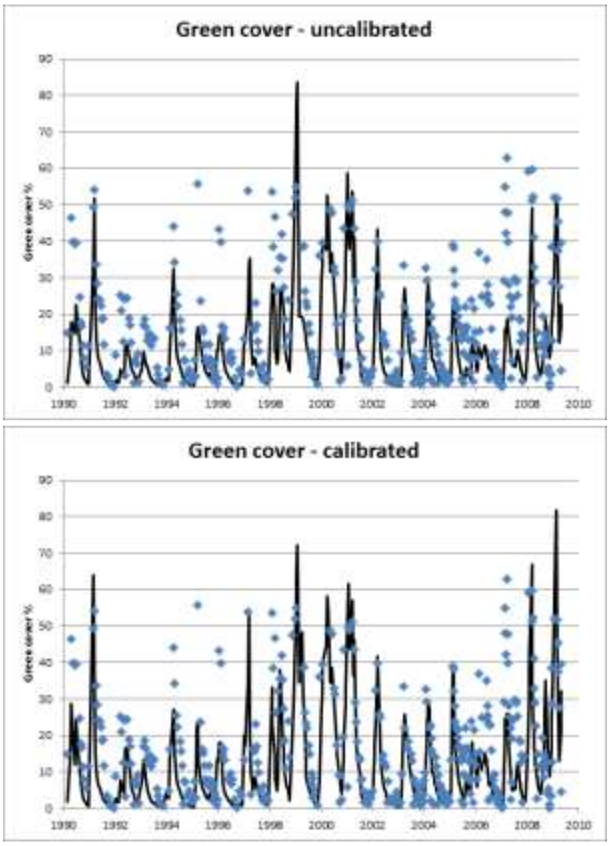

Figure 16. (a) Time series of observed and predicted green cover un-calibrated and calibrated runs of GRASP green cover compared to satellite estimated green cover (blue points).

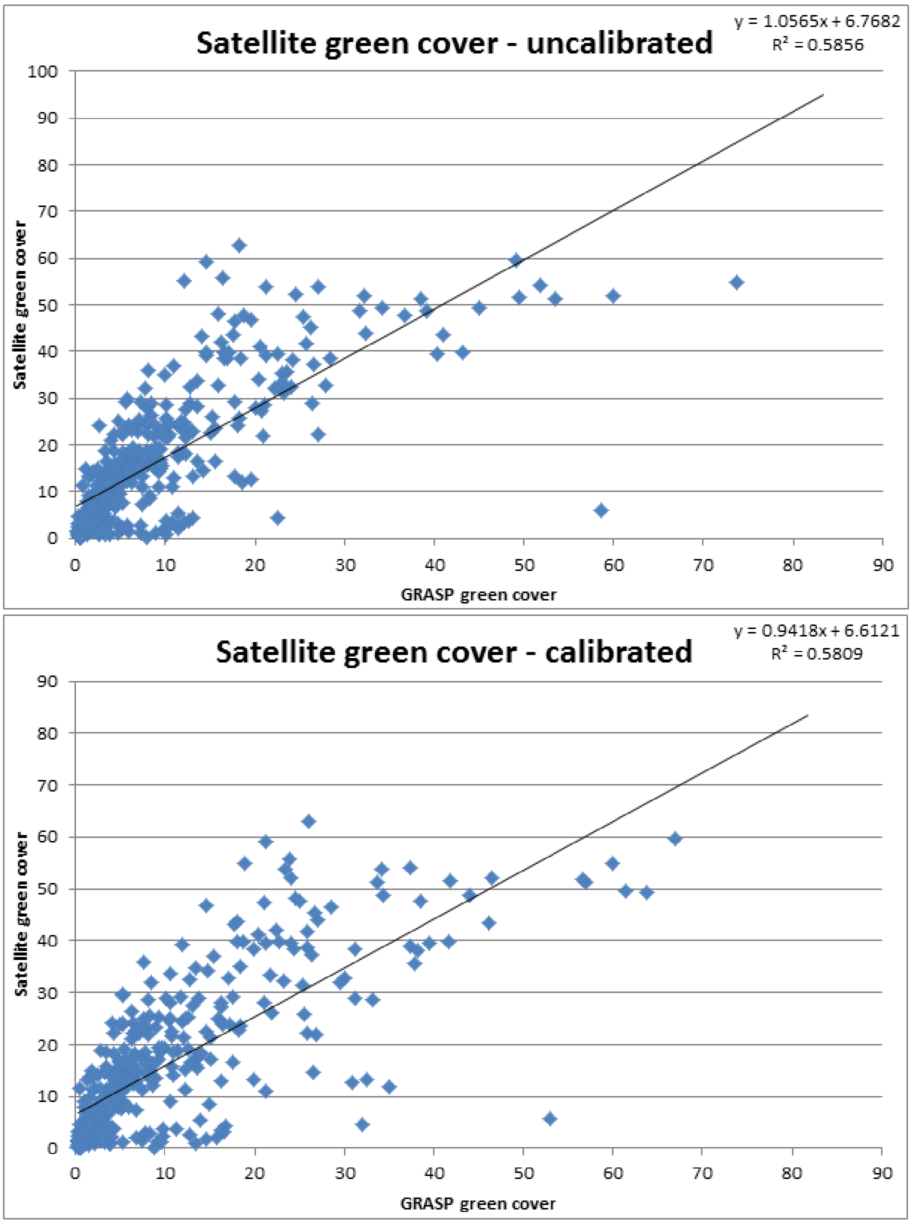

Figure 16. (b) Observed and predicted green cover from an un-calibrated and calibrated runs of GRASP green cover compared to satellite estimated green cover (blue points).

Discussion

Statistical model selection and performance.

The model performance across methods and grazing trials is summarised in Figure 17, where the estimate RMSE for the trial (from square root of the mean of individual paddock RMSE squared values) is plotted. Best results are achieved using regional scale calibration and a complex model with 8 parameters. Reducing calibration data to just one sampling time gives by far the largest errors and use of data from a single paddock also degrades performance. Models and locations with RMSE of 5 or less on transformed data would appear to be useful.

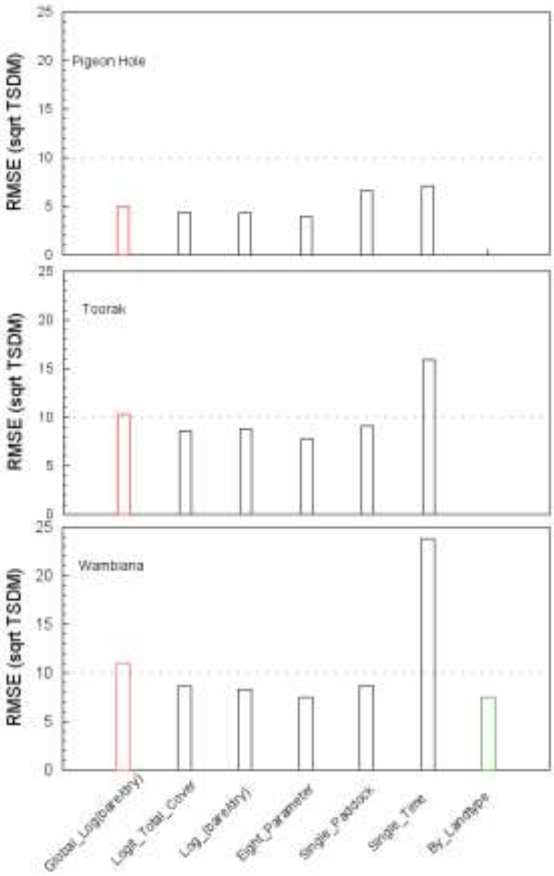

Figure 17. Estimated trial level, mean RMSE of transformed TSDM for three grazing trials. Black bars indicate calibration at the regional (grazing trial) scale, red bars represent functions fitted across all grazing trials and green bars have calibration at land type within grazing trial scale.

Satellite Data, quality and availability.

This study was aimed at directly estimating paddock scale TSDM using fractional cover data from the Landsat satellite, but did not examine the estimation of pasture growth. The reason for this is that pasture growth measurements are usually made at single Landsat pixel scale (after removal of carry over TSDM by mowing or burning). There are relatively few of these measurements made, and even if growth is estimated, losses via eating, detachment and fire need to be accounted for in feed budgeting, as northern Australia typically has substantial amounts of dry carry-over material from previous years plant growth.

The development of the Landsat-based fractional cover product is relatively recent and calibration of satellite imagery to ground cover could be a significant issue for some locations (e.g. Wambiana); as anecdotal evidence suggests that the non-green (dry) cover fraction is currently biased high on highly reflective "bright" soils. This issue is likely to be investigated as part of ongoing continuous model improvement, but may require some targeted field sampling.

The satellite data also contains a number of spurious spikes and falls (Appendix 5) most likely due to undetected cloud, cloud shadow or aerosol effects. These problems appear mainly with the non-green and bare fractions with few problems with the green fraction. These poor data issues can be largely overcome by seasonal compositing based on median values or development of more advanced filtering. However, while these techniques are available to clean the data, they also delay data delivery for up to 3 months or more, generating a trade-off between data quality and timeliness for proactive grazing management.

While Landsat satellite data is nominally available every 14 days, cloud cover in many parts of northern Australia would preclude frequent biomass estimates in the wet season. MODIS satellite data is potentially a substitute that could be used to provide up to daily imagery, however, there are a number of issues which could degrade the already usually poor estimates of TSDM, as follows;

- no identified replacement for the current satellites (now about 15 years old).
- reduced spatial resolution 250-500 m, with pixels at the path edges sampling a significantly larger area.
- less well calibrated (less consistency in radiometric adjustment over annual time-scales).
- less well matched to field calibration data sets in part due to pixel size (Guerschman *et al.* 2015).
- automated processing to calibrated fractional ground cover yet to be developed.

Data from Sentinal-3, a Landsat-like platform from the European Space Agency could potentially double the amount of freely available high resolution imagery. Providers such as Digital Globe can provide at significant cost, very high resolution imagery for small areas on an almost daily basis. All new platforms would need some calibration to field data or cross calibration to Landsat.

Generic equation for all sites and times

The most useful outcome would be a single generic equation that works well across large spatial extents and land types however, the 95% prediction limits for a generic equation at paddock level are very large and sometimes the mean TSDM is very biased and therefor, probably of little direct use to graziers. Parameterisation of AussieGRASS suggests that there may be broad scale variation in mass-to-cover relationships related to vapour pressure deficit (Carter *et al.* 2010).

Individual grazing trials

Functions that operate at a regional level are an alternative to a generic equation. The errors are significantly reduced in some systems (e.g. Pigeon Hole), when calibration data is restricted to one location, and results may be usable by industry (Figures 17 and 18).

The spatial extent to which a function developed for the Pigeon Hole trial could be used is unknown. The extent of spatial applicability may be restricted to just one or a few land types, or even just the grazing trial. The conservative range of pasture utilisation values at Pigeon Hole and Wambiana, as compared to Toorak (Appendices 1-3) and those of the wider industry would suggest the need for wider testing before any implementation. As the current function has been developed in on dry season data only, the model should be tested in the growing season when there is a large green component. As the Pigeon Hole parameterisation is for an essentially tree less area, the algorithm probably should not be applied to areas where persistent green is above 7%.

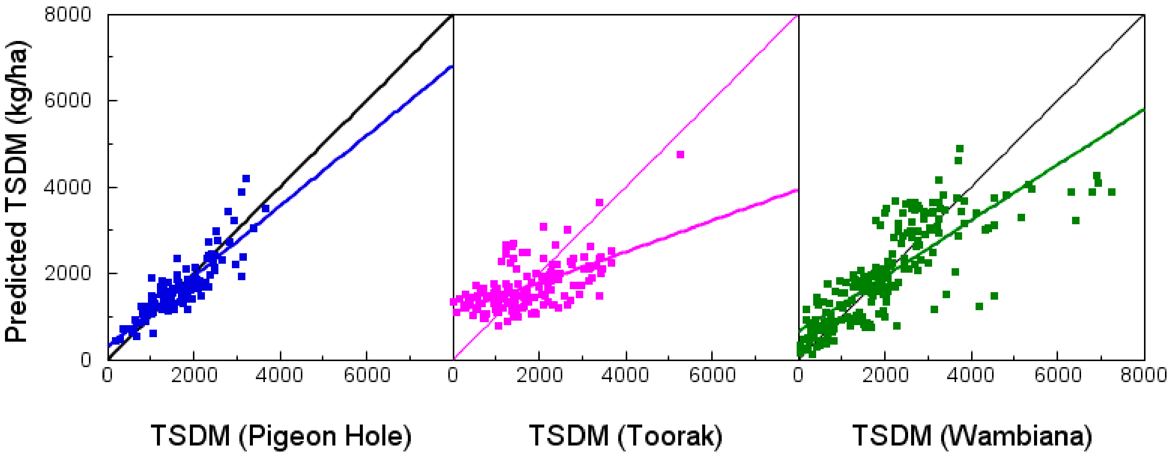

Figure 17. Observed and predicted TSDM for three grazing trials log(bare/dry):

- Pigeon Hole Y = 298.6 + 0.81*X, r^2 = 0.81 MAE=283 kg/ha;
- Toorak Y = 1076.0 + 0.36*X, r^2 = 0.34, MAE = 631 kg/ha;
- Wambiana Y = 648.6 + 0.64*X, r^2 = 0.66, MAE = 548 kg/ha

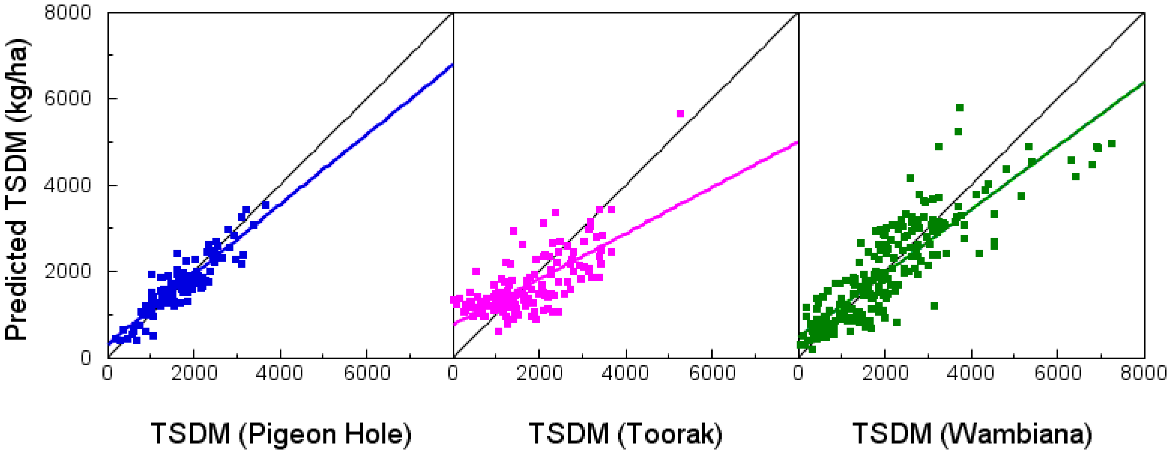

Figure 18. Observed and predicted TSDM for three grazing trials 8 parameter model:

- Pigeon Hole: Y = 310.2 + 0.81*X, r^2 = 0.81 MAE=240 kg/ha;
- Toorak: Y = 763.7 + 0.53*X, r^2 = 0.51, MAE = 525 kg/ha;
- Wambiana: Y = 471.5 + 0.74*X, r^2 =0.74, MAE = 515 kg/ha.

Paddock level

If high precision is required, then it may be feasible to calibrate individual paddocks by collecting data over time (i.e. years) and fitting to satellite data. While this is possible for long term grazing trials, it is unlikely to happen to any extent in the current grazing industry, although more rapid methodologies for field sampling are possible (Mundava *et al*. 2015).

Landsat covariates

Landsat provides time-series data for green cover, non-green (dry) cover, bare ground and persistent green cover fractions. It is likely that green ground cover has slightly different mass-to-cover compared to non-green cover with green cover possibly requiring more mass per unit cover than dry, as leaves are turgid and likely be more vertical. The grazing trial data set was inadequate to test this hypothesis as field data collections were at the end of the wet season and or at the end of the dry season when the green component is low. Analysis showed a log ratio of dry/bare log(bare/dry) to be more useful than functions with green cover in the context of the available data sets. In analysis of data from the Kimberley region, locally sensed NDVI has been shown been shown to be useful (in combination of other variables) for prediction of TSDM, perhaps because the calibration set included growing season samples (Mundava *et al*. 2015).

The time-series of green ground cover should provide an index of plant growth over preceding times. Use of average green ground cover over the last year is a proxy for growth via the "area under the curve" approach where it is assumed that subject to temperature constraints, that net primary production will be proportional to radiation interception by green cover or its surrogate NDVI (e.g. Hill *et al.* 2004). A challenge for this approach is describing the dynamics of root shoot partitioning and removal of growth by herbivores. There were significant improvements in TSDM estimates (especially at Wambiana in high TSDM years) Figure 18, when using a satellite derived growth "index" combined with persistent green and interaction terms. However, the grazing trial data is not suitable for directly estimating pasture growth due to carryover TSDM.

Temporal Scale

The alternative to fitting data by paddock over time is to sample all paddocks in a property at a single point in time, with the hope that there will be enough variation in space to adequately cover temporal variability. A one-off calibration by a property owner is more likely to succeed than a 5-10 year program, as occurs in scientific grazing trials. However, it is unlikely that a single sample will capture the necessary variation in greenness, climate variation and grazing.

Spatial Scale

The analysis fitted averaged pixel data to average paddock level TSDM. The functions derived ideally should only be applied at this scale and not to individual pixels to produce maps of TSDM within paddocks. The more complex functions are likely to produce noisy data at the individual pixel scale. The simple log(bare/dry) function would be more robust at this scale. Functions built from finer scale data (e.g. quadrat level estimates at Pigeon Hole), might be useful if geo-location was of sufficient accuracy to match TSDM values to a 3x3 set of pixels. While collection at this spatial is possible for long term grazing trials and programs such as TERN Rangelands, it is unlikely to happen to any extent in the current grazing industry and parameterisation at fine scale may not overcome changing mass-to-cover relationships at larger scales.

At Wambiana a semi-independent data set for November 2014 (field measured TSDM not included in fitting statistical models) was used to test scale issues. The log (bare/dry) ratio model was applied at the pixel level with TSDM (Figure 19) summed by pixel to estimate paddock mean TSDM. The algorithm was also evaluated using the paddock mean cover bare ground cover and paddock mean non-green (dry) cover for input. The TSDM estimates for the two scales (Figure 20) were slightly different, (pixel level calculation about 6% higher than paddock level calculation) due to the non-linear nature of the function applied. The overall results at both scales were poor with TSDM being underestimated in most paddocks and overestimated in heavily grazed paddocks.

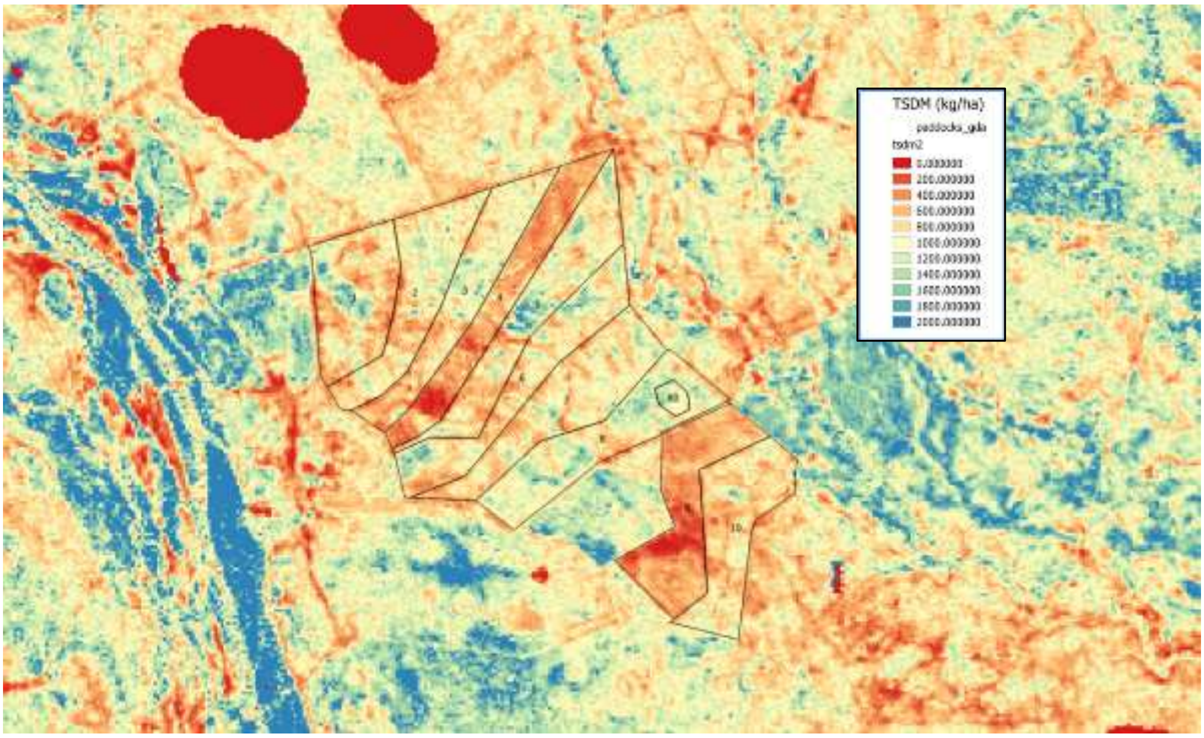

Figure 19 Predicted TSDM for Wambiana (November 2014), (large blobs are cloud mask)

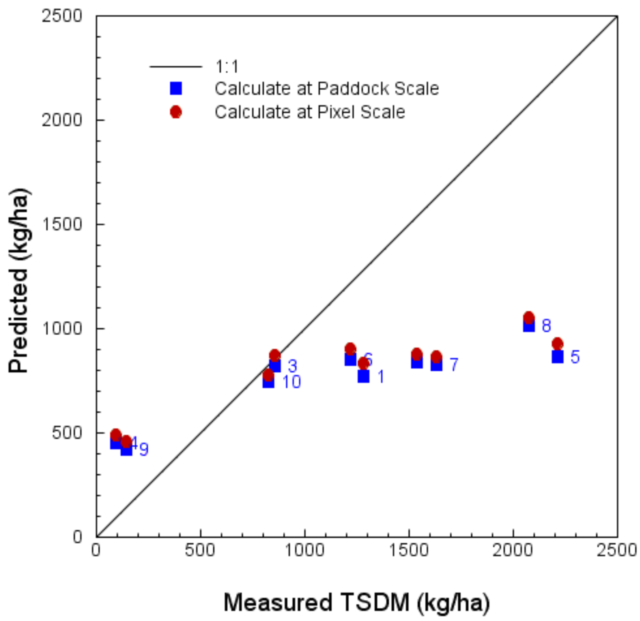

Figure 20. Measured and predicted TSDM for Wambiana (November 2014) calculated from Landsat data at two scales. Measured TSDM data was not used in calibration.

Pigeon Hole

This trial showed excellent results (Figures 17 and 21), where satellite based estimates of dry season TSDM seemed adequate. The low range of average utilisation rates in the trial, however, may not reflect industry practice. Persistent green was also quite low in this grazing trial (generally less than 6%) therefore; it would be unwise to apply the eight parameter model to more woody situations without further calibration.

Toorak

The Toorak grazing trial displayed by far the worst results of the analysis. There was little predictability of TSDM (Figures 17 and 21), despite the trial being small enough to have very uniform soils and rainfall compared to the other trials. The reason for the poor predictability is yet unknown, but potential causes are: effects of stocking rate and pasture utilisation, changing proportions of annual vs perennial species, trampling effects on soil crusts, litter dynamics and more climate variability.

A poor correlation is also observed between field cover and satellite cover (Table 1) with field cover and TSDM being slightly better correlated than satellite cover and TSDM. Toorak had by far the widest range of pasture utilisation rates 0-40% with the poorest fits for low utilisation/high biomass treatment.

Wambiana

The Wambiana trial had the highest woody cover (19.5%) of the three trials and algorithms gave reasonable predictions at low ground cover levels (Figures 17 and 21). Field observed cover was about 14% lower than satellite cover estimates and it is unclear if the bias is in the satellite data, field data or both.

At high cover levels biomass ranged from 2000 kg/ha to 7000 kg/ha for similar levels of cover (90-100%). TSDM predictions from satellite derived cover in good years are highly problematic in this system. Despite trial design (to explore multiple modes of grazing management), long term average pasture utilisation remained in the range 14-23% (Stone and McKeon 2013), which is likely constrained relative to variability in the industry and much less than at Toorak. This site also had no measurements of TSDM in the un-grazed control area, which also restricted data for calibration.

It should be noted that two significant fires occurred during the trial (Oct 1999 and Nov 2011). These fires significantly reduced woody foliage cover at the time of the fire (by 60-70%), with full woody recovery taking some time. The persistent green cover product is designed to minimise short term variability and extract long term average trends and thus, did not reflect the fires. This almost certainly degraded the statistics to some extent as ground cover is adjusted using the persistent green and not woody component on the day.

Biases due to woody canopy removal may be modified as pasture growth is likely to be better at the reduced woody canopy pasture. TSDM will likely be poorly estimated in woody systems that have a woody canopy removal event.

The increase in density of currant bush is captured in satellite data and its impacts were incorporated in the eight parameter model. The eight parameter model also improved estimates for high biomass years, where the inclusion the average greenness over the preceding year also seems to have improved predictions.

Tests with a TSDM data set not used in satellite calibration indicated quite poor performance for the log(bare/dry) model (Figure 20).

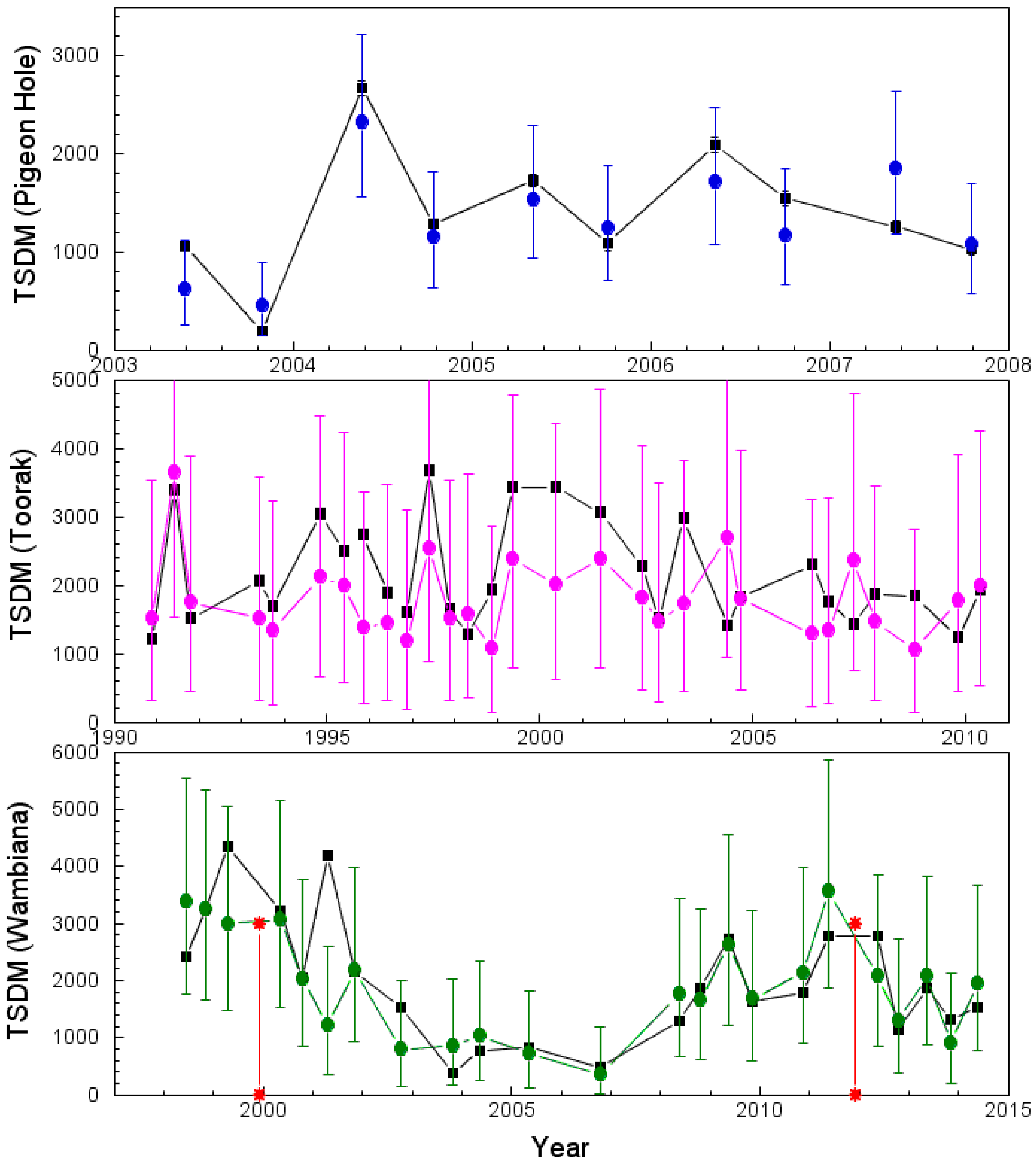

Figure 21. Time series of observed and predicted TSDM log(bare/dry) method for selected paddocks in three grazing trials (Pigeon Hole: "Barra Paddock"; Toorak: "20% Utilization Paddock"; and Wambiana "Paddock 2"). Red lines indicate fires at Wambiana. Error bars indicate 95% prediction limit.

Modelling

This modelling exercise converts TSDM to an estimate of cover. A test of using the two forms of the cover equation used in the GRASP model (using the field measured biomass and satellite total cover), showed that there was little difference between the function forms in terms of fit statistics, with the green cover formulation tending to be marginally better.

Using Landsat green ground cover as for calibration target for GRASP indicated that it was not easy to simulate the full green cover time series while maintaining a good simulation of TSDM. Parameter adjustments needed to match modelled and satellite green were more complex than initially assumed and not fully explored. Some model development is required to address issues such as correctly estimating dead material covering green, death rate of green, and litter dynamics.

Recommendations

Field Data

- More effort in ensuring good operator calibration for field based cover estimates.
- Influence TERN rangelands monitoring to collect pasture biomass when collecting biodiversity and cover information.
- Use existing field stations (e.g. Spyglass, Brian Pastures, Kidman Springs) to provide integrated field measurement programs that address knowledge gaps for remote sensing and modelling.
- Assemble TSDM data for Tier 2 locations (Appendix 5) and test established functions.
- Assemble sub-paddock scale data from Pigeon Hole and test if calibration can be improved at small plot and land type scales.
- Capture GIS data for historical grazing trials to enable studies such as this.

Remote sensing

- Test if pasture growth measured at various "Gunsynd / Swiftsynd" sites can be estimated from an "area under the NDVI or green cover curve" methodology using Landsat and or MODIS platforms.
- Improve satellite estimates of NVP and BS for locations with bright soils using the Wambiana data as one of the test locations.
- Effort to identify causes of occasional spikes and dropouts in the Landsat cover times-series data.
- Evaluate if a rolling average / median / medoid (Flood, 2013) for cover is superior to single date data (see above).
- Improve data extraction system to supply data at points (e.g. 3x3 pixels) as well as polygons.
- Improve data extraction procedure to cope with east/west scene boundaries.
- Investigate if tree canopy removing fires could be included in a variant of the persistent green cover product to improve ground cover estimates.

Test requirements for any development of an operational system

- Use data from the tier 2 grazing trials to conduct a fully spatially independent evaluation of parameters for TSDM estimation selected from the "best matched" of the three calibrated grazing trials and any future satellite to biomass models developed.

- Investigate variations on "average 365 days of green cover" (e.g. add 24, 18, 6, and 3 months as additional independent variables).
- Assess level of accuracy required to provide better estimates of TSDM than currently being used by the grazing industry. For example the large errors (often under-estimates) at high biomass and cover levels may not be a limiting factor. Would information derived from prediction limits be useful? e.g. "There is a 95% chance that TSDM is between 0 kg/ha and 950 kg/ha".

- Assessment of timing requirements (i.e. is a seasonal mean from composite images good enough or is information required from single date images) or is better than Landsat frequency required?

- What are the prospects for gathering enough quality biomass data to enable calibration at the paddock, property or land type scale (e.g. crowd sourcing, funded large scale sampling campaign etc.)

Modelling

- Inclusion of a new management record data type (Fractional cover) into GRASP functionality.
- In new version of GRASP the runoff cover function is eventually replaced with the function used for green cover.
- A cover algorithm that accounts for layered cover and litter should be implemented in the future. Modelling where satellite cover data is used in calibration / validation may require modifications to parameters to reflect the differences between quadrat based cover and point intercept based measures.
- Modelling at the paddock and property scale should take advantage of remote sensed products for validation and possible calibration with due regards to the cover method and model parameters.

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Acknowledgments

We would like to thank the owners of Wambiana and Pigeon Hole for making land on their properties available for research. The individuals, who participated in field sampling over many years, are thanked for their great efforts. We thank Meat and Livestock Australia for proving funding for this investigation, the CRC Spatial Information for project co-ordination and the Queensland Government for staff resources.

Appendix 1 Pigeon Hole Grazing Trial (site 1)

Data prepared and collated with the assistance of Robyn Cowley and other members of the NT government.

Analysis: John Carter, Rebecca Trevithick, Grant Stone

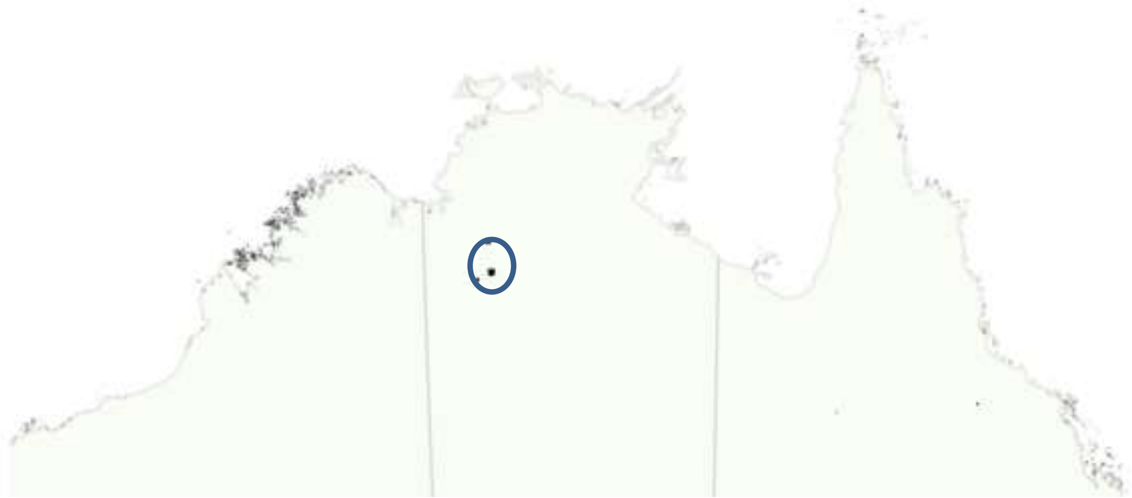

Figure 1. Location: Pigeon Hole Station (circled), 400 kilometres south-west of Katherine, Northern Territory.

Period of study: 2003-07

The 300km^2 Pigeon Hole site was sampled over a two week period, by up to 10 observers, with most paddocks taking > 1 day to sample.
There was usually a day of rest during the 2 week period, and sometimes paddocks were sampled before and after day of rest.
Where > 1 day use first date if 2 days
Where three days, use mid date
Where four days, use 2nd date
Where five days, use mid date
Refer to date summary tab "all data collection dates" for actual dates sampled

The following paddocks have small exclosures in them. They were sampled as part of the larger paddock, and are included in paddock summaries

- Brolga
- Bauhinia
- Dead Cat
- Sandstone
- Villiers

The second grazing study, at Pigeon Hole Station in the VRD, was also conducted on fertile black cracking clay soils. The Pigeon Hole paddocks tended to be in C land condition and the optimum utilisation rate for balancing land condition and animal production targets was found to be 19% (Hunt et al. 2010). The stocking rates required to achieve a 19% average utilisation rate ranged between 9 and 17 AE/km² depending on season. Average utilisation rates between 13% and 17% had positive or stable trends in plant species composition and cover whilst an average utilisation rate of 24% failed to meet some important yield and cover targets at Pigeon Hole Station (Hunt et al. 2010). A higher average utilisation rate (32%) resulted in the greatest decline in land condition, negative trends in species composition and an increased risk of unacceptably low ground cover levels (Hunt et al. 2010).

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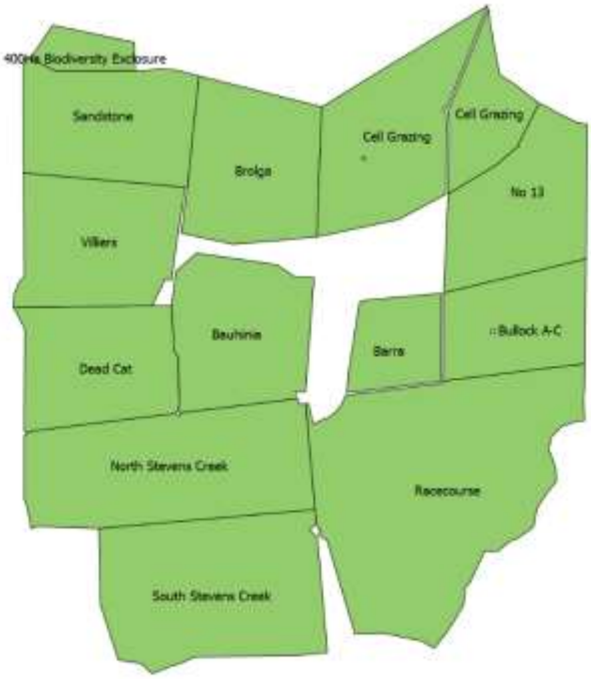


Figure 2. The Pigeon Hole grazing trial

Table 1. Paddock treatments of the Pigeon Hole grazing trial

PaddockName	Treatment	Target Util	Years Of Study	AreaKM2	PdkPerimkm
Barra	1km Grazing Radius/1 Water	20	2003-2007	8.9	12.0
Bauhinia	25% Utilisation	25	2003-2007	21.5	18.2
Brolga	15% Utilisation	15	2003-2007	21.8	18.6
Bullock A-C	Wet Season Spell	20	2003-2007	15.4	16.9
Cell Grazing	Cell Grazing	20	2003-2007	32.6	37.6
Dead Cat	40% Utilisation	40	2003-2007	20.0	18.4
No 13	Set Stocking	20	2003-2007	20.6	19.0
North Stevens Creek	2 Waters	20	2003-2007	34.3	26.2
Racecourse	Multiple Waters	20	2003-2007	57.0	33.6
Sandstone	20% Utilisation/2km grazing radius/Set Utilisation	20	2003-2007	21.3	19.1
South Stevens Creek	3km Grazing Radius	20	2003-2007	34.5	24.1
Villiers	30% Utilisation	30	2003-2007	21.7	19.1

Table 2. Paddock output of the Pigeon Hole grazing trial

Paddock Number	Paddock	Area (Ha)	No Pixels	Long term %Util	Ave obs TSDM	Persistent green (tree cover)	Total cover (ground cover)
1	Barra	892	9893	23	1289	4.2	64.8
2	Bauhinia	2146	23834	25	1651	5.6	81.4
3	Brolga	2183	24255	15	1860	5.0	81.9
4	Biodiversity	400	4396	-	2731	6.3	86.0
5	Bullock A-C	1541	17094	28	1220	5.2	68.4
6	Cell Grazing	3263	36255	25	1620	4.6	79.1
7	Dead Cat	2002	22250	44	1398	6.3	73.8
8	No 13	2058	22866	22	1293	6.1	70.9
9	North Stevens Creek	3428	38108	20	1717	5.4	79.5
10	Racecourse	5705	63379	20	1441	5.9	79.2
11	Sandstone	2131	23730	20	1903	5.7	80.1
12	South Stevens Creek	3448	38301	20	1715	5.2	76.9
13	Villiers	2170	24109	30	1587	6.1	76.2

Appendix 2 Toorak Grazing Trial (site 2)

Data prepared and collated with the assistance of Madonna Hoffman and David Phelps from the Queensland Department of Agriculture Fisheries and Forestry

Analysis: John Carter, Rebecca Trevithick, Grant Stone

Period of study: June 1984 - May 2010

TSDM collected annually from June 1984 – May 1999 then twice yearly (May and November) until May 2010. In 2001, 2003 there were May samplings only

Figure 1. Location: Toorak research station (circled), 45km south of Julia Creek, Queensland

Treatments were 0, 10, 20, 30, 50 and 80% utilisation (subsequently referred to as treatments U0, U10, U20, U30, U50 and U80) of the total herbage mass on a DM basis at the end of summer except in 1988 where the mass of the sub-shrub *Salsola kali* was excluded for animal welfare reasons. The months of April and May are generally used as the end of the summer growing period in northern Australia. Weathered grass stalks carried over from the previous growing seasons were excluded. Paddock sizes were 1, 54, 27, 18, 12 and 7 ha for treatments U0, U10, U20, U30, U50 and U80, respectively (Fig. 1), having been scaled to be grazed by 20 sheep each at the commencement of grazing in June 1984.

At the end of each summer (April or May), Merino wethers with a fat score of 2.5 or higher were stratified on shorn live weight and allocated to treatment paddocks using the formula NS = Y/ISUPS where: NS is sheep numbers, Y is herbage mass (kgDMha–1), IS is the intake by sheep (kg dry sheep equivalent–1 and assumed to be 400 kg), U is utilisation level (%) and PS is paddock size (ha). Grazing commenced in July 1984. Herbage mass Herbage mass was estimated at the end of the summer growing season in 1984 and 1985 using a tied rank technique (Halls and Dell 1966) and in subsequent years using BOTANAL (Tothill et al. 1992). Only total herbage mass was recorded in 1984 and 1985. Since May 1986, herbage mass and species composition were measured by between four and nine trained operators who assessed a minimum of 60, 250, 200, 150, 140 and 80 quadrats (not permanent quadrats), each 0.50.5 m, in the U0, U10, U20, U30, U50 and U80 treatments, respectively.

The calibration data of individual operators were used to adjust their individual rankings to herbage mass of the different species. *Astrebla* spp. were combined at the genus level until 1993 when *A. squarrosa* was recorded separately following observations that its occurrence was declining on the high levels of utilisation treatments. This paper reports total herbage mass and that of *Astrebla* spp. and *Iseilema* spp. (pasture dominants) while plant species richness and abundance is reported in Orr and Phelps (2013 14?).

Orr, D. M., and D. G. Phelps. "Corrigendum to: Impacts of level of utilisation by grazing on an Astrebla (Mitchell grass) grassland in north-western Queensland between 1984 and 2010. 1. Herbage mass and population dynamics of Astrebla spp." *The Rangeland Journal* 36.3 (2014): 309-309.

Pringle, M. J., et al. "The effect of pasture utilization rate on stocks of soil organic carbon and total nitrogen in a semi-arid tropical grassland." *Agriculture, Ecosystems & Environment* 195 (2014): 83-90.

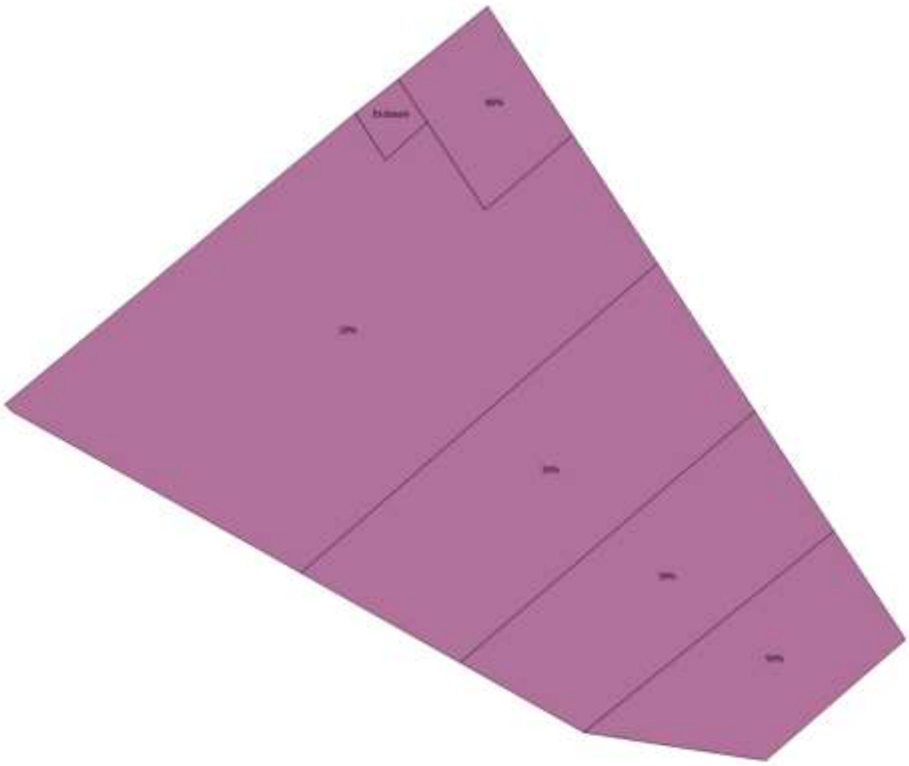


Figure 2. The Toorak grazing trial

Table 1. Paddock output of the Toorak grazing trial

Paddock Number	Paddock Name	Area (Ha)	No Pixels	Long term %Util	Ave obs TSDM	Persistent green (tree cover)	Total cover (ground cover)
1	10%	55.6	611	11	2388	0.7	63.3
2	20%	27.3	310	18	2153	0.8	63.1
3	30%	17.9	197	24	1703	1.2	57.6
4	50%	12.4	140	31	1351	1.1	54.9
5	80%	6.5	73	40	930	1.1	55.5
6	Exclosure	1.1	12	0	2497	0.7	68.6

Appendix 3 Wambiana Grazing Trial (by paddock) Site 3

Data prepared and collated with the assistance of Peter O'Reagain and John Bushell from the Qld Dept of Agriculture Fisheries and Forestry

Analysis: John Carter, Rebecca Trevithick, Grant Stone

Location: 70km south west of Charters Towers, Queensland

10 paddocks + 1 exclosure (no sampling)

Sample date: 6/12/1998 – 20/5/2014

Sample timing: end of wet season (April, May) end of dry season (October, November)

Sample data: TSDM, cover

Method of sample: Botanal, visual estimate of cover

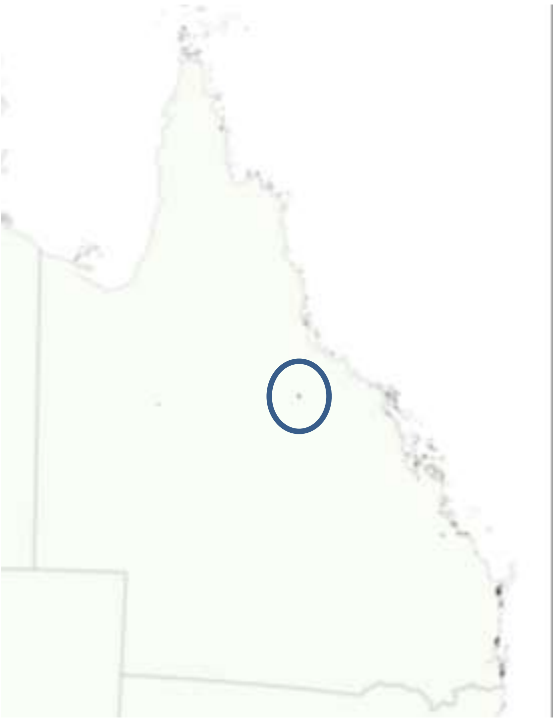


Figure 1. The Wambiana grazing trial location: south west Charters Towers (circled)

O'Reagain, P. J., and J. J. Bushell. *The Wambiana grazing trial: key learnings for sustainable and profitable management in a variable environment*. Department of Employment, Economic Development and Innovation, 2011.

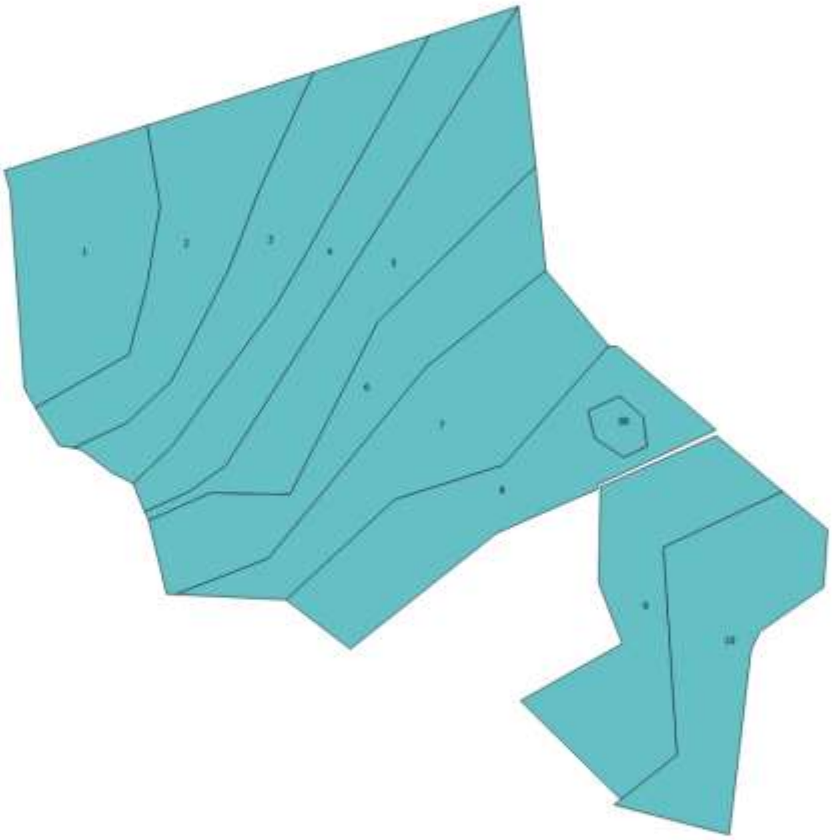


Figure 2. The Wambiana grazing trial

Table 1. Paddock output of the Wambiana grazing trial

Paddock	Area (Ha)	No Pixels	Long term %Util	Ave obs TSDM	Persistent green (tree cover)	Total cover (ground cover)
1	97	1075	19.5	2024	19.5	80.7
2	99	1096	14.3	1907	19.8	81.5
3	97	1084	16.8	2130	21.6	87.6
4	92	1023	21.2	1415	22.0	82.6
5	114	1267	13.9	2228	19.3	87.4
6	103	1148	17.4	1662	19.6	79.6
7	115	1282	13.4	2107	18.4	80.6
8	106	1181	14.7	2236	18.1	81.6
9	103	1138	23.0	1806	18.0	83.1
10	101	1122	15.8	1856	18.4	84.1

Appendix 4 Wambiana Grazing Trial (site 4, by paddock and land type)

Stone, G. S. and McKeon G. M. (2013). Grazing trials for liveweight gain analysis, Appendix 3. In Improved empirical models of cattle growth, reproduction and mortality from native pastures in northern Australia Project Report B.NBP.0641 Meat & Livestock Australia Brisbane.

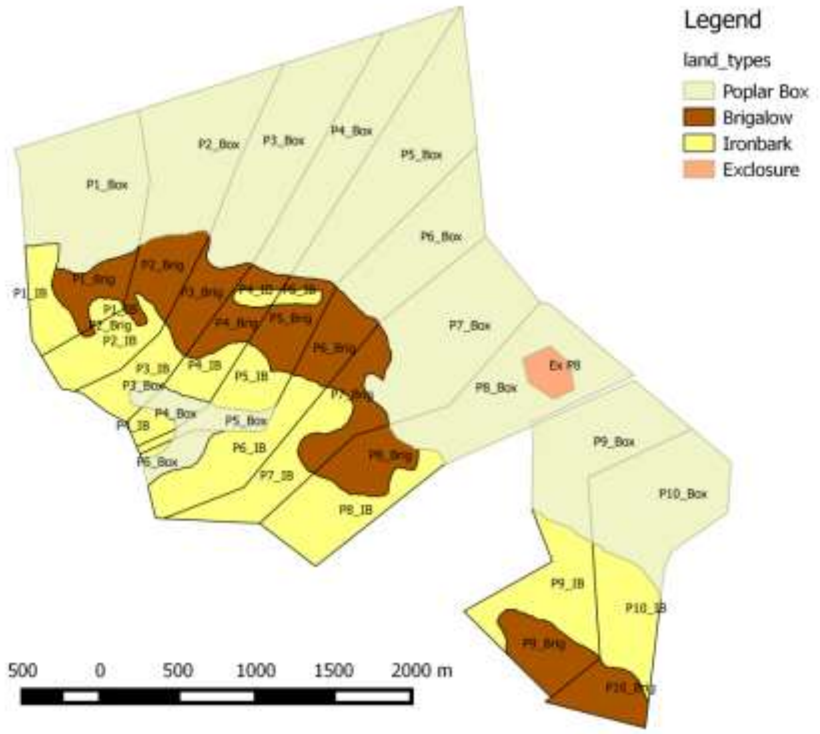
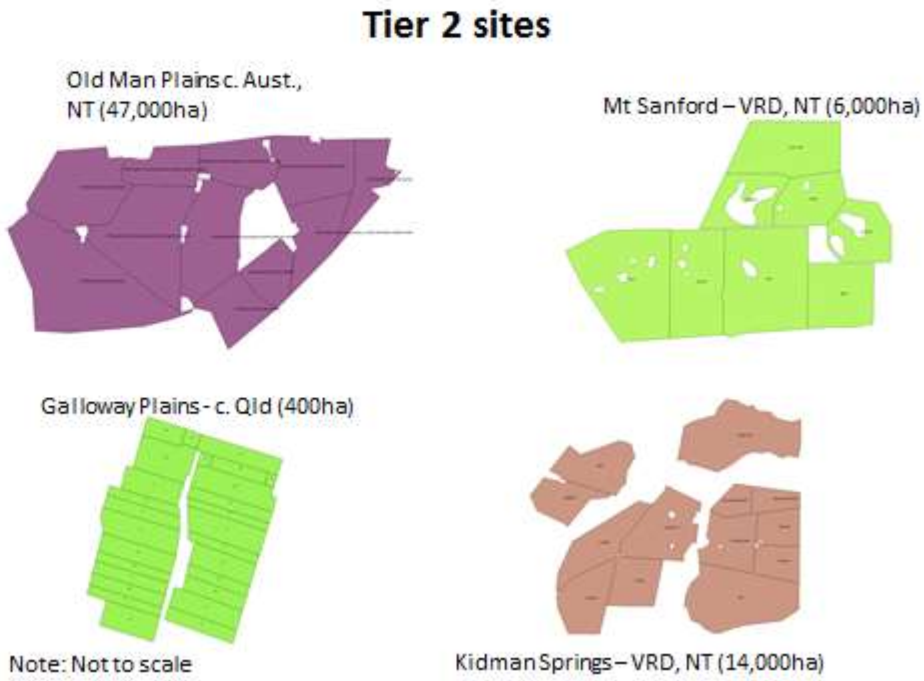


Figure 1. The Wambiana grazing trial with land types.

Table 1. Land type summary for the Wambiana grazing trial

Paddock Number	Paddock	Area (Ha)	No Pixels	Long term %Util	Ave obs TSDM	Persistent green (tree cover)	Total cover (ground cover)
1	P1_Box	65.9	729	-	2021	19.8	82.2
2	P1_Brig	13.7	151	-	2237	18.3	83.5
3	P1_IB	17.3	195	-	1686	18.2	79.7
4	P2_Box	58.5	650	-	2063	21.1	83.2
5	P2_Brig	18.8	212	-	1996	18.5	85.3
6	P2_IB	21.5	234	-	1717	19.0	85.9
7	P3_Box	65.7	728	-	2338	22.7	89.1
8	P3_Brig	15.9	182	-	2113	22.3	87.0
9	P3_IB	15.2	174	-	1831	18.9	85.5
10	P4_Box	60.9	676	-	1524	22.3	79.8
11	P4_Brig	13.4	150	-	1418	23.5	84.4
12	P4_IB	18.0	115	-	1414	19.4	84.9
13	P5_Box	80.8	891	-	2555	21.1	90.3
14	P5_Brig	16.5	186	-	2491	19.2	86.6
15	P5_IB	17.2	146	-	2177	18.6	88.7
16	P6_Box	53.2	595	-	1824	22.9	88.0
17	P6_Brig	16.7	183	-	1769	20.1	77.7
18	P6_IB	32.9	370	-	2097	18.7	87.0
19	P7_Box	69.1	767	-	2409	21.0	83.4
20	P7_Brig	19.3	217	-	2554	19.0	87.0
21	P7_IB	26.8	298	-	2465	18.2	87.6
22	P8_Box	57.5	638	-	2667	20.0	84.1
23	P8_Brig	17.7	195	-	2463	16.0	87.5
24	P8_IB	31.1	347	-	2543	19.0	87.7
25	P9_Box	49.6	545	-	1963	21.8	85.6
26	P9_Brig	19.1	213	-	1730	16.3	84.1
27	P9_IB	34.3	380	-	1828	15.7	84.7
28	P10_Box	57.1	635	-	1793	85.9	21.4
29	P10_Brig	16.1	177	-	1865	16.0	86.7
30	P10_IB	27.8	310	-	2085	16.7	86.7

Appendix 5 (Tier 2 and Tier 3 grazing trials for future analysis).

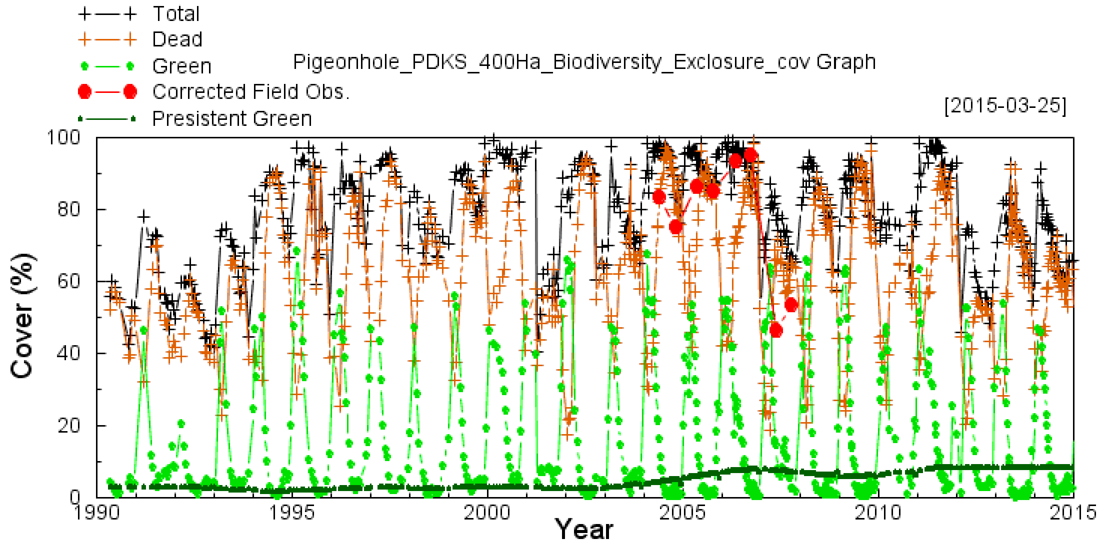


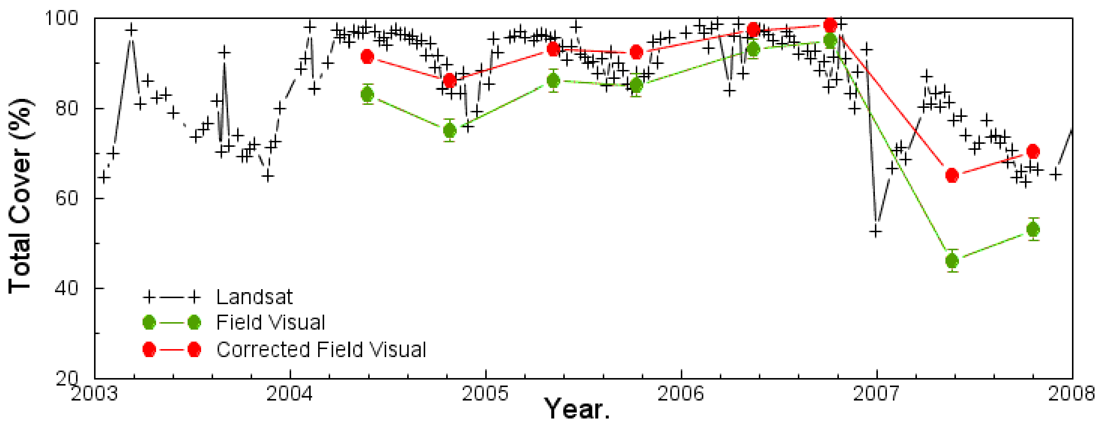
Tier 3 Potential Sites.

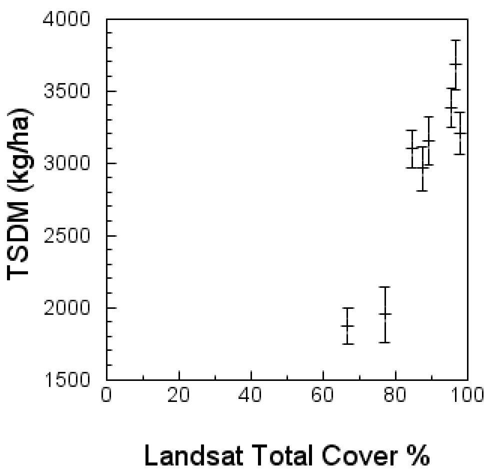
Appendix 6 Plots of Cover time series and TSDM

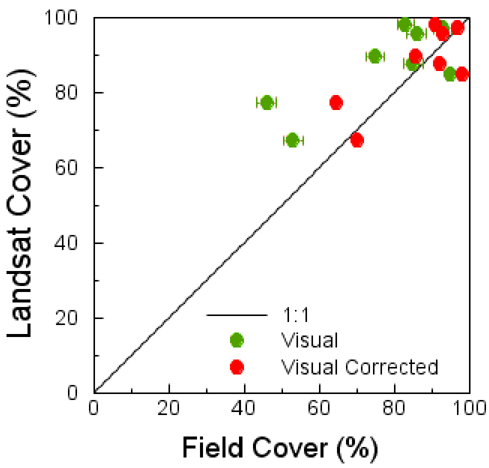
Plots showing satellite and field measured cover and its components over the duration of each trial.

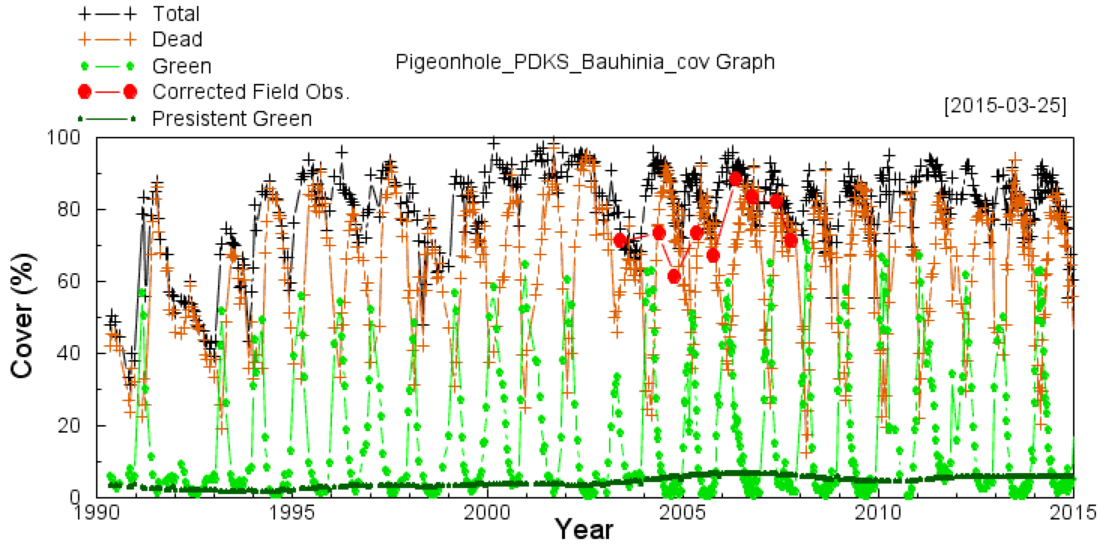
- Pigeon Hole (13 plots)
- Toorak (6 plots)
- Wambiana (10) plots
- Wambiana Land types (30 plots)

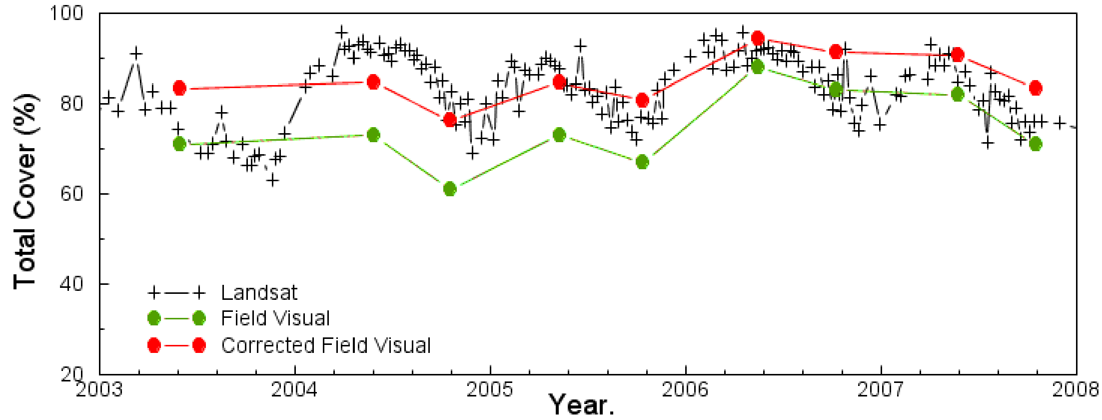

Total
Dead
Green
Corrected Field Obs.
Presistent Green
Pigeonhole_PDKS_400Ha_Biodiversity_Exclosure_cov Graph
[2015-03-25]
Cover (%)
Year


Total Cover (%)
Landsat
Field Visual
Corrected Field Visual
Year.


TSDM (kg/ha)
Landsat Total Cover %


Landsat Cover (%)
1:1
Visual
Visual Corrected
Field Cover (%)


Total
Dead
Green
Corrected Field Obs.
Presistent Green
Pigeonhole_PDKS_Bauhinia_cov Graph
[2015-03-25]
Cover (%)
Year


Total Cover (%)
Landsat
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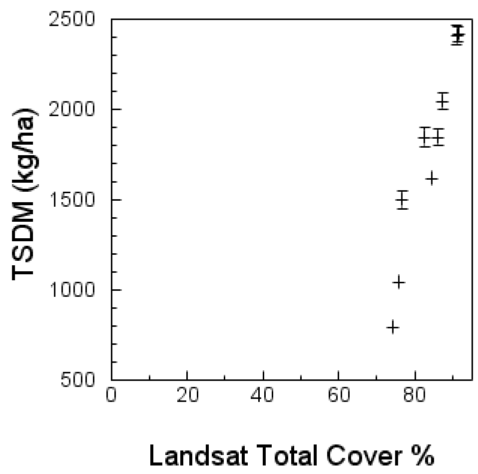
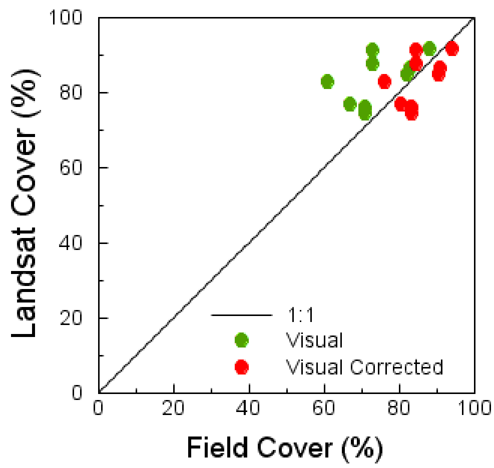
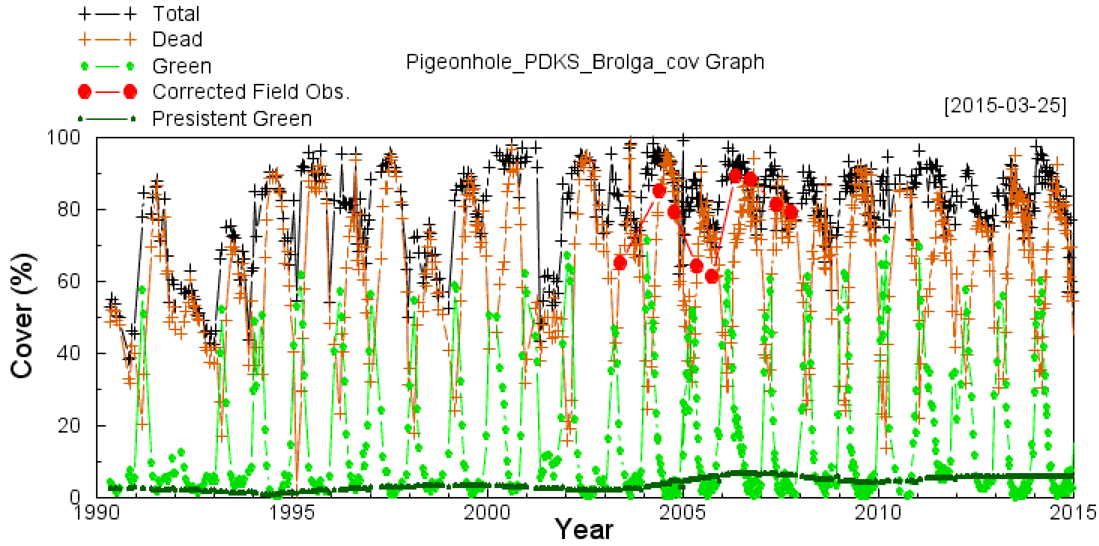
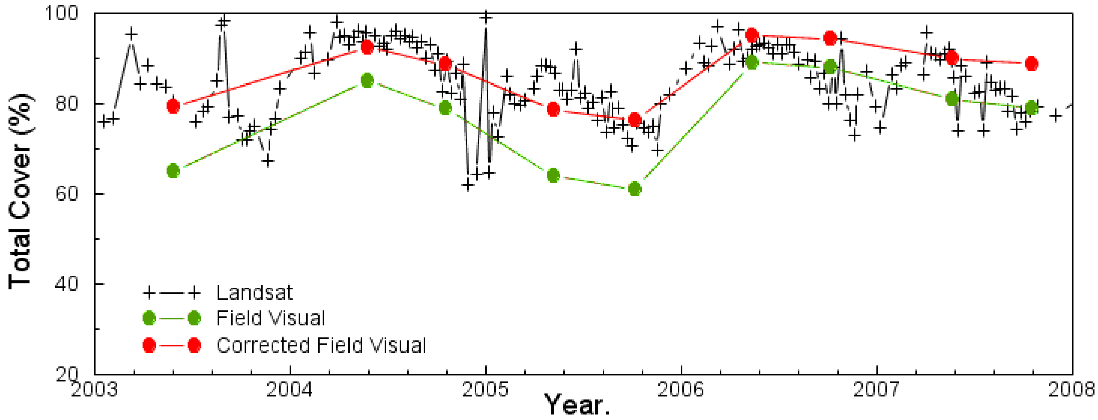
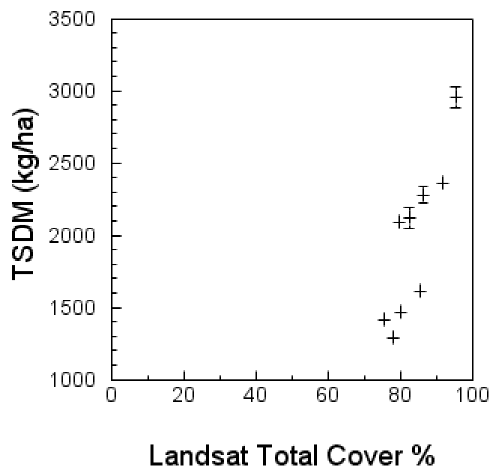
Year.

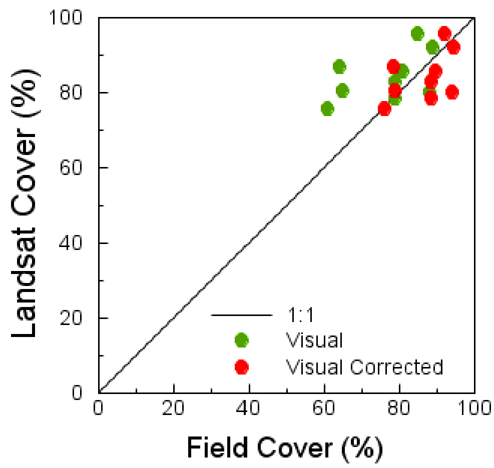

TSDM (kg/ha)
Landsat Total Cover %

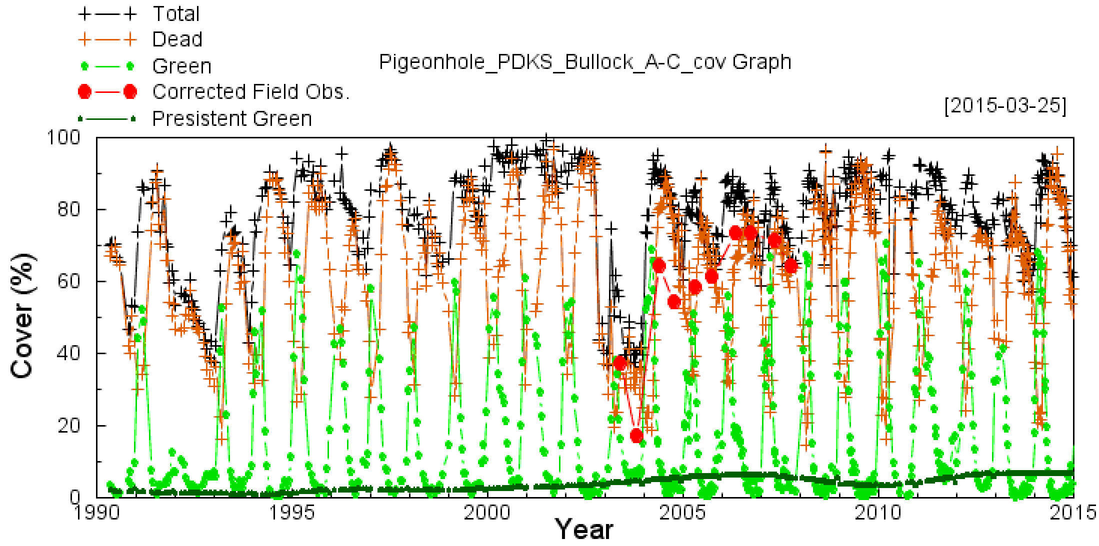

Landsat Cover (%)
1:1
Visual
Visual Corrected
Field Cover (%)

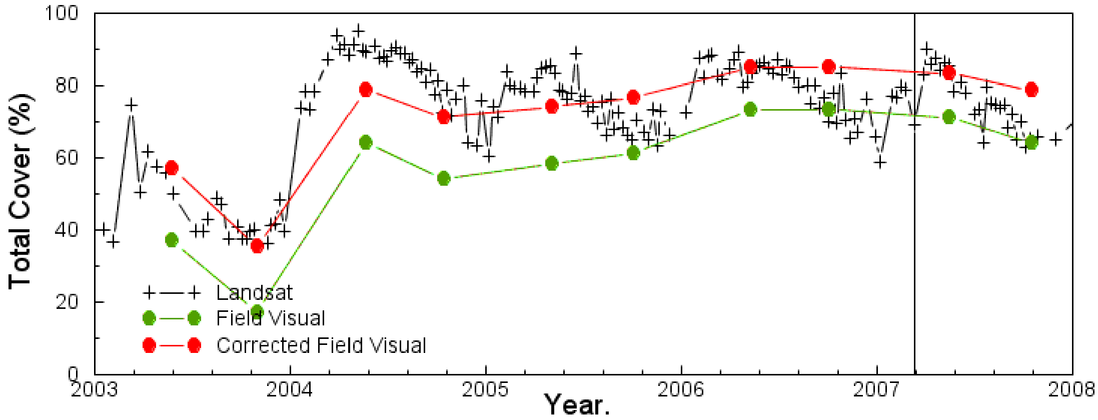

Total
Dead
Green
Corrected Field Obs.
Presistent Green
Pigeonhole_PDKS_Brolga_cov Graph
[2015-03-25]
Cover (%)
Year

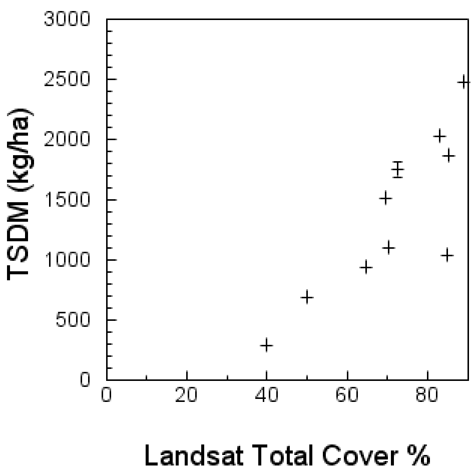

Total Cover (%)
Landsat
Field Visual
Corrected Field Visual
Year.

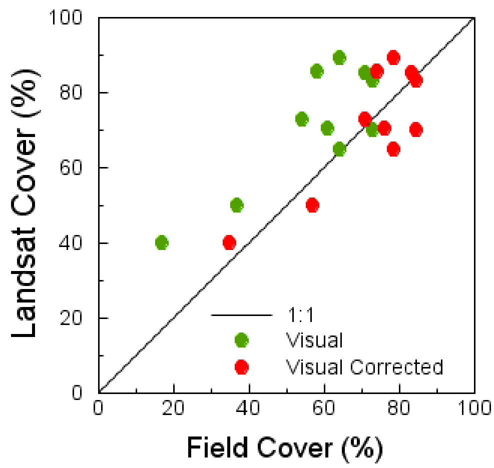

TSDM (kg/ha)
Landsat Total Cover %

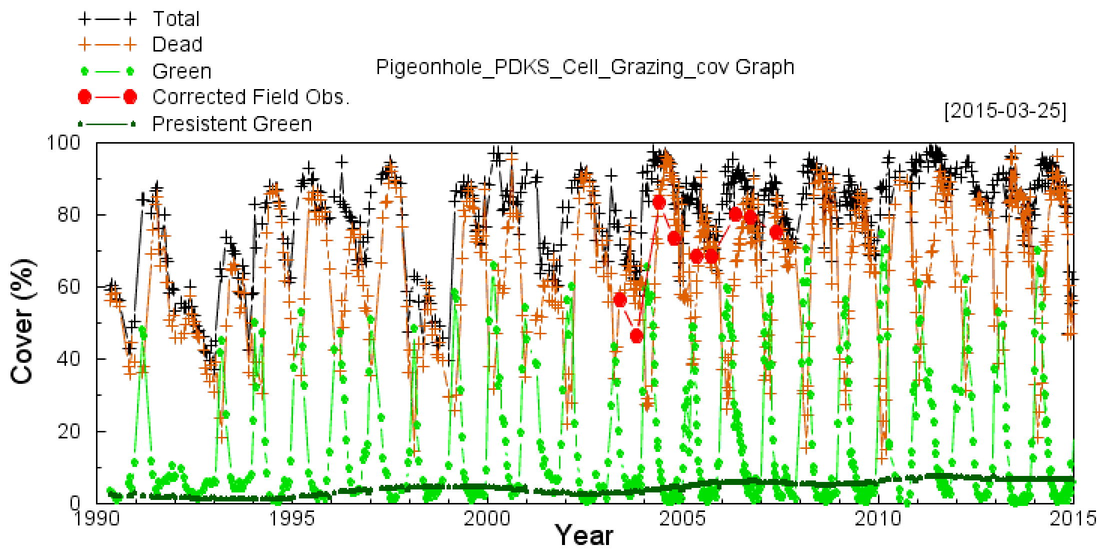

Landsat Cover (%)
1:1
Visual
Visual Corrected
Field Cover (%)

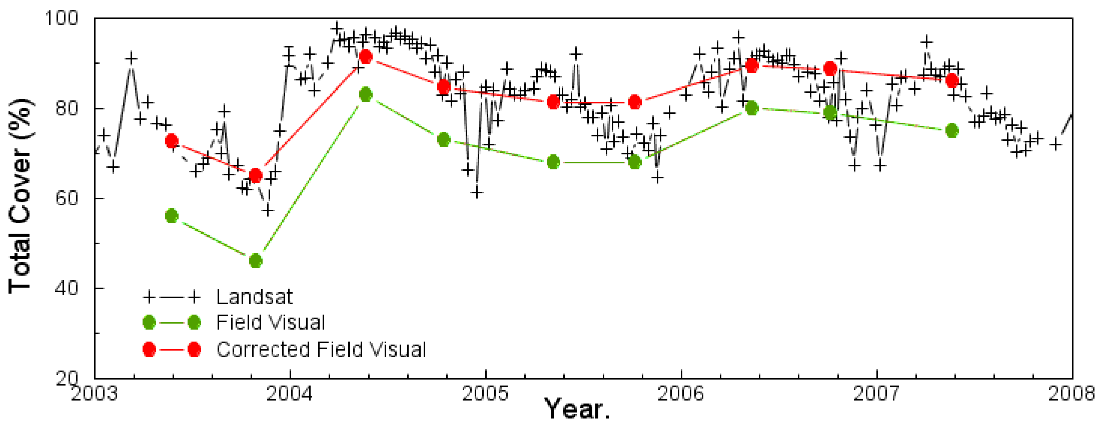

Total
Dead
Green
Corrected Field Obs.
Presistent Green
Pigeonhole_PDKS_Bullock_A-C_cov Graph
[2015-03-25]
Cover (%)
Year

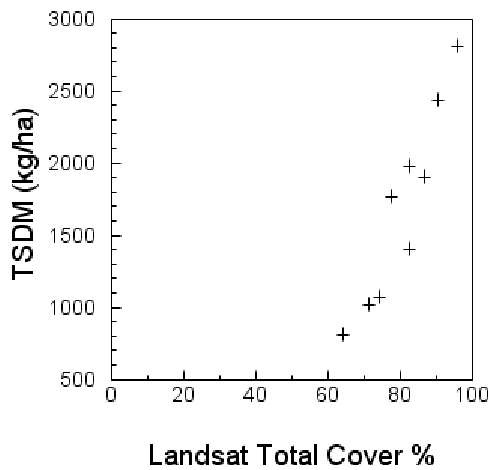

Total Cover (%)
Landsat
Field Visual
Corrected Field Visual
Year.

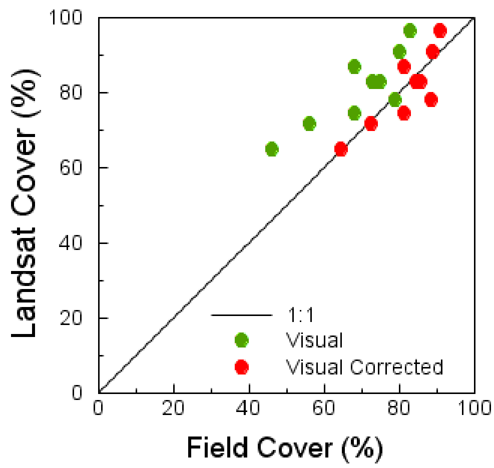

TSDM (kg/ha)
Landsat Total Cover %

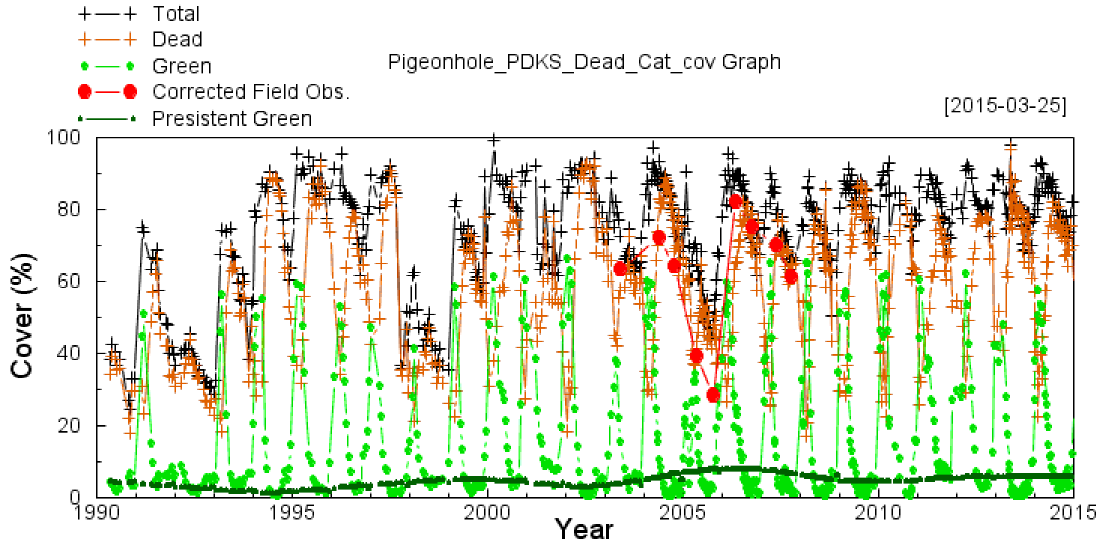

Landsat Cover (%)
1:1
Visual
Visual Corrected
Field Cover (%)

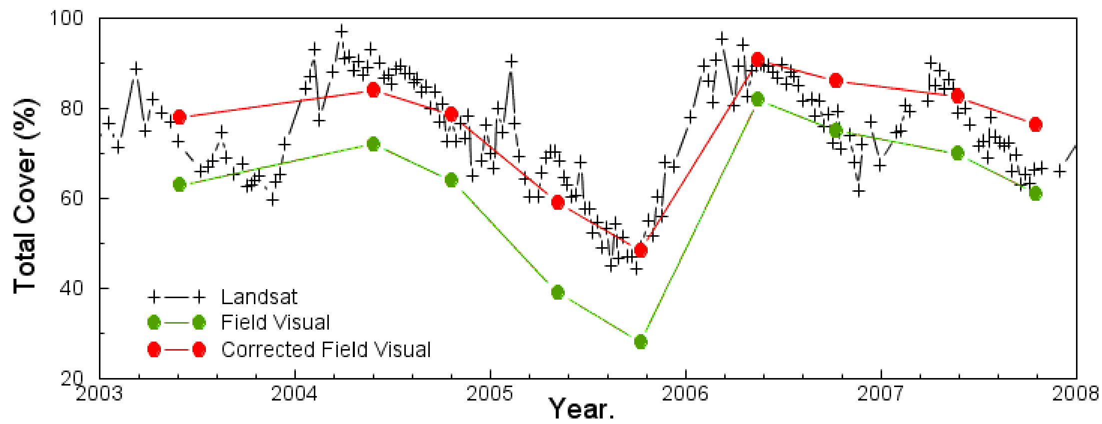

Total
Dead
Green
Corrected Field Obs.
Presistent Green
Pigeonhole_PDKS_Cell_Grazing_cov Graph
[2015-03-25]
Cover (%)
Year
0
20
40
60
80
100
1990
1995
2000
2005
2010
2015

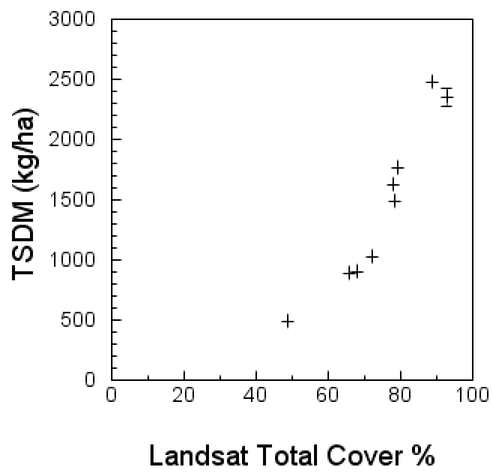

Total Cover (%)
Year.
Landsat
Field Visual
Corrected Field Visual
20
40
60
80
100
2003
2004
2005
2006
2007
2008

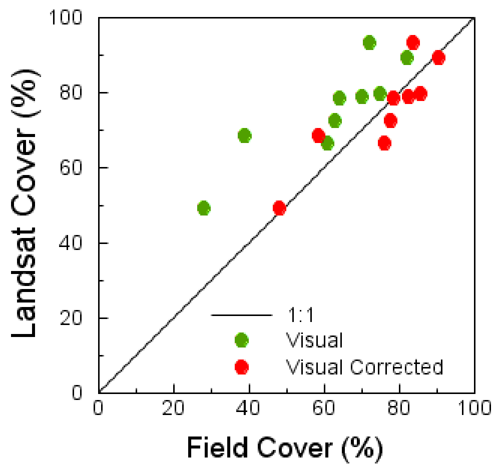

TSDM (kg/ha)
Landsat Total Cover %
500
1000
1500
2000
2500
3000
0
20
40
60
80
100

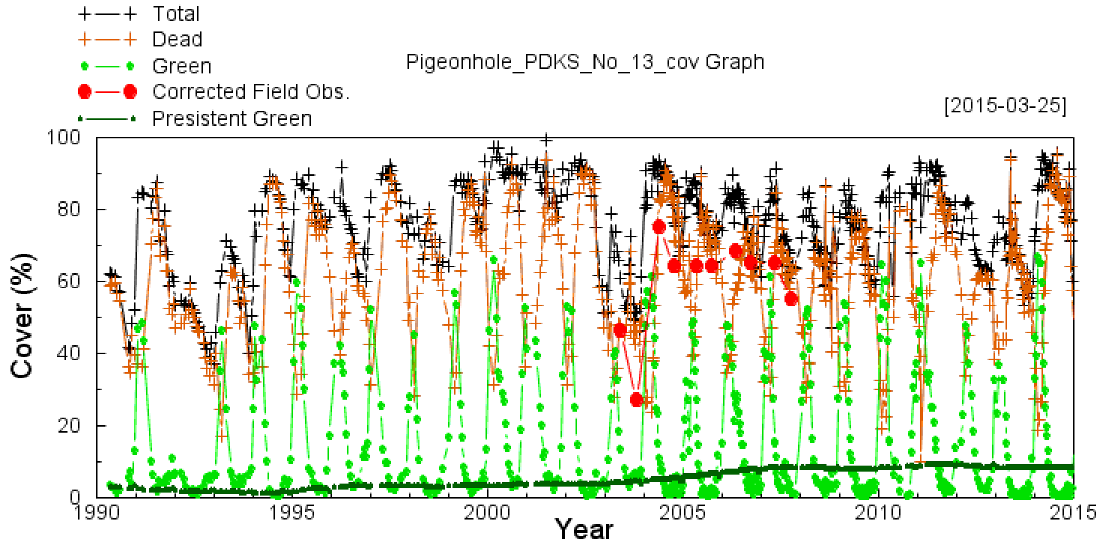

Landsat Cover (%)
Field Cover (%)
1:1
Visual
Visual Corrected
0
20
40
60
80
100

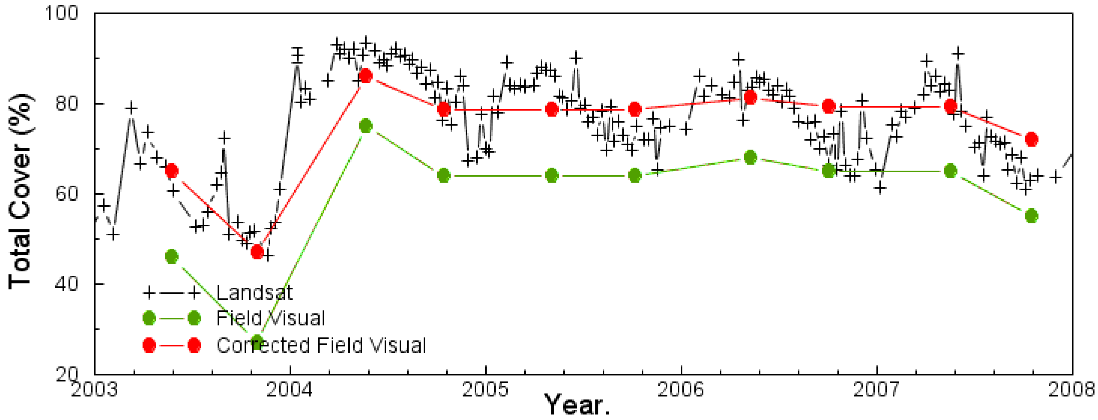

Total
Dead
Green
Corrected Field Obs.
Presistent Green
Pigeonhole_PDKS_Dead_Cat_cov Graph
[2015-03-25]
Cover (%)
Year

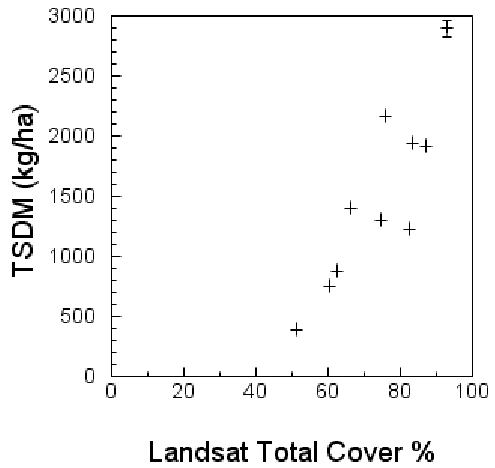

Total Cover (%)
Landsat
Field Visual
Corrected Field Visual
Year.

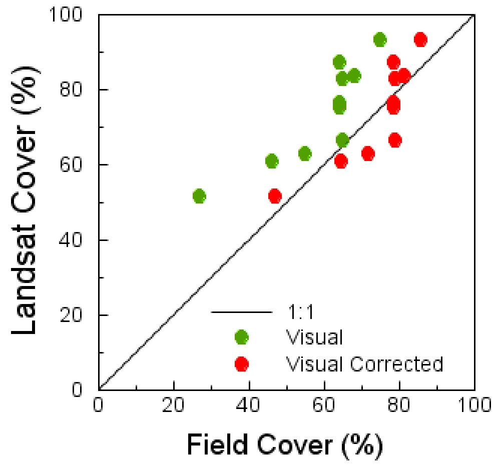

TSDM (kg/ha)
Landsat Total Cover %

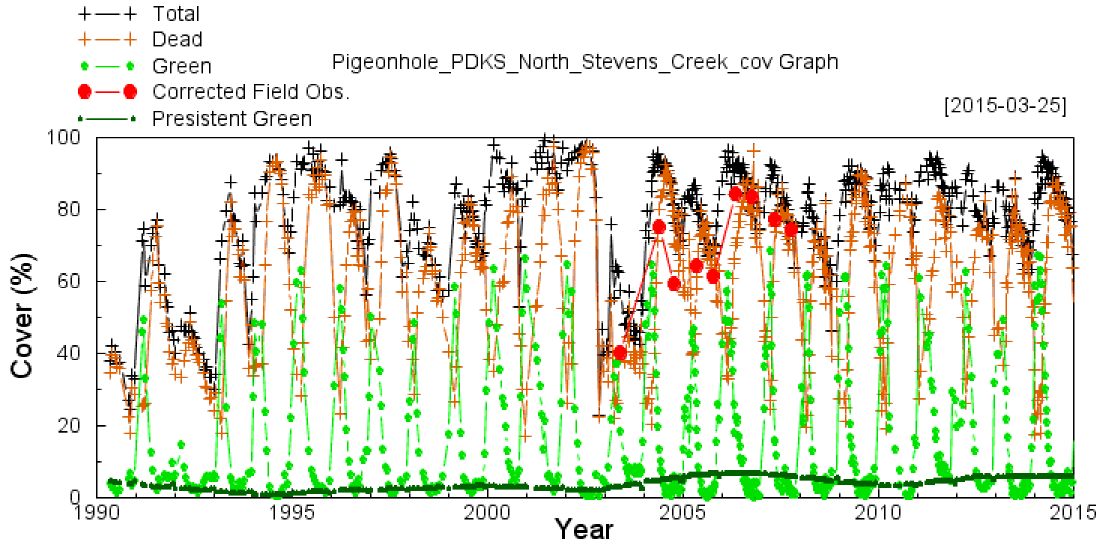

Landsat Cover (%)
1:1
Visual
Visual Corrected
Field Cover (%)

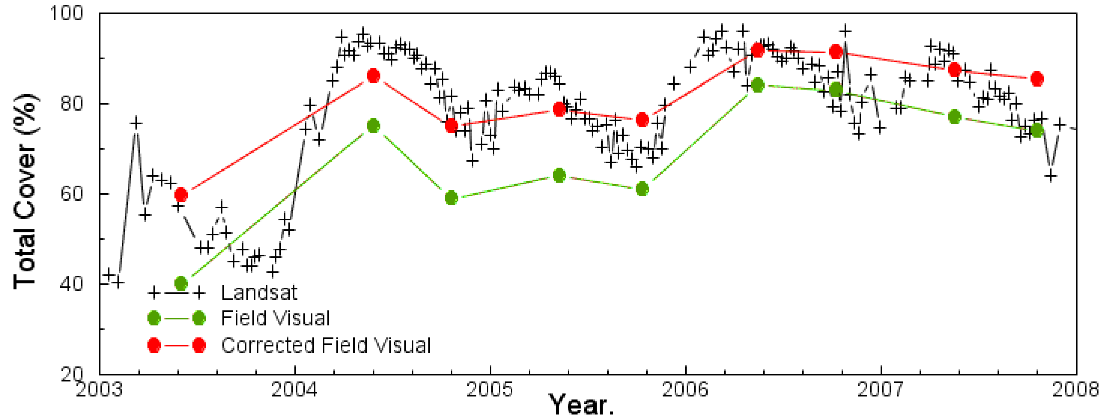

Total
Dead
Green
Corrected Field Obs.
Presistent Green
Pigeonhole_PDKS_No_13_cov Graph
[2015-03-25]
Cover (%)
100
80
60
40
20
0
1990
1995
2000
2005
2010
2015
Year

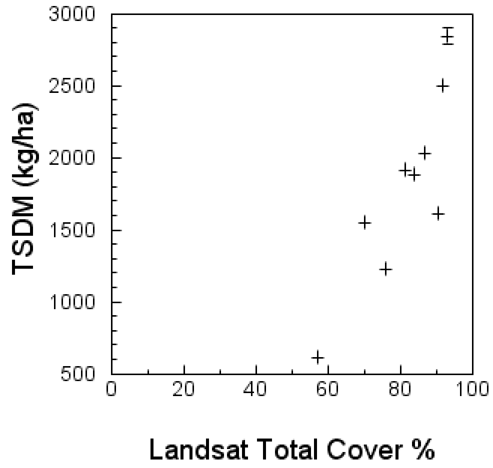

Total Cover (%)
100
80
60
40
20
Landsat
Field Visual
Corrected Field Visual
2003
2004
2005
2006
2007
2008
Year.

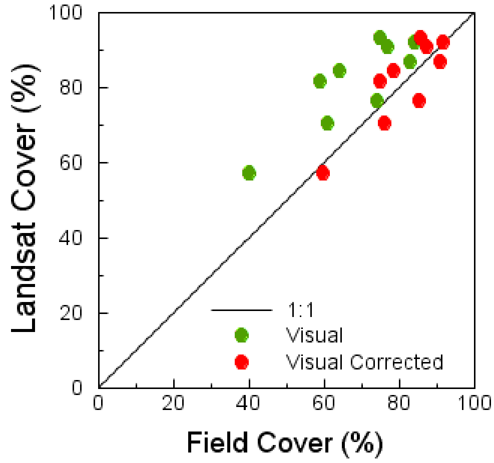

TSDM (kg/ha)
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
100
Landsat Total Cover %

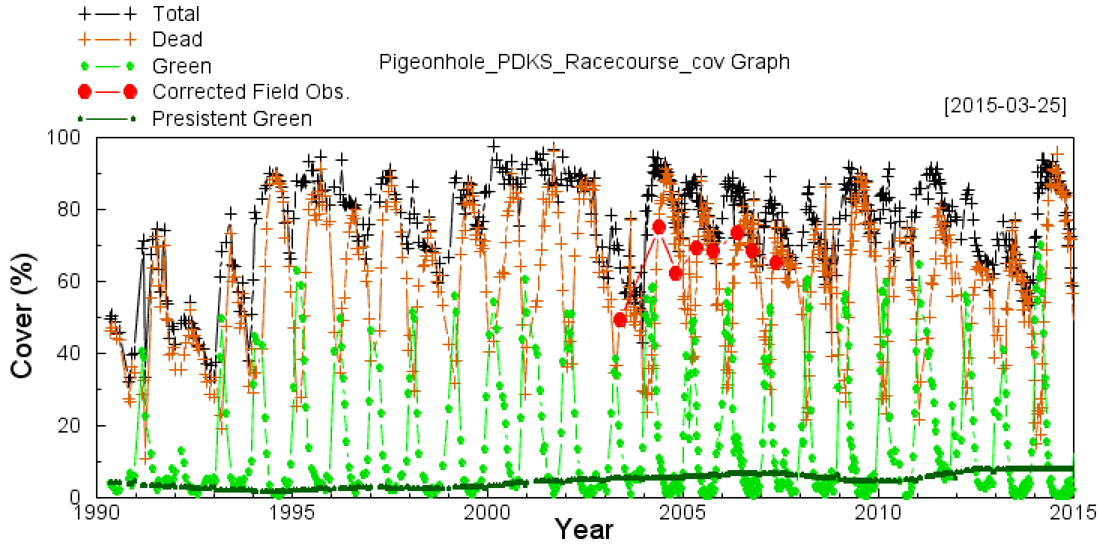

Landsat Cover (%)
100
80
60
40
20
0
1:1
Visual
Visual Corrected
0
20
40
60
80
100
Field Cover (%)

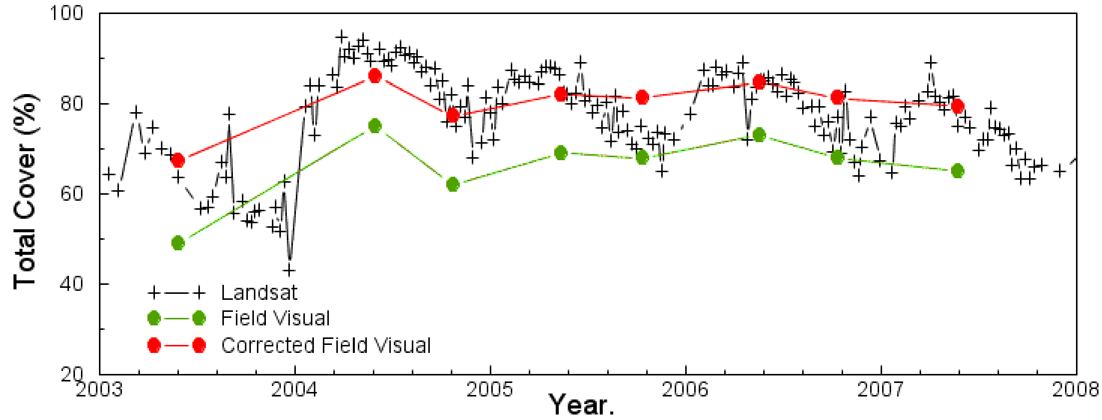

Total
Dead
Green
Corrected Field Obs.
Presistent Green
Pigeonhole_PDKS_North_Stevens_Creek_cov Graph
[2015-03-25]
Cover (%)
Year

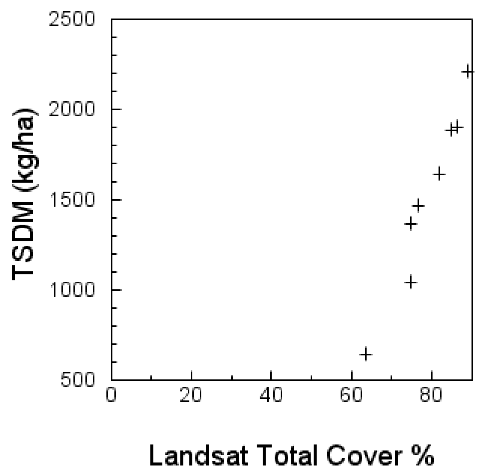

Total Cover (%)
Landsat
Field Visual
Corrected Field Visual
Year.

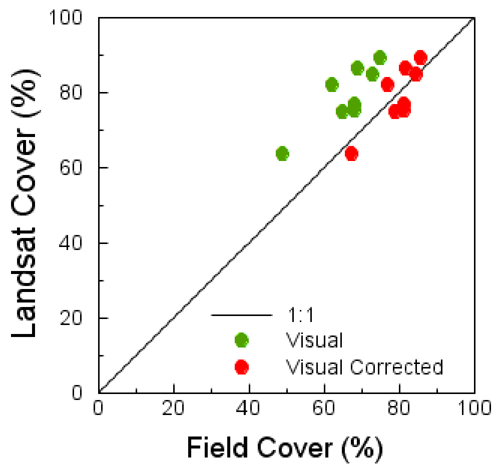

TSDM (kg/ha)
Landsat Total Cover %

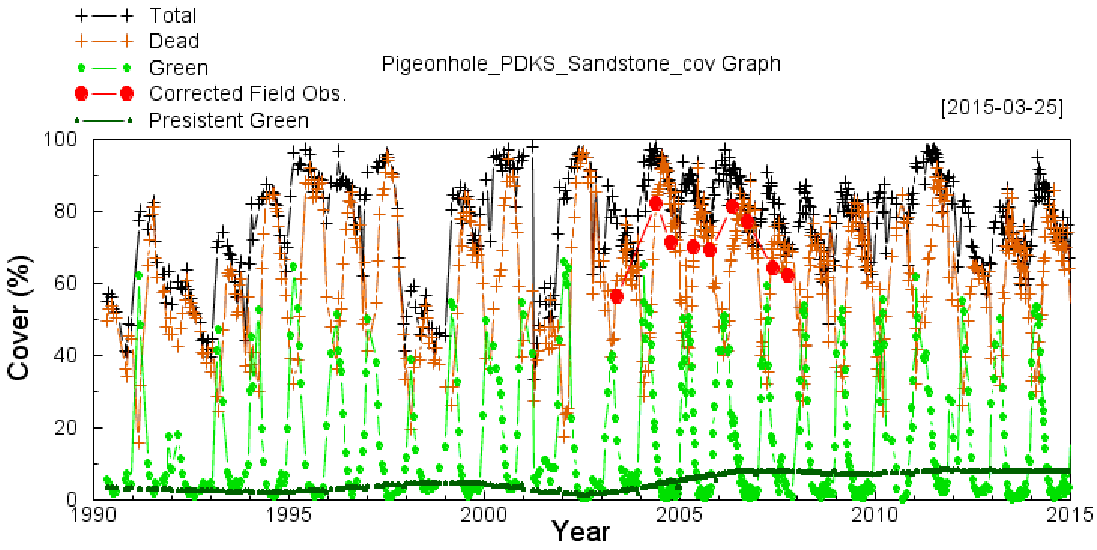

Landsat Cover (%)
1:1
Visual
Visual Corrected
Field Cover (%)

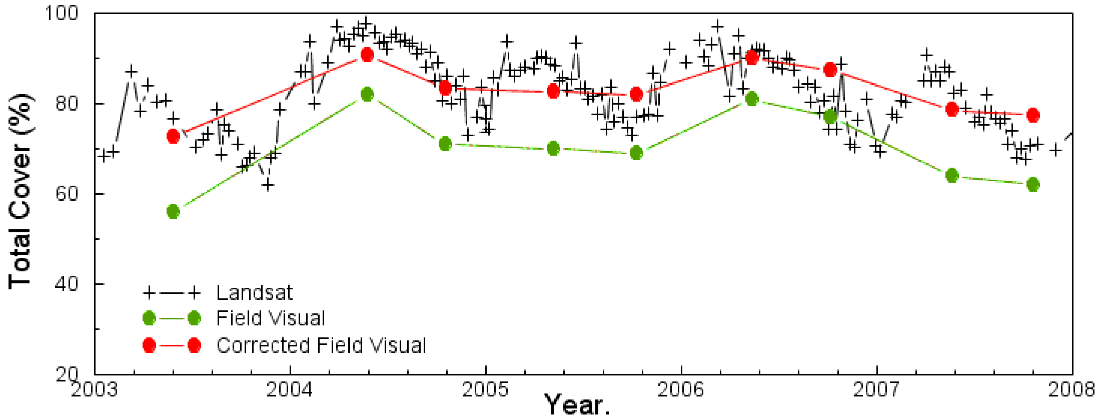

Total
Dead
Green
Corrected Field Obs.
Presistent Green
Pigeonhole_PDKS_Racecourse_cov Graph
[2015-03-25]
Cover (%)
100
80
60
40
20
0
1990
1995
2000
2005
2010
2015
Year

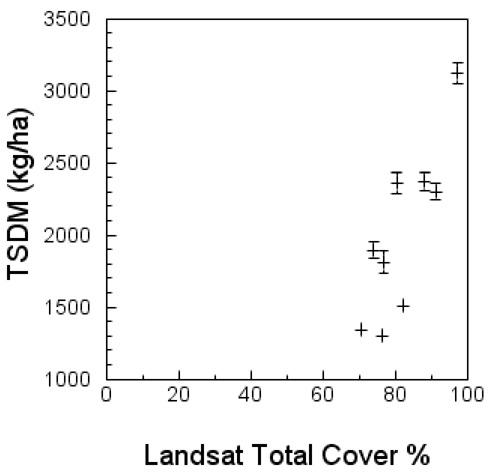

Total Cover (%)
100
80
60
40
20
Landsat
Field Visual
Corrected Field Visual
2003
2004
2005
2006
2007
2008
Year.

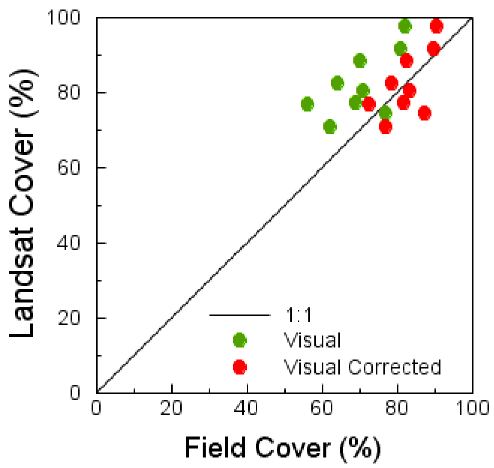

TSDM (kg/ha)
2500
2000
1500
1000
500
0
20
40
60
80
Landsat Total Cover %

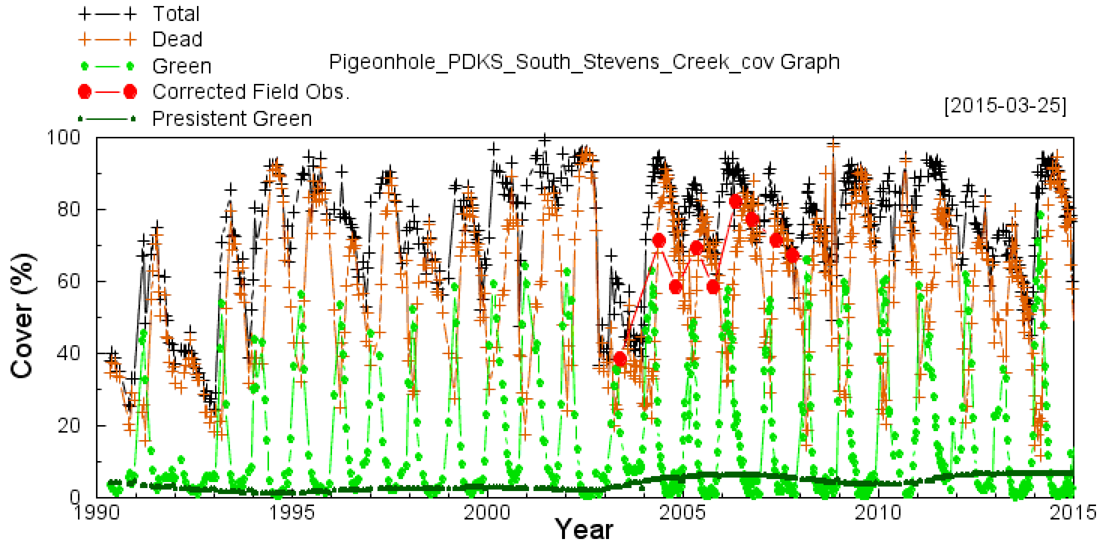

Landsat Cover (%)
100
80
60
40
20
0
1:1
Visual
Visual Corrected
0
20
40
60
80
100
Field Cover (%)

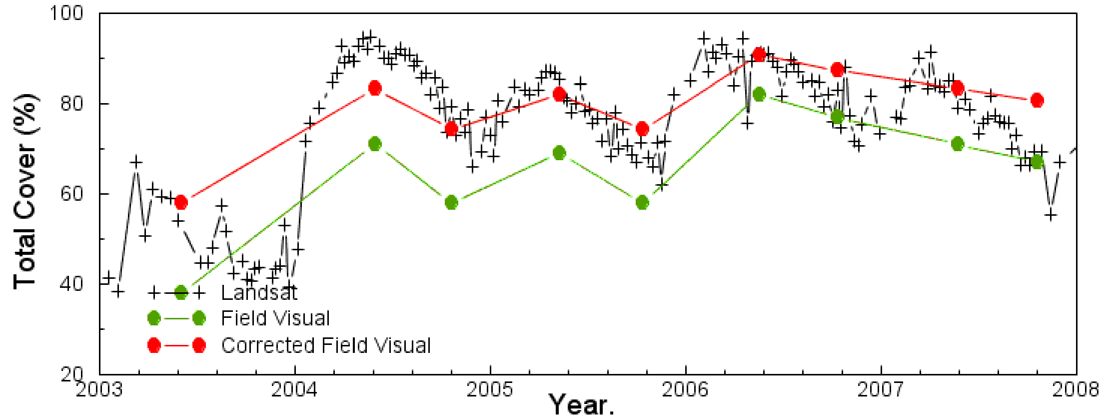

Total
Dead
Green
Corrected Field Obs.
Presistent Green
Pigeonhole_PDKS_Sandstone_cov Graph
[2015-03-25]
Cover (%)
Year

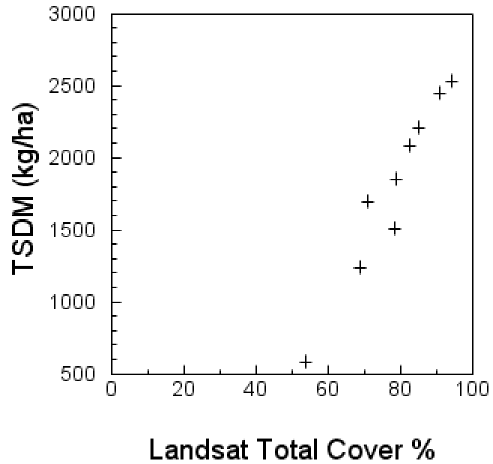

Total Cover (%)
Landsat
Field Visual
Corrected Field Visual
Year.

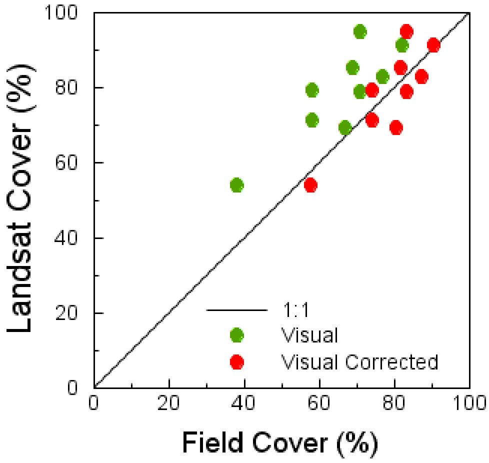

TSDM (kg/ha)
Landsat Total Cover %

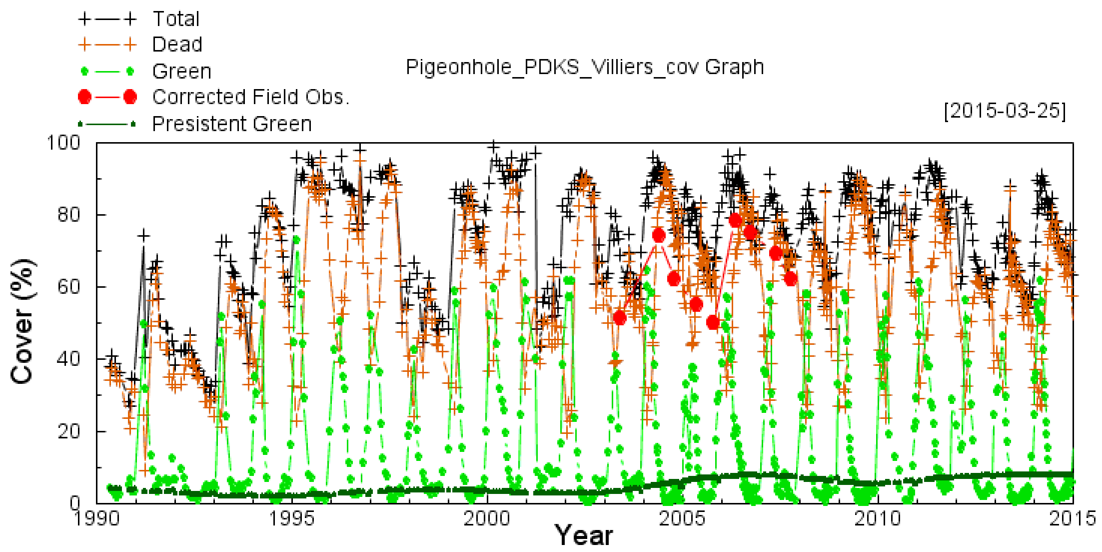

Landsat Cover (%)
1:1
Visual
Visual Corrected
Field Cover (%)

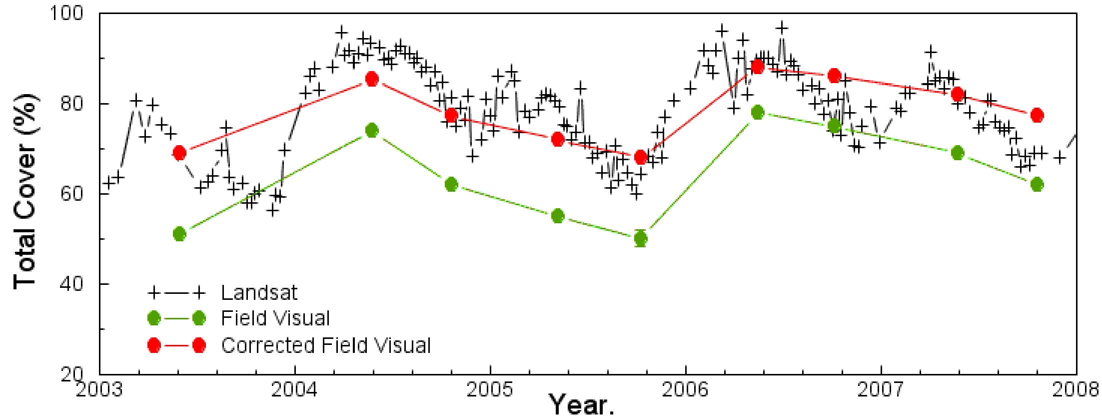

Total
Dead
Green
Corrected Field Obs.
Presistent Green
Pigeonhole_PDKS_South_Stevens_Creek_cov Graph
[2015-03-25]
Cover (%)
Year

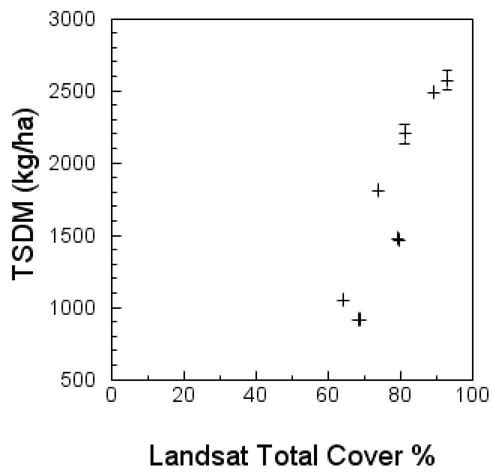

Total Cover (%)
Landsat
Field Visual
Corrected Field Visual
Year.

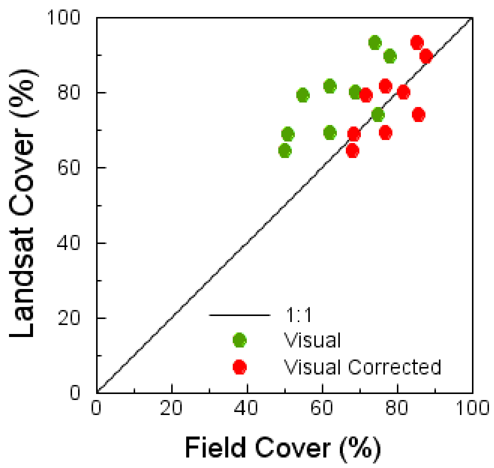

TSDM (kg/ha)
Landsat Total Cover %

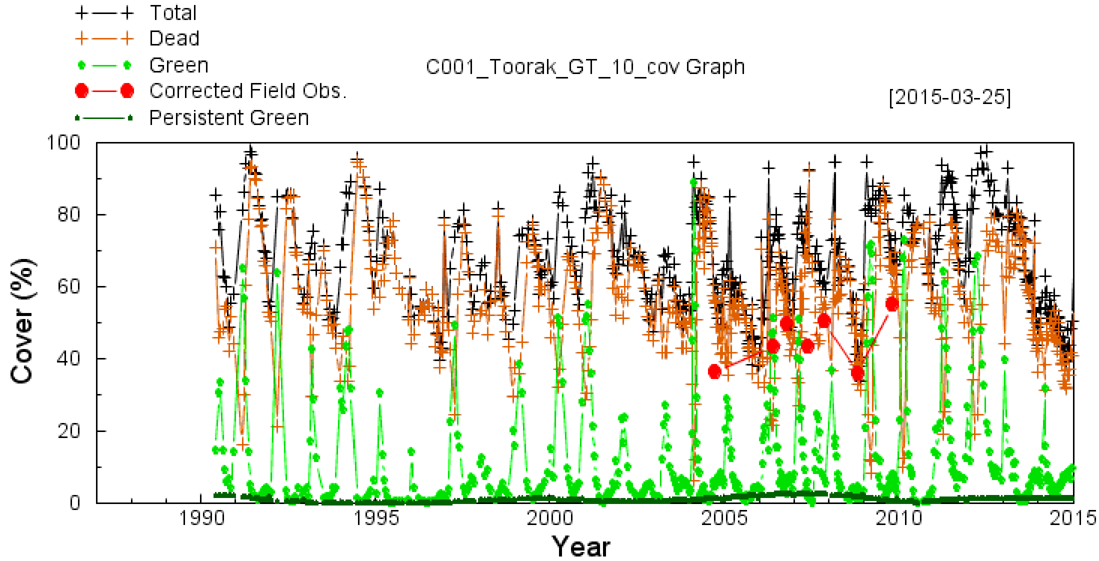

Landsat Cover (%)
1:1
Visual
Visual Corrected
Field Cover (%)

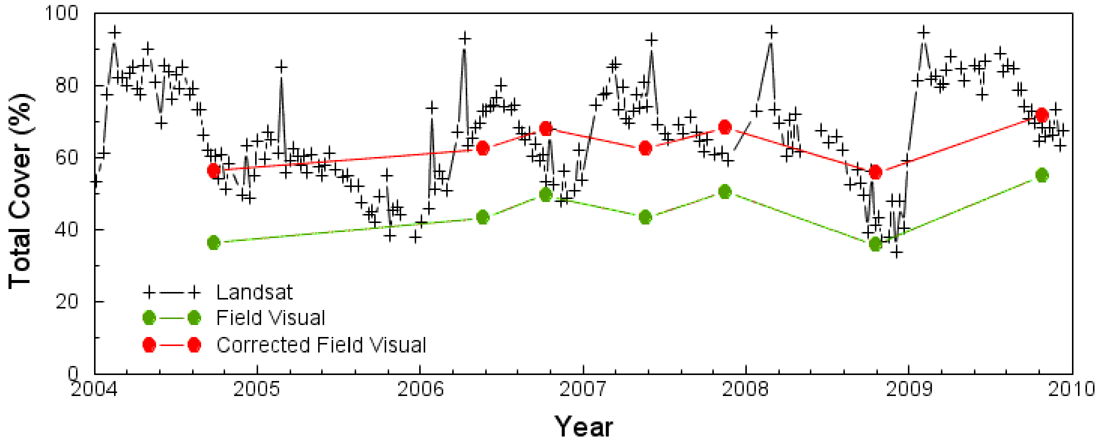

Total
Dead
Green
Corrected Field Obs.
Presistent Green
Pigeonhole_PDKS_Villiers_cov Graph
[2015-03-25]
Cover (%)
Year
0
20
40
60
80
100
1990
1995
2000
2005
2010
2015

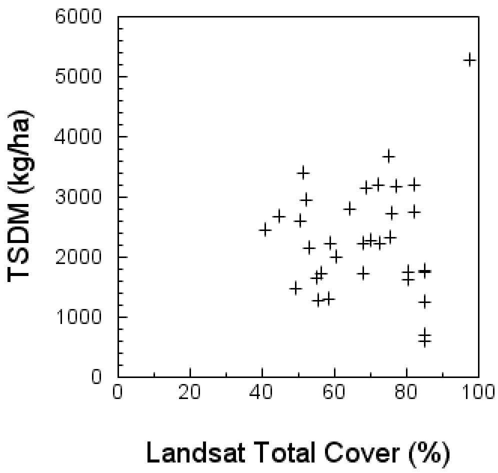

Total Cover (%)
Year.
Landsat
Field Visual
Corrected Field Visual
20
40
60
80
100
2003
2004
2005
2006
2007
2008

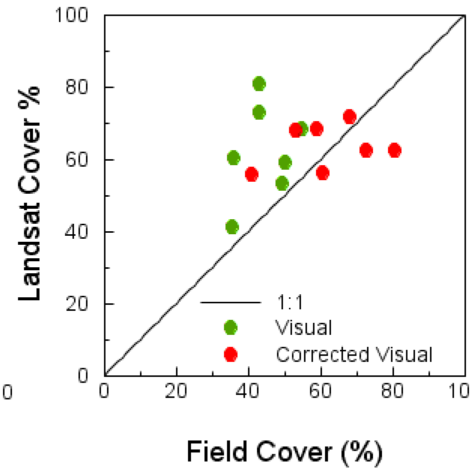

TSDM (kg/ha)
Landsat Total Cover %
500
1000
1500
2000
2500
3000
0
20
40
60
80
100

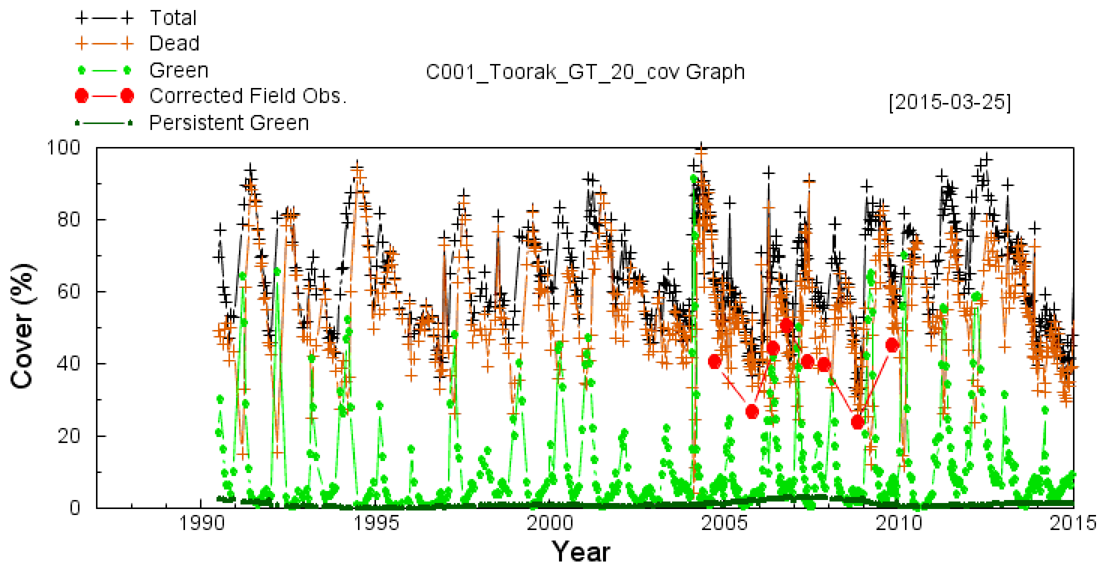

Landsat Cover (%)
Field Cover (%)
1:1
Visual
Visual Corrected
0
20
40
60
80
100

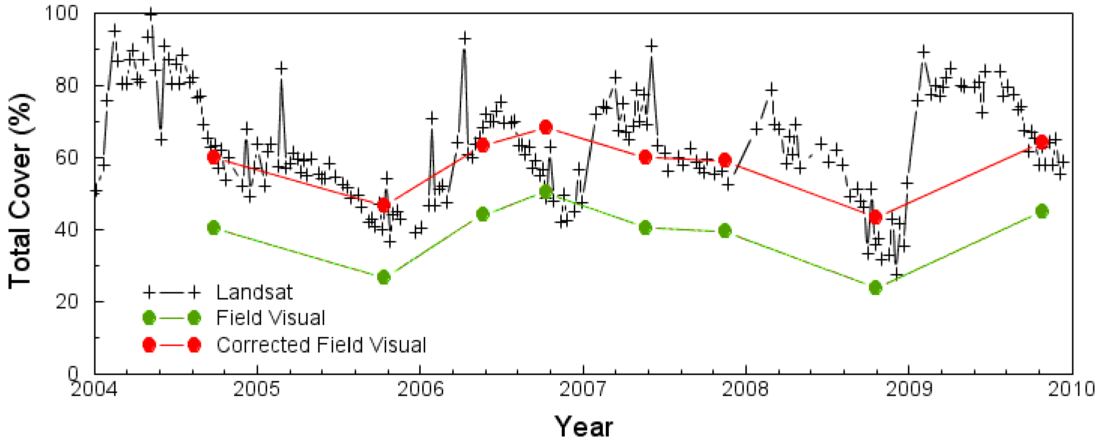

Total
Dead
Green
Corrected Field Obs.
Persistent Green
C001_Toorak_GT_10_cov Graph
[2015-03-25]
Cover (%)
100
80
60
40
20
0
1990
1995
2000
2005
2010
2015
Year

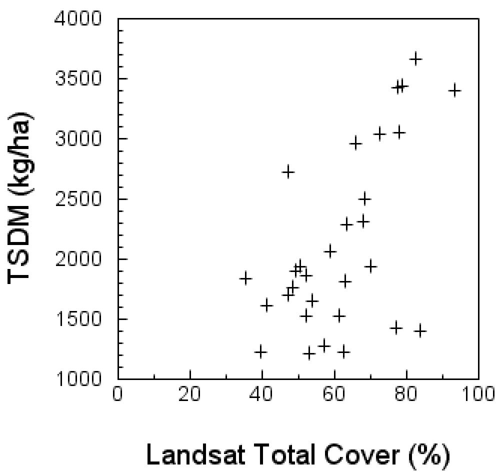

Total Cover (%)
100
80
60
40
20
0
2004
2005
2006
2007
2008
2009
2010
Landsat
Field Visual
Corrected Field Visual
Year

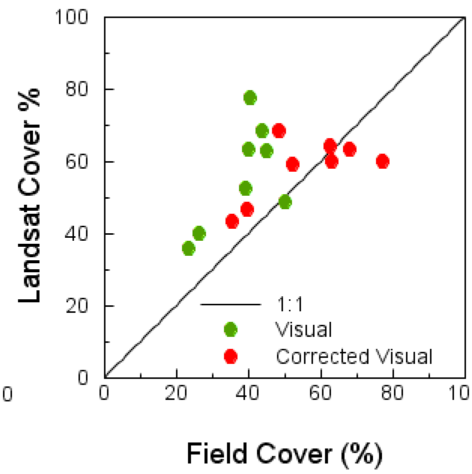

TSDM (kg/ha)
6000
5000
4000
3000
2000
1000
0
0
20
40
60
80
100
Landsat Total Cover (%)

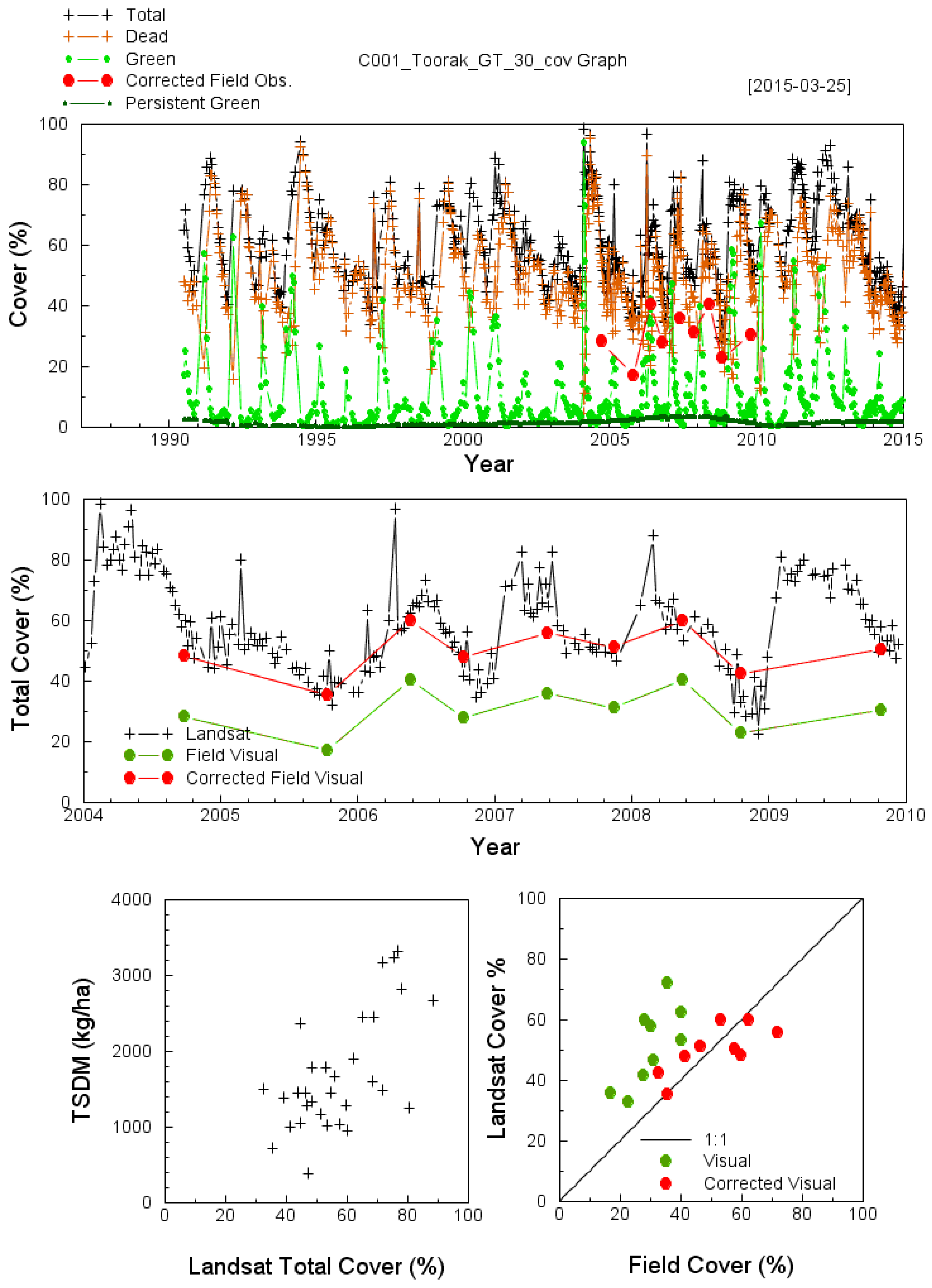

Landsat Cover %
100
80
60
40
20
0
0
20
40
60
80
100
1:1
Visual
Corrected Visual
Field Cover (%)

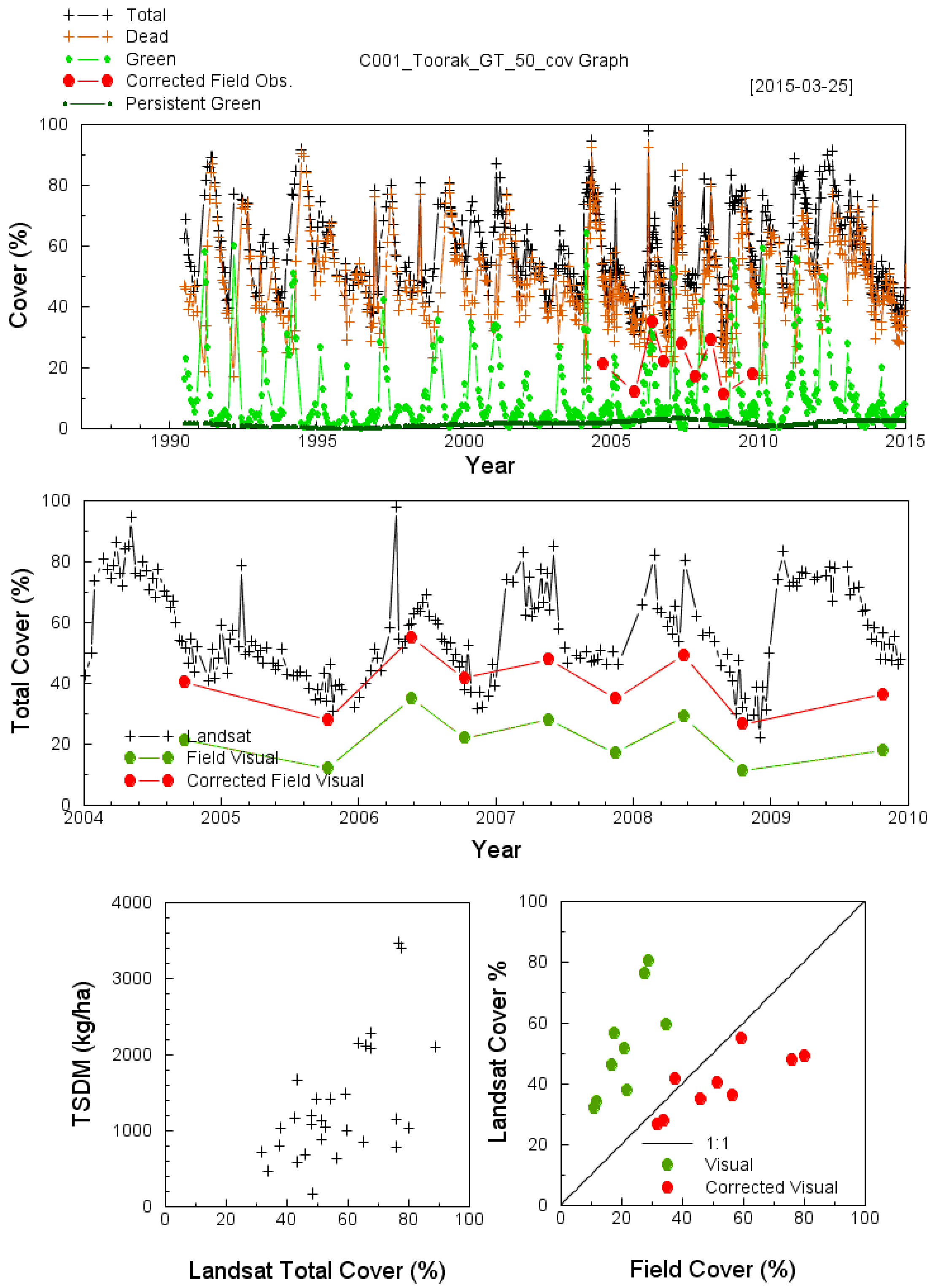

Total
Dead
Green
Corrected Field Obs.
Persistent Green
C001_Toorak_GT_20_cov Graph
[2015-03-25]
Cover (%)
0
20
40
60
80
100
1990
1995
2000
2005
2010
2015
Year


Total Cover (%)
0
20
40
60
80
100
2004
2005
2006
2007
2008
2009
2010
Landsat
Field Visual
Corrected Field Visual
Year

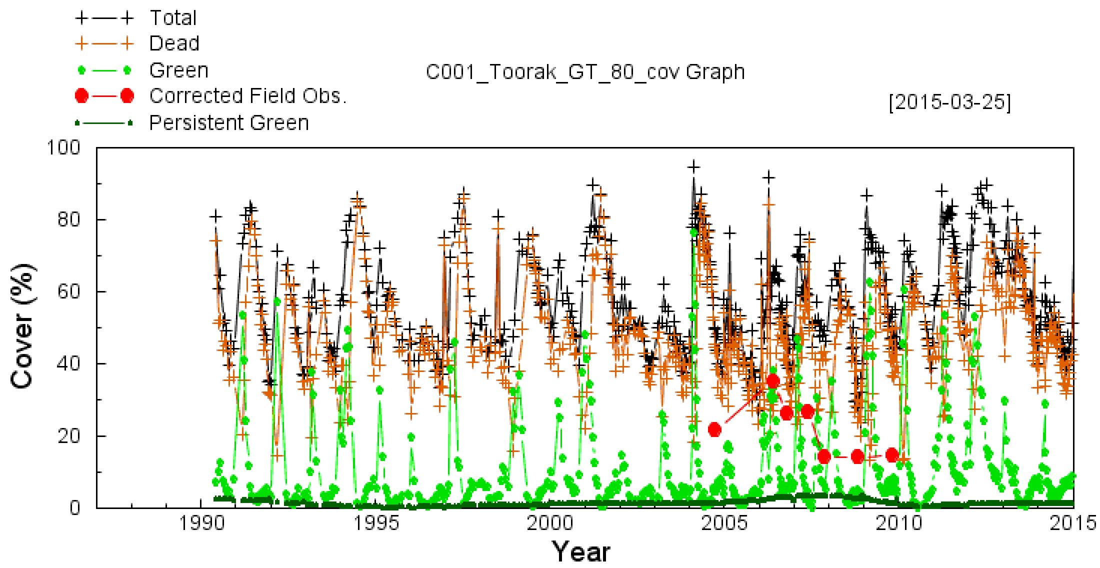

TSDM (kg/ha)
1000
1500
2000
2500
3000
3500
4000
0
20
40
60
80
100
Landsat Total Cover (%)

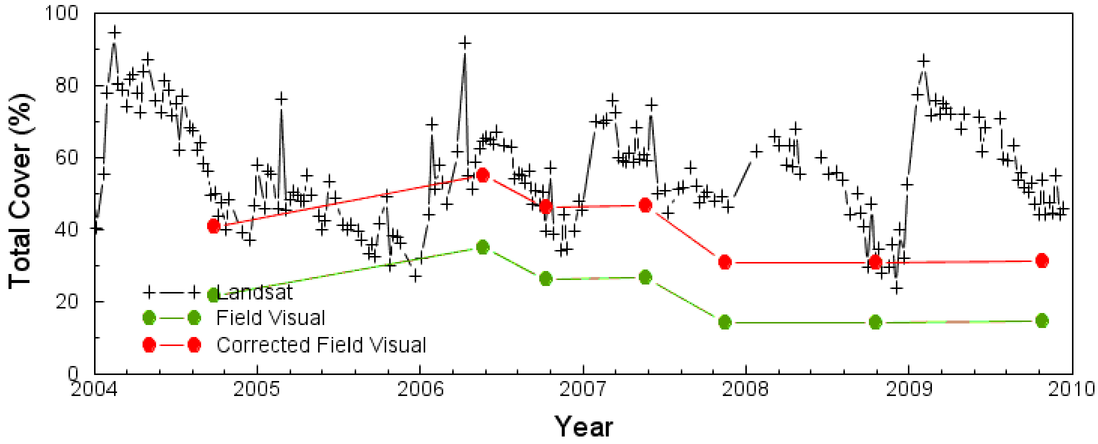

Landsat Cover %
0
20
40
60
80
100
1:1
Visual
Corrected Visual
Field Cover (%)

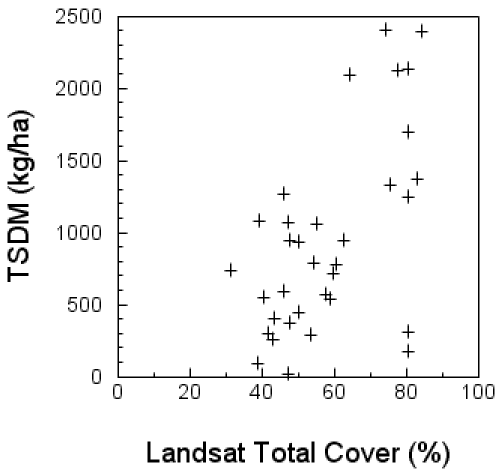

Total
Dead
Green
Corrected Field Obs.
Persistent Green
C001_Toorak_GT_30_cov Graph
[2015-03-25]
Cover (%)
Year
Total Cover (%)
Landsat
Field Visual
Corrected Field Visual
Year
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover %
1:1
Visual
Corrected Visual
Field Cover (%)

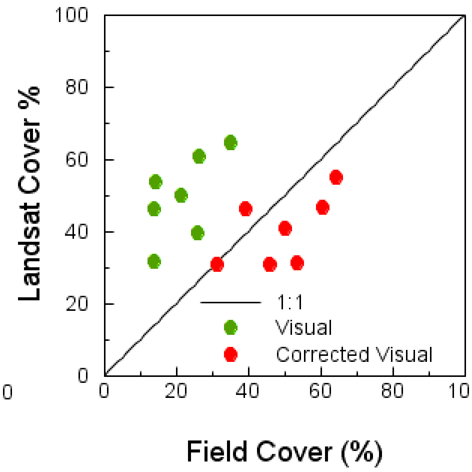


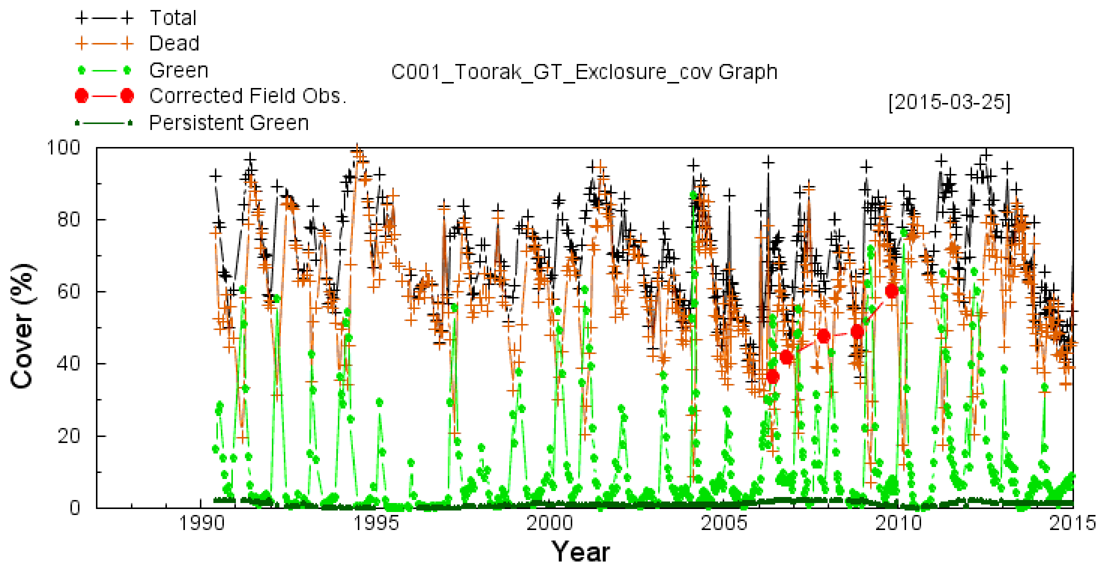
Total
Dead
Green
Corrected Field Obs.
Persistent Green
C001_Toorak_GT_50_cov Graph
[2015-03-25]
Cover (%)
Year
Total Cover (%)
Landsat
Field Visual
Corrected Field Visual
Year
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover %
1:1
Visual
Corrected Visual
Field Cover (%)

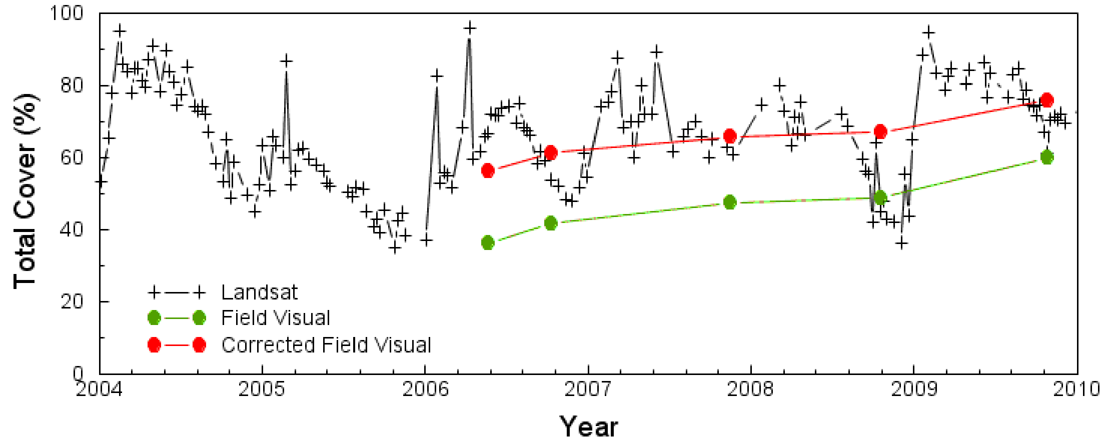

Total
Dead
Green
Corrected Field Obs.
Persistent Green
C001_Toorak_GT_80_cov Graph
[2015-03-25]
Cover (%)
Year
0
20
40
60
80
100
1990
1995
2000
2005
2010
2015

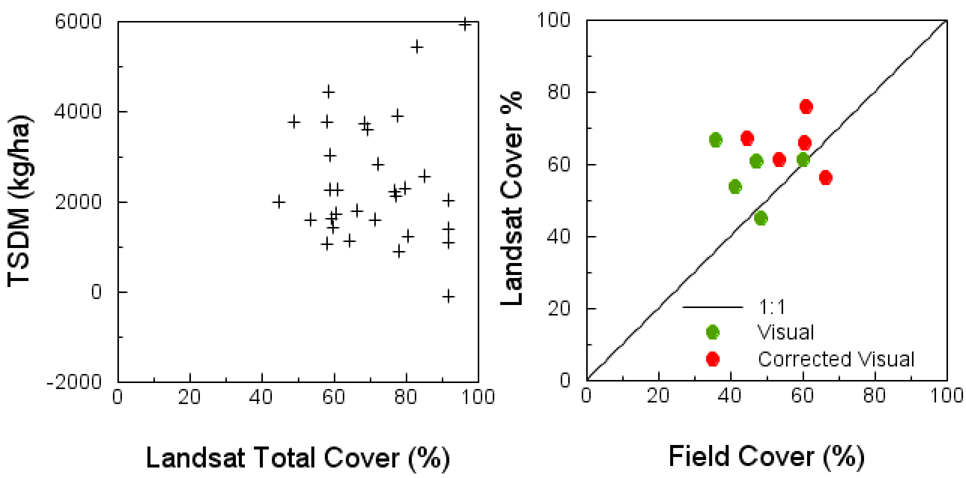

Total Cover (%)
Year
Landsat
Field Visual
Corrected Field Visual
0
20
40
60
80
100
2004
2005
2006
2007
2008
2009
2010


TSDM (kg/ha)
Landsat Total Cover (%)
0
500
1000
1500
2000
2500
0
20
40
60
80
100

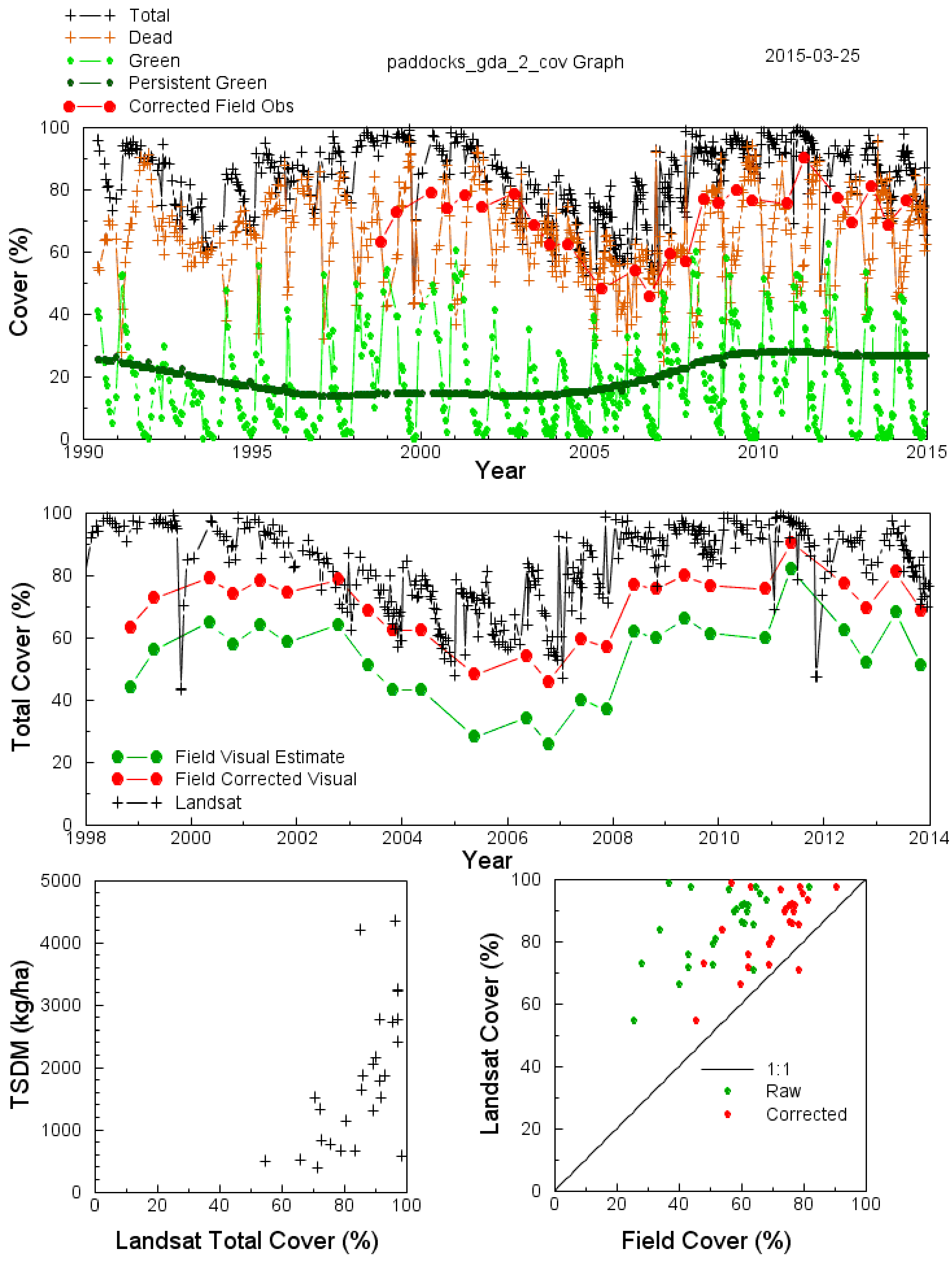

Landsat Cover %
Field Cover (%)
1:1
Visual
Corrected Visual
0
20
40
60
80
100

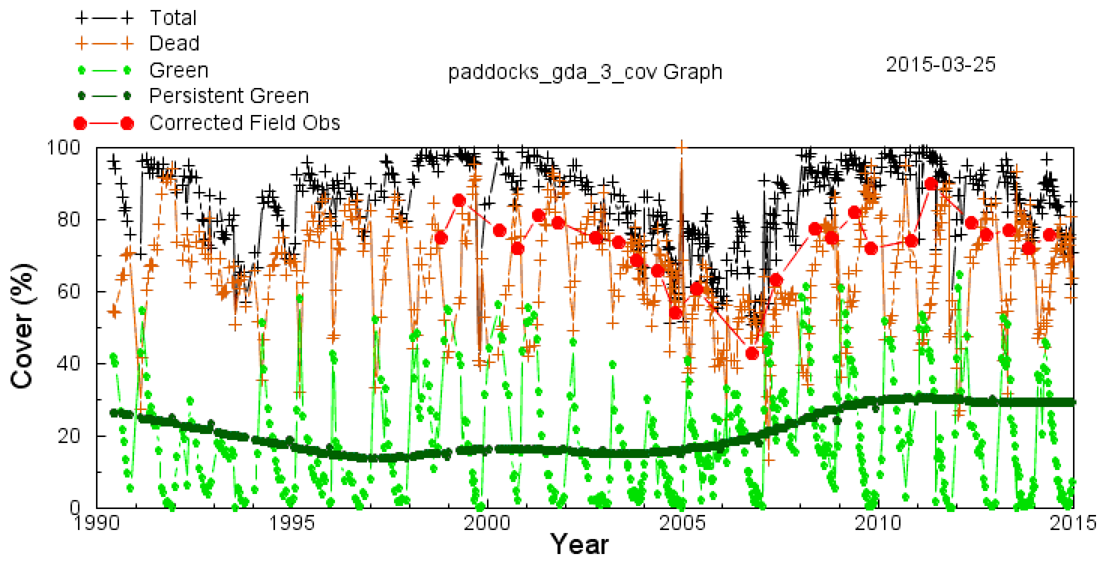

Total
Dead
Green
Corrected Field Obs.
Persistent Green
C001_Toorak_GT_Exclosure_cov Graph
[2015-03-25]
Cover (%)
Year
0
20
40
60
80
100
1990
1995
2000
2005
2010
2015

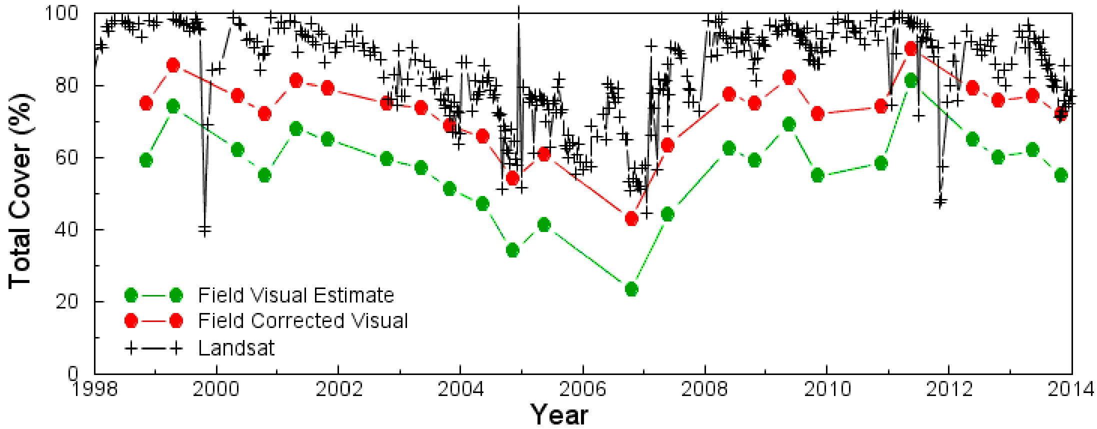

Total Cover (%)
Year
Landsat
Field Visual
Corrected Field Visual
0
20
40
60
80
100
2004
2005
2006
2007
2008
2009
2010

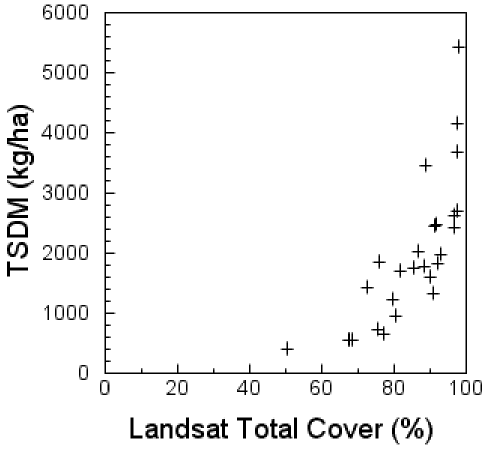

TSDM (kg/ha)
Landsat Total Cover (%)
-2000
0
2000
4000
6000
Landsat Cover %
Field Cover (%)
1:1
Visual
Corrected Visual
0
20
40
60
80
100

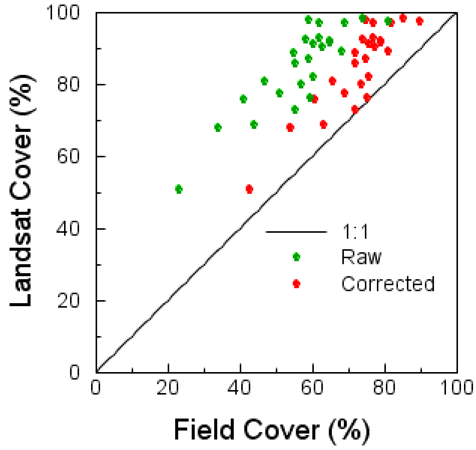
Plots

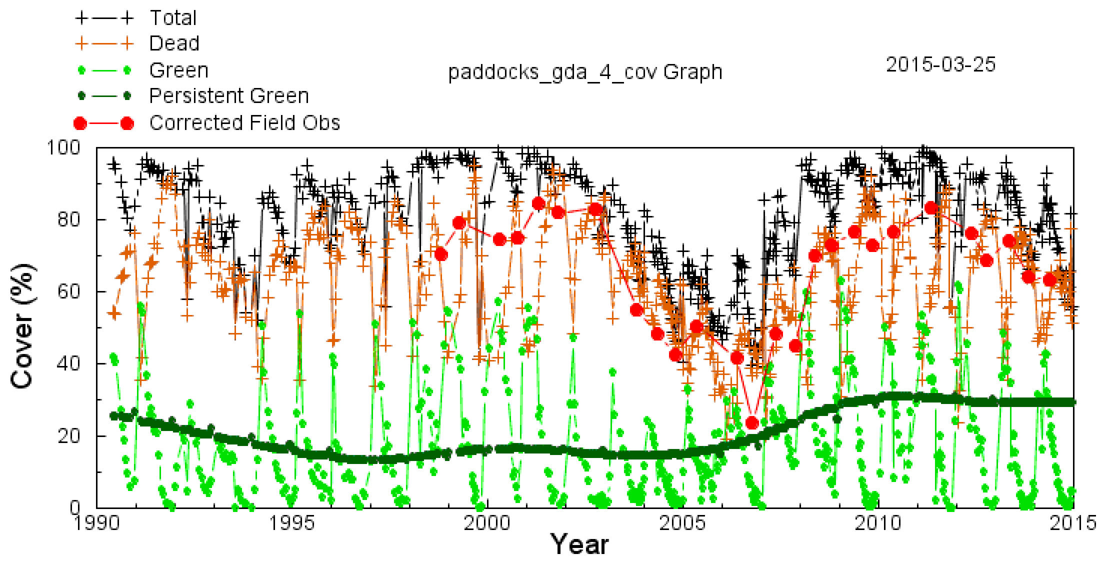

Total
Dead
Green
Persistent Green
Corrected Field Obs
paddocks_gda_2_cov Graph
2015-03-25
Cover (%)
Year
Field Visual Estimate
Field Corrected Visual
Landsat
Total Cover (%)
Year
TSDM (kg/ha)
Landsat Total Cover (%)
1:1
Raw
Corrected
Landsat Cover (%)
Field Cover (%)

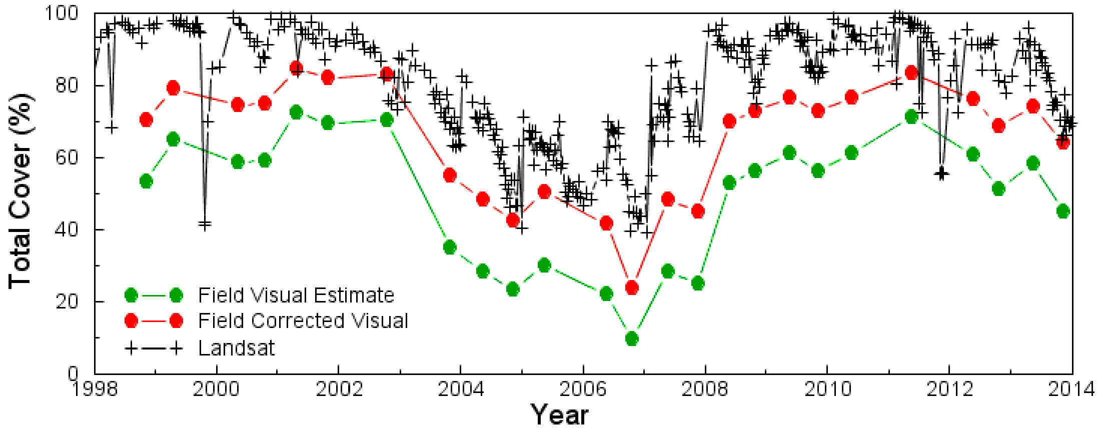

Total
Dead
Green
Persistent Green
Corrected Field Obs
paddocks_gda_3_cov Graph
2015-03-25
Cover (%)
Year

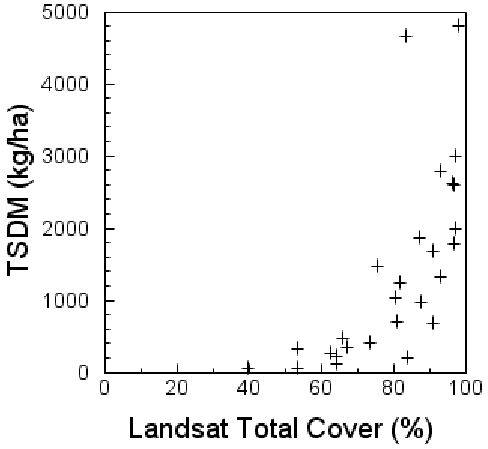

Total Cover (%)
Field Visual Estimate
Field Corrected Visual
Landsat
Year

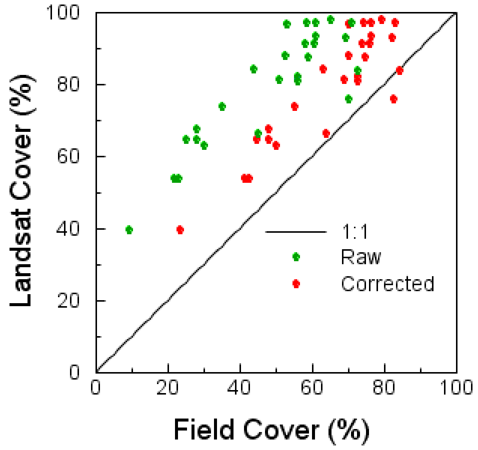

TSDM (kg/ha)
Landsat Total Cover (%)

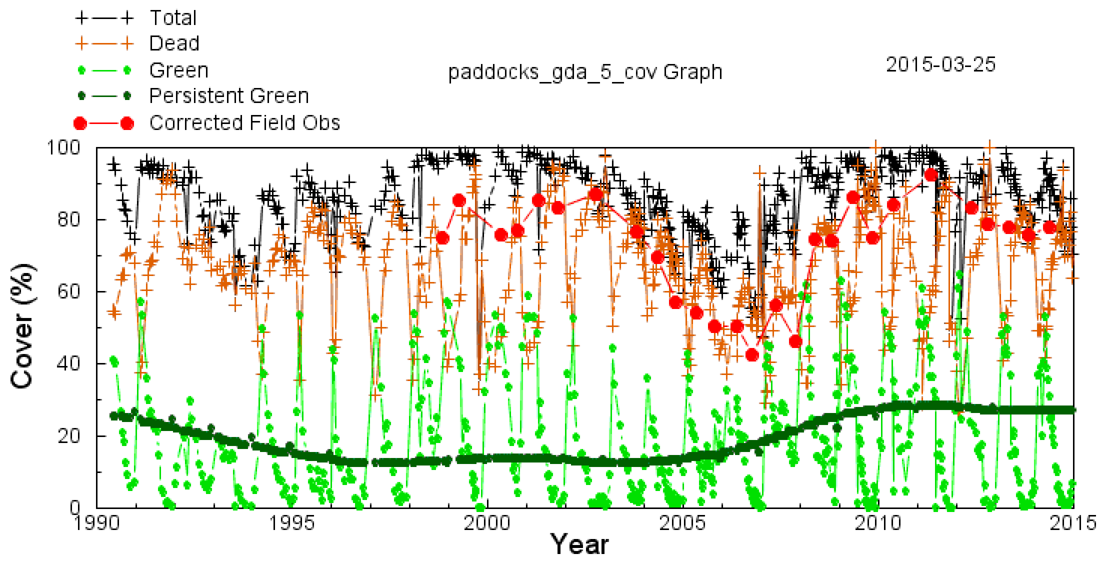

Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)


Total
Dead
Green
Persistent Green
Corrected Field Obs
paddocks_gda_4_cov Graph
2015-03-25
Cover (%)
Year

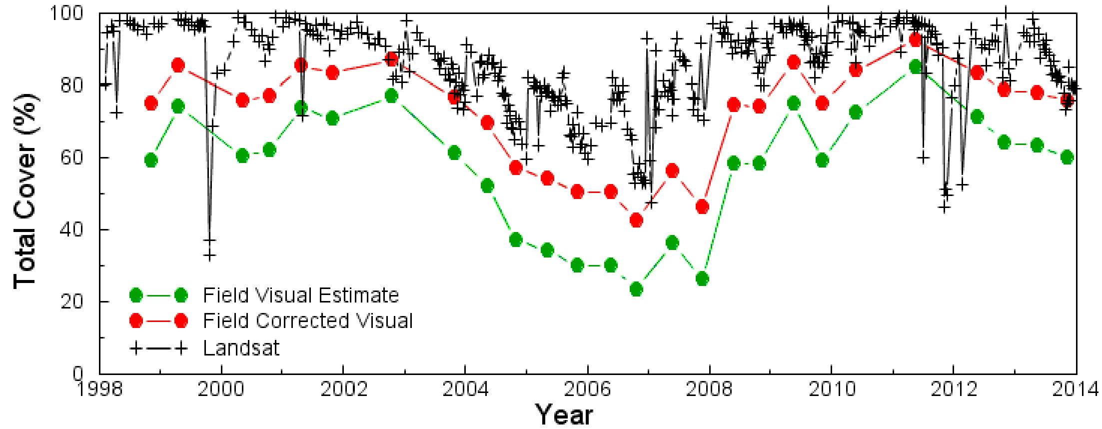

Total Cover (%)
Field Visual Estimate
Field Corrected Visual
Landsat
Year


TSDM (kg/ha)
Landsat Total Cover (%)

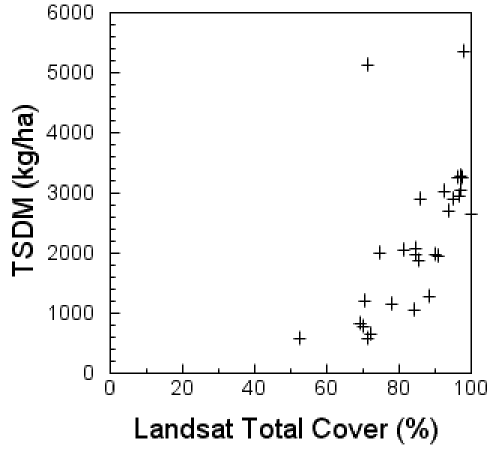

Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)



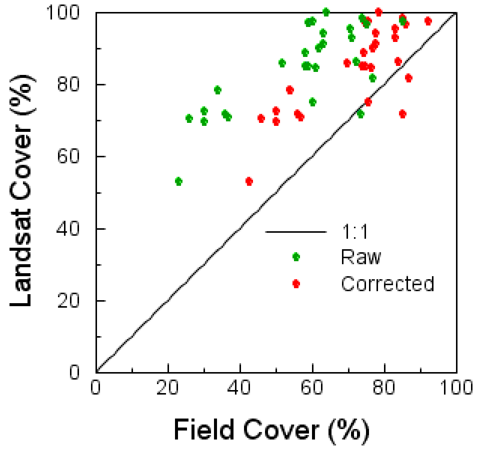
Total
Dead
Green
Persistent Green
Corrected Field Obs
paddocks_gda_5_cov Graph
2015-03-25
Cover (%)
Year



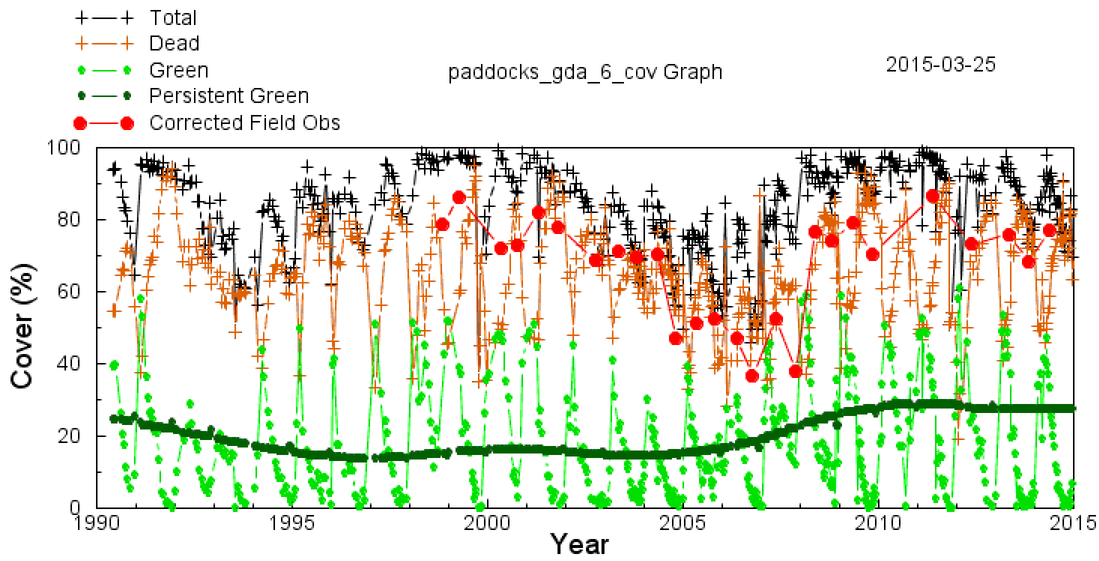
Total Cover (%)
Field Visual Estimate
Field Corrected Visual
Landsat
Year

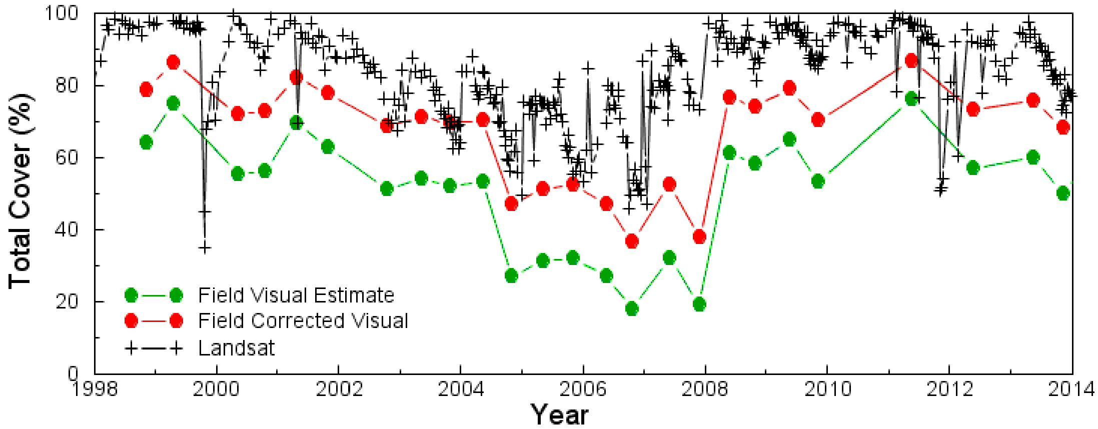


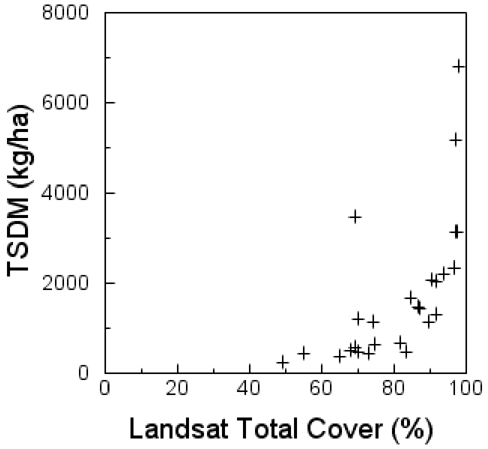
TSDM (kg/ha)
Landsat Total Cover (%)

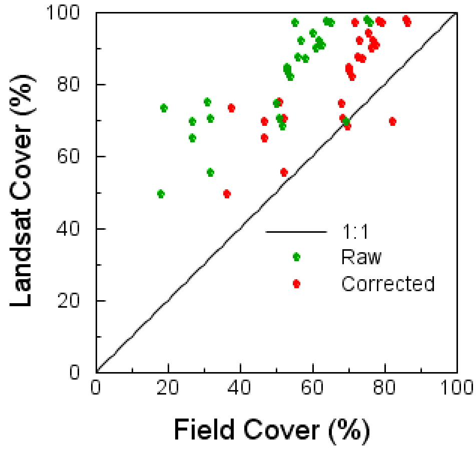


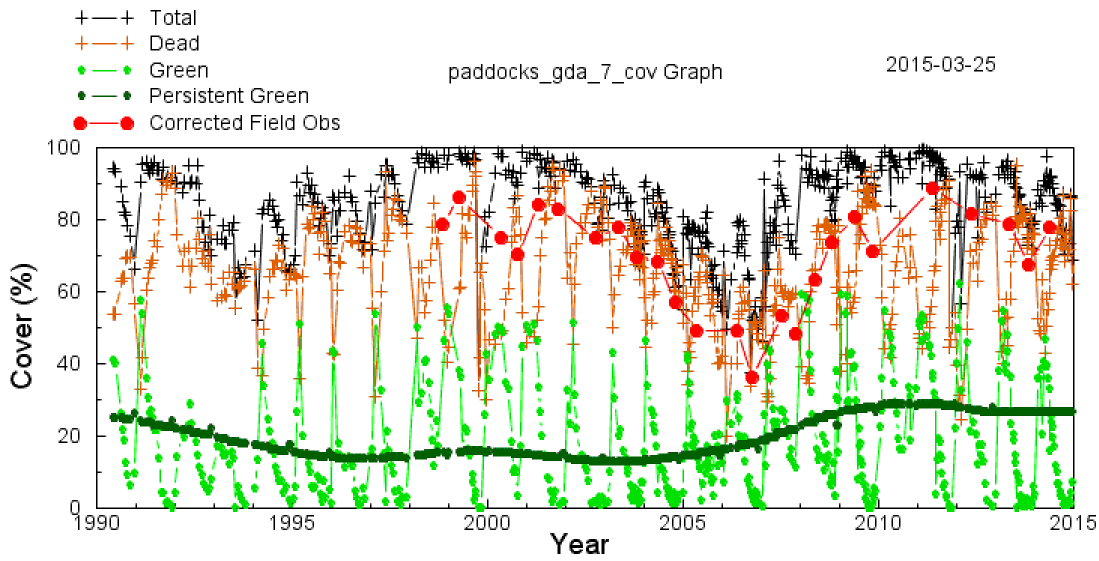
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

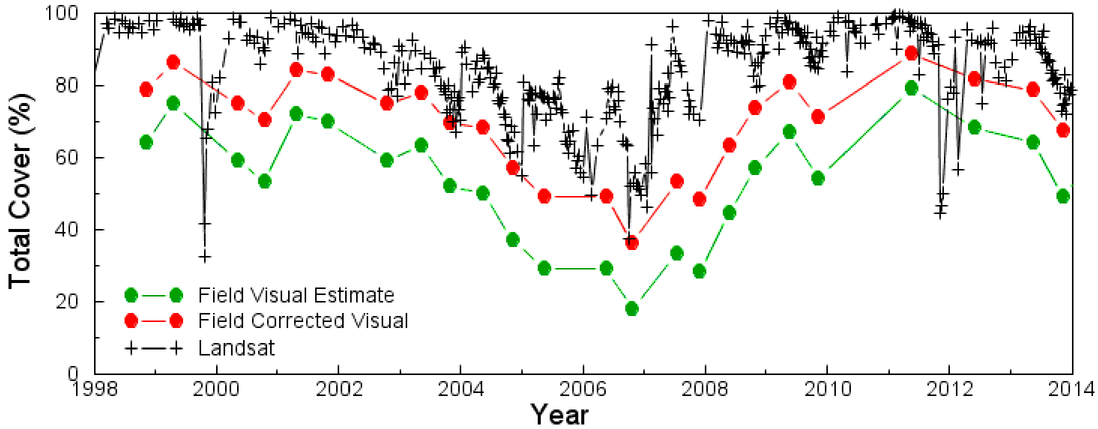

Total
Dead
Green
Persistent Green
Corrected Field Obs
paddocks_gda_6_cov Graph
2015-03-25
Cover (%)
Year
0
20
40
60
80
100
1990
1995
2000
2005
2010
2015

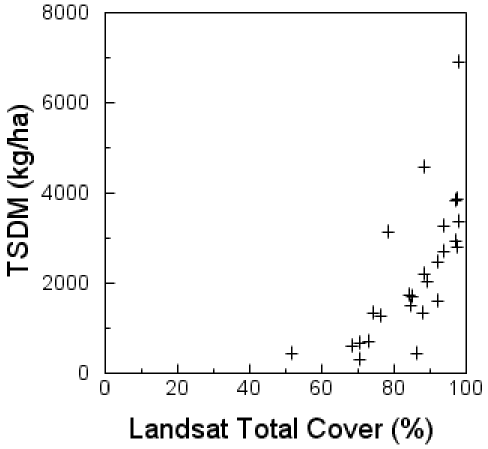

Total Cover (%)
Field Visual Estimate
Field Corrected Visual
Landsat
Year
0
20
40
60
80
100
1998
2000
2002
2004
2006
2008
2010
2012
2014

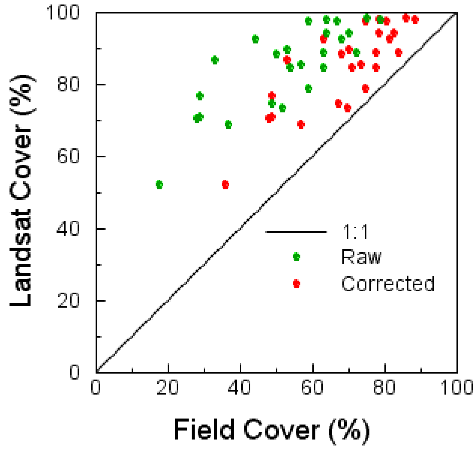

TSDM (kg/ha)
Landsat Total Cover (%)
0
2000
4000
6000
8000
0
20
40
60
80
100

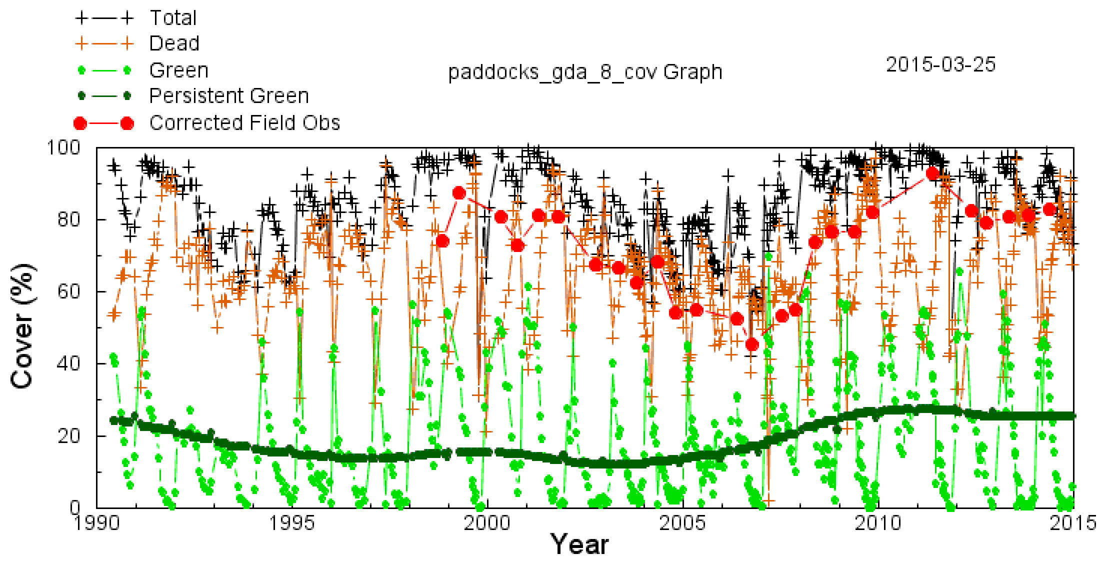

Landsat Cover (%)
Field Cover (%)
1:1
Raw
Corrected
0
20
40
60
80
100

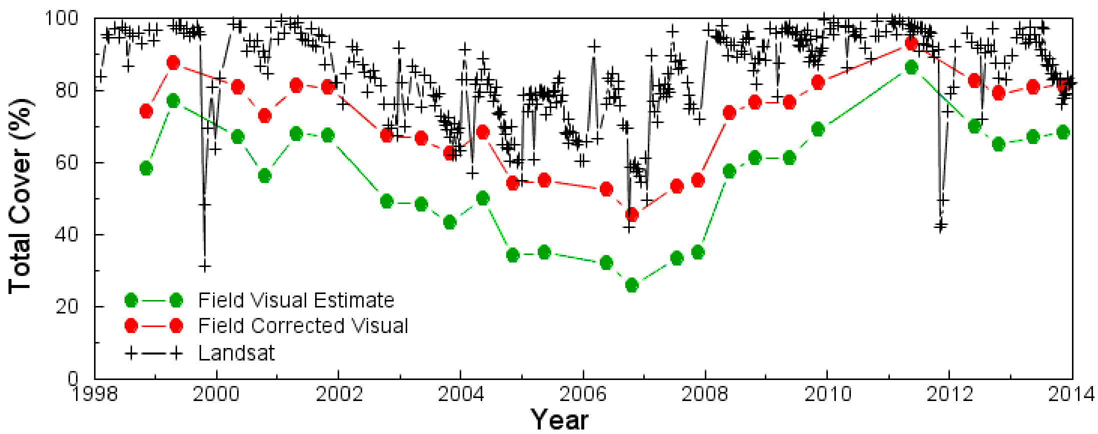

Total
Dead
Green
Persistent Green
Corrected Field Obs
paddocks_gda_7_cov Graph
2015-03-25
Cover (%)
Year

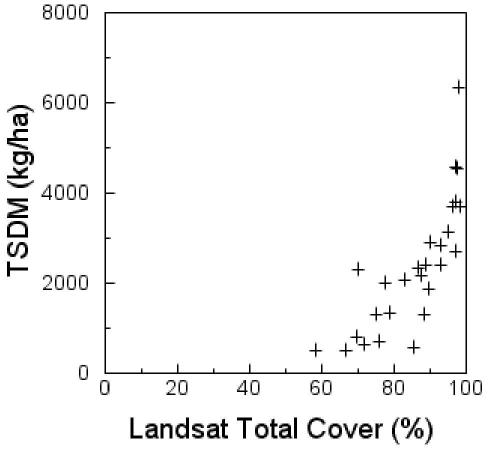

Total Cover (%)
Year
Field Visual Estimate
Field Corrected Visual
Landsat

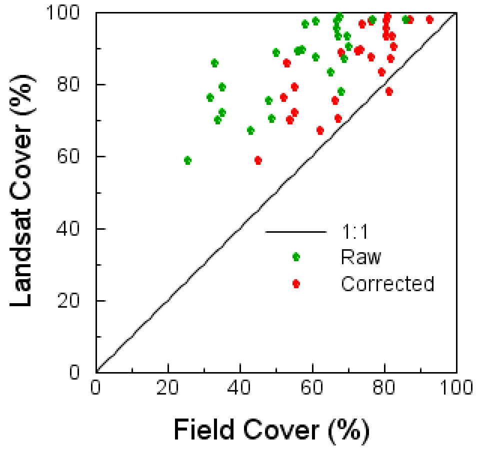

TSDM (kg/ha)
Landsat Total Cover (%)

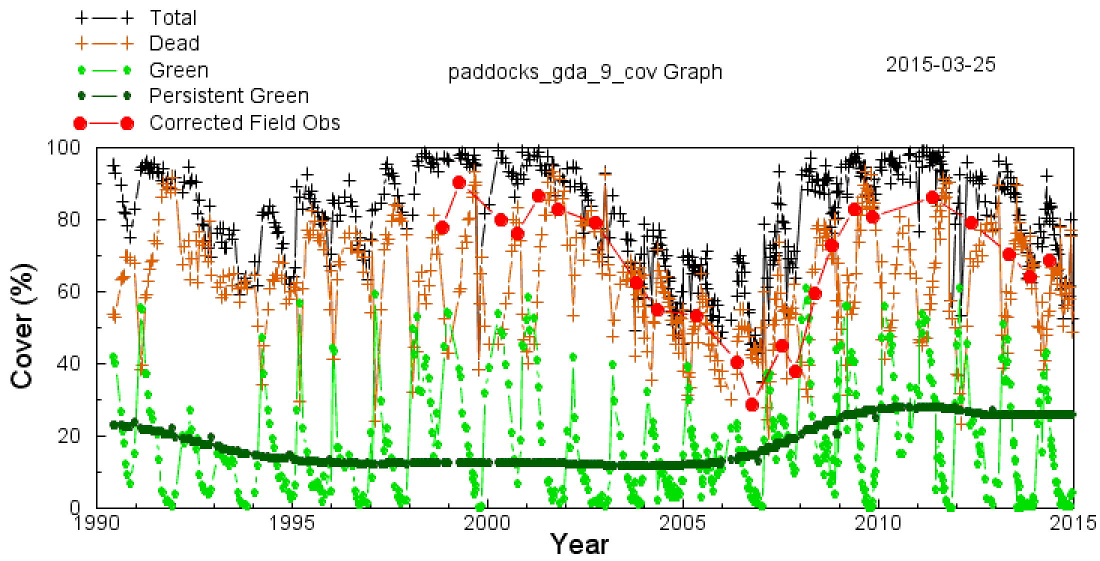

Landsat Cover (%)
Field Cover (%)
1:1
Raw
Corrected

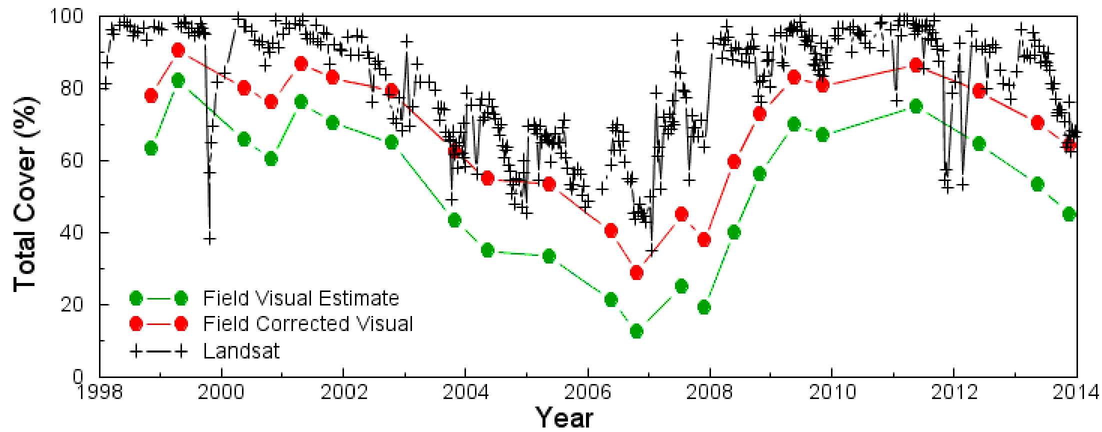

Total
Dead
Green
Persistent Green
Corrected Field Obs
paddocks_gda_8_cov Graph
2015-03-25
Cover (%)
Year

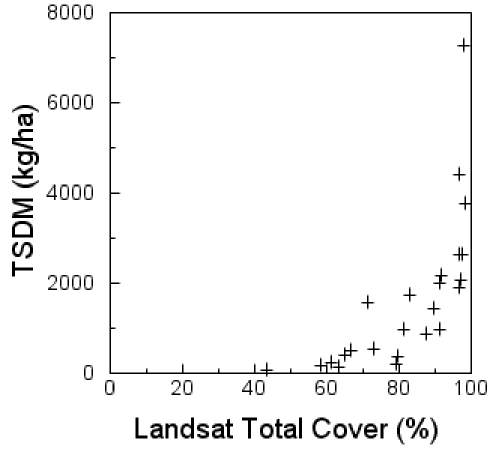

Total Cover (%)
Field Visual Estimate
Field Corrected Visual
Landsat
Year

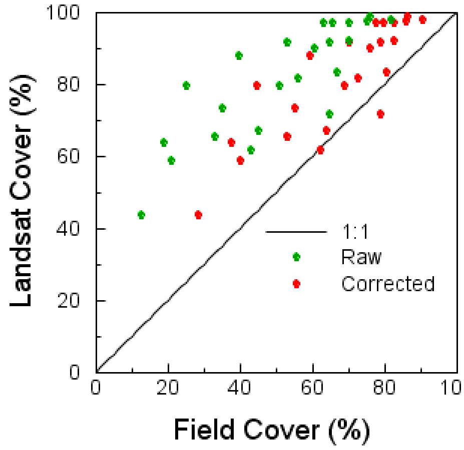

TSDM (kg/ha)
Landsat Total Cover (%)

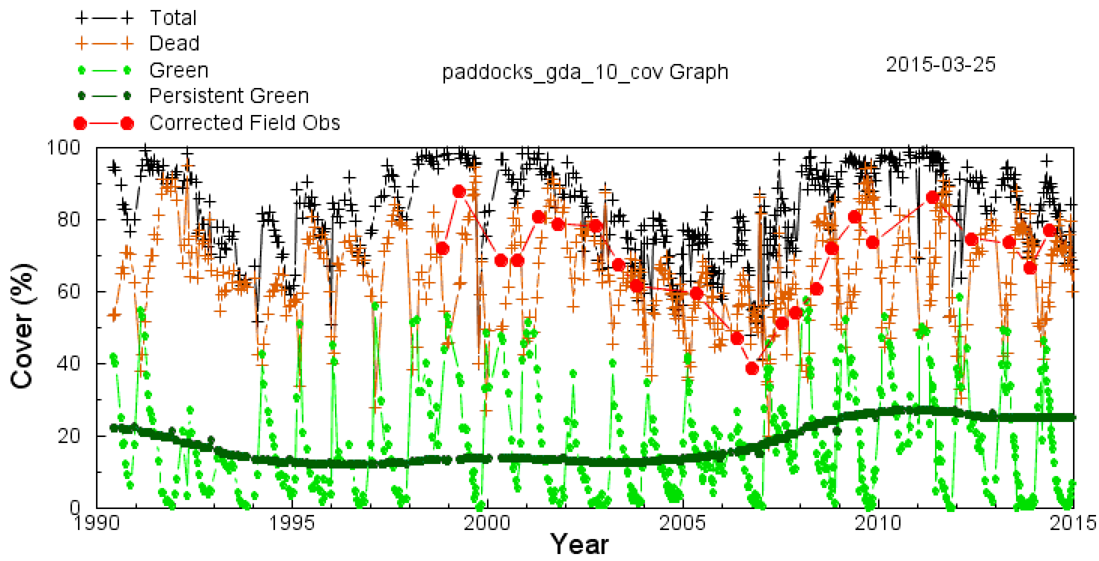

Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

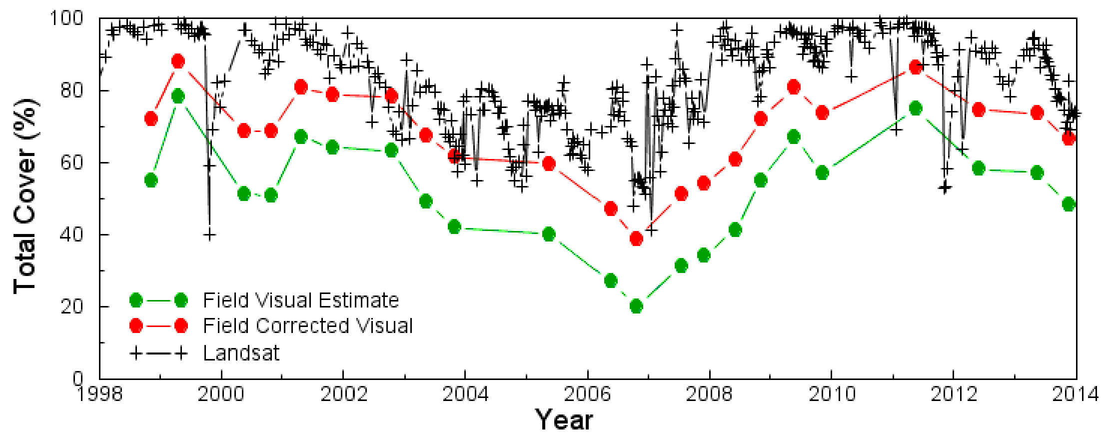

Total
Dead
Green
Persistent Green
Corrected Field Obs
paddocks_gda_9_cov Graph
2015-03-25
Cover (%)
Year

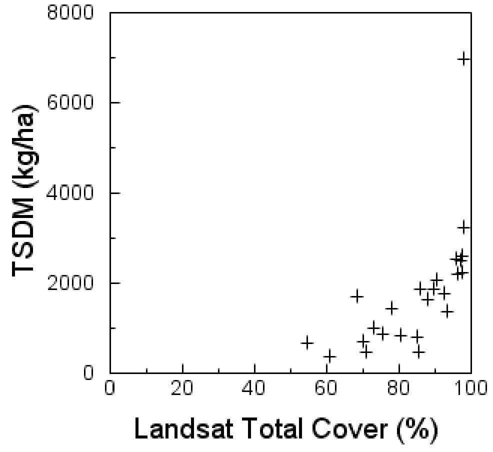

Total Cover (%)
Field Visual Estimate
Field Corrected Visual
Landsat
Year

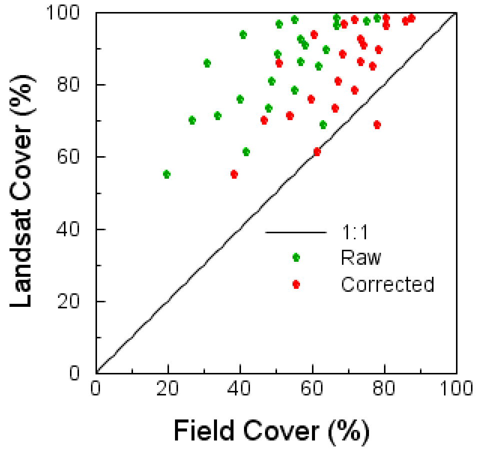

TSDM (kg/ha)
Landsat Total Cover (%)

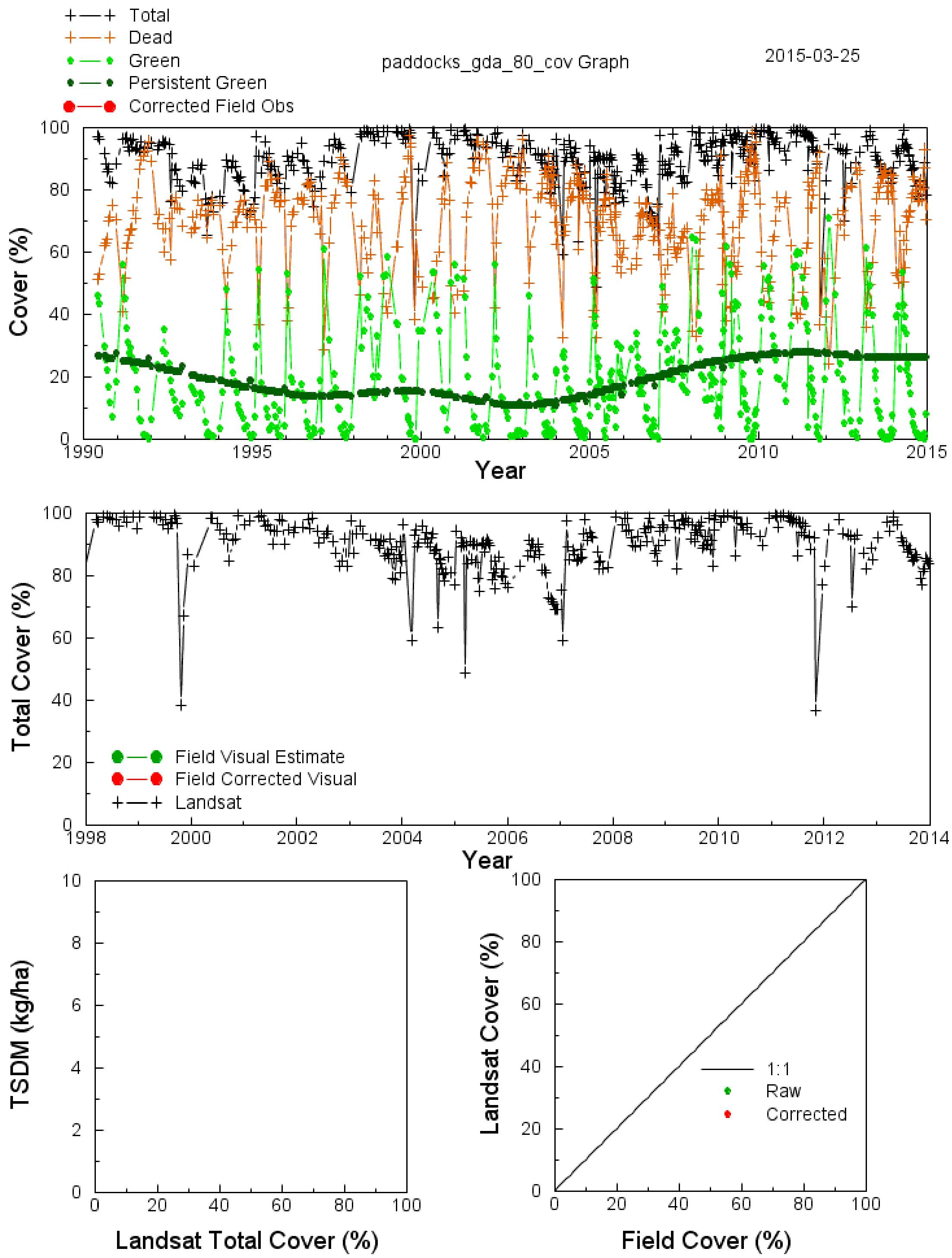

Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)


Total
Dead
Green
Persistent Green
Corrected Field Obs
paddocks_gda_10_cov Graph
2015-03-25
Cover (%)
Year

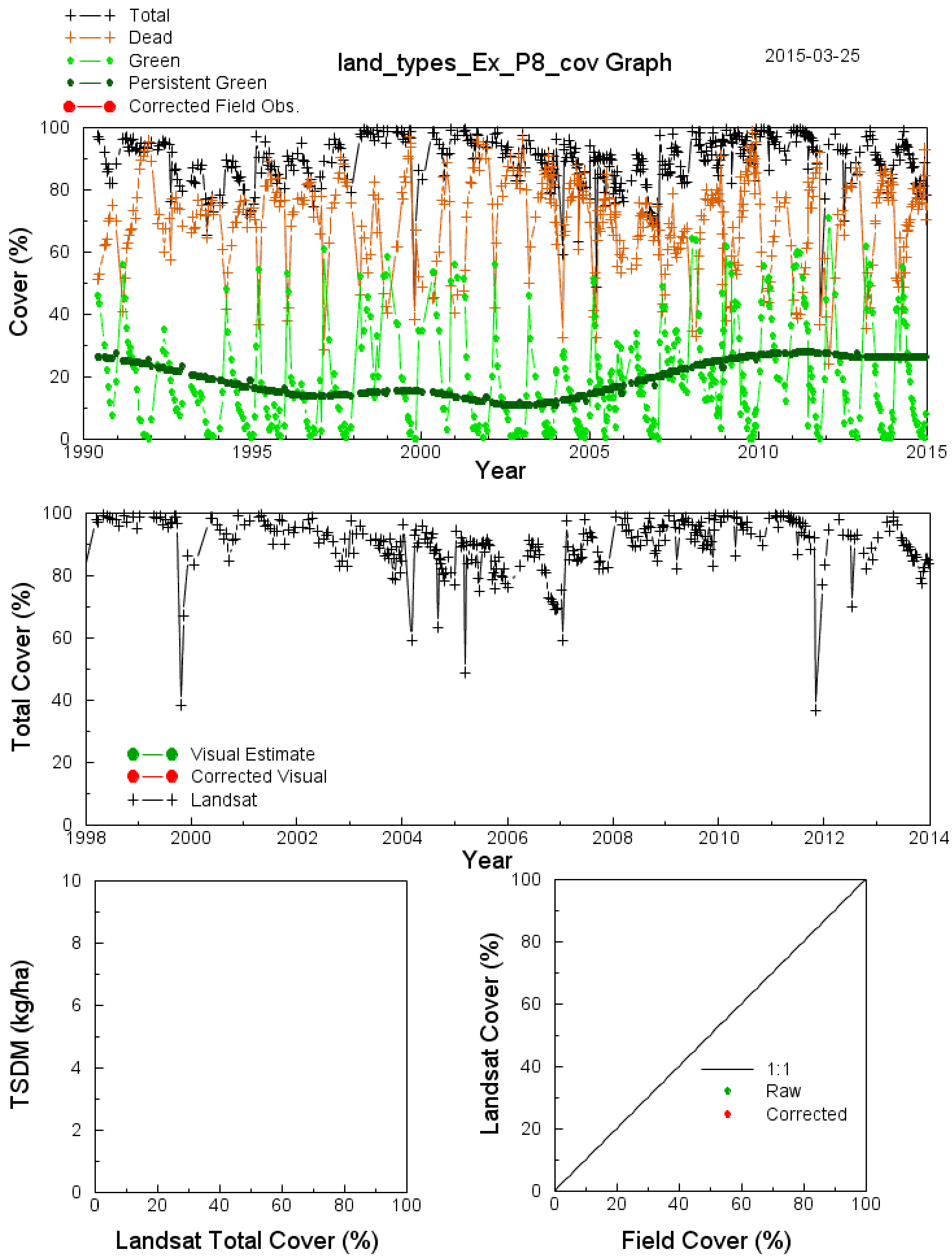

Total Cover (%)
Field Visual Estimate
Field Corrected Visual
Landsat
Year

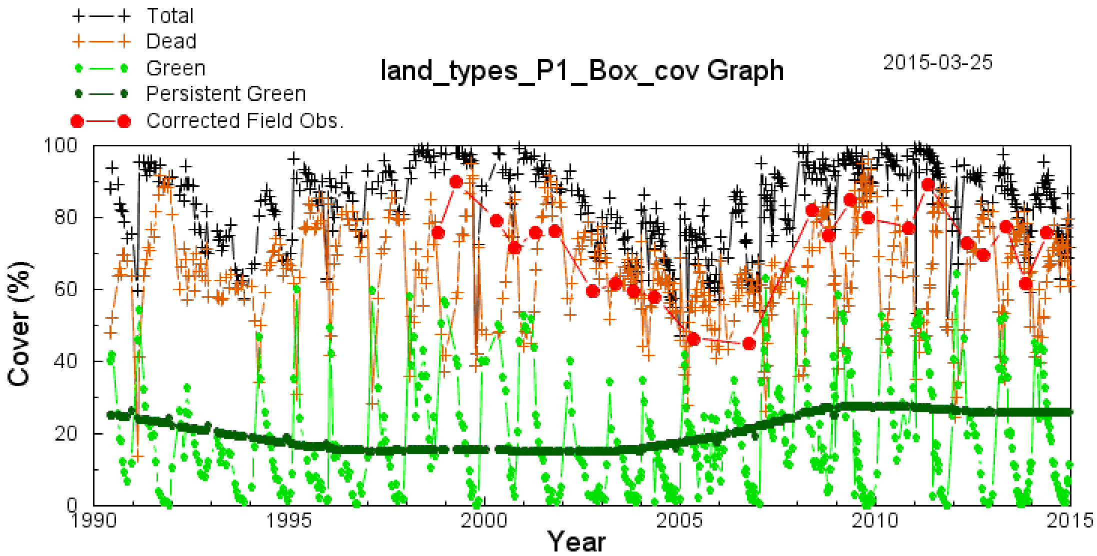

TSDM (kg/ha)
Landsat Total Cover (%)

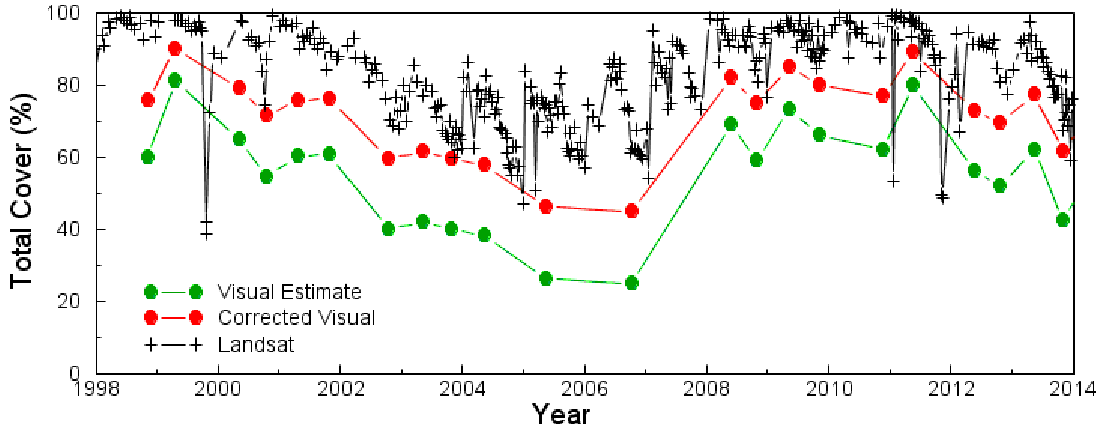

Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

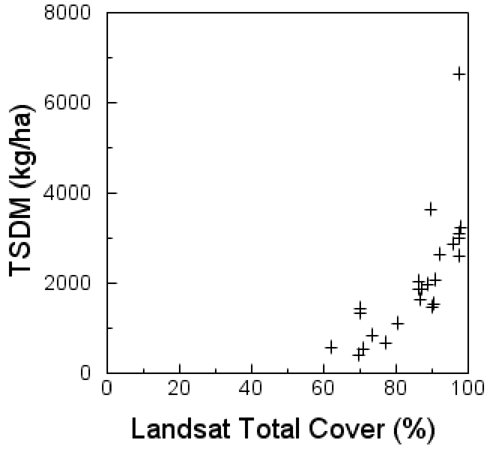


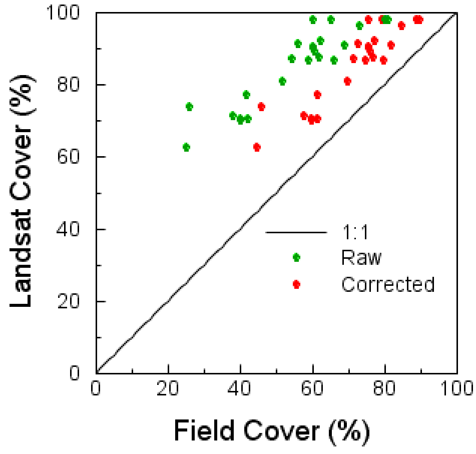
Total
Dead
Green
Persistent Green
Corrected Field Obs
paddocks_gda_80_cov Graph
2015-03-25
Cover (%)
Year
Total Cover (%)
Field Visual Estimate
Field Corrected Visual
Landsat
Year
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

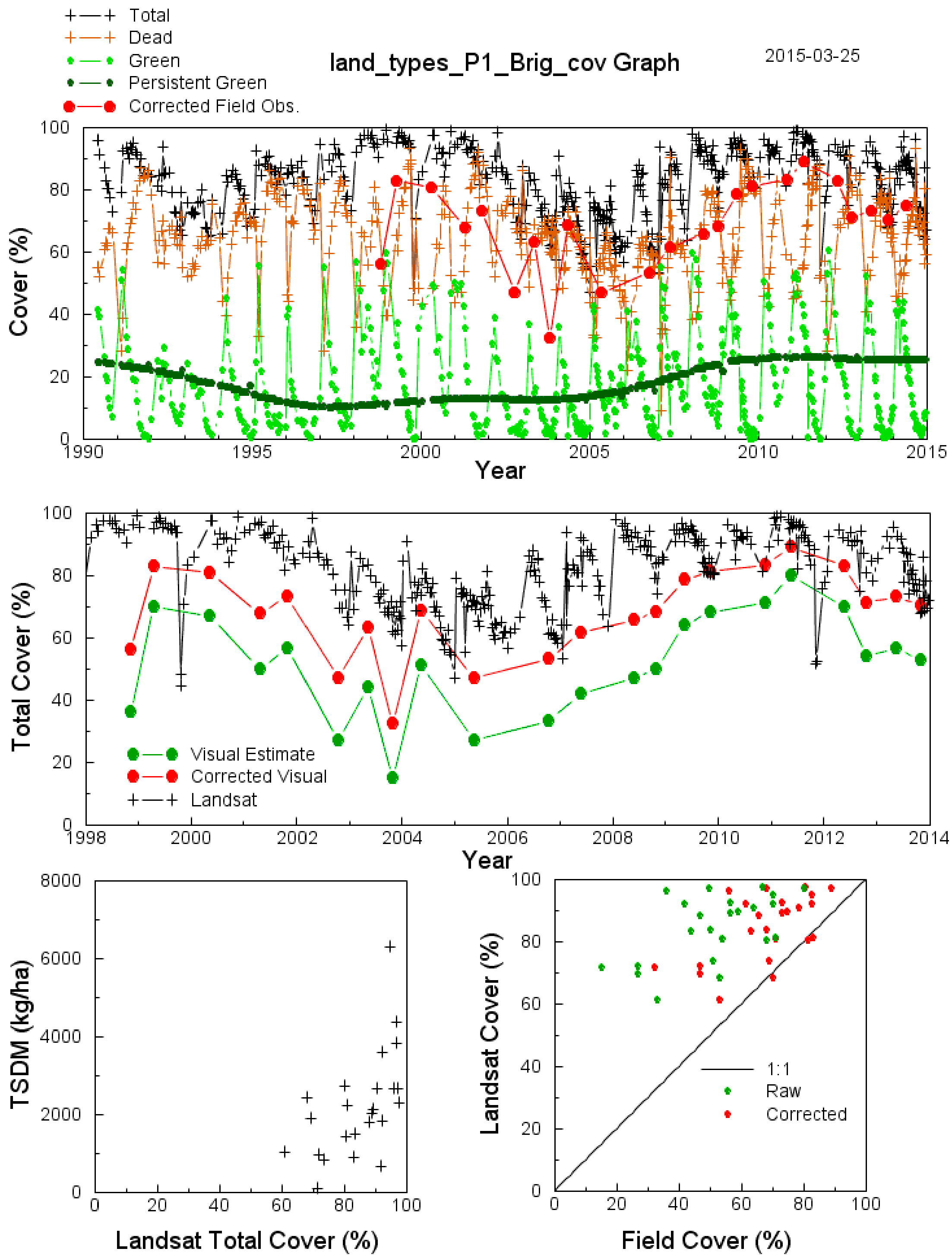

Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_Ex_P8_cov Graph
2015-03-25
Cover (%)
Year
Visual Estimate
Corrected Visual
Landsat
Total Cover (%)
Year
TSDM (kg/ha)
Landsat Total Cover (%)
1:1
Raw
Corrected
Landsat Cover (%)
Field Cover (%)

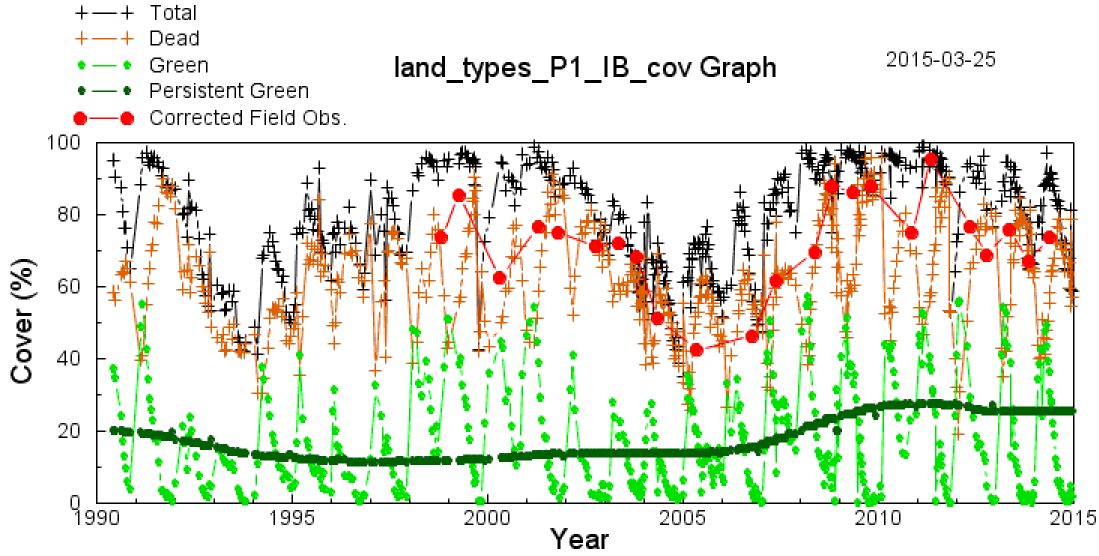

Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P1_Box_cov Graph
2015-03-25
Cover (%)
Year
0
20
40
60
80
100
1990
1995
2000
2005
2010
2015

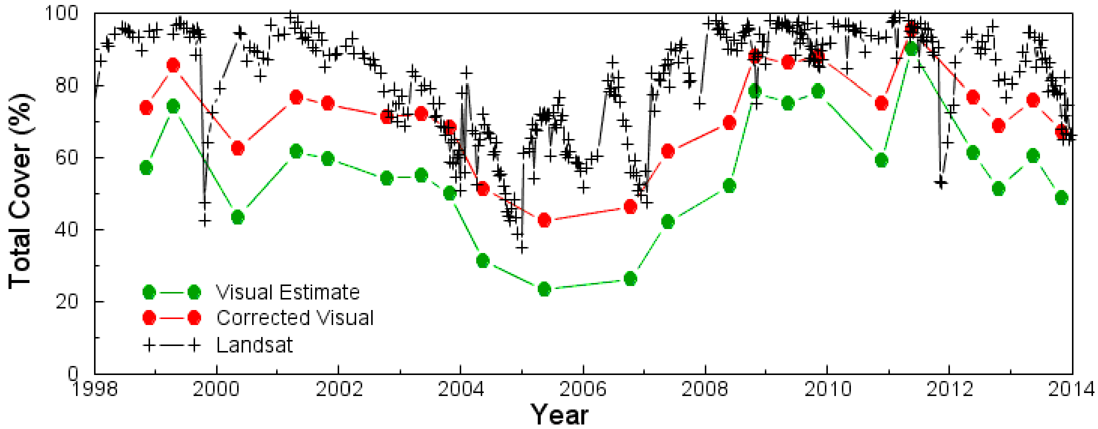

Total Cover (%)
Year
Visual Estimate
Corrected Visual
Landsat
0
20
40
60
80
100
1998
2000
2002
2004
2006
2008
2010
2012
2014

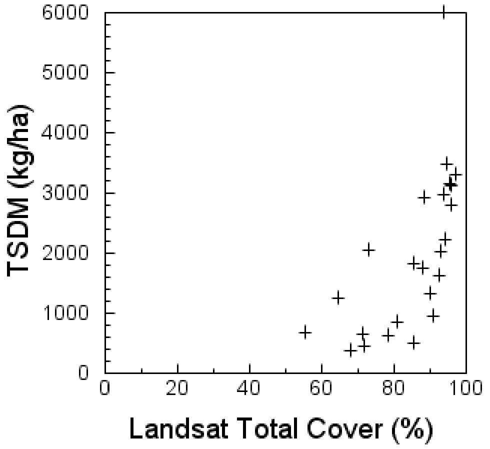

TSDM (kg/ha)
Landsat Total Cover (%)
0
2000
4000
6000
8000
0
20
40
60
80
100

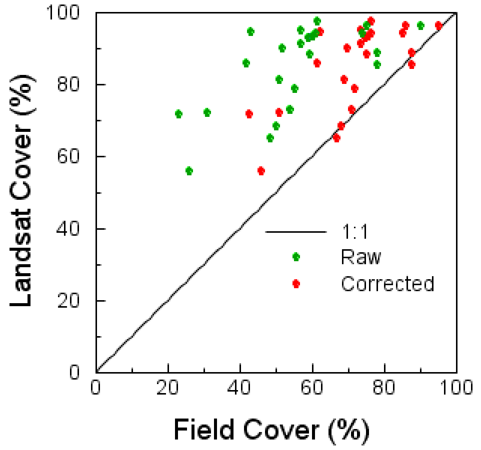

Landsat Cover (%)
Field Cover (%)
1:1
Raw
Corrected
0
20
40
60
80
100
0
20
40
60
80
100

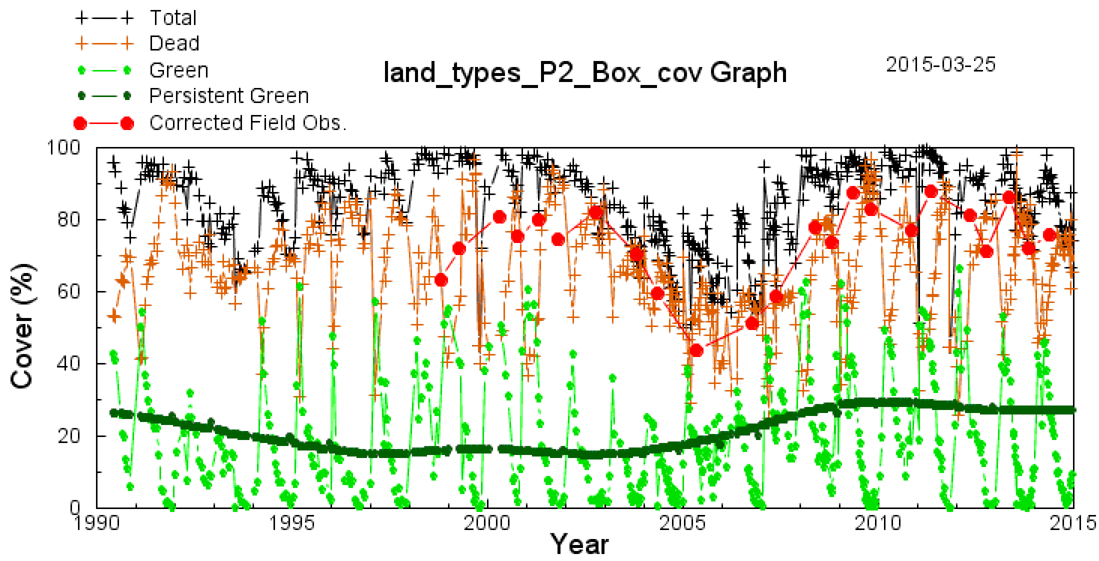

land_types_P1_Brig_cov Graph
2015-03-25
Total
Dead
Green
Persistent Green
Corrected Field Obs.
Cover (%)
Year
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
Year
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)


Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P1_IB_cov Graph
2015-03-25
Cover (%)
100
80
60
40
20
0
1990
1995
2000
2005
2010
2015
Year

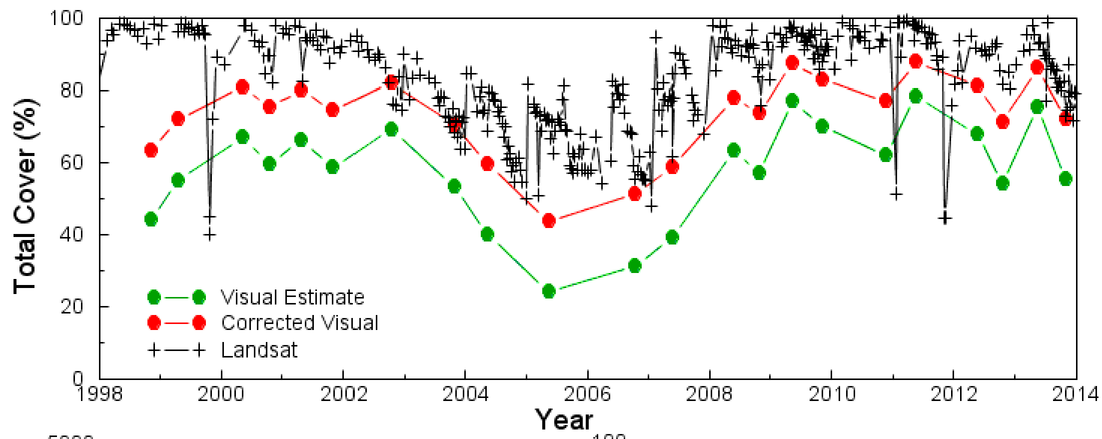

Total Cover (%)
100
80
60
40
20
0
Visual Estimate
Corrected Visual
Landsat
1998
2000
2002
2004
2006
2008
2010
2012
2014
Year


TSDM (kg/ha)
6000
5000
4000
3000
2000
1000
0
0
20
40
60
80
100
Landsat Total Cover (%)

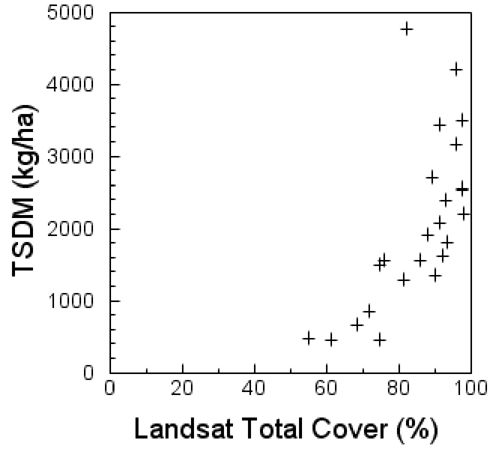

Landsat Cover (%)
100
80
60
40
20
0
1:1
Raw
Corrected
0
20
40
60
80
100
Field Cover (%)



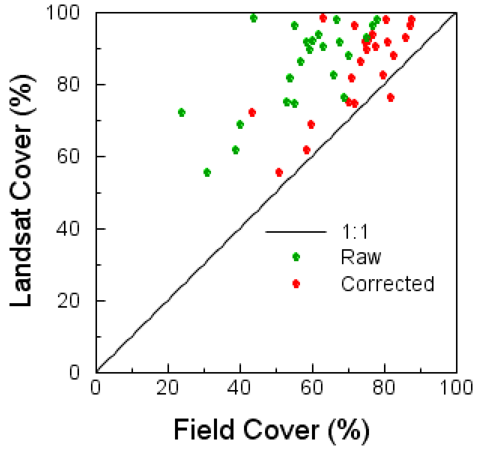
Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P2_Box_cov Graph
2015-03-25
Cover (%)
Year



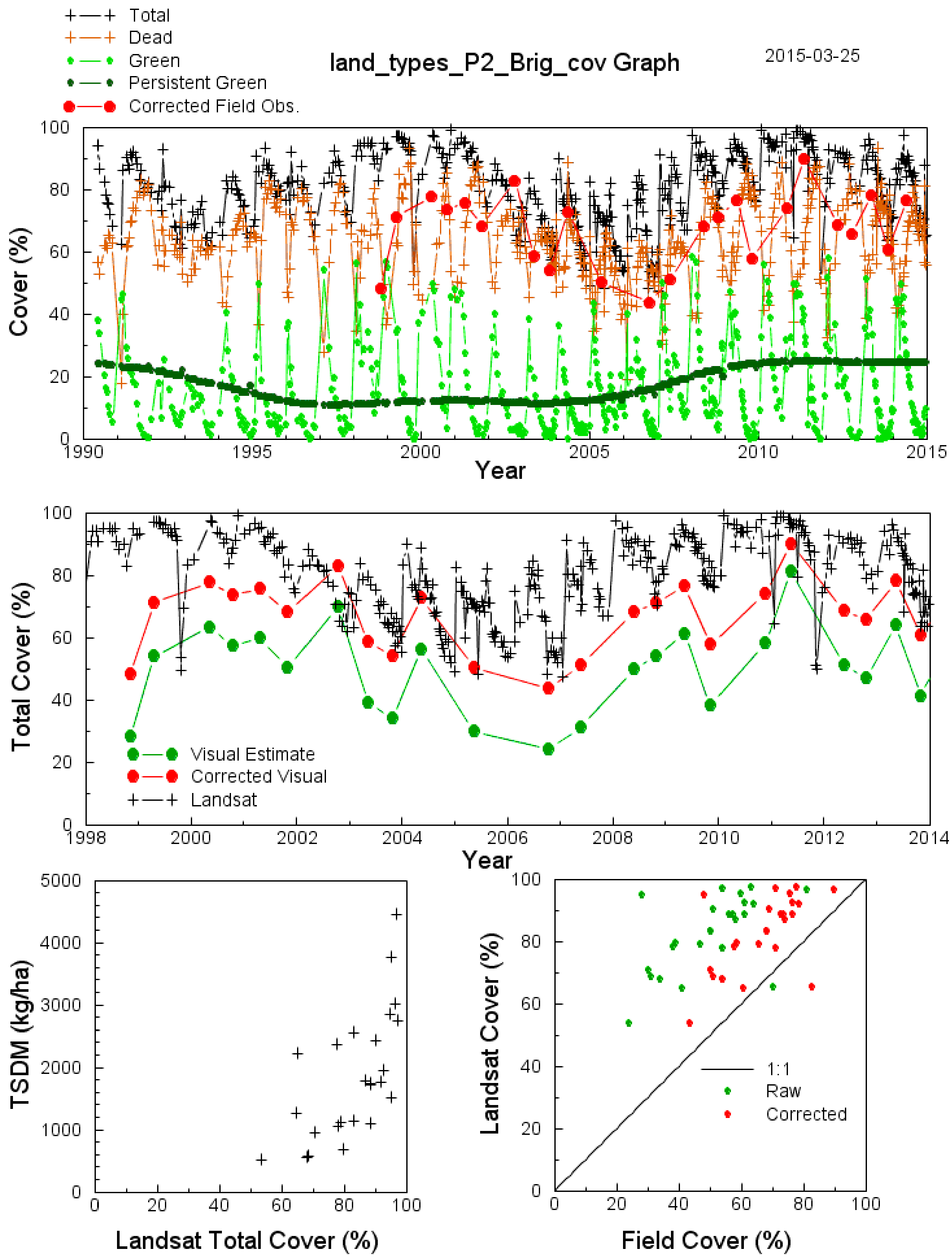
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
Year

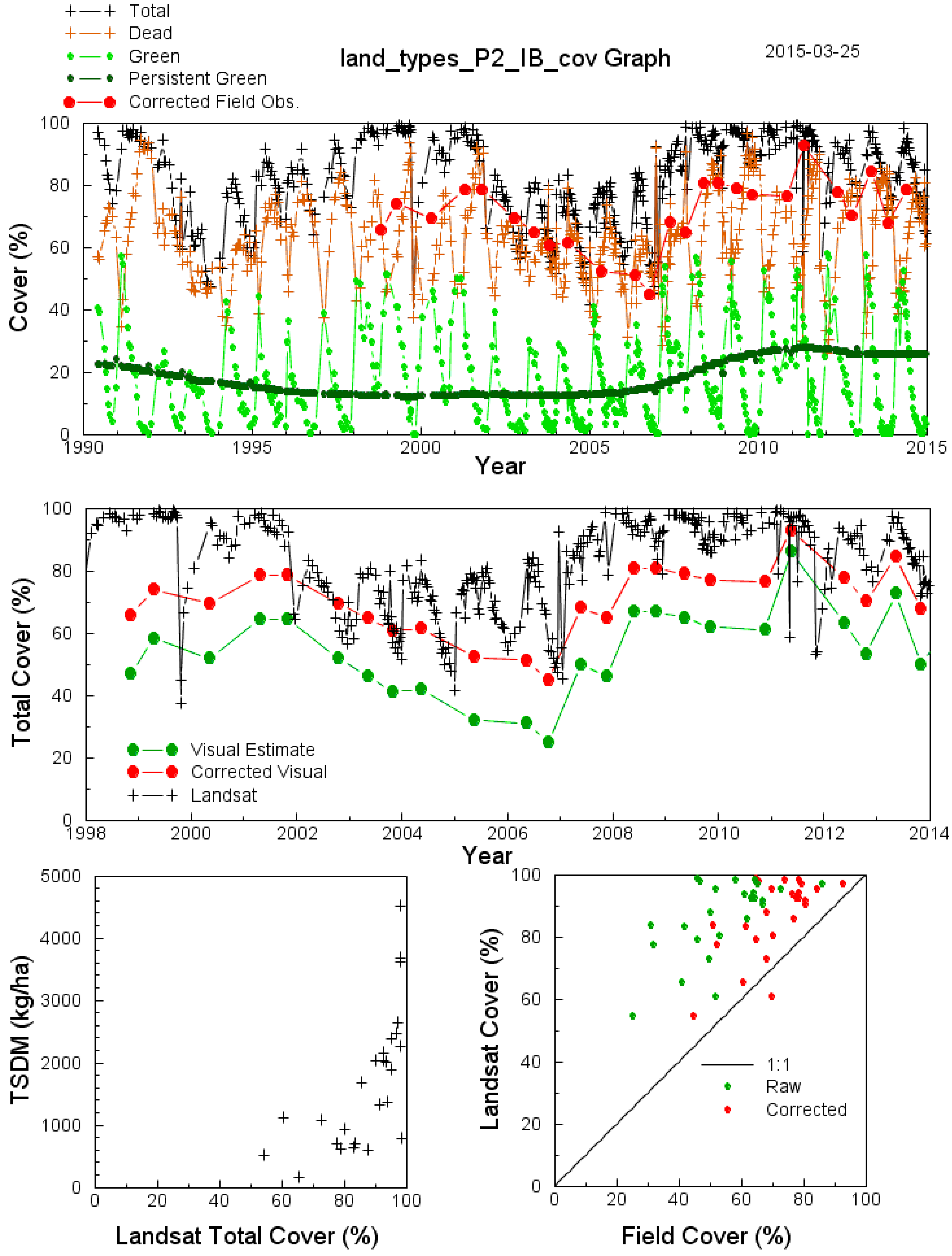


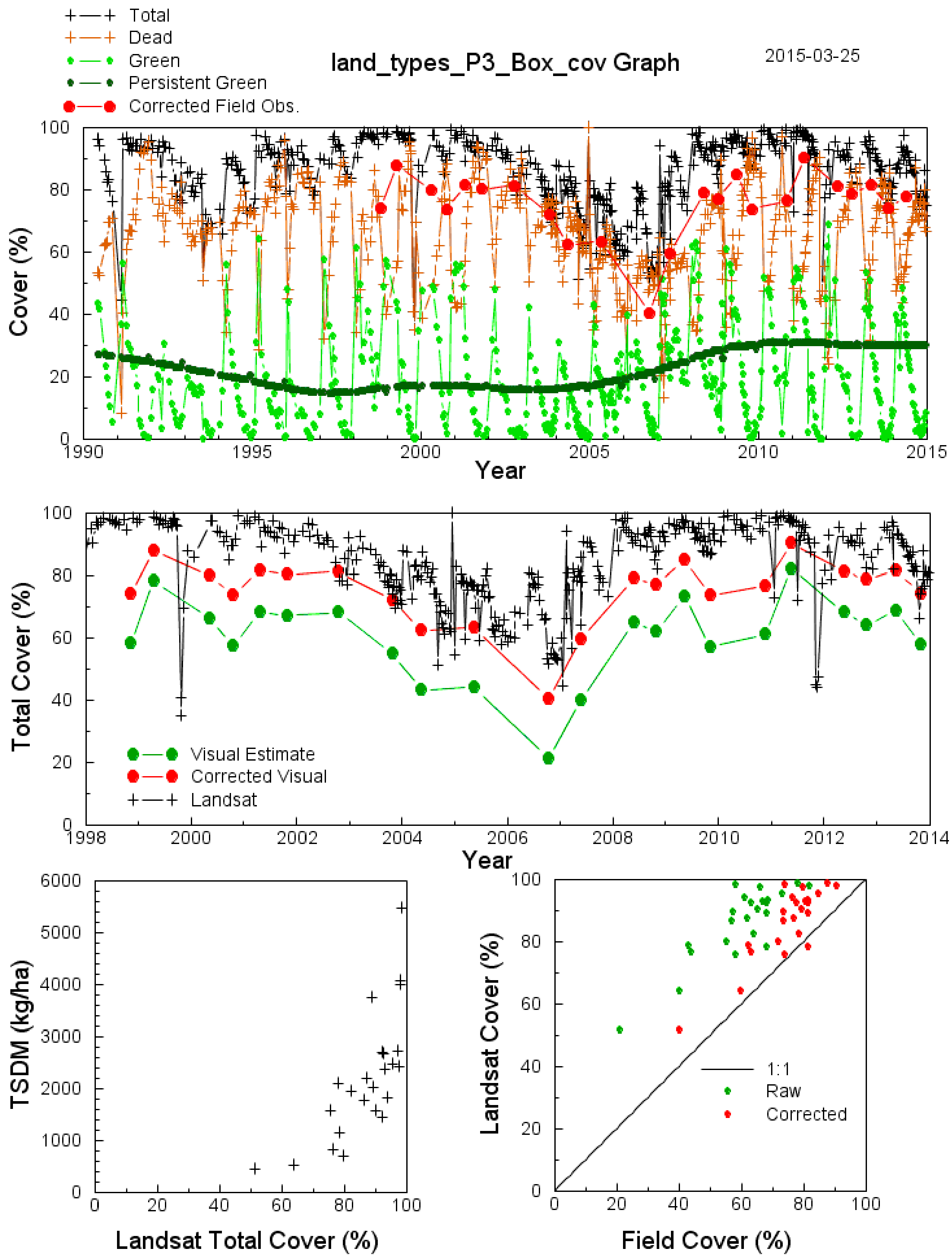
TSDM (kg/ha)
Landsat Total Cover (%)



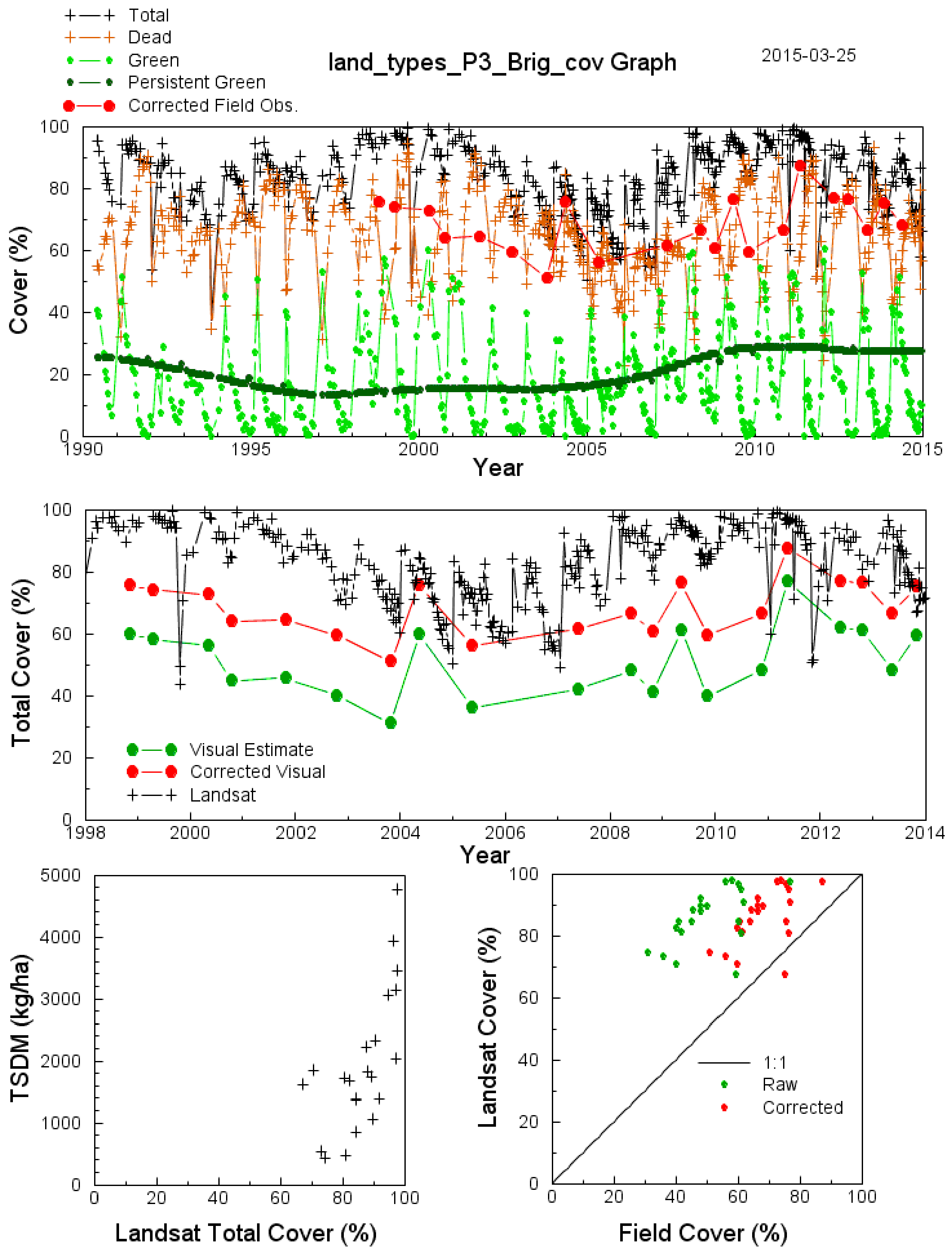
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

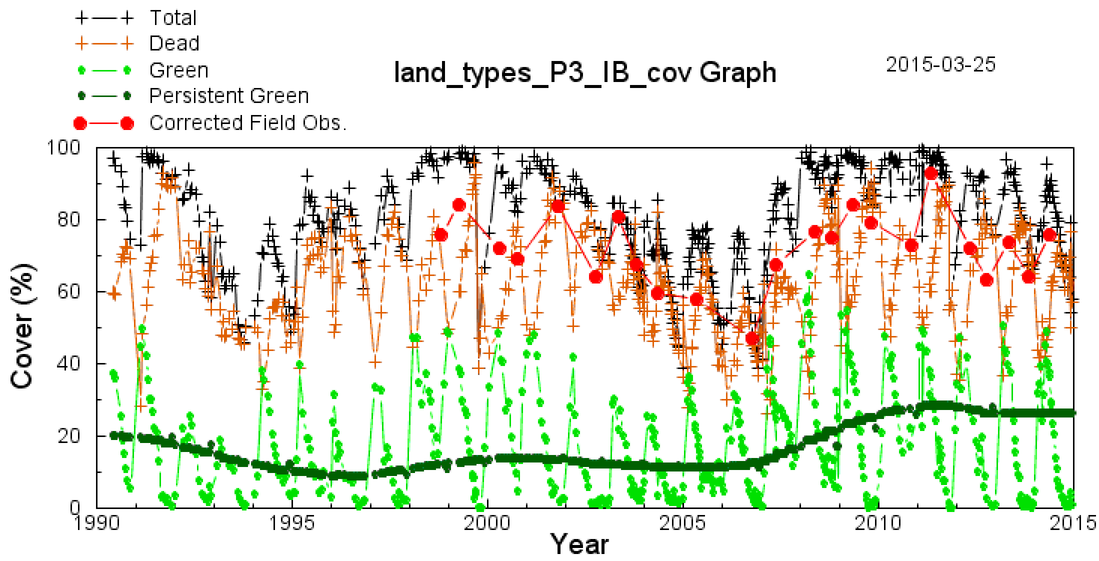

Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P2_Brig_cov Graph
2015-03-25
Cover (%)
Year
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
Year
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

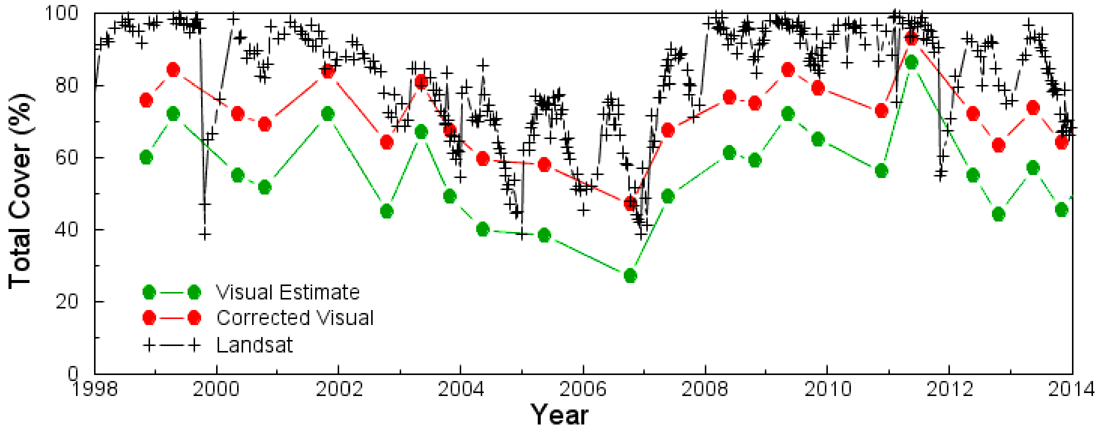

Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P2_IB_cov Graph
2015-03-25
Cover (%)
Year
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
Year
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)



Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P3_Box_cov Graph
2015-03-25
Cover (%)
Year
Visual Estimate
Corrected Visual
Landsat
Total Cover (%)
Year
TSDM (kg/ha)
Landsat Total Cover (%)
1:1
Raw
Corrected
Landsat Cover (%)
Field Cover (%)


land_types_P3_Brig_cov Graph
2015-03-25
Total
Dead
Green
Persistent Green
Corrected Field Obs.
Cover (%)
100
80
60
40
20
0
1990
1995
2000
2005
2010
2015
Year
Visual Estimate
Corrected Visual
Landsat
Total Cover (%)
1998
2000
2002
2004
2006
2008
2010
2012
2014
TSDM (kg/ha)
5000
4000
3000
2000
1000
Landsat Total Cover (%)
1:1
Raw
Corrected
Landsat Cover (%)
Field Cover (%)


Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P3_IB_cov Graph
2015-03-25
Cover (%)
0
20
40
60
80
100
1990
1995
2000
2005
2010
2015
Year


Total Cover (%)
0
20
40
60
80
100
Visual Estimate
Corrected Visual
Landsat
1998
2000
2002
2004
2006
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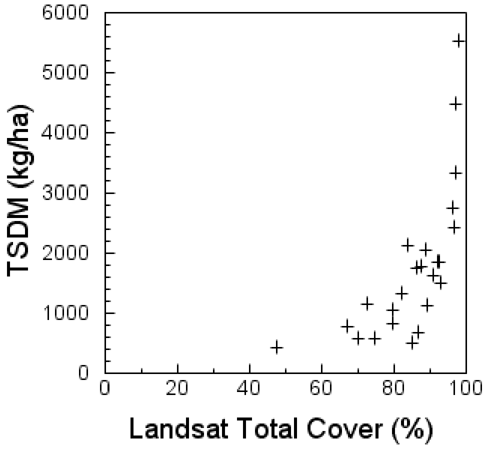
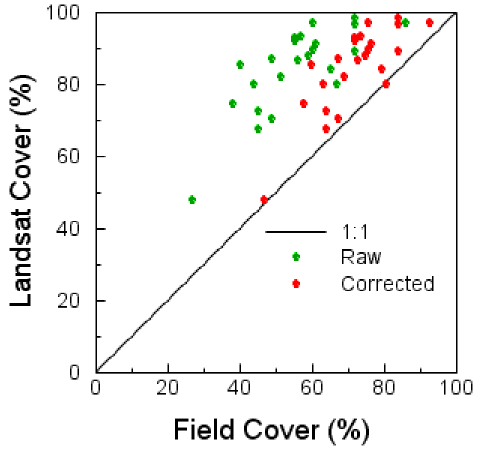
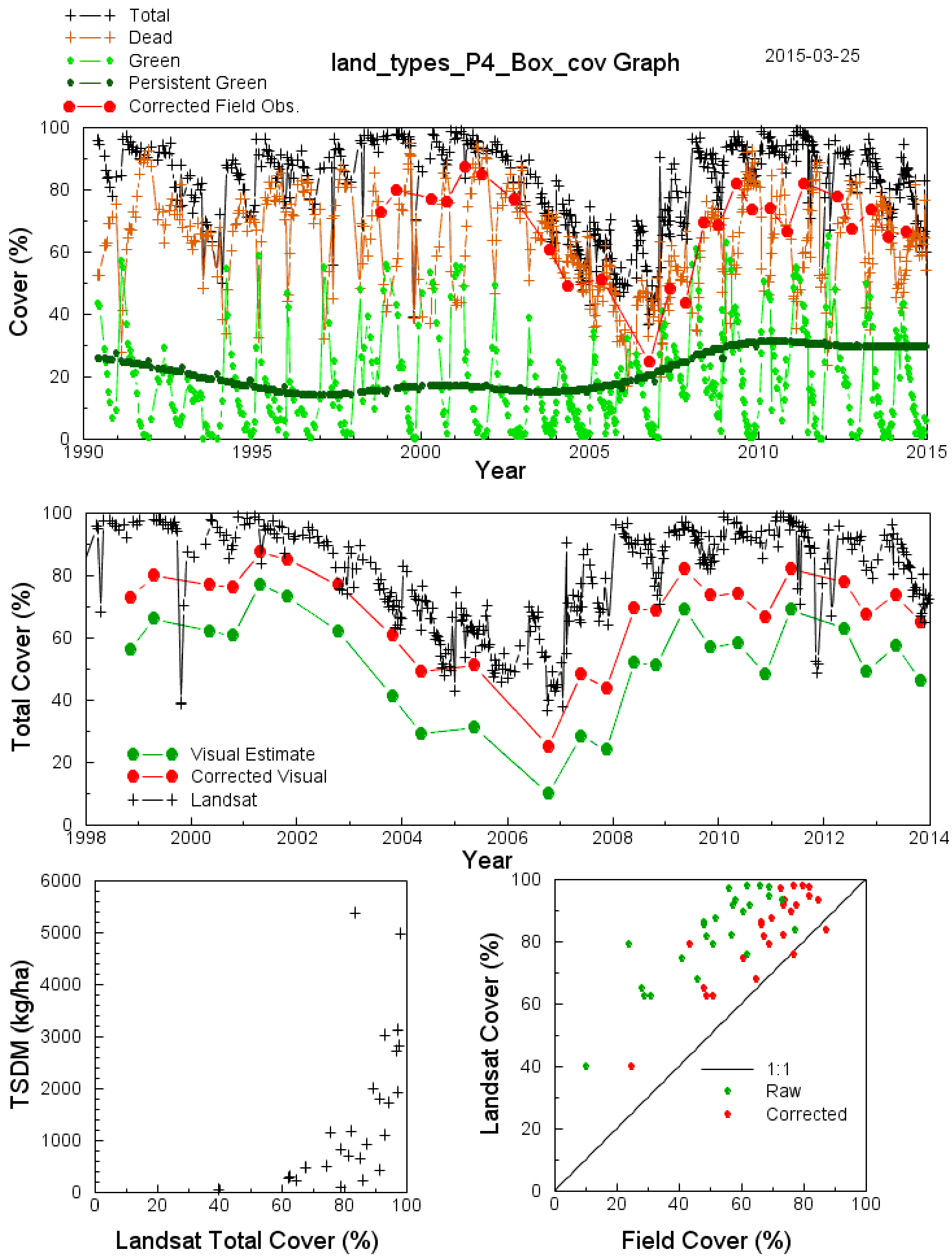
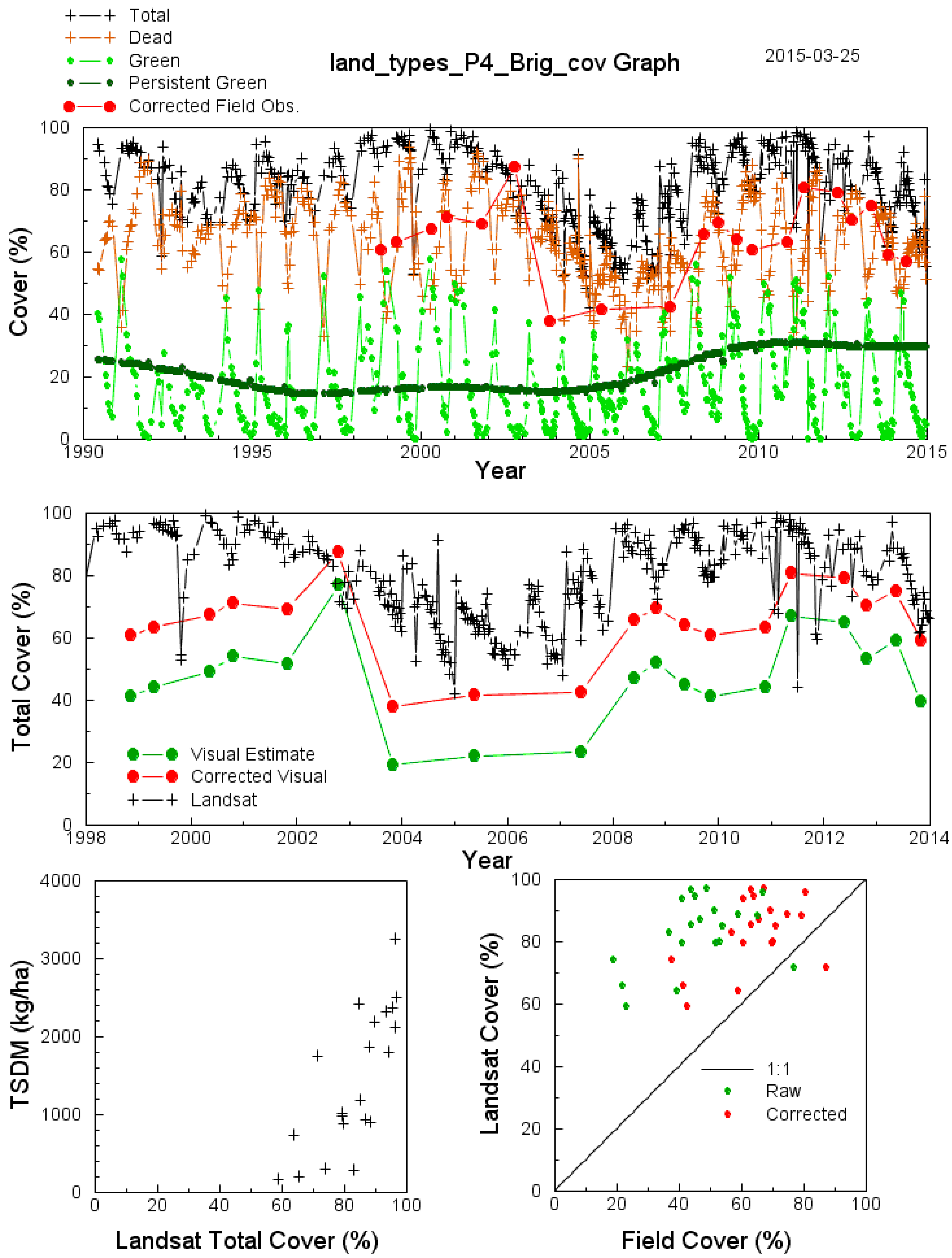
2010
2012
2014
Year


TSDM (kg/ha)
0
1000
2000
3000
4000
5000
6000
0
20
40
60
80
100
Landsat Total Cover (%)

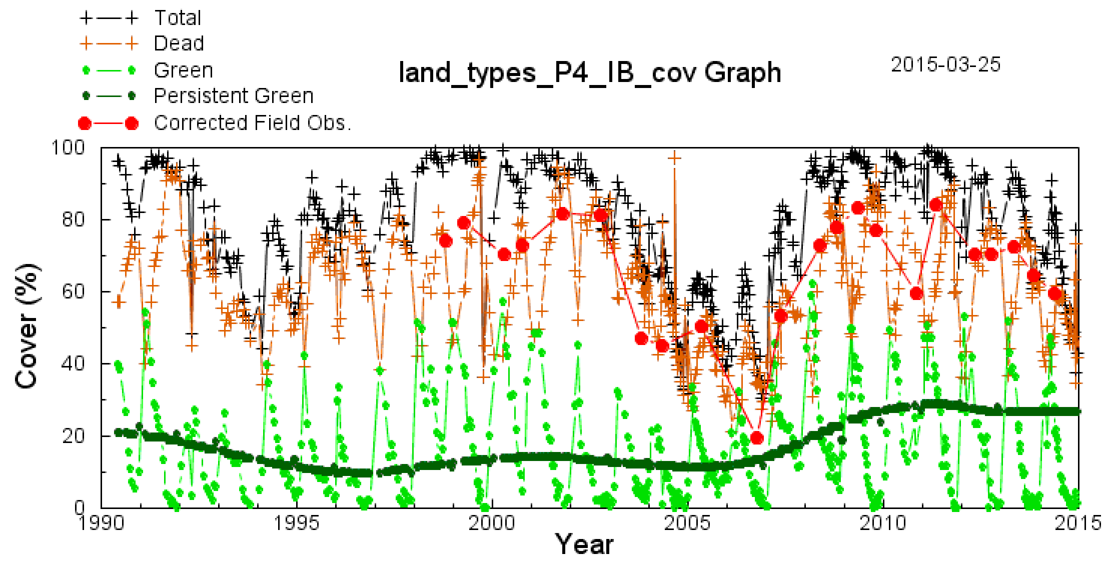

Landsat Cover (%)
0
20
40
60
80
100
1:1
Raw
Corrected
Field Cover (%)

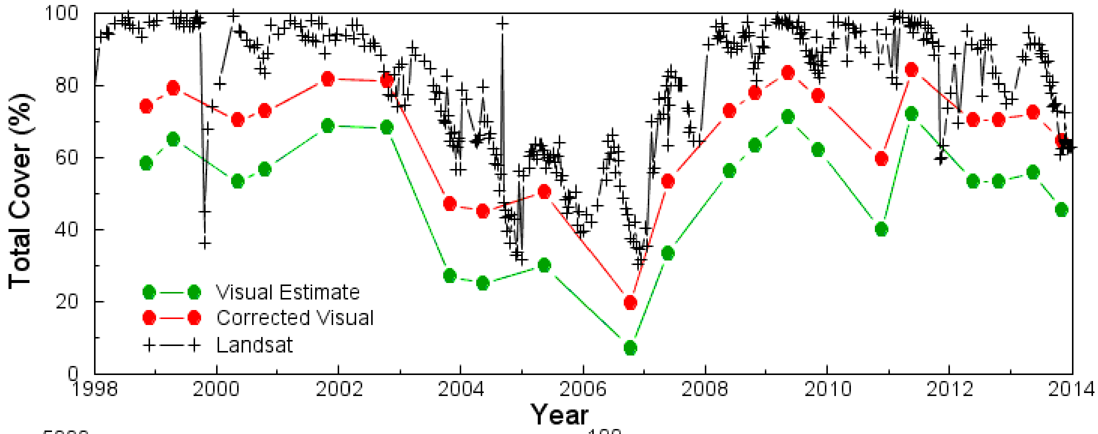


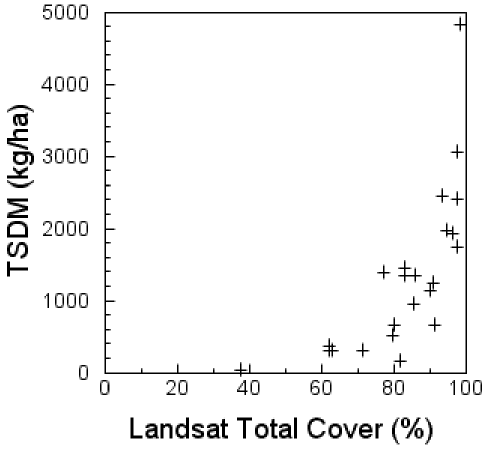
Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P4_Box_cov Graph
2015-03-25
Cover (%)
Year
Visual Estimate
Corrected Visual
Landsat
Total Cover (%)
Year
TSDM (kg/ha)
Landsat Total Cover (%)
1:1
Raw
Corrected
Landsat Cover (%)
Field Cover (%)

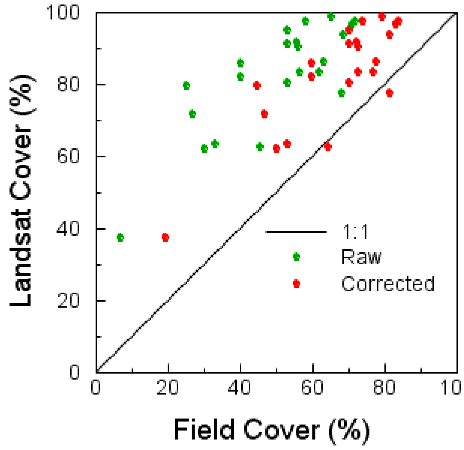


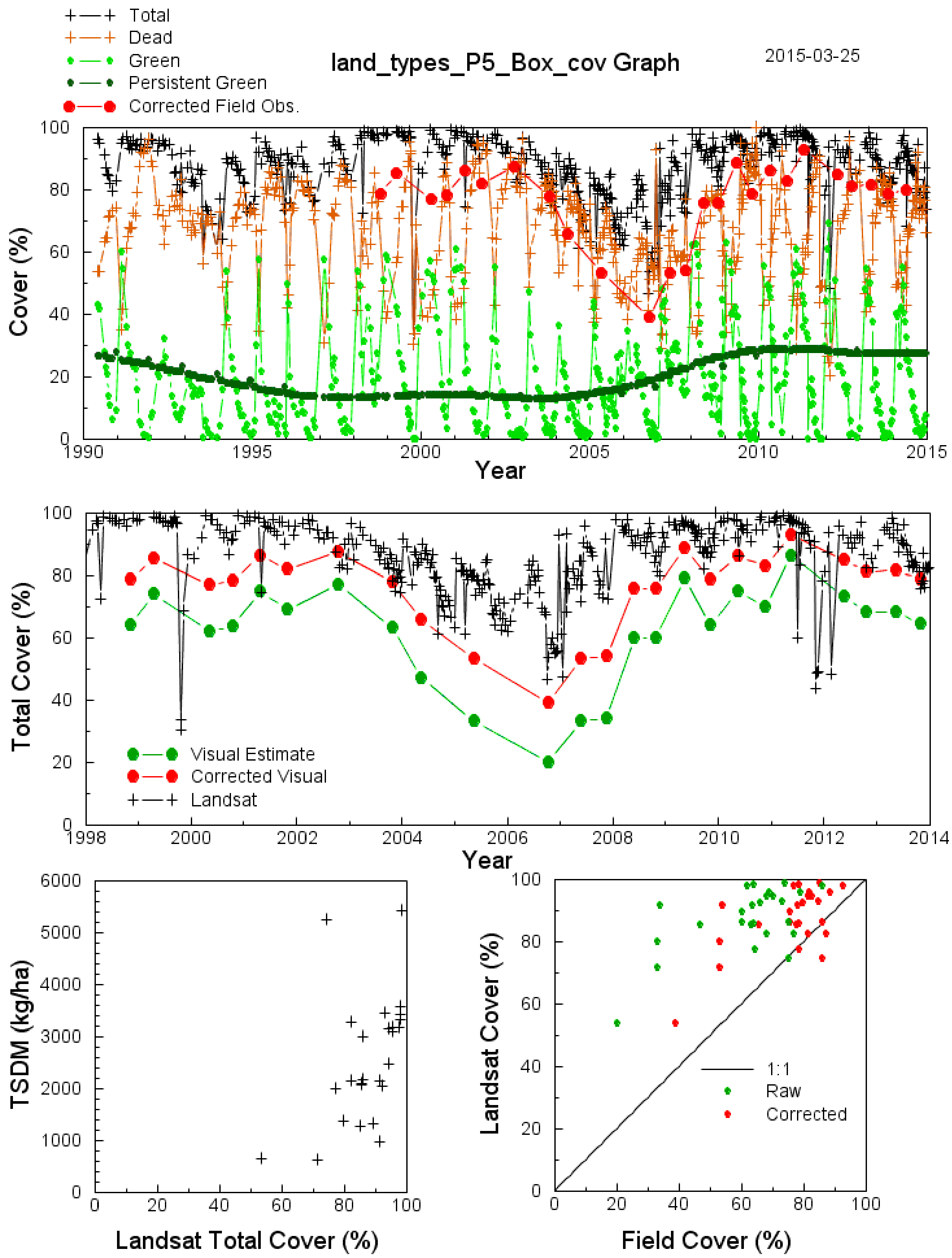
Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P4_Brig_cov Graph
2015-03-25
Cover (%)
Year
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)


Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P4_IB_cov Graph
2015-03-25
Cover (%)
Year
0
20
40
60
80
100
1990
1995
2000
2005
2010
2015

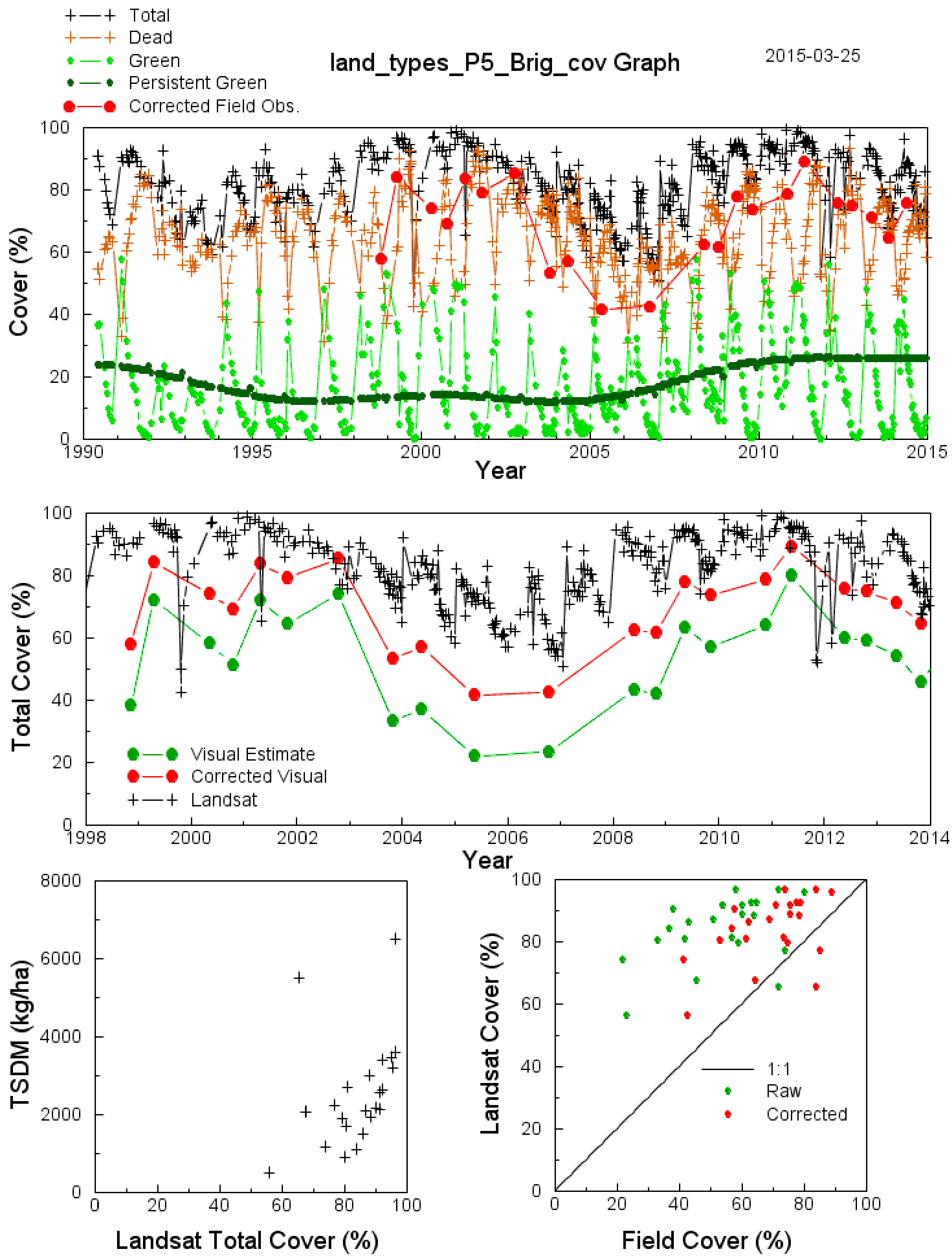

Total Cover (%)
Year
Visual Estimate
Corrected Visual
Landsat
0
20
40
60
80
100
1998
2000
2002
2004
2006
2008
2010
2012
2014

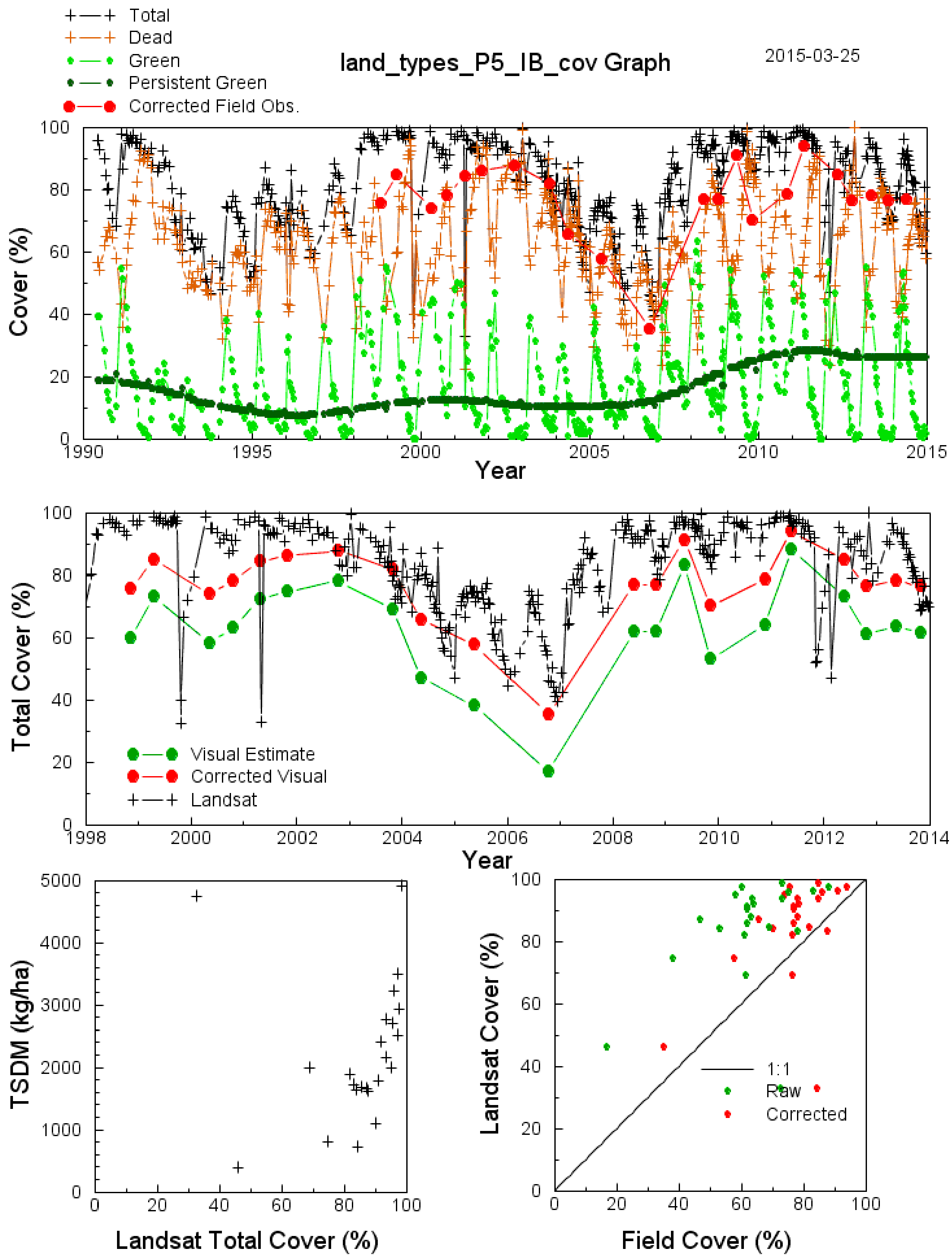

TSDM (kg/ha)
Landsat Total Cover (%)
0
1000
2000
3000
4000
5000
0
20
40
60
80
100

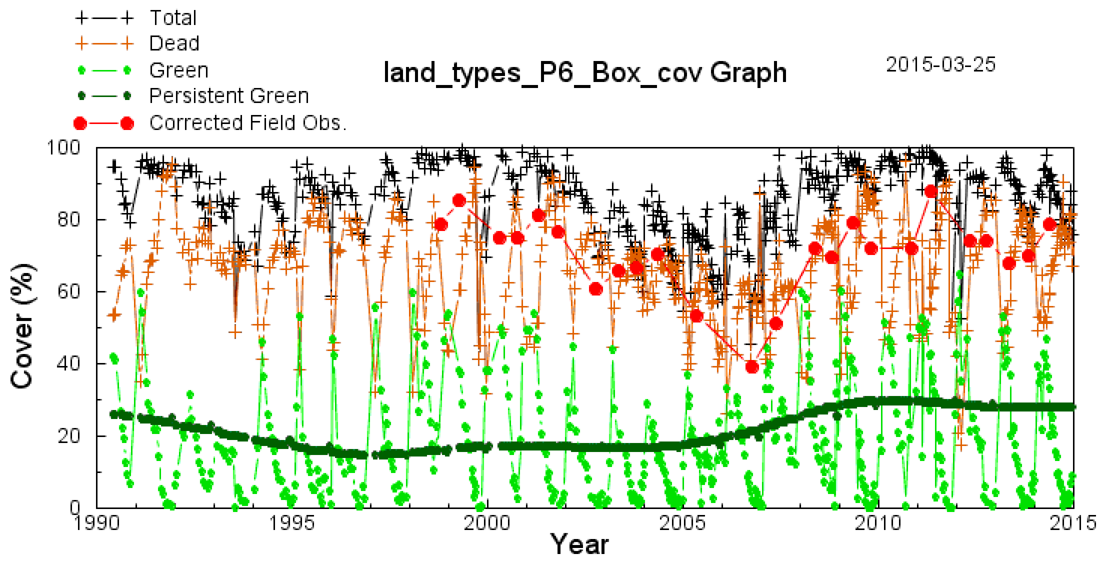

Landsat Cover (%)
Field Cover (%)
1:1
Raw
Corrected
0
20
40
60
80
100

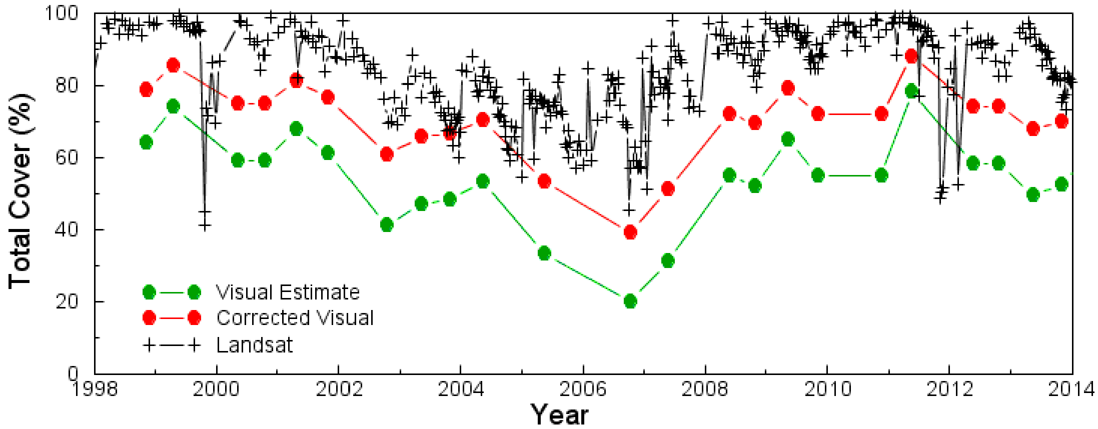


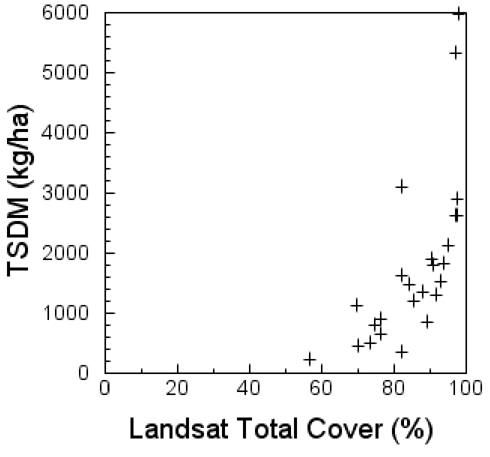
land_types_P5_Box_cov Graph
2015-03-25
Total
Dead
Green
Persistent Green
Corrected Field Obs.
Cover (%)
Year
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

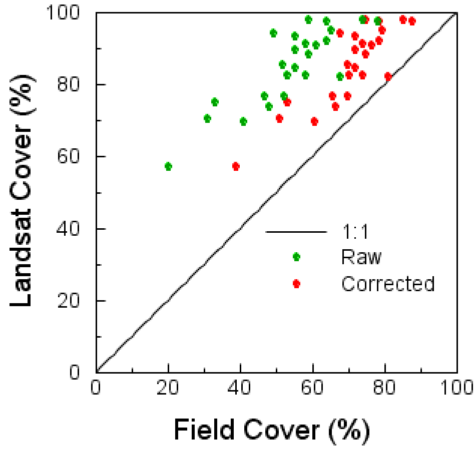

land_types_P5_Brig_cov Graph
2015-03-25
Total
Dead
Green
Persistent Green
Corrected Field Obs.
Cover (%)
Year
Visual Estimate
Corrected Visual
Landsat
Total Cover (%)
Year
TSDM (kg/ha)
Landsat Total Cover (%)
1:1
Raw
Corrected
Landsat Cover (%)
Field Cover (%)

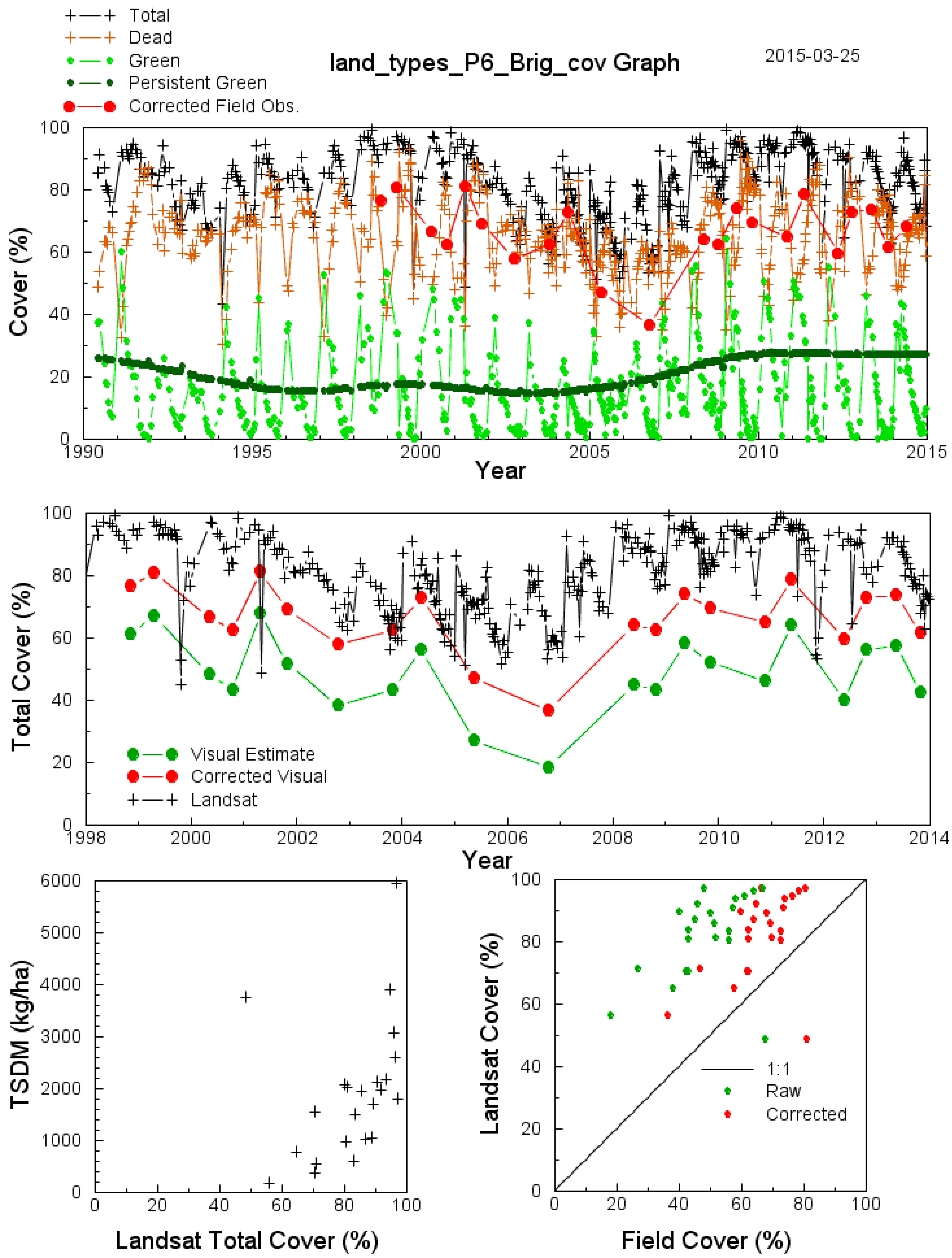

Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P5_IB_cov Graph
2015-03-25
Cover (%)
Year
Visual Estimate
Corrected Visual
Landsat
Total Cover (%)
Year
TSDM (kg/ha)
Landsat Total Cover (%)
1:1
Raw
Corrected
Landsat Cover (%)
Field Cover (%)


Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P6_Box_cov Graph
2015-03-25
Cover (%)
Year
0
20
40
60
80
100
1990
1995
2000
2005
2010
2015

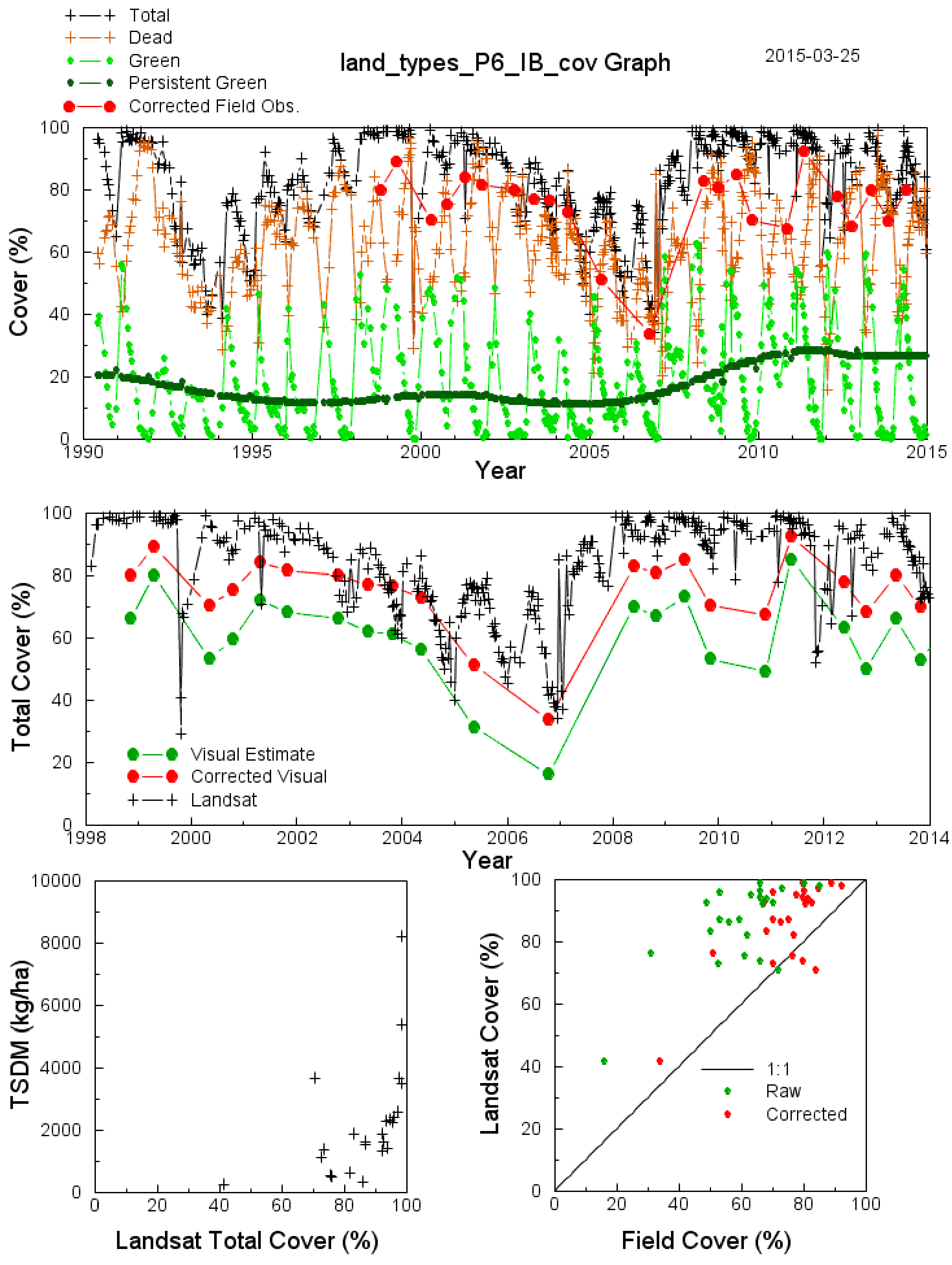

Total Cover (%)
Year
Visual Estimate
Corrected Visual
Landsat
0
20
40
60
80
100
1998
2000
2002
2004
2006
2008
2010
2012
2014

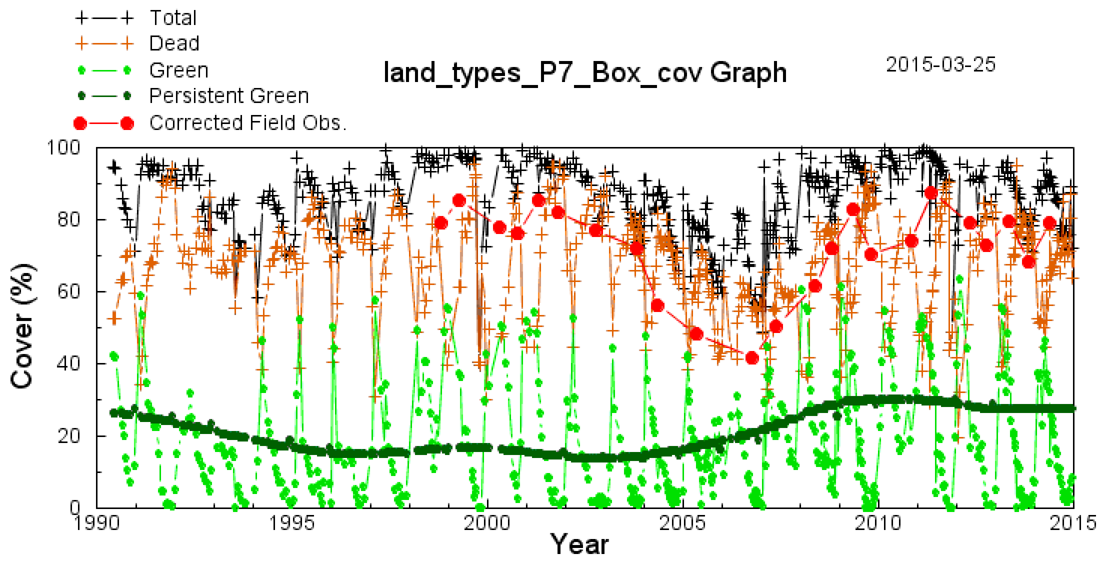

TSDM (kg/ha)
Landsat Total Cover (%)
0
1000
2000
3000
4000
5000
6000
20
40
60
80
100


Landsat Cover (%)
Field Cover (%)
1:1
Raw
Corrected
0
20
40
60
80
100

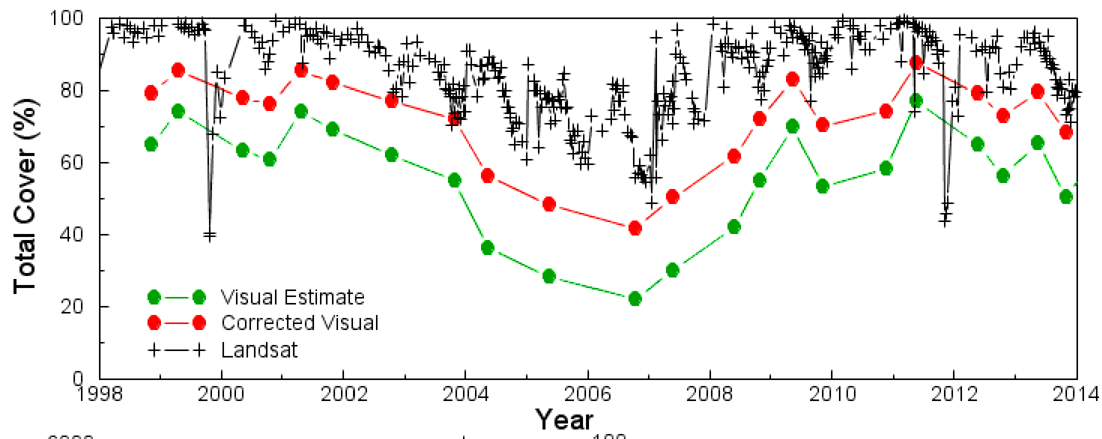


Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P6_Brig_cov Graph
2015-03-25
Cover (%)
Year
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
Year
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

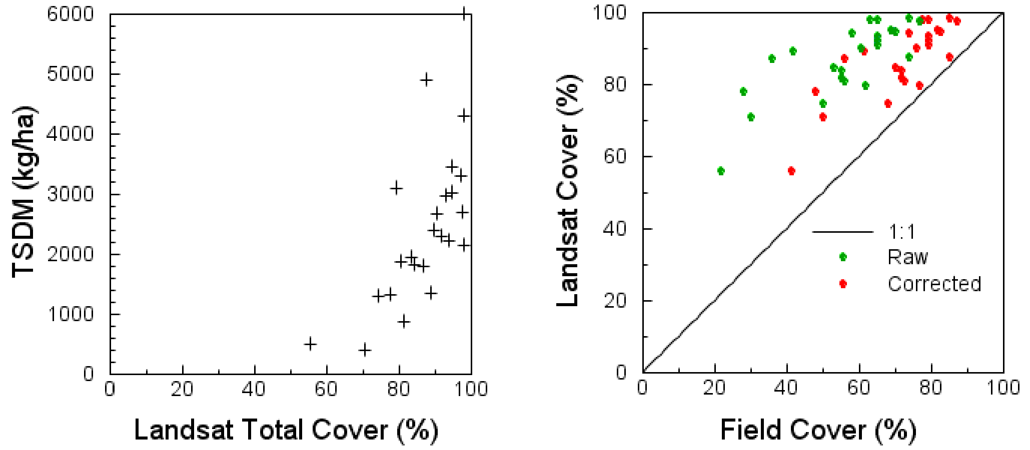

land_types_P6_IB_cov Graph
2015-03-25
Total
Dead
Green
Persistent Green
Corrected Field Obs.
Cover (%)
Year
Visual Estimate
Corrected Visual
Landsat
Total Cover (%)
Year
TSDM (kg/ha)
Landsat Total Cover (%)
1:1
Raw
Corrected
Landsat Cover (%)
Field Cover (%)



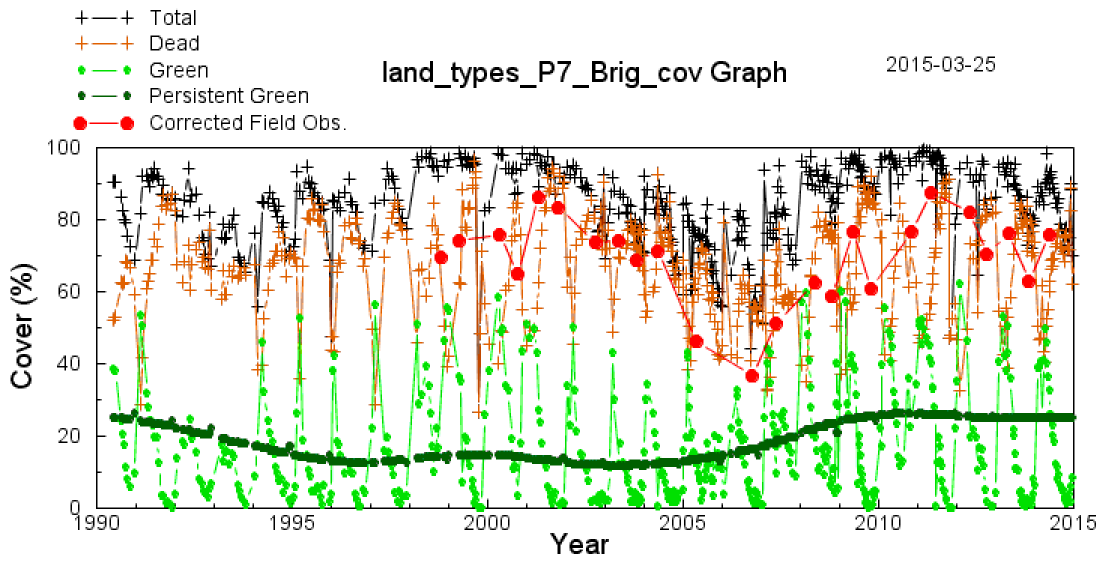
Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P7_Box_cov Graph
2015-03-25
Cover (%)
Year

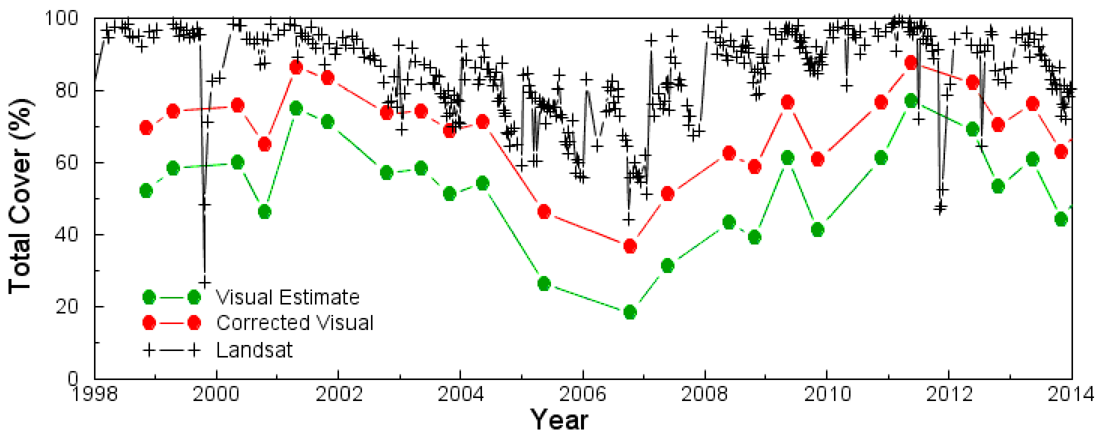


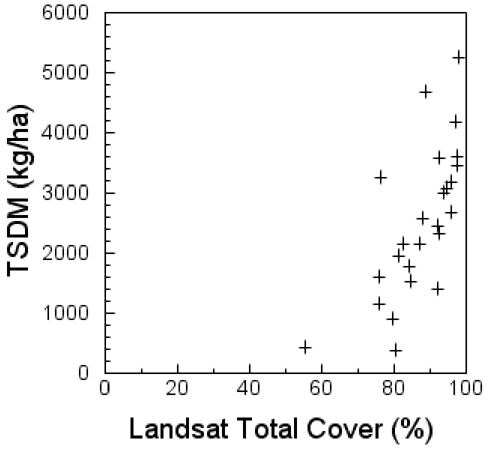
Total Cover (%)
Year
Visual Estimate
Corrected Visual
Landsat

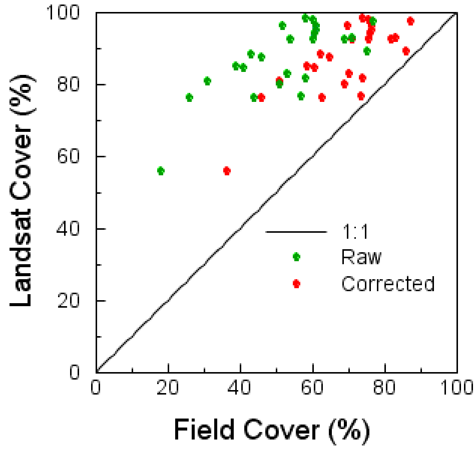


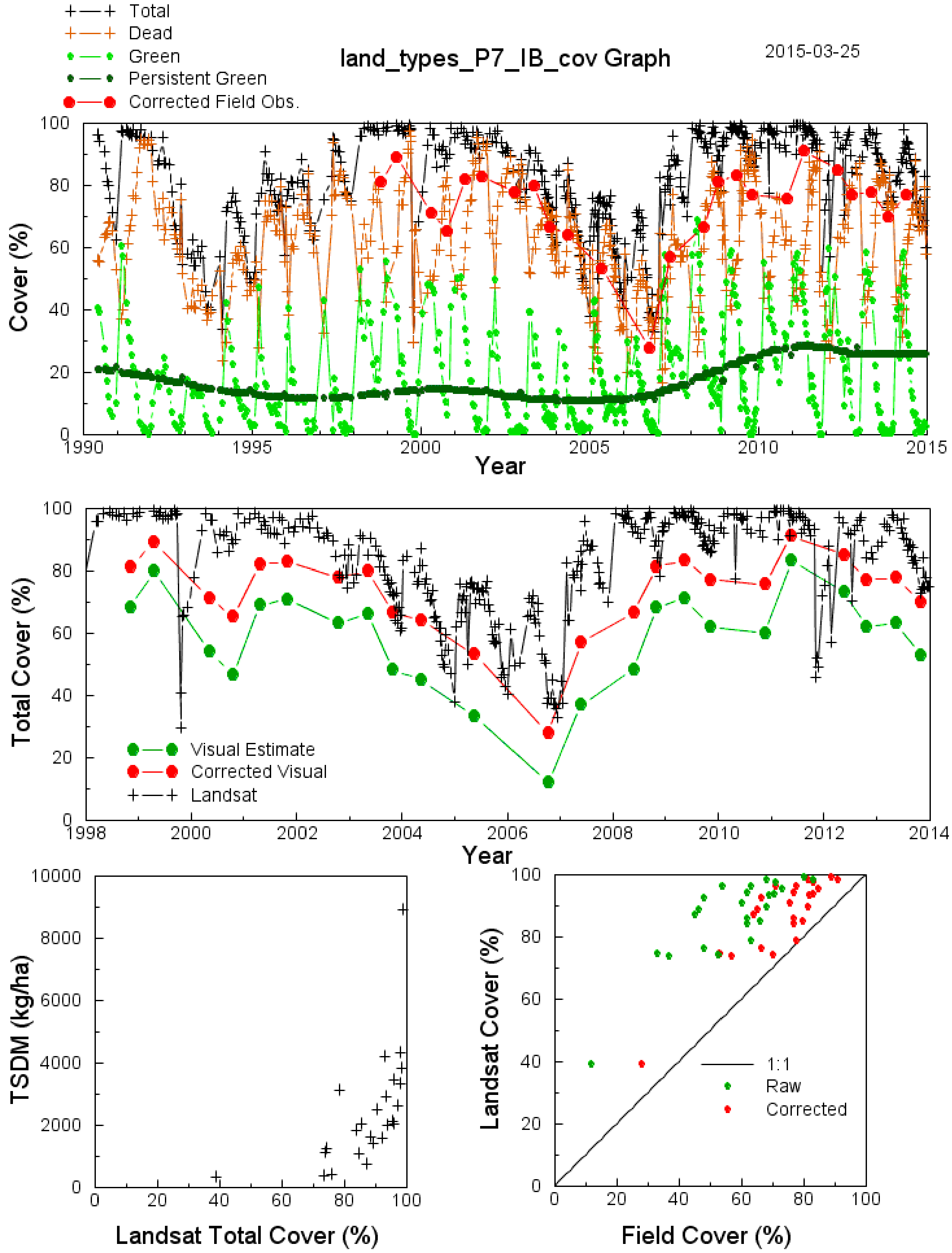
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
Field Cover (%)
1:1
Raw
Corrected

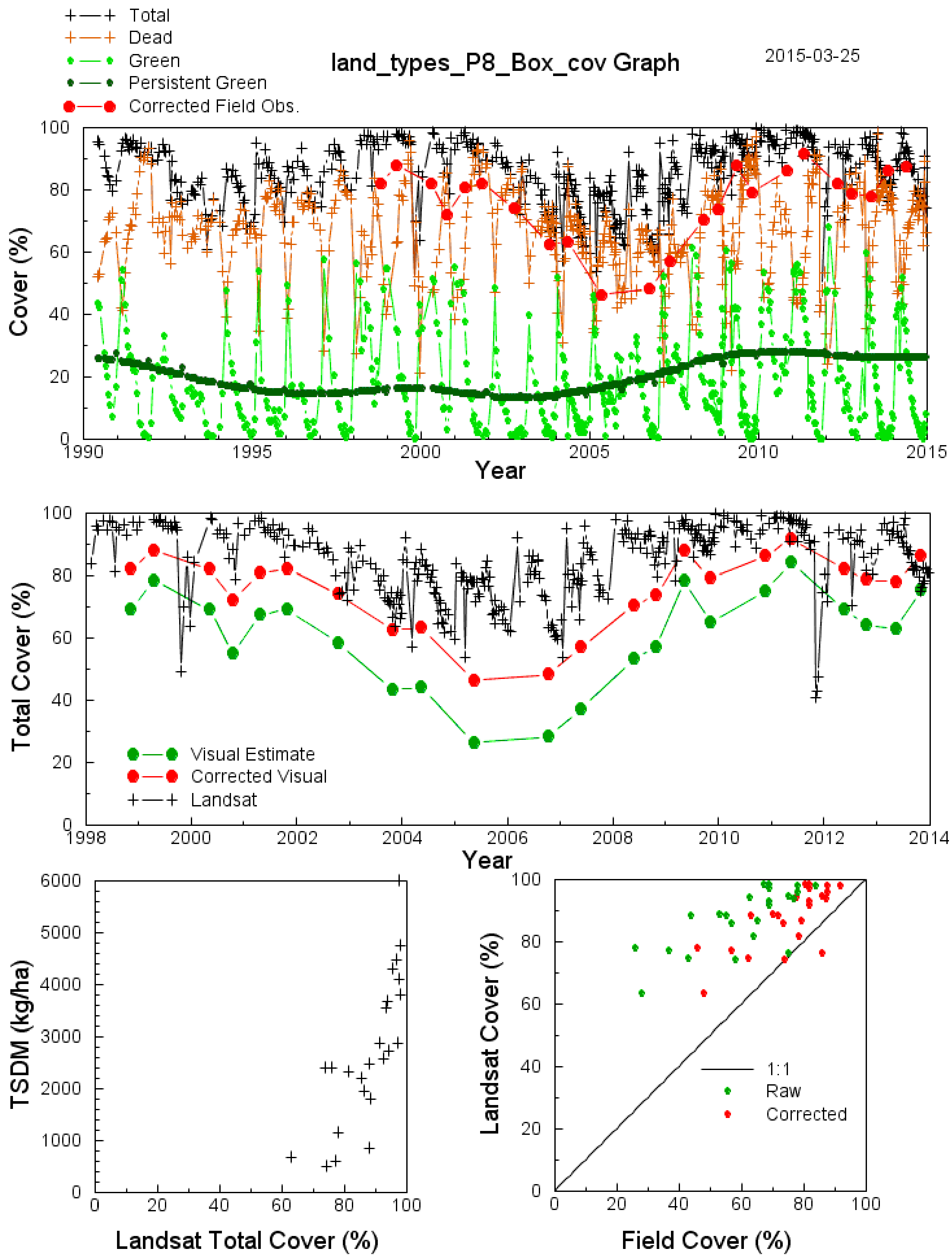

Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P7_Brig_cov Graph
2015-03-25
Cover (%)
Year


Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
Year

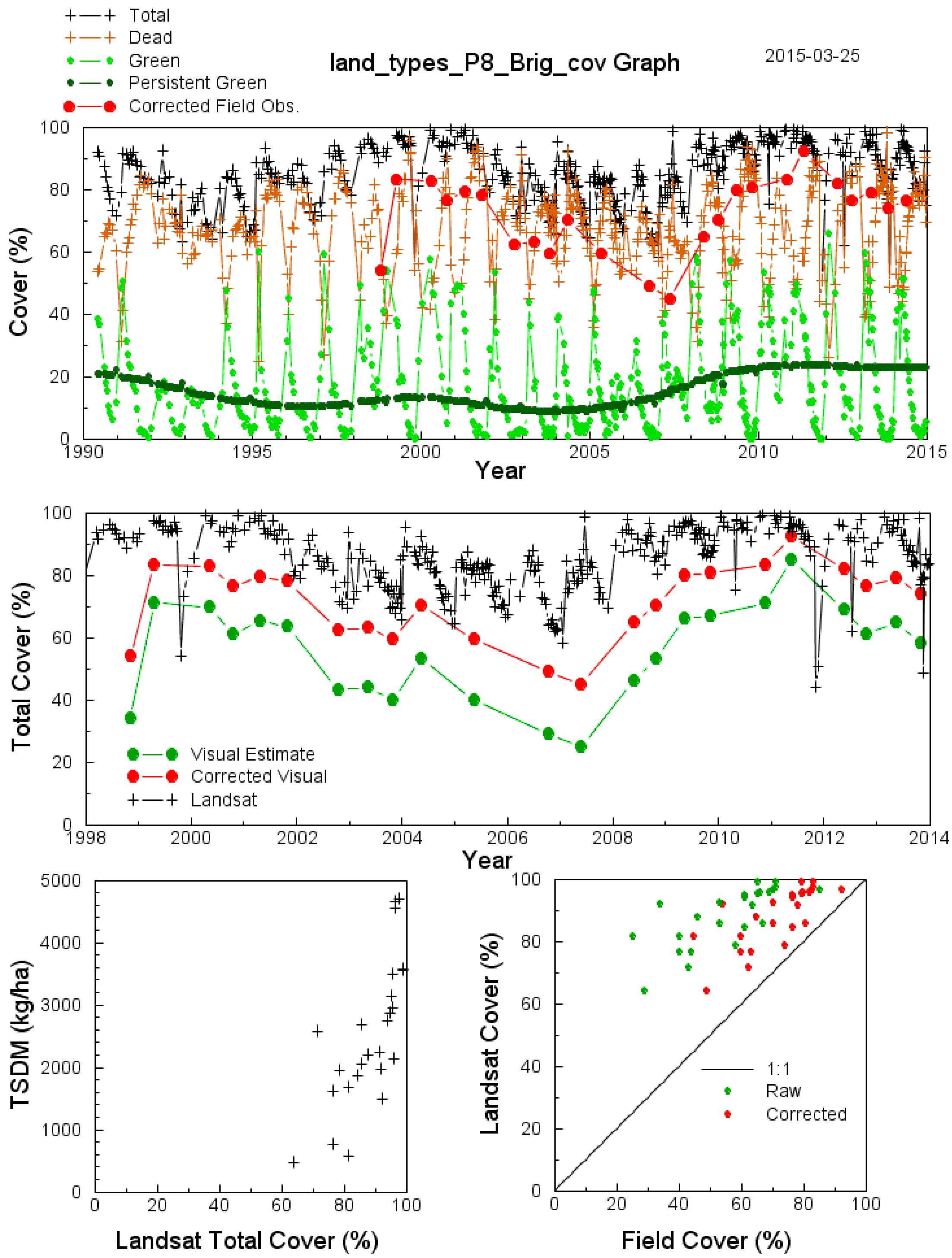

TSDM (kg/ha)
Landsat Total Cover (%)

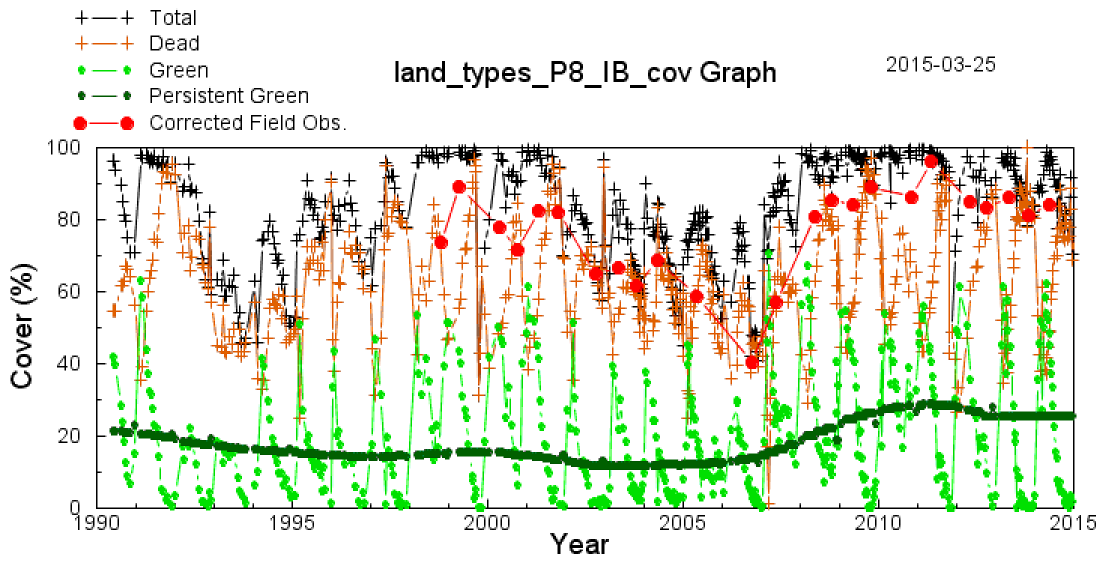

Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

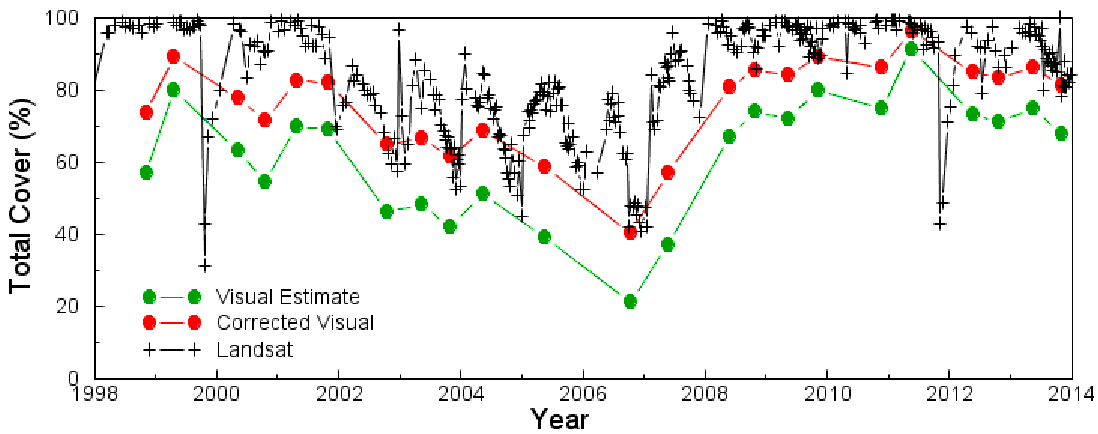

land_types_P7_IB_cov Graph
2015-03-25
Total
Dead
Green
Persistent Green
Corrected Field Obs.
Cover (%)
Year
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
Year
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

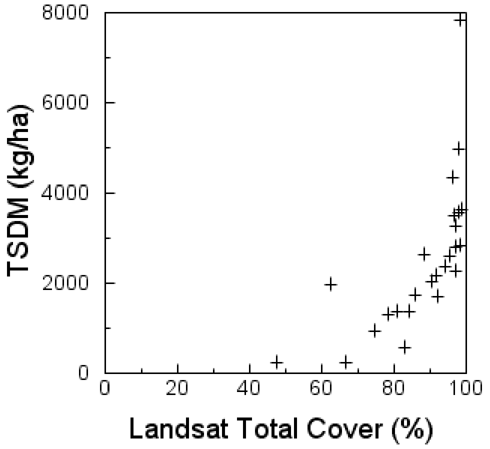


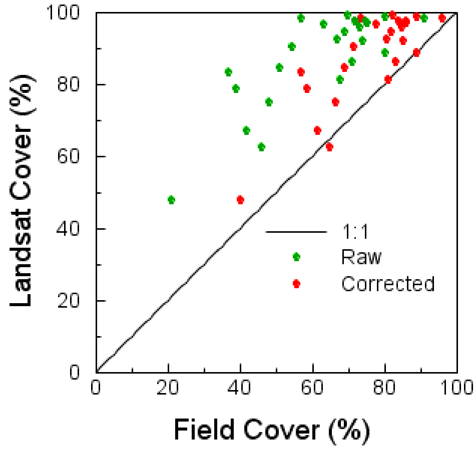
land_types_P8_Box_cov Graph
2015-03-25
Total
Dead
Green
Persistent Green
Corrected Field Obs.
Cover (%)
Year
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
Year
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

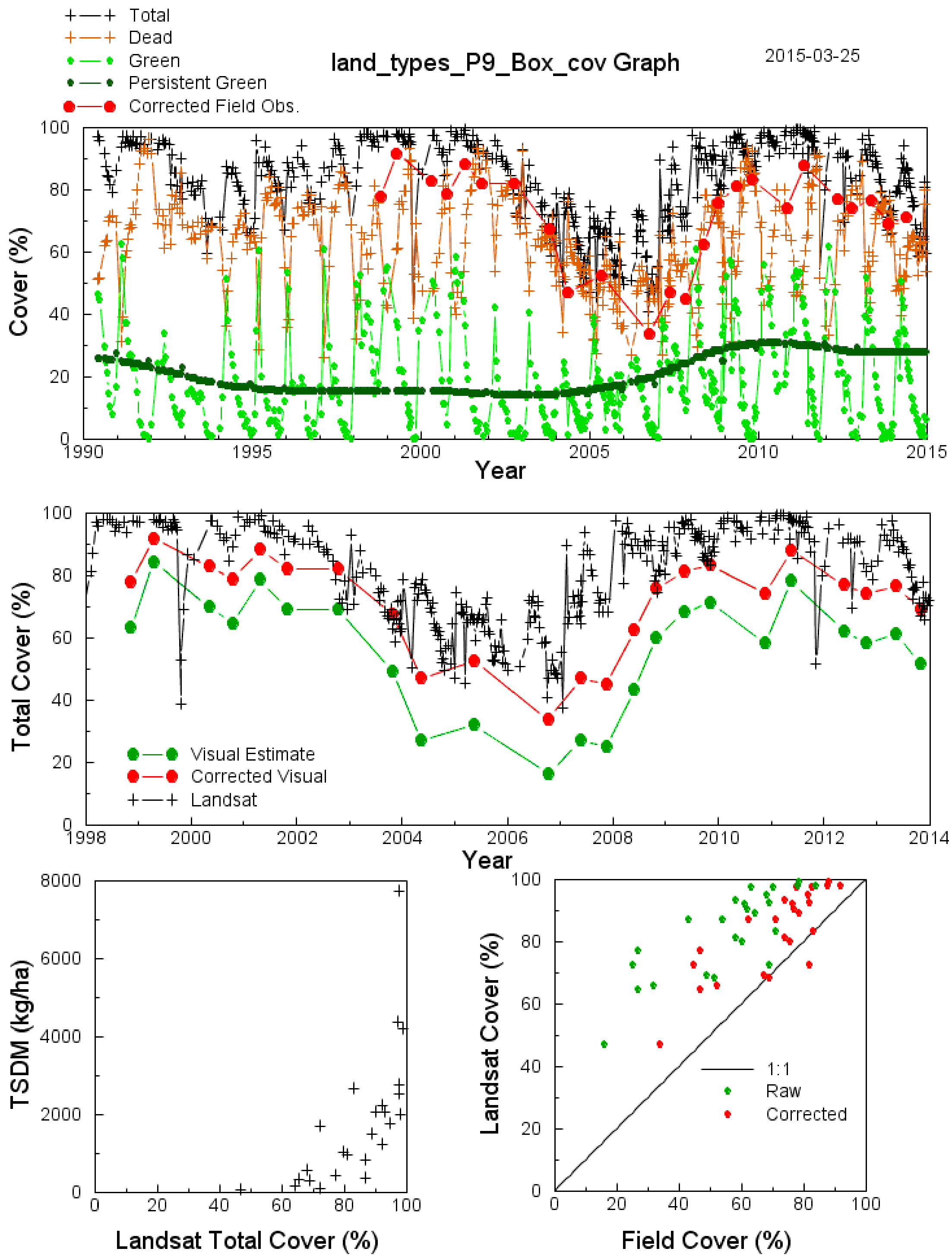

Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P8_Brig_cov Graph
2015-03-25
Cover (%)
Year
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
Year
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)


Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P8_IB_cov Graph
2015-03-25
Cover (%)
Year

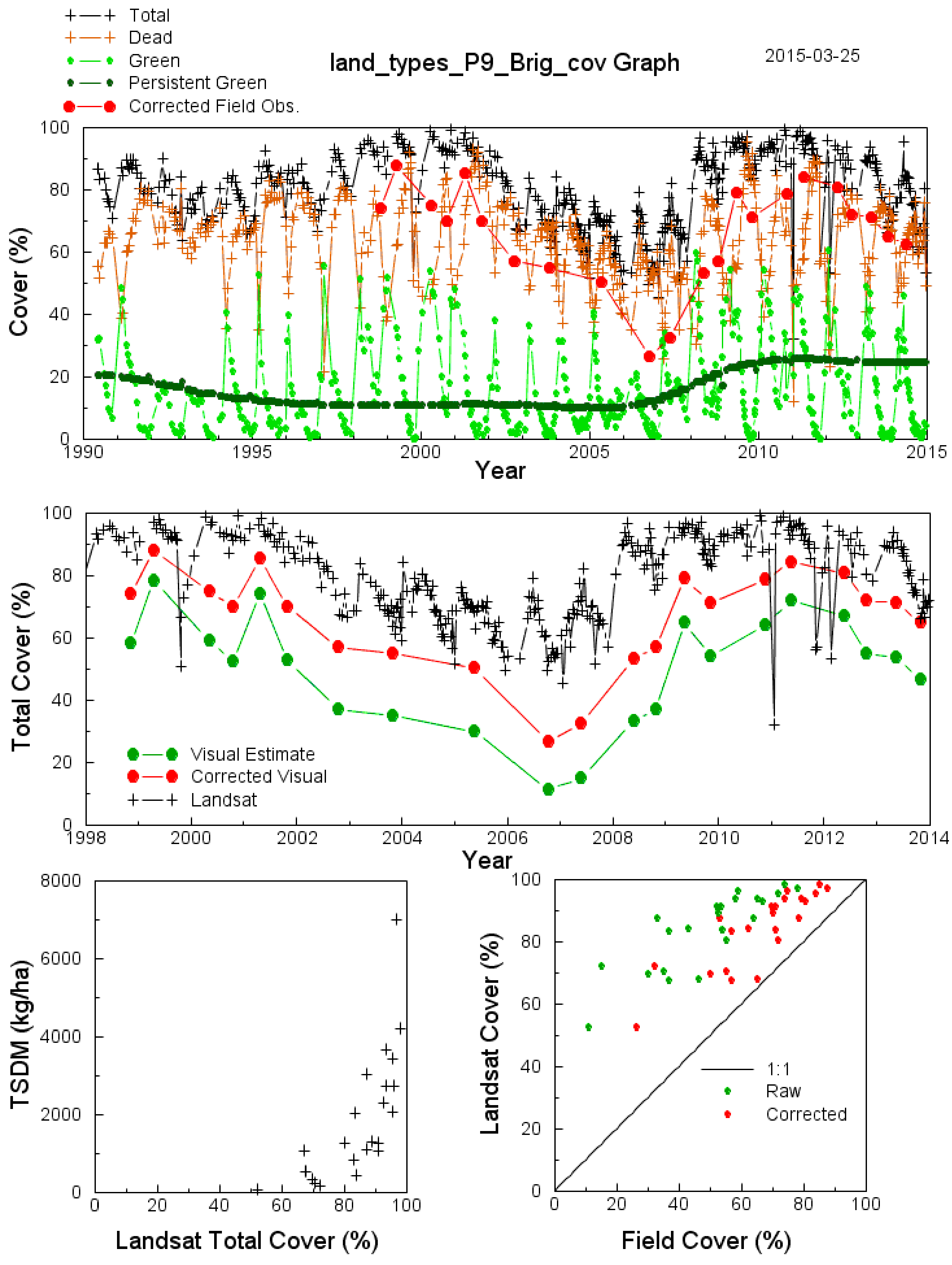

Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
Year

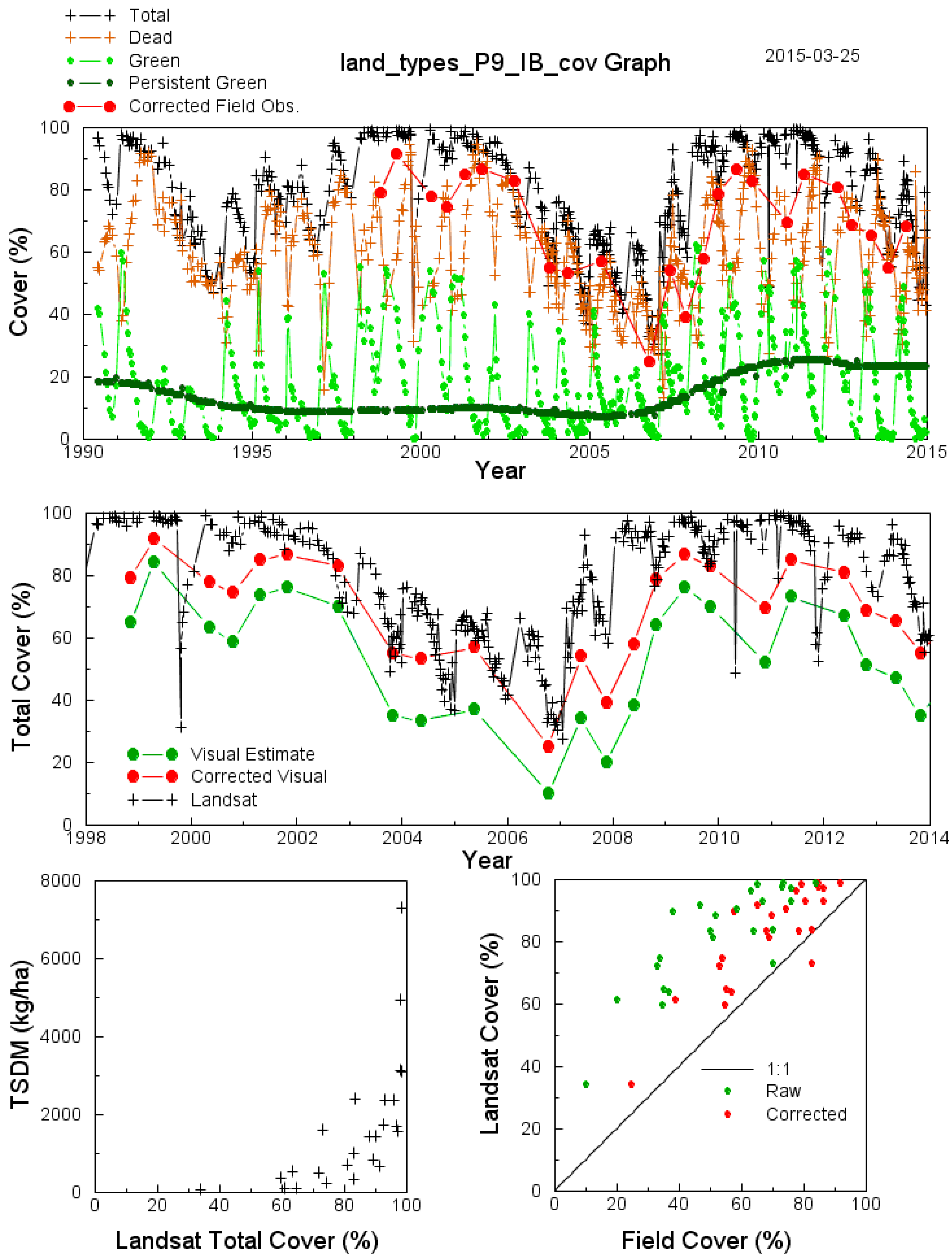

TSDM (kg/ha)
Landsat Total Cover (%)

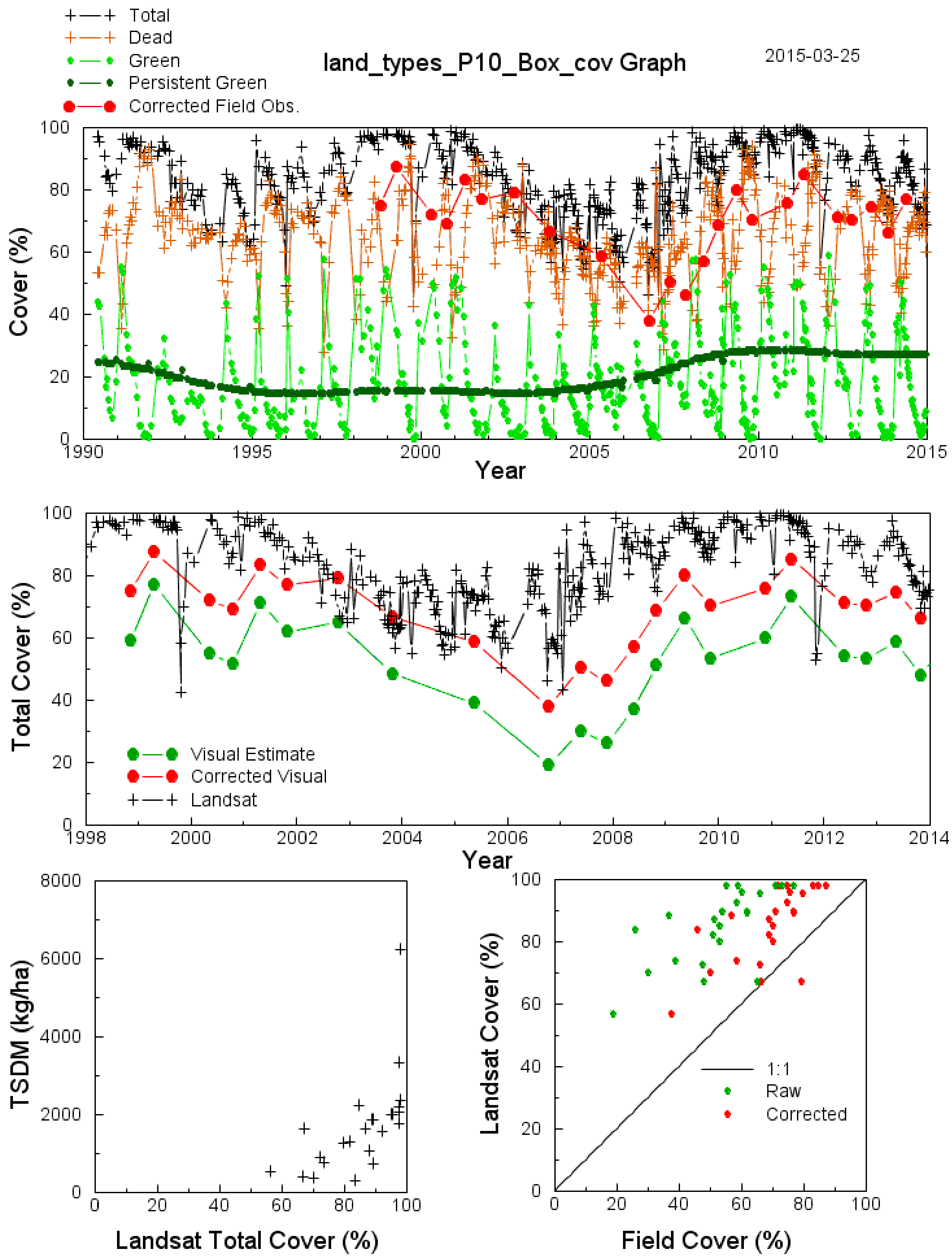

Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

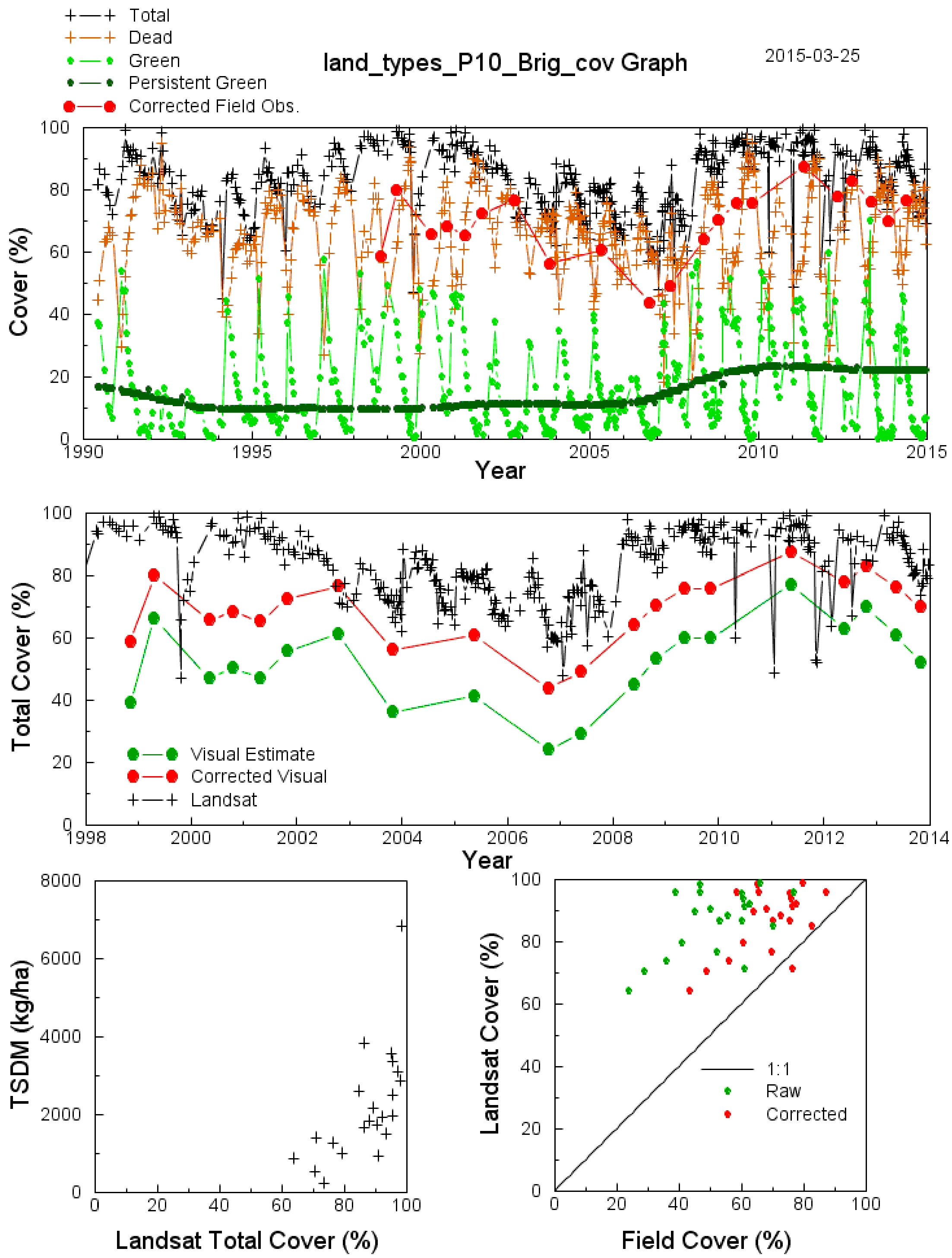


Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P9_Box_cov Graph
2015-03-25
Cover (%)
Year
Visual Estimate
Corrected Visual
Landsat
Total Cover (%)
Year
TSDM (kg/ha)
Landsat Total Cover (%)
1:1
Raw
Corrected
Landsat Cover (%)
Field Cover (%)

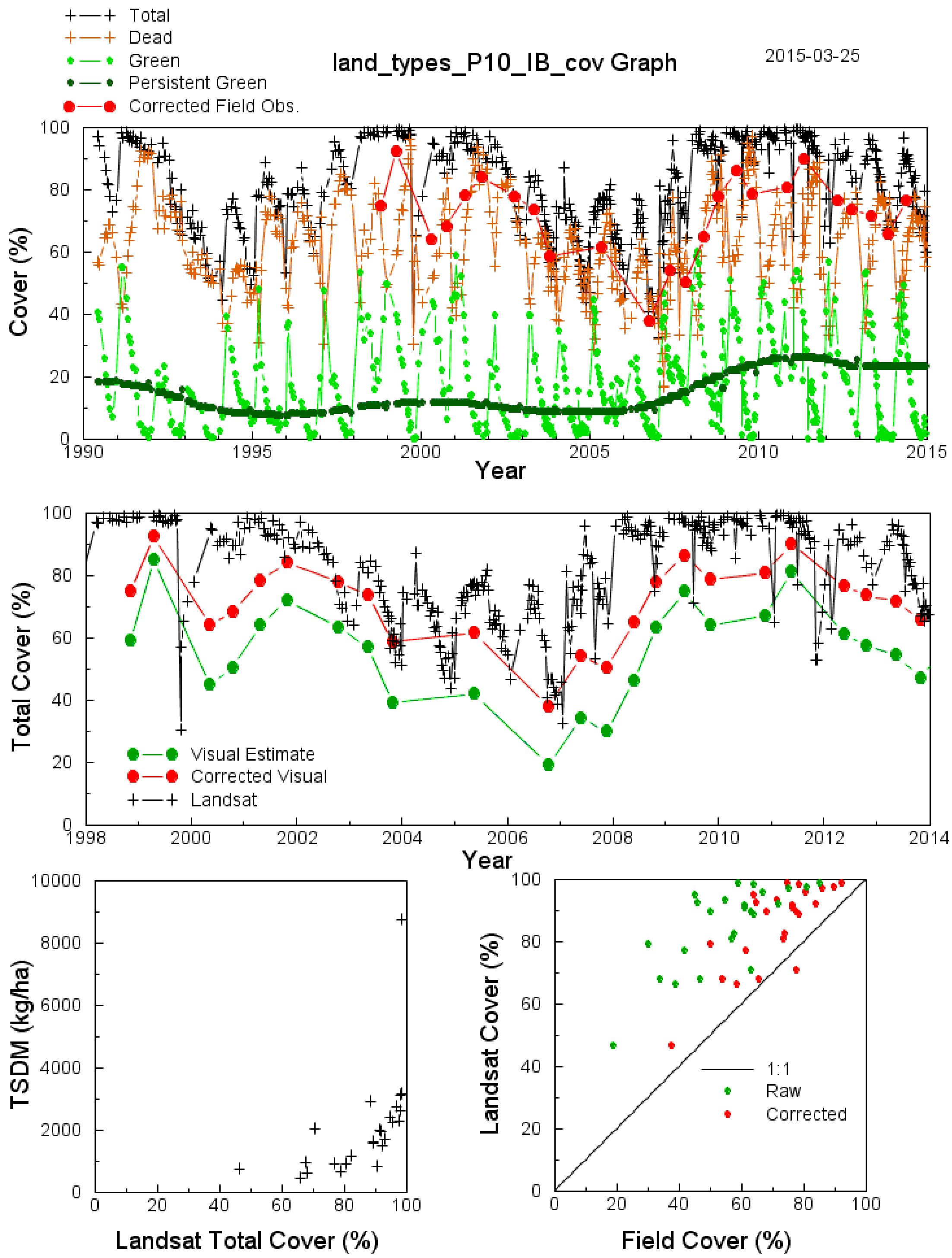

land_types_P9_Brig_cov Graph
2015-03-25
Total
Dead
Green
Persistent Green
Corrected Field Obs.
Cover (%)
Year
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)


Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P9_IB_cov Graph
2015-03-25
Cover (%)
Year
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)


land_types_P10_Box_cov Graph
2015-03-25
Total
Dead
Green
Persistent Green
Corrected Field Obs.
Cover (%)
Year
Visual Estimate
Corrected Visual
Landsat
Total Cover (%)
Year
TSDM (kg/ha)
Landsat Total Cover (%)
1:1
Raw
Corrected
Landsat Cover (%)
Field Cover (%)

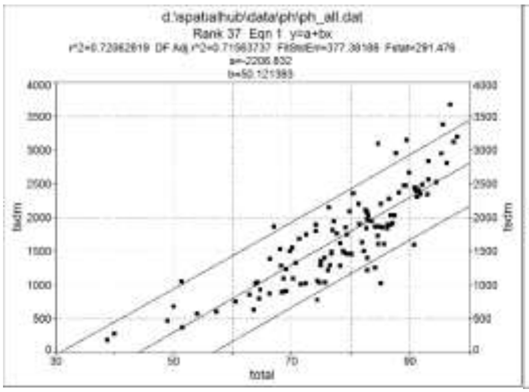


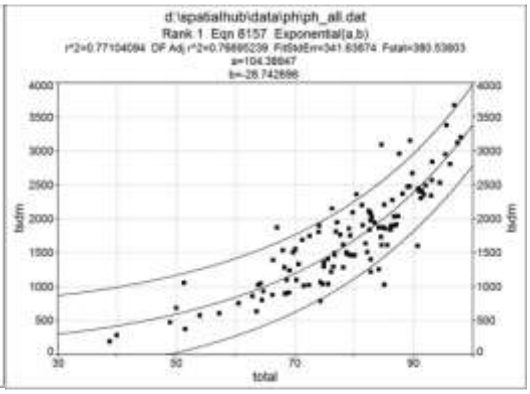
Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P10_Brig_cov Graph
2015-03-25
Cover (%)
Year
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

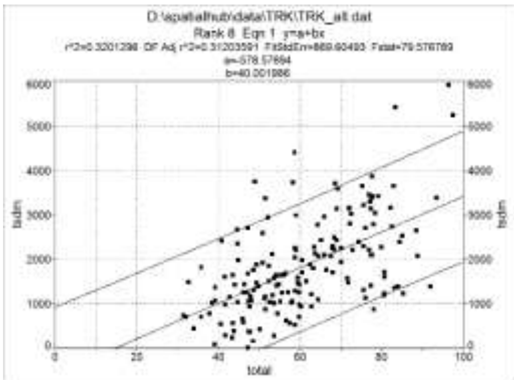

Total
Dead
Green
Persistent Green
Corrected Field Obs.
land_types_P10_IB_cov Graph
2015-03-25
Cover (%)
Year
Total Cover (%)
Visual Estimate
Corrected Visual
Landsat
Year
TSDM (kg/ha)
Landsat Total Cover (%)
Landsat Cover (%)
1:1
Raw
Corrected
Field Cover (%)

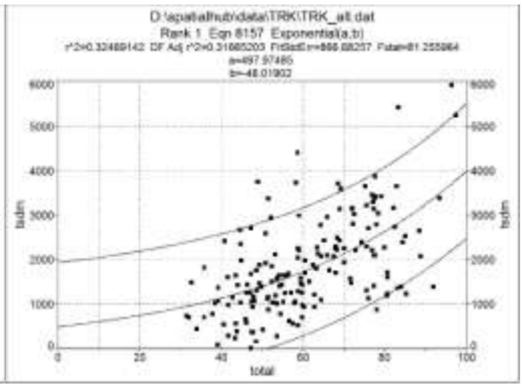
Appendix 7 Simple linear and non-linear fits by grazing trial

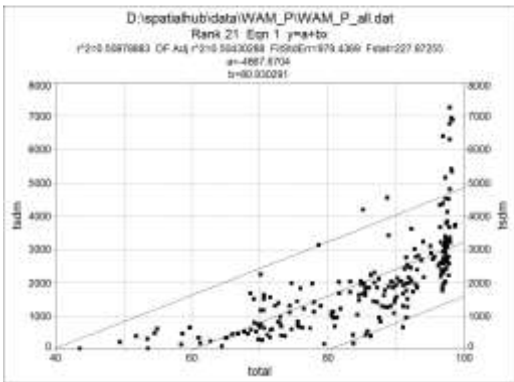
Simple Linear and non-linear it of TSDM vs Landsat cover using un-transformed data with Tablecurve2D and showing 95% prediction intervals for the three grazing trials.

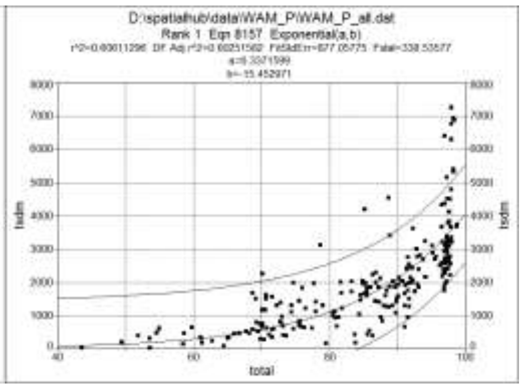




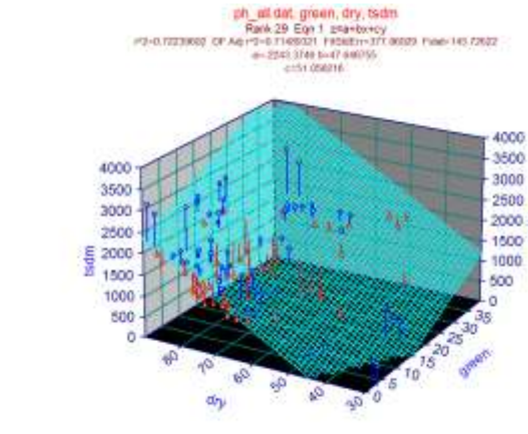


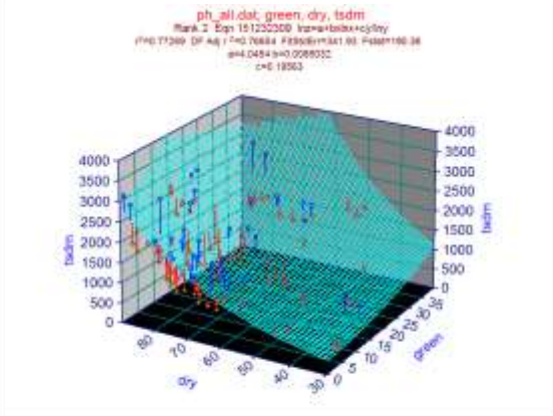


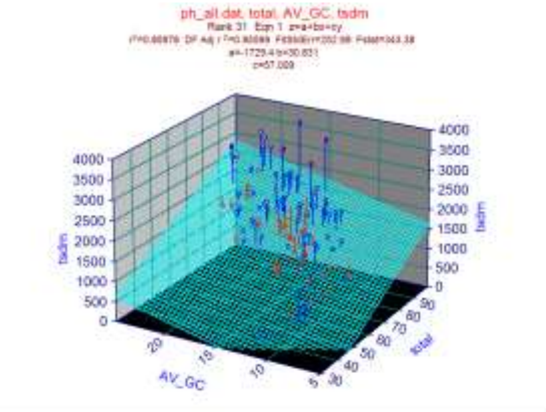


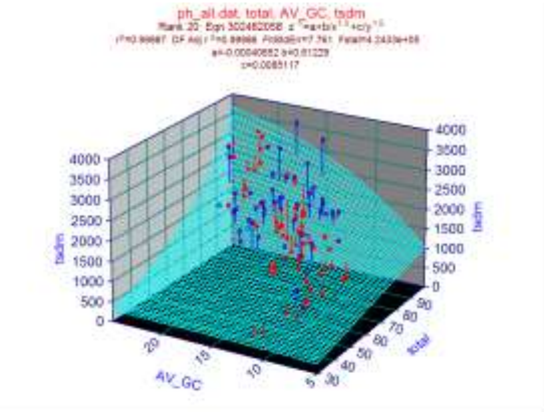


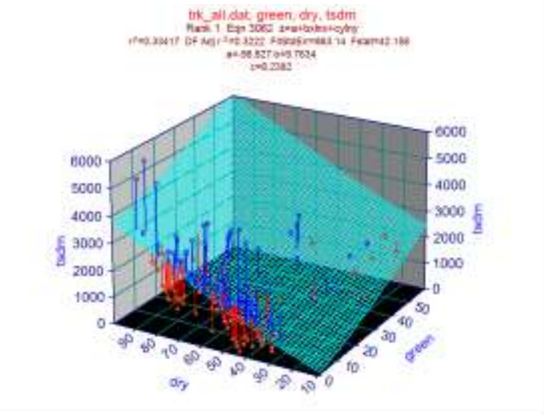
Simple linear and non-linear two predictors fit of TSDM vs Landsat cover (green and dead) or ground cover with average greenness (previous 365 days) using un-transformed data with Tablecurve3D.

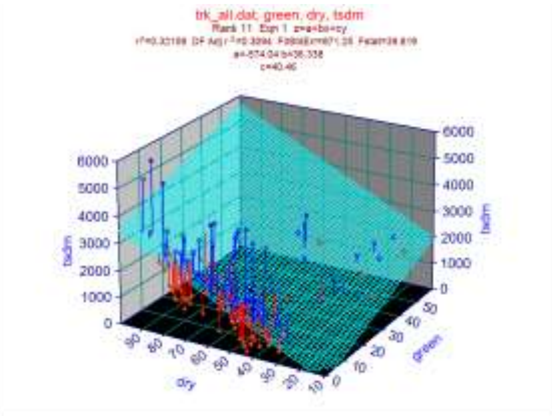


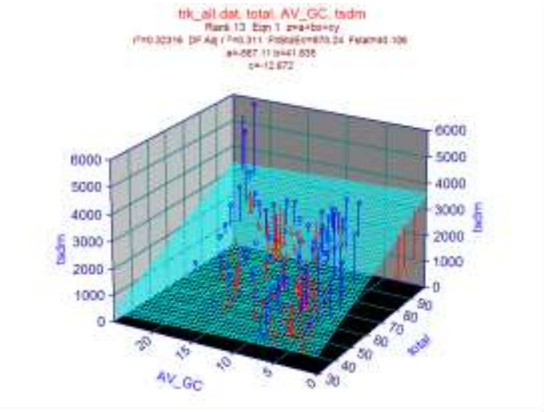


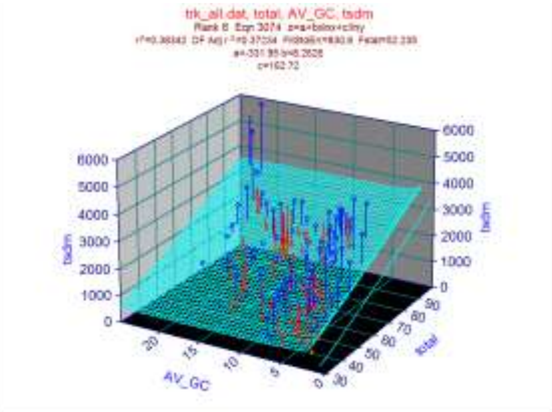


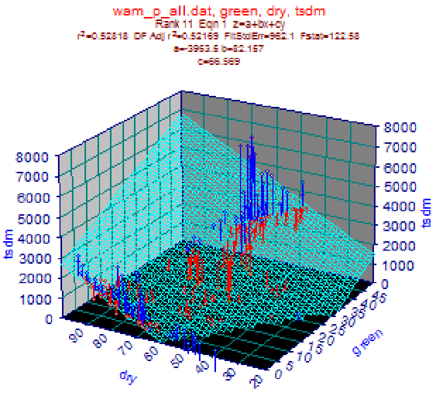


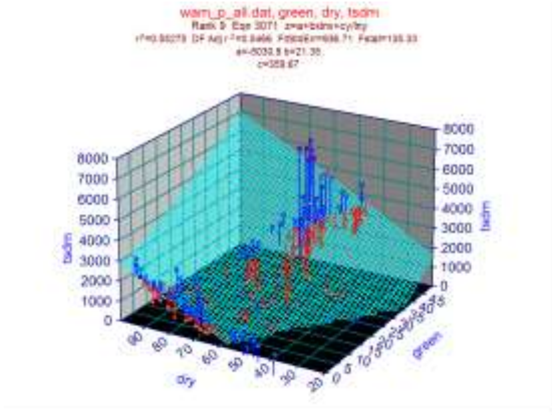

trk_all.dat, green, dry, tsdm
tsdm
dry
green

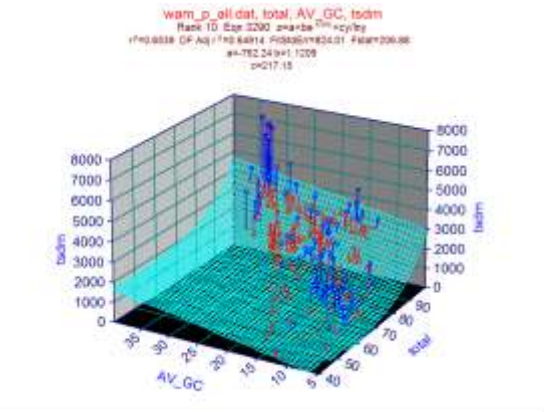

trk_all.dat, green, dry, tsdm
Rank 11 Eqn 1
tsdm
dry
green

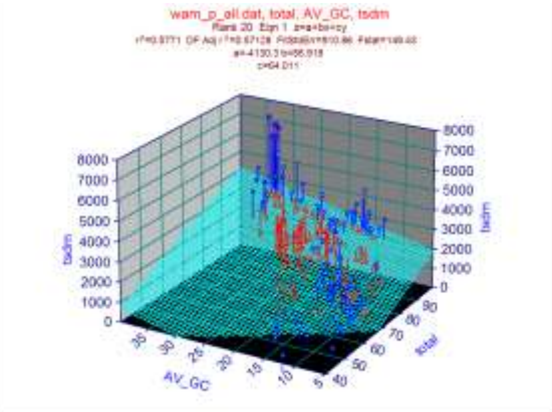

trk_all.dat, total, AV_GC, tsdm
Rank 13 Eqn 1
tsdm
AV_GC
total


trk_all.dat, total, AV_GC, tsdm
tsdm
AV_GC
total


wam_p_all.dat, green, dry, tsdm
tsdm
dry
green


wam_p_all.dat, green, dry, tsdm
tsdm
dry
green


wam_p_all.dat, total, AV_GC, tsdm
tsdm
AV_GC
total


wam_p_all.dat, total, AV_GC, tsdm
tsdm
AV_GC
total

Appendix 8 Statistics for regression by paddock, r^2 and mean average error (MAE).

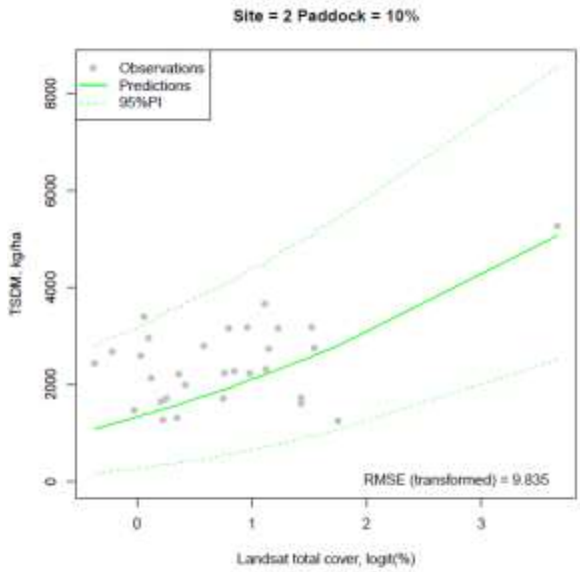
Correlation (r^2) and mean average (absolute) error for paddock by paddock regressions with the paddock means, standard deviations and coefficient of variation (%) for the three grazing trials. NB untransformed data unless indicated in column heading.

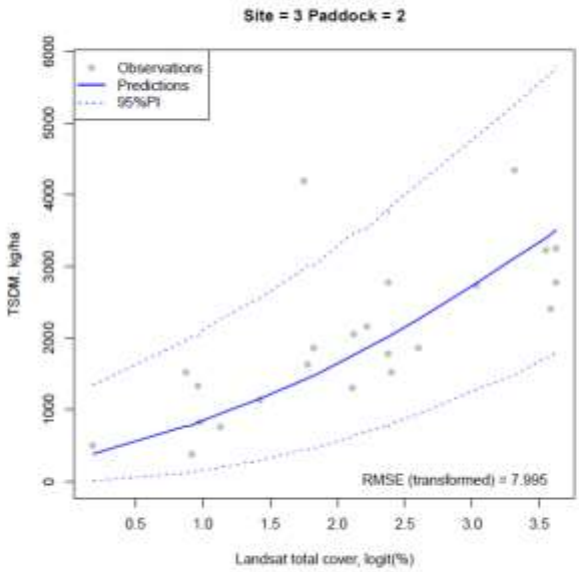
Trial	Paddock	Pad.	Obs.	TSDM	COVER	PG	Field cover (corrected)	Field Cover	Sat. Tot. Cover	Sat. Tot. Cover sqrt (tsdm)	Logit Cover	Sat. Tot. Cover + av_green	Sat Green, Dead Cover
		Num.	Num.	Avg. kg/ha			r^2	r^2	r^2	r^2	r^2	r^2	r^2
PH	Barra	1	10	1289	64.8	4.15	0.509	0.493	0.734	0.779	0.767	0.775	0.735
PH	Bauhinia	2	10	1651	81.4	5.62	0.222	0.227	0.795	0.783	0.863	0.846	0.799
PH	Brolga	3	10	1860	81.9	4.95	0.343	0.346	0.754	0.774	0.801	0.879	0.755
PH	Biodiversity	4	9	2731	86.0	6.31	0.427	0.437	0.725	0.689	0.632	0.776	0.725
PH	Bullock	5	10	1220	68.4	5.19	0.461	0.447	0.663	0.721	0.627	0.678	0.674
PH	Cell Grazing	6	10	1620	79.1	4.56	0.676	0.695	0.867	0.878	0.889	0.914	0.869
PH	Dead Cat	7	10	1398	73.8	6.32	0.641	0.682	0.894	0.932	0.919	0.929	0.899
PH	NO_13	8	10	1293	70.9	6.06	0.591	0.616	0.695	0.731	0.655	0.729	0.703
PH	North_Stephens	9	10	1717	79.5	5.41	0.481	0.474	0.781	0.815	0.795	0.830	0.781
PH	Racecourse	10	9	1441	79.2	5.94	0.608	0.598	0.793	0.801	0.683	0.813	0.796
PH	Sandstone	11	10	1903	80.1	5.72	0.719	0.720	0.769	0.768	0.776	0.898	0.886
PH	South_Stephens	12	10	1715	76.9	5.19	0.588	0.590	0.949	0.942	0.891	0.949	0.949
PH	Villiers	13	10	1587	76.2	6.09	0.548	0.556	0.839	0.833	0.832	0.922	0.886
AVERAGE				**1648**	**76.8**	**5.50**	**0.524**	**0.529**	**0.789**	**0.803**	**0.779**	**0.841**	**0.804**
STDEV				392	5.9	0.67	0.139	0.144	0.081	0.077	0.102	0.084	0.086
%COVAR				24	7.7	12.26	26.460	27.187	10.274	9.552	13.084	9.973	10.702
TRK	10%	1	30	2388	63.3	0.71	0.173	0.174	0.114	0.088	0.226	0.119	0.136
TRK	20%	2	30	2153	63.1	0.81	0.011	0.010	0.319	0.291	0.331	0.405	0.350
TRK	30%	3	30	1703	57.6	1.15	0.555	0.567	0.427	0.404	0.421	0.482	0.439
TRK	50%	4	30	1351	54.9	1.07	0.739	0.762	0.530	0.511	0.507	0.572	0.544
TRK	80%	5	30	930	55.5	1.13	0.477	0.502	0.518	0.470	0.519	0.540	0.586
TRK	Exclosure	6	28	2497	68.6	0.72	0.155	0.165	0.054	0.036	0.101	0.056	0.144
Average				**1837**	**60.5**	**0.93**	**0.352**	**0.363**	**0.327**	**0.300**	**0.351**	**0.362**	**0.367**
stdev				619	5.4	0.21	0.281	0.290	0.204	0.199	0.165	0.221	0.194
% COVAR				34	8.9	22.25	79.828	79.732	62.410	66.454	47.094	61.015	52.819
WAM	P1	1	21	2024	80.7	19.51	0.526	0.553	0.533	0.644	0.615	0.643	0.549
WAM	P2	2	23	1907	81.5	19.76	0.266	0.262	0.500	0.595	0.537	0.626	0.578
WAM	P3	3	23	2130	87.6	21.59	0.491	0.502	0.532	0.609	0.656	0.607	0.545
WAM	P4	4	23	1415	82.6	22.00	0.464	0.484	0.561	0.685	0.709	0.574	0.568
WAM	P5	5	23	2228	87.4	19.30	0.490	0.506	0.601	0.664	0.751	0.640	0.610
WAM	P6	6	23	1662	79.6	19.56	0.410	0.459	0.482	0.651	0.671	0.591	0.526
WAM	P7	7	22	2107	80.6	18.39	0.622	0.667	0.519	0.614	0.616	0.621	0.536
WAM	P8	8	22	2236	81.6	18.14	0.653	0.669	0.607	0.672	0.740	0.653	0.633
WAM	P9	9	22	1806	83.1	17.95	0.480	0.540	0.446	0.653	0.593	0.526	0.465
WAM	P10	10	22	1856	84.1	18.42	0.512	0.562	0.429	0.567	0.548	0.542	0.429
Average				**1937**	**82.9**	**19.46**	**0.491**	**0.520**	**0.521**	**0.635**	**0.644**	**0.602**	**0.544**
stdev				263	2.8	1.39	0.107	0.115	0.059	0.038	0.075	0.043	0.061
% COVAR				14	3.3	7.14	21.776	22.134	11.383	5.904	11.680	7.191	11.275

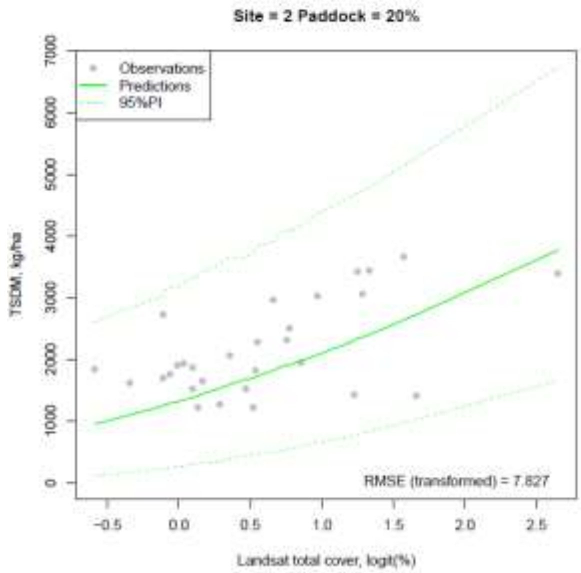
Trial	Paddock	Pad.	Field cover (corrected)	Field Cover	Sat. Tot. Cover	Sat. Tot. Cover sqrt (tsdm)	Logit cover	Sat Green, Dead Cover	Sat Green, Dead Cover
		Num.	MAE (kg/ha)	MAE (kg/ha)	MAE (kg/ha)	MAE (kg/ha)	MAE (kg/ha)	MAE (kg/ha)	MAE (kg/ha)
PH	Barra	1	317.8	325.1	272.9	270.1	258.9	264.1	273.3
PH	Bauhinia	2	408.2	407.7	209.0	192.9	166.2	198.5	212.7
PH	Brolga	3	353.9	353.6	253.6	236.2	206.5	161.6	252.7
PH	Biodiversity	4	403.4	402.5	317.8	321.0	387.1	323.2	317.1
PH	Bullock	5	328.3	334.9	234.3	234.1	378.1	233.6	216.5
PH	Cell Grazing	6	324.3	314.3	207.5	188.8	239.6	148.4	200.0
PH	Dead Cat	7	324.4	313.0	169.2	143.2	191.8	124.2	159.7
PH	NO_13	8	315.8	303.2	218.6	230.0	239.8	185.9	216.0
PH	North_Stephens	9	381.3	381.3	221.4	220.9	217.9	216.6	217.7
PH	Racecourse	10	221.9	225.4	164.0	178.9	209.4	141.7	157.7
PH	Sandstone	11	288.3	285.0	234.4	233.9	247.9	145.7	177.7
PH	South_Stephens	12	330.8	335.5	97.4	117.7	178.8	95.5	97.4
PH	Villiers	13	365.1	360.6	215.5	215.5	220.3	141.0	175.5
AVERAGE			**335.6**	**334.0**	**216.6**	**214.1**	**241.7**	**183.1**	**205.7**
STDEV			49.5	49.6	53.9	52.3	68.0	63.1	55.9
%COVAR			14.7	14.8	24.9	24.4	28.1	34.5	27.2
TRK	10%	1	50.1	49.9	645.7	639.6	618.9	659.0	642.2
TRK	20%	2	54.8	54.9	463.2	465.8	448.7	457.8	473.5
TRK	30%	3	47.9	48.0	457.3	457.2	467.2	431.9	464.8
TRK	50%	4	41.1	38.5	415.1	413.4	421.9	389.2	405.6
TRK	80%	5	73.5	71.3	385.4	366.4	382.4	371.1	341.5
TRK	Exclosure	6	18.8	18.7	1087.6	1052.2	1072.4	1098.3	1033.1
Average			**47.7**	**46.9**	**575.7**	**565.8**	**568.6**	**567.9**	**560.1**
stdev			17.9	17.5	266.7	255.6	259.7	279.6	252.5
% COVAR			37.5	37.4	46.3	45.2	45.7	49.2	45.1
WAM	P1	1	658.4	651.2	615.0	549.1	592.1	509.7	620.0
WAM	P2	2	674.1	675.4	563.6	508.2	475.3	498.3	508.6
WAM	P3	3	516.1	504.8	614.0	568.4	538.2	562.2	609.7
WAM	P4	4	560.6	545.2	560.0	477.2	449.3	575.9	546.1
WAM	P5	5	488.6	477.3	428.7	400.7	385.4	439.9	436.8
WAM	P6	6	766.4	761.9	737.4	601.1	615.9	710.0	741.7
WAM	P7	7	695.7	666.4	786.8	684.3	668.6	751.2	780.6
WAM	P8	8	679.4	661.8	674.1	596.6	540.8	536.7	630.8
WAM	P9	9	832.0	786.9	804.2	676.6	692.9	776.6	822.2
WAM	P10	10	618.6	595.2	596.4	515.5	551.8	584.1	596.9
Average			**649.0**	**632.6**	**638.0**	**557.8**	**551.0**	**594.5**	**629.3**
stdev			107.1	102.3	115.1	87.6	96.4	113.6	121.5
% COVAR			16.5	16.2	18.0	15.7	17.5	19.1	19.3

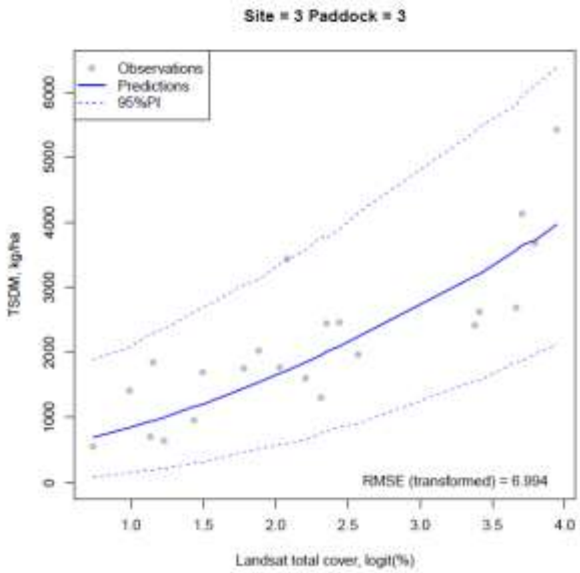
Appendix (9) Paddock performance using a different function of total cover for each grazing trail.

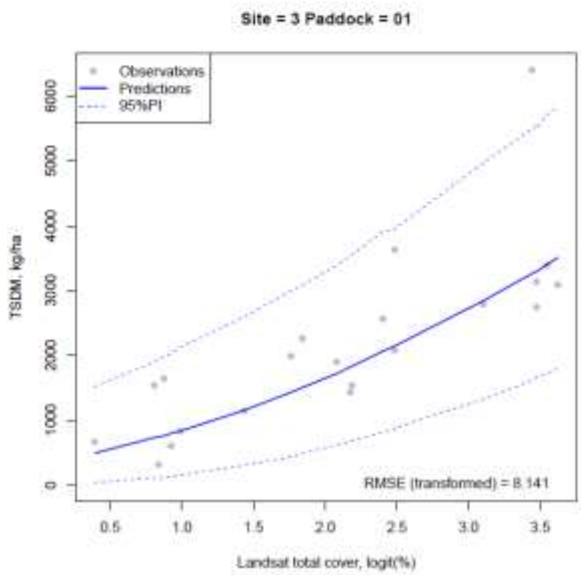
At this stage the hypothesis that a single function could represent all three grazing trials been rejected (as slopes and intercepts significantly different for each grazing trial). Paddock level fits of TSDM for fitted (for individual grazing trials) as function of Landsat total cover (ground cover). Site 1 = Pigeon Hole, Site 2 = Toorak and Site3 = Wambiana. Note bias issues for most paddocks at Toorak and Biodiversity paddock at Pigeon Hole.

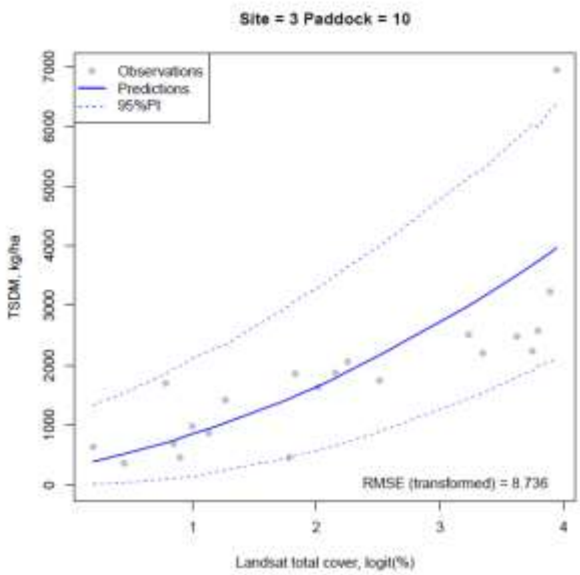

Site = 2 Paddock = 10%
Observations
Predictions
95%PI
RMSE (transformed) = 9.835
TSDM, kg/ha
Landsat total cover, logit(%)

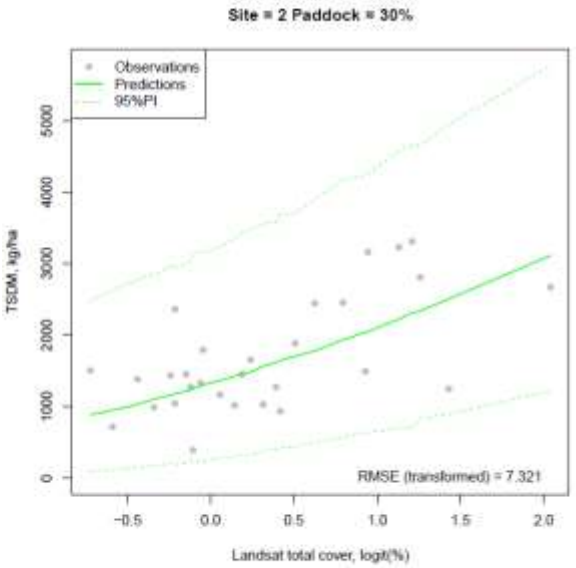

Site = 3 Paddock = 2
Observations
Predictions
95%PI
RMSE (transformed) = 7.995
TSDM, kg/ha
Landsat total cover, logit(%)

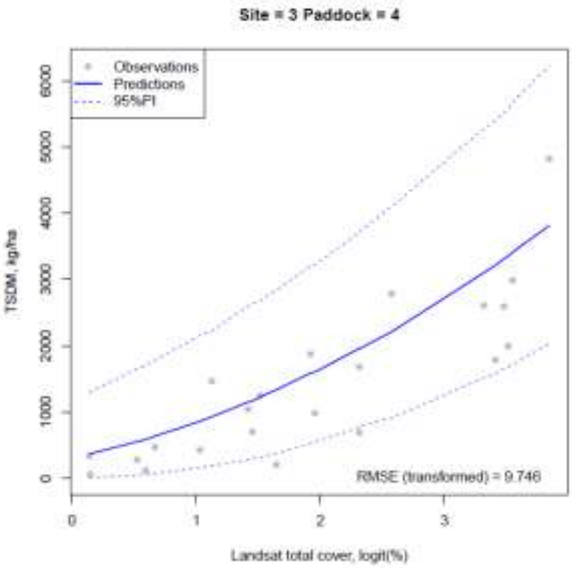

Site = 2 Paddock = 20%
Observations
Predictions
95%PI
RMSE (transformed) = 7.827
TSDM, kg/ha
Landsat total cover, logit(%)

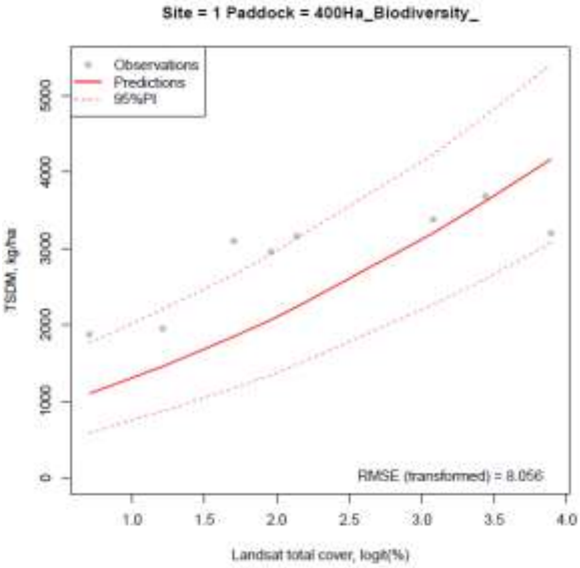

Site = 3 Paddock = 3
Observations
Predictions
95%PI
RMSE (transformed) = 6.994
TSDM, kg/ha
Landsat total cover, logit(%)

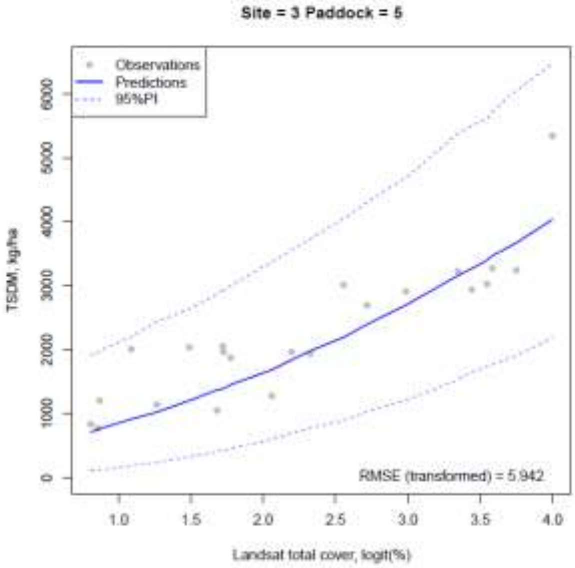

Site = 3 Paddock = 01
Observations
Predictions
95%PI
RMSE (transformed) = 8.141
TSDM, kg/ha
Landsat total cover, logit(%)

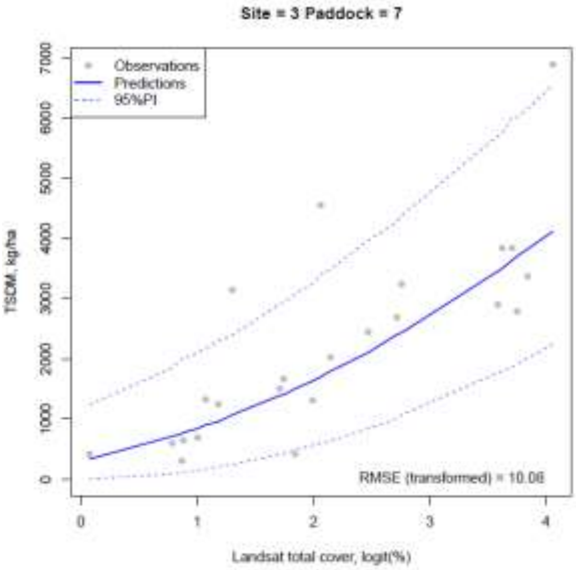

Site = 3 Paddock = 10
Observations
Predictions
95%PI
RMSE (transformed) = 8.736
TSDM, kg/ha
Landsat total cover, logit(%)

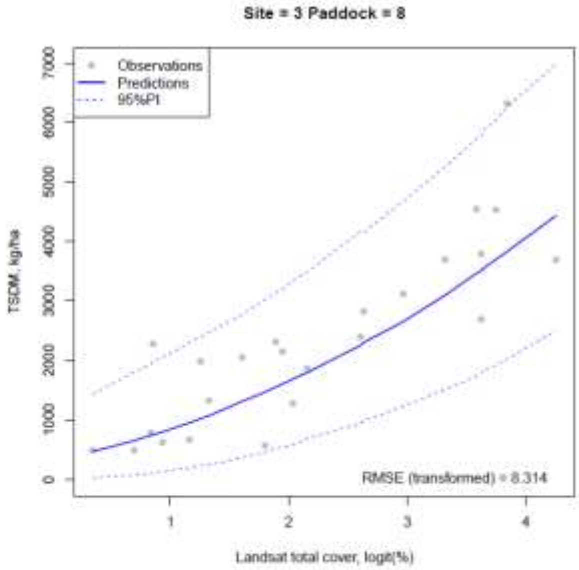

Site = 2 Paddock = 30%
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 7.321
Landsat total cover, logit(%)

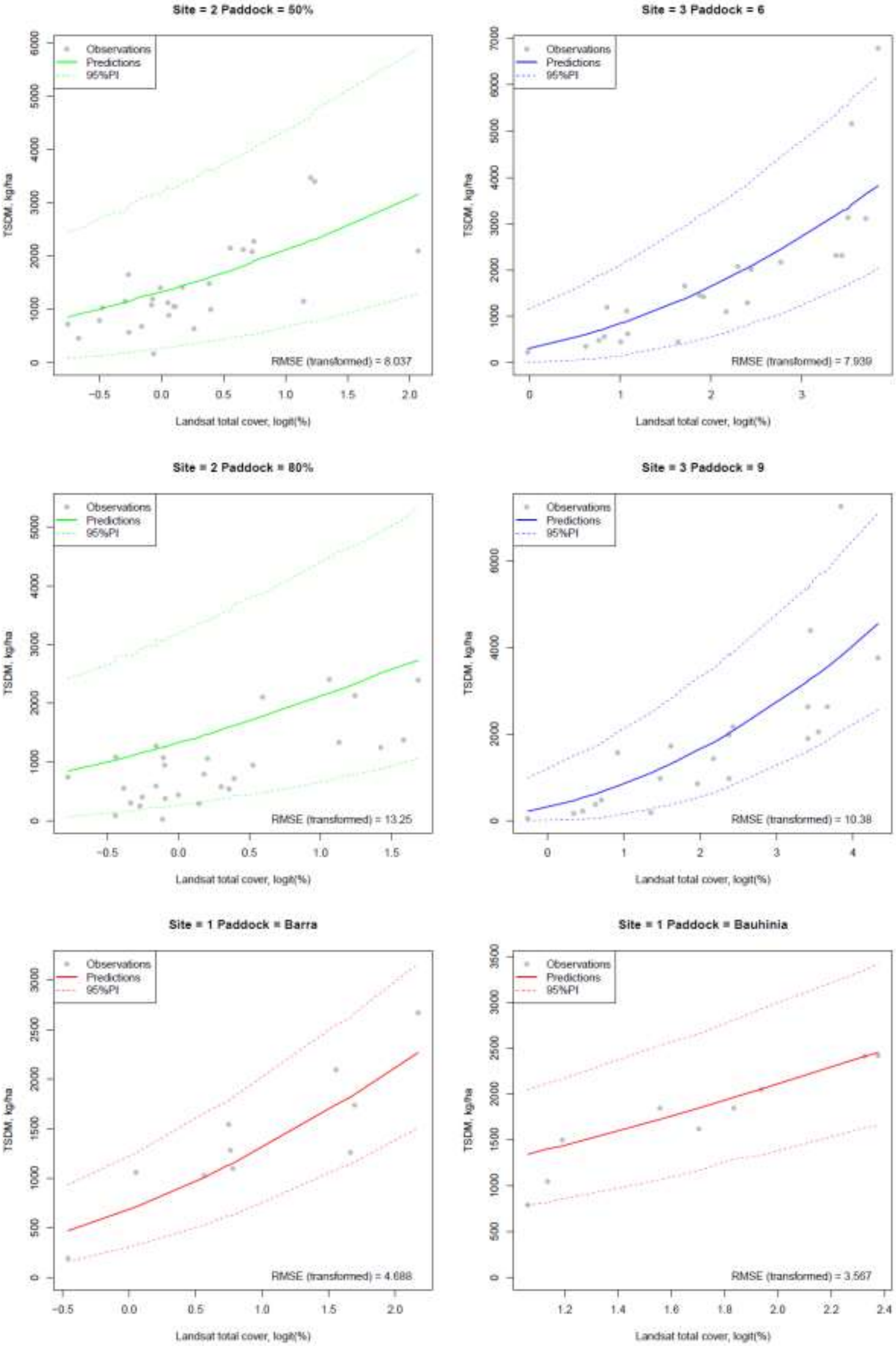

Site = 3 Paddock = 4
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 9.746
Landsat total cover, logit(%)

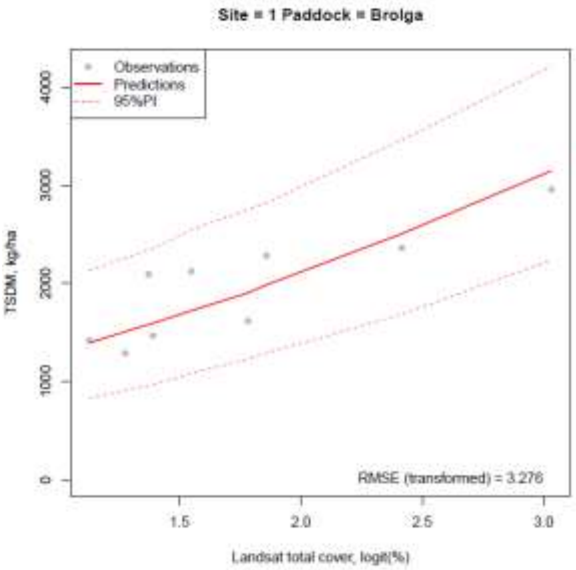

Site = 1 Paddock = 400Ha_Biodiversity_
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 8.056
Landsat total cover, logit(%)

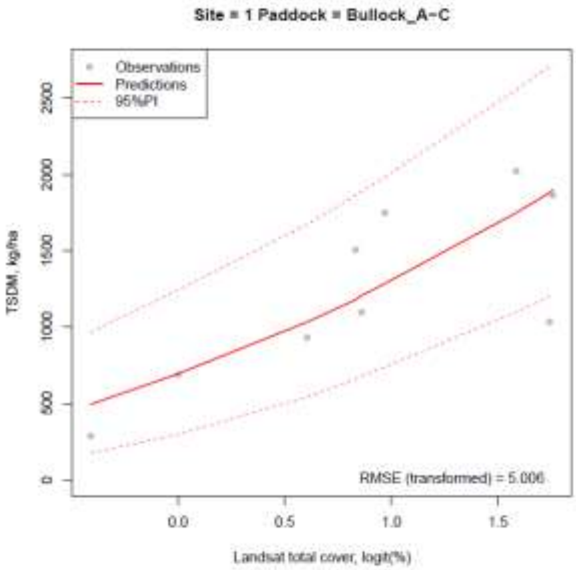

Site = 3 Paddock = 5
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 5.942
Landsat total cover, logit(%)

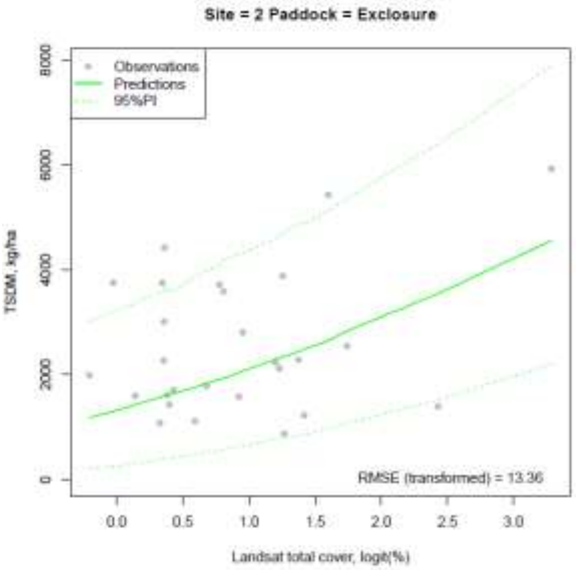

Site = 3 Paddock = 7
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 10.08
Landsat total cover, logit(%)

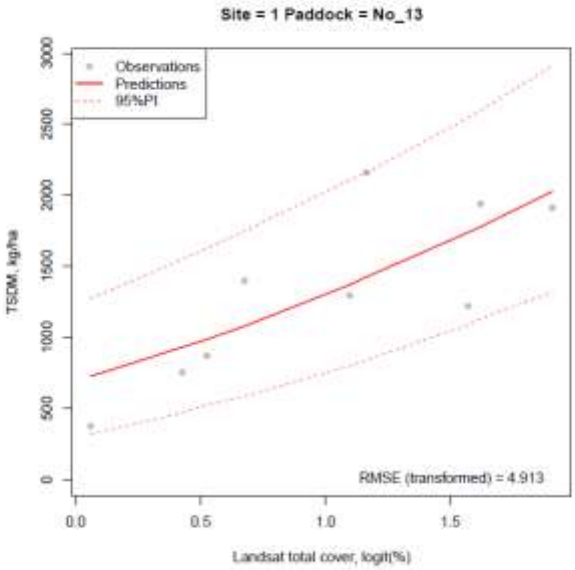

Site = 3 Paddock = 8
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 8.314
Landsat total cover, logit(%)

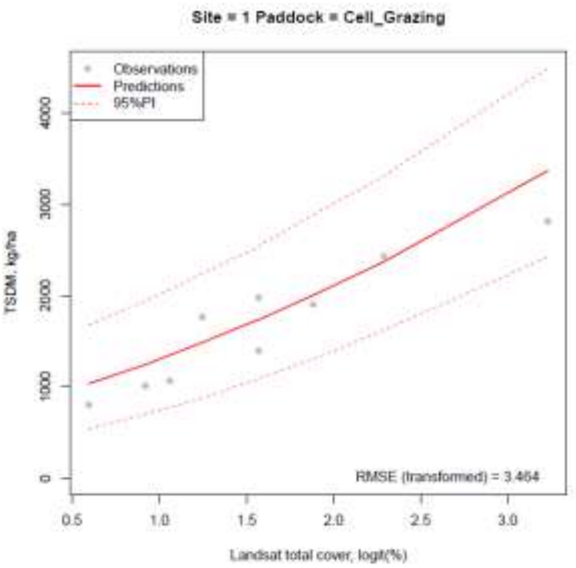

Site = 2 Paddock = 50%
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 8.037
Landsat total cover, logit(%)
Site = 3 Paddock = 6
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 7.939
Landsat total cover, logit(%)
Site = 2 Paddock = 80%
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 13.25
Landsat total cover, logit(%)
Site = 3 Paddock = 9
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 10.38
Landsat total cover, logit(%)
Site = 1 Paddock = Barra
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 4.688
Landsat total cover, logit(%)
Site = 1 Paddock = Bauhinia
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 3.567
Landsat total cover, logit(%)

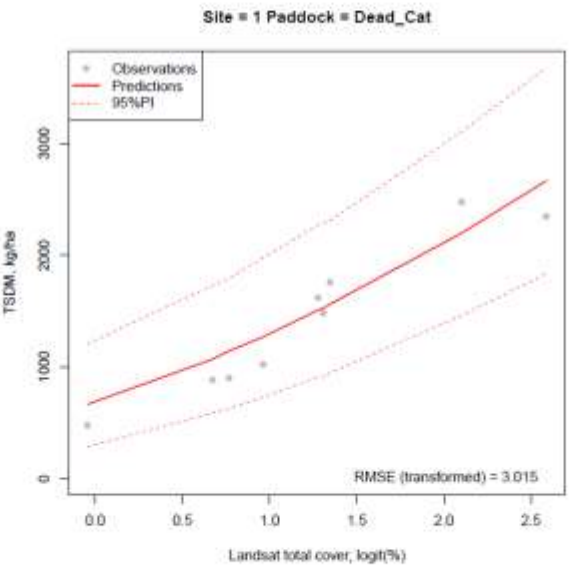

Site = 1 Paddock = Brolga
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 3.276
Landsat total cover, logit(%)

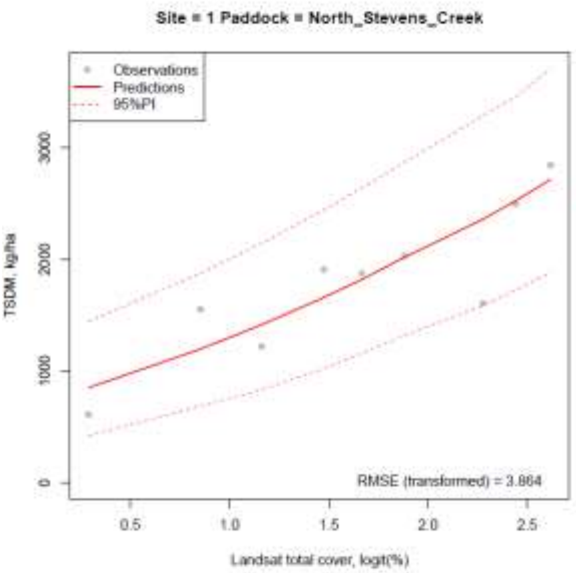

Site = 1 Paddock = Bullock_A-C
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 5.006
Landsat total cover, logit(%)

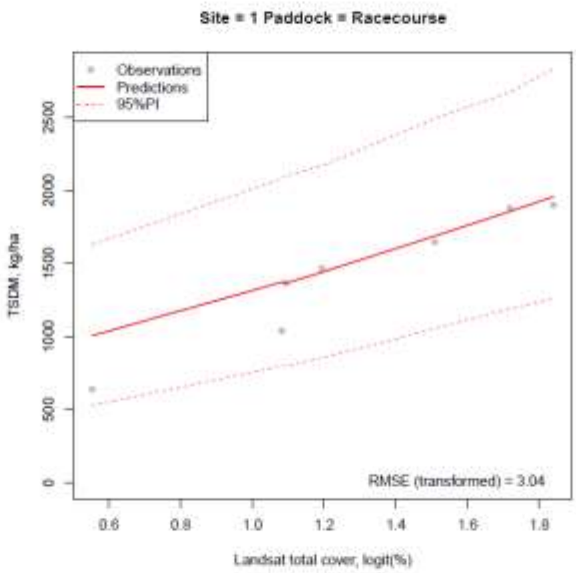

Site = 2 Paddock = Exclosure
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 13.36
Landsat total cover, logit(%)

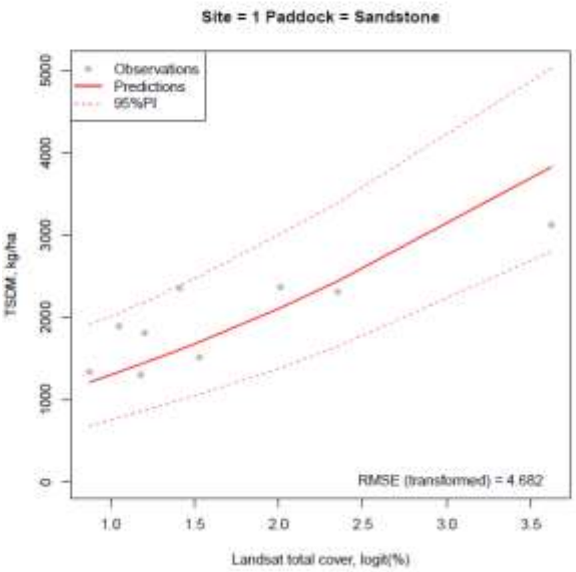

Site = 1 Paddock = No_13
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 4.913
Landsat total cover, logit(%)

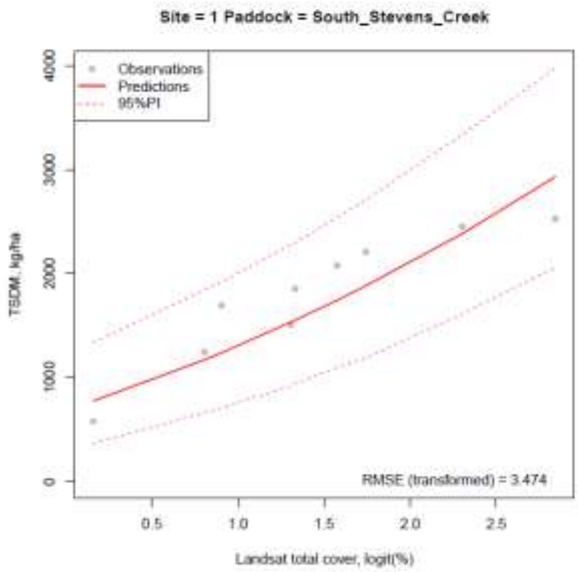

Site = 1 Paddock = Cell_Grazing
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 3.464
Landsat total cover, logit(%)

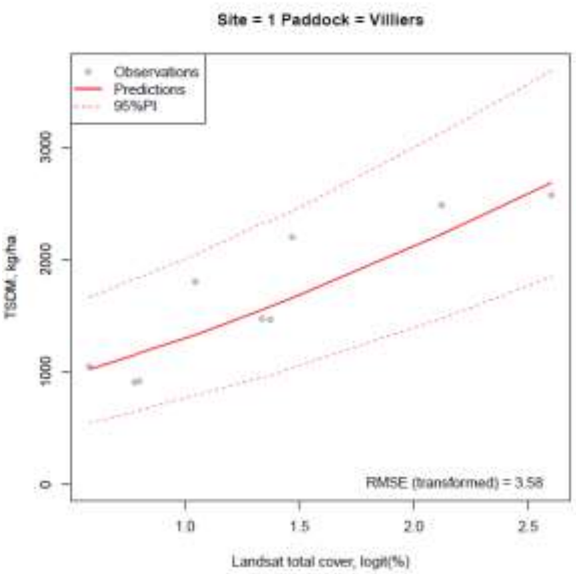

Site = 1 Paddock = Dead_Cat
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 3.015
Landsat total cover, logit(%)


Site = 1 Paddock = North_Stevens_Creek
Observations
Predictions
95%PI
TSDM, kg/ha
Landsat total cover, logit(%)
RMSE (transformed) = 3.864


Site = 1 Paddock = Racecourse
Observations
Predictions
95%PI
TSDM, kg/ha
Landsat total cover, logit(%)
RMSE (transformed) = 3.04

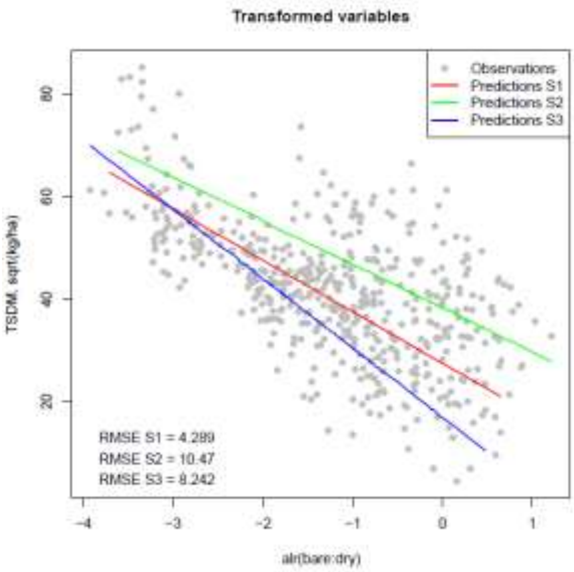

Site = 1 Paddock = Sandstone
Observations
Predictions
95%PI
TSDM, kg/ha
Landsat total cover, logit(%)
RMSE (transformed) = 4.682

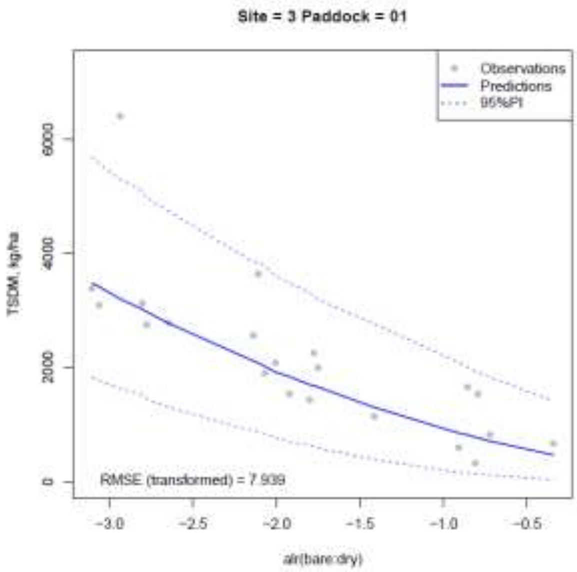

Site = 1 Paddock = South_Stevens_Creek
Observations
Predictions
95%PI
TSDM, kg/ha
Landsat total cover, logit(%)
RMSE (transformed) = 3.474

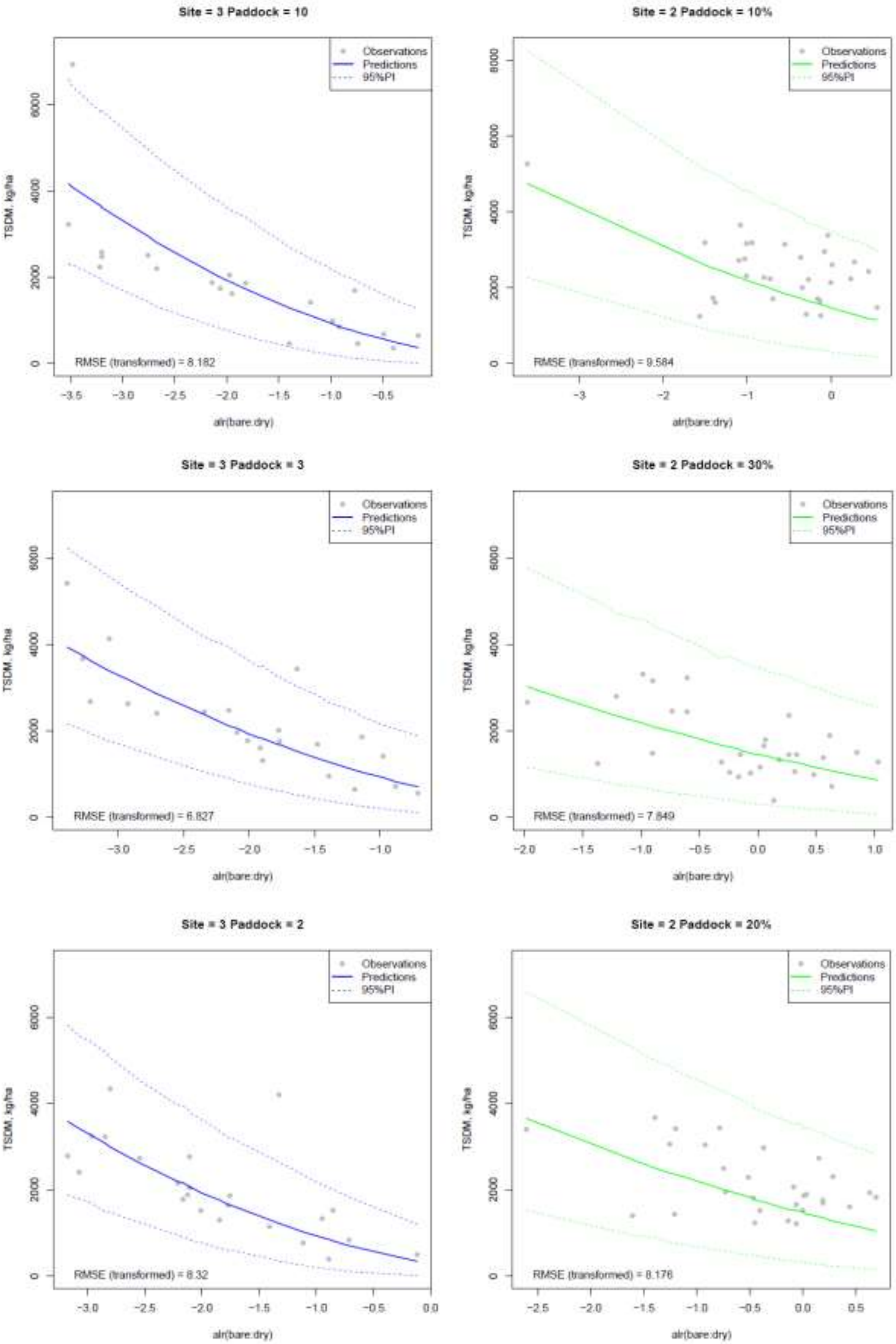

Site = 1 Paddock = Villiers
Observations
Predictions
95%PI
TSDM, kg/ha
Landsat total cover, logit(%)
RMSE (transformed) = 3.58

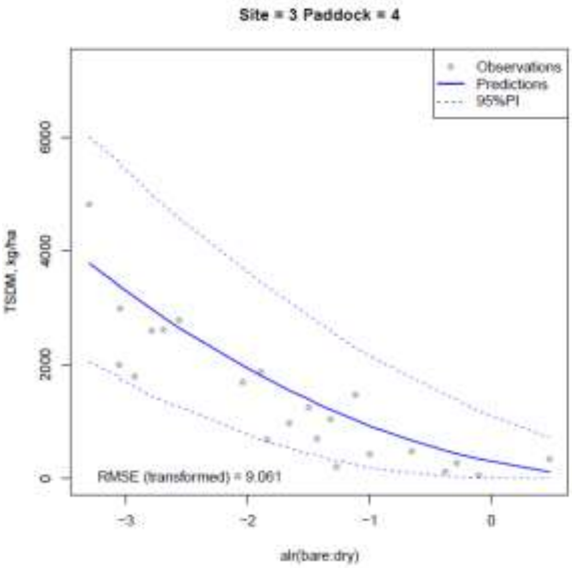
Appendix (10) Paddock performance using individual grazing trial based functions of log (bare/dry).

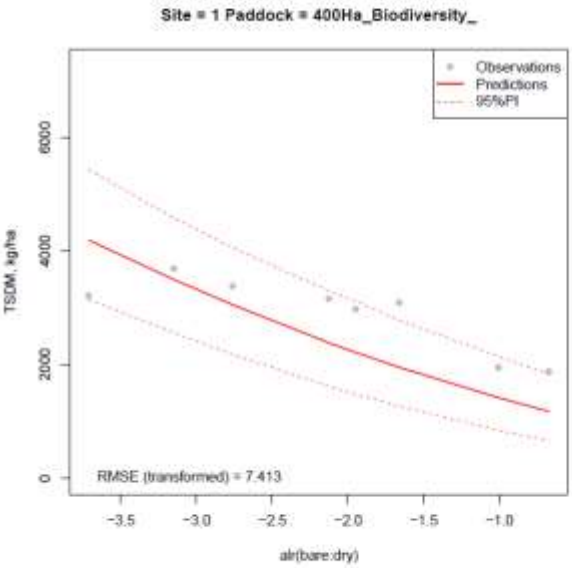
Paddock level fits of TSDM for each 3 grazing trials for a function of log (bare/dry). Site 1 = Pigeon Hole, Site 2 = Toorak and Site 3 = Wambiana. Note bias reduced bias issues for most paddocks at Toorak and Biodiversity paddock - Pigeon Hole relative to total cover method applied across all trials (Appendix 9).

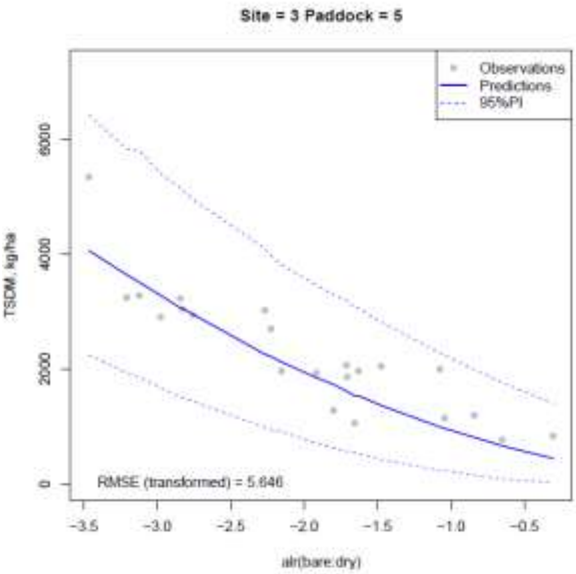


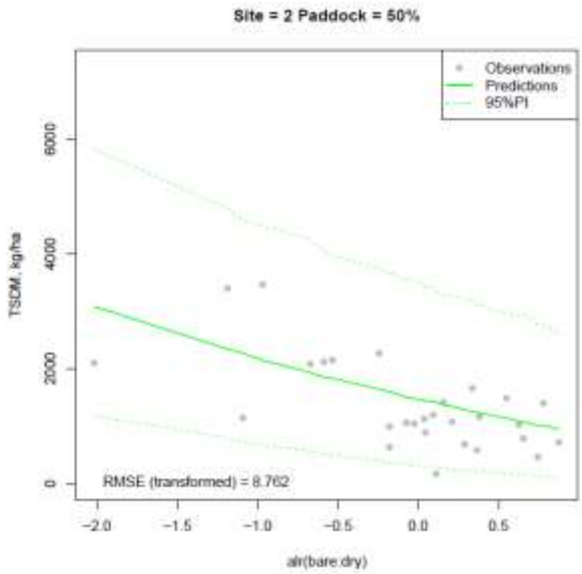


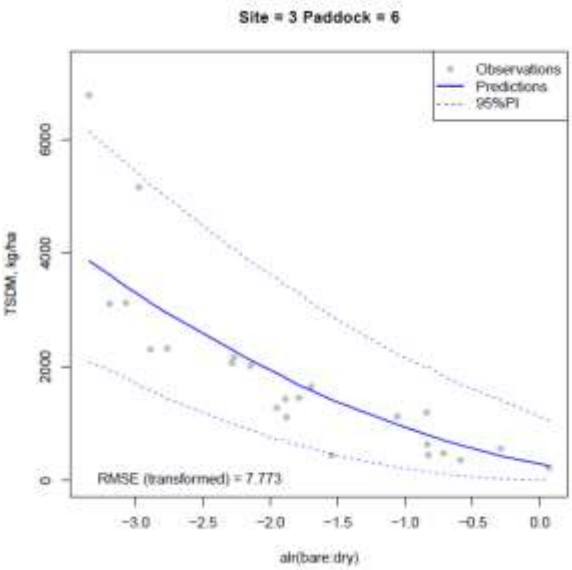

Site = 3 Paddock = 10
Observations
Predictions
95%PI
RMSE (transformed) = 8.182
TSDM, kg/ha
alr(bare:dry)
Site = 2 Paddock = 10%
Observations
Predictions
95%PI
RMSE (transformed) = 9.584
TSDM, kg/ha
alr(bare:dry)
Site = 3 Paddock = 3
Observations
Predictions
95%PI
RMSE (transformed) = 6.827
TSDM, kg/ha
alr(bare:dry)
Site = 2 Paddock = 30%
Observations
Predictions
95%PI
RMSE (transformed) = 7.849
TSDM, kg/ha
alr(bare:dry)
Site = 3 Paddock = 2
Observations
Predictions
95%PI
RMSE (transformed) = 8.32
TSDM, kg/ha
alr(bare:dry)
Site = 2 Paddock = 20%
Observations
Predictions
95%PI
RMSE (transformed) = 8.176
TSDM, kg/ha
alr(bare:dry)

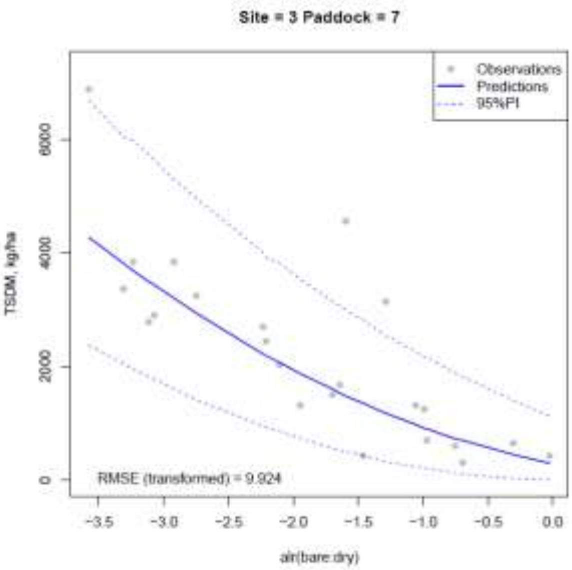

Site = 3 Paddock = 4
Observations
Predictions
95%PI
RMSE (transformed) = 9.061
TSDM, kg/ha
alr(bare:dry)

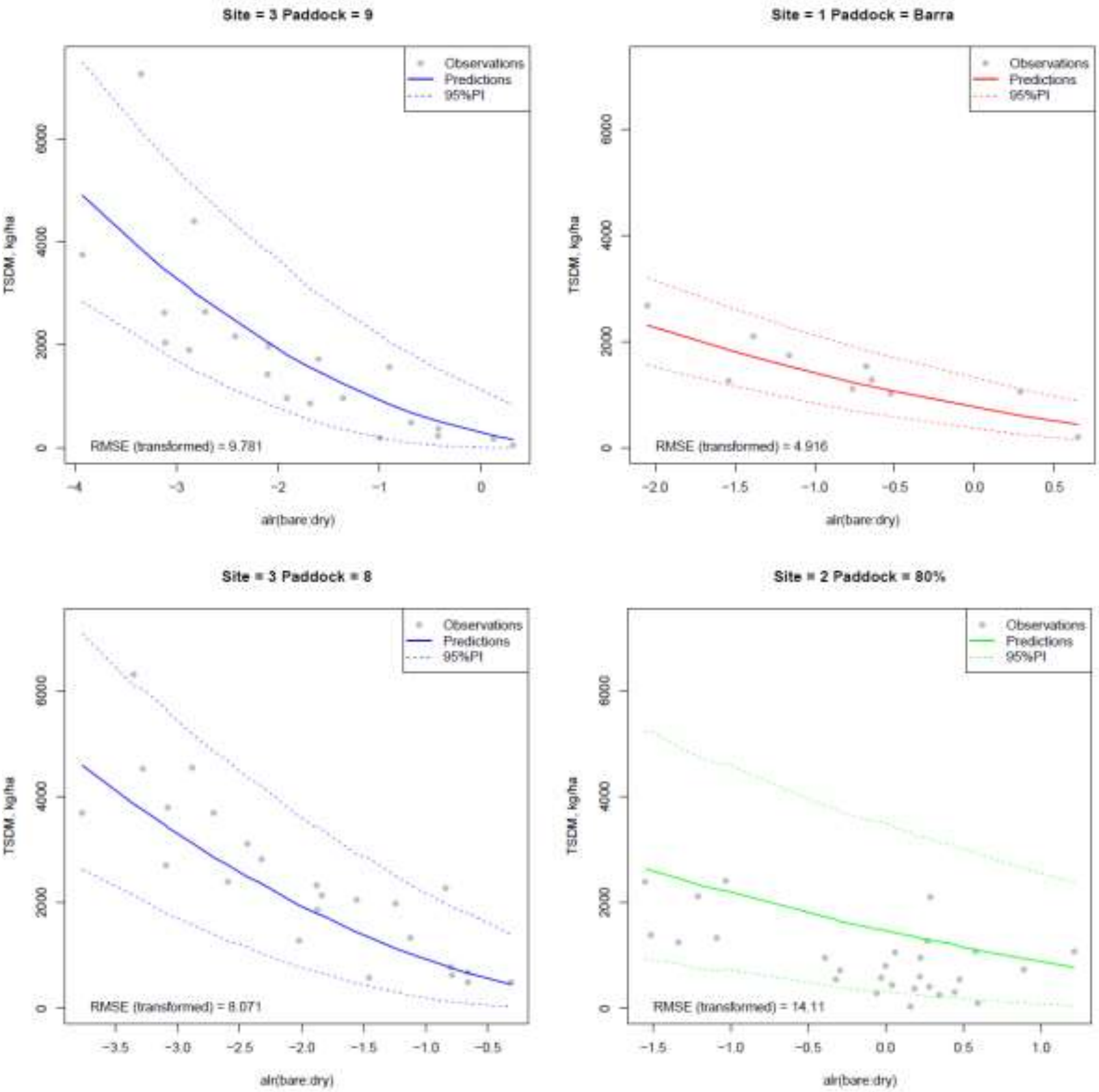

Site = 1 Paddock = 400Ha_Biodiversity_
Observations
Predictions
95%PI
RMSE (transformed) = 7.413
TSDM, kg/ha
alr(bare:dry)


Site = 3 Paddock = 5
Observations
Predictions
95%PI
RMSE (transformed) = 5.646
TSDM, kg/ha
alr(bare:dry)

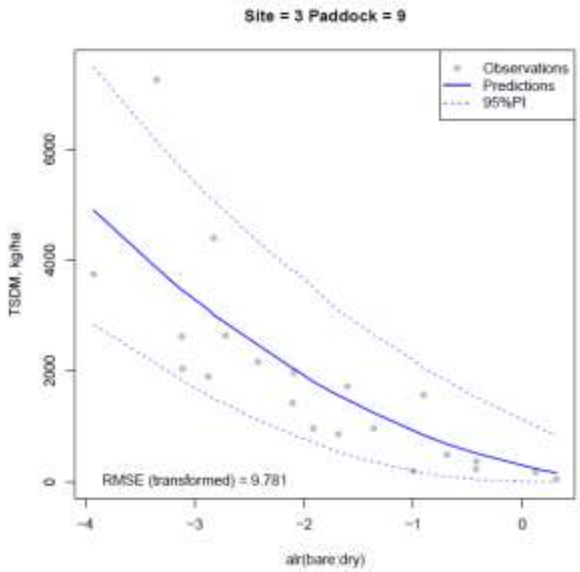

Site = 2 Paddock = 50%
Observations
Predictions
95%PI
RMSE (transformed) = 8.762
TSDM, kg/ha
alr(bare:dry)

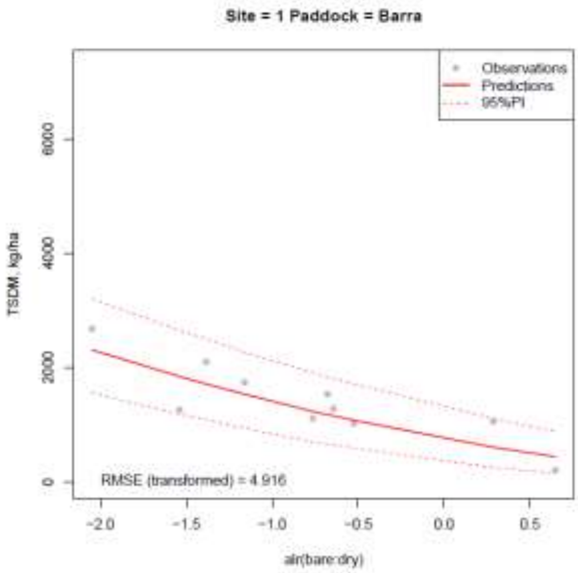

Site = 3 Paddock = 6
Observations
Predictions
95%PI
RMSE (transformed) = 7.773
TSDM, kg/ha
alr(bare:dry)

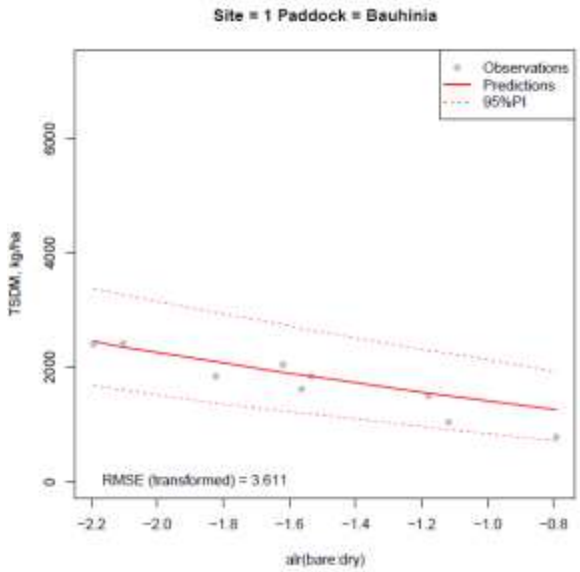

Site = 3 Paddock = 7
Observations
Predictions
95%PI
RMSE (transformed) = 9.924
TSDM, kg/ha
alr(bare:dry)

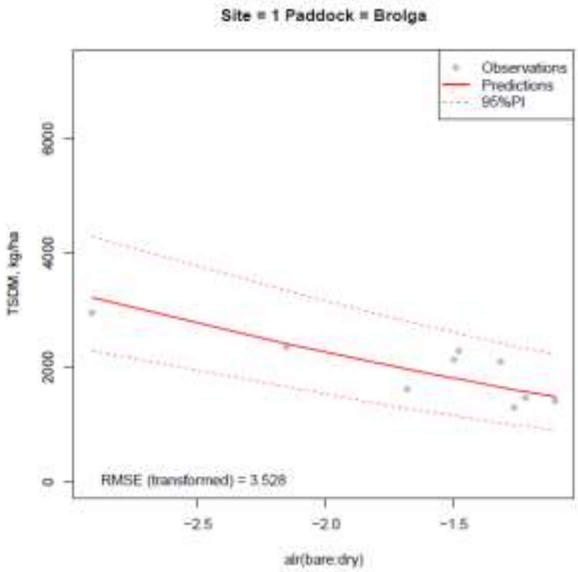


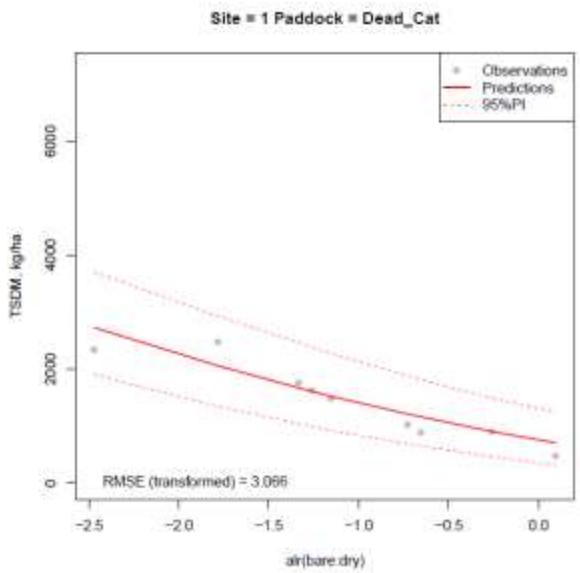
Site = 3 Paddock = 9
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 9.781
alr(bare:dry)
Site = 1 Paddock = Barra
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 4.916
alr(bare:dry)
Site = 3 Paddock = 8
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 8.071
alr(bare:dry)
Site = 2 Paddock = 80%
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 14.11
alr(bare:dry)

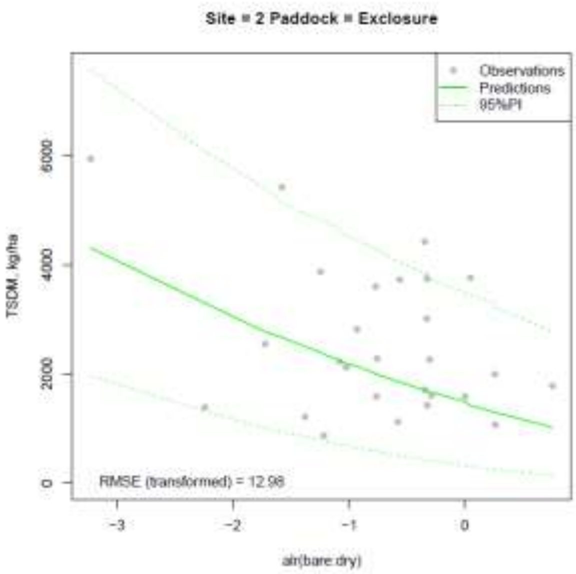

Site = 3 Paddock = 9
Observations
Predictions
95%PI
RMSE (transformed) = 9.781
TSDM, kg/ha
alr(bare:dry)

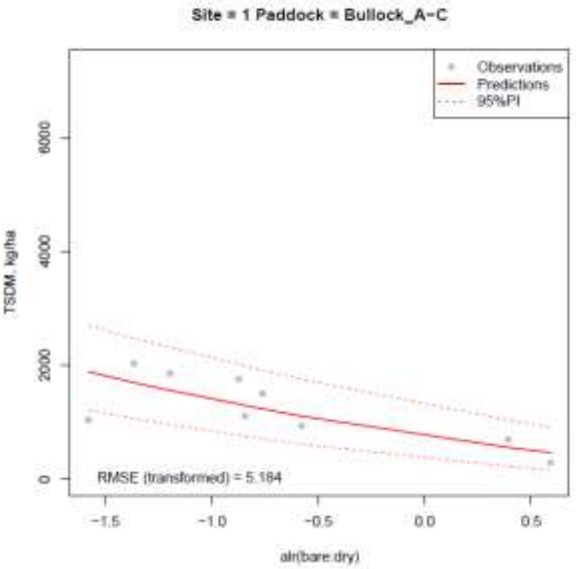

Site = 1 Paddock = Barra
Observations
Predictions
95%PI
RMSE (transformed) = 4.916
TSDM, kg/ha
alr(bare:dry)

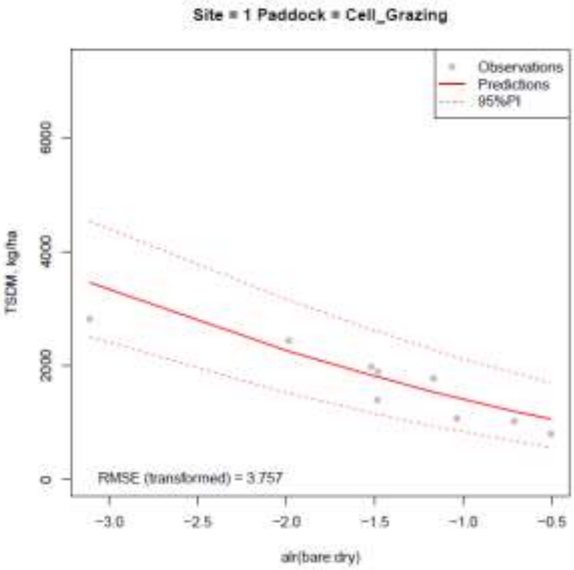

Site = 1 Paddock = Bauhinia
Observations
Predictions
95%PI
RMSE (transformed) = 3.611
TSDM, kg/ha
alr(bare:dry)

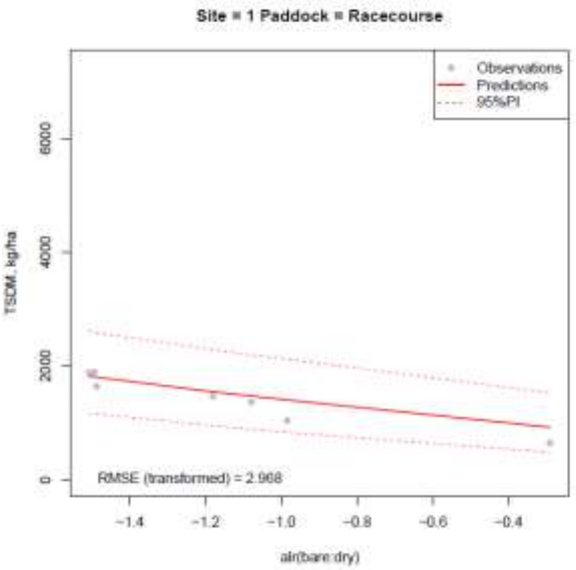

Site = 1 Paddock = Brolga
Observations
Predictions
95%PI
RMSE (transformed) = 3.528
TSDM, kg/ha
alr(bare:dry)

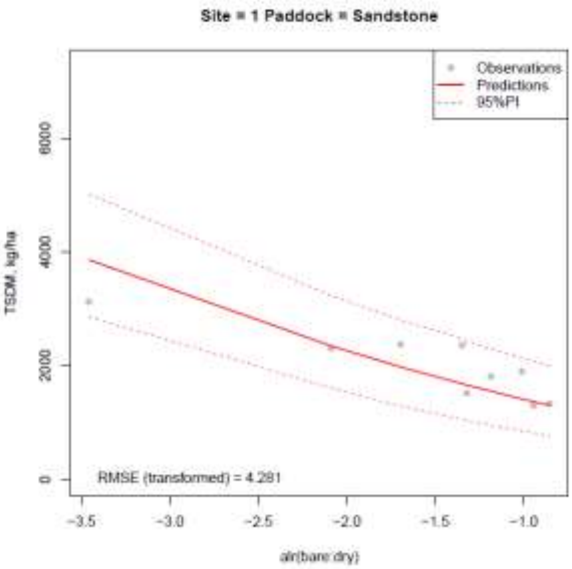

Site = 1 Paddock = Dead_Cat
Observations
Predictions
95%PI
RMSE (transformed) = 3.066
TSDM, kg/ha
alr(bare:dry)

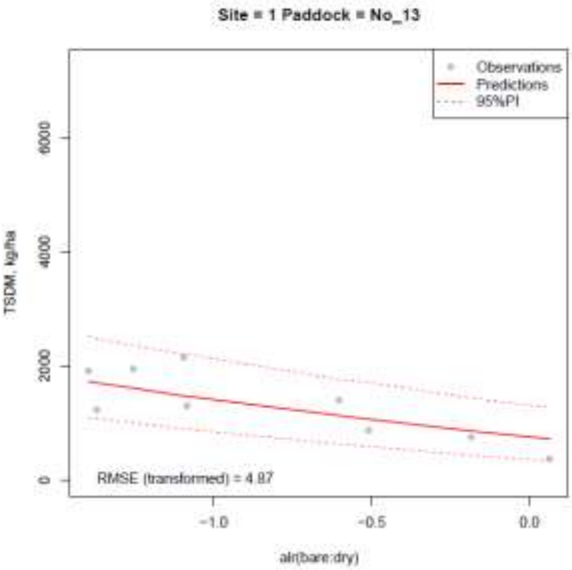

Site = 2 Paddock = Exclosure
Observations
Predictions
95%PI
RMSE (transformed) = 12.98
TSDM, kg/ha
alr(bare:dry)


Site = 1 Paddock = Bullock_A−C
Observations
Predictions
95%PI
TSDM, kg/ha
0
2000
4000
6000
RMSE (transformed) = 5.184
−1.5
−1.0
−0.5
0.0
0.5
alr(bare:dry)

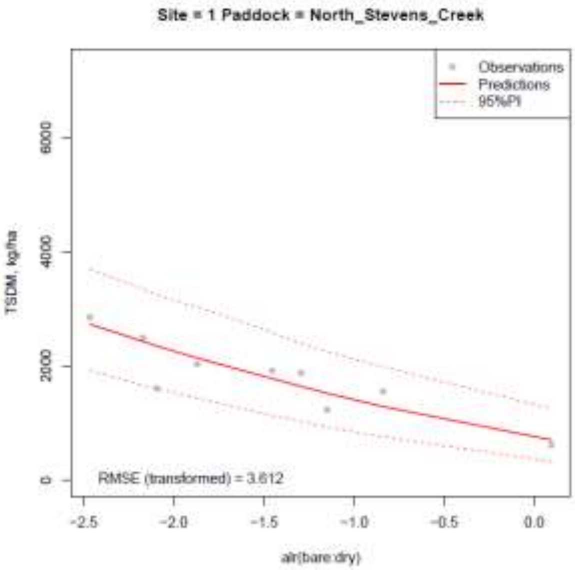

Site = 1 Paddock = Cell_Grazing
Observations
Predictions
95%PI
TSDM, kg/ha
0
2000
4000
6000
RMSE (transformed) = 3.757
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
alr(bare:dry)


Site = 1 Paddock = Racecourse
Observations
Predictions
95%PI
TSDM, kg/ha
0
2000
4000
6000
RMSE (transformed) = 2.968
−1.4
−1.2
−1.0
−0.8
−0.6
−0.4
alr(bare:dry)

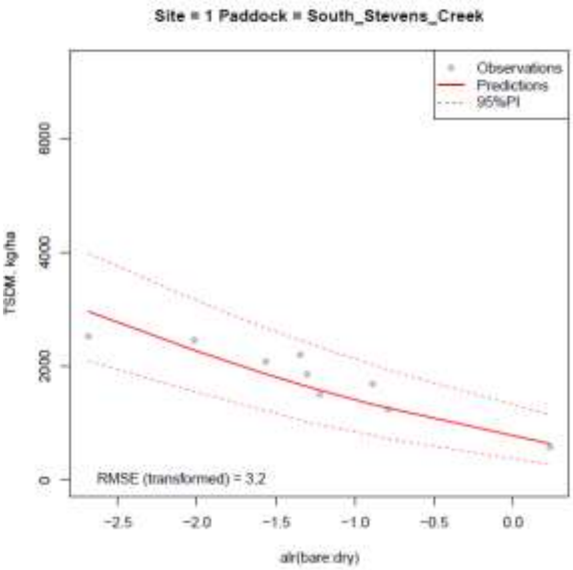

Site = 1 Paddock = Sandstone
Observations
Predictions
95%PI
TSDM, kg/ha
0
2000
4000
6000
RMSE (transformed) = 4.281
−3.5
−3.0
−2.5
−2.0
−1.5
−1.0
alr(bare:dry)



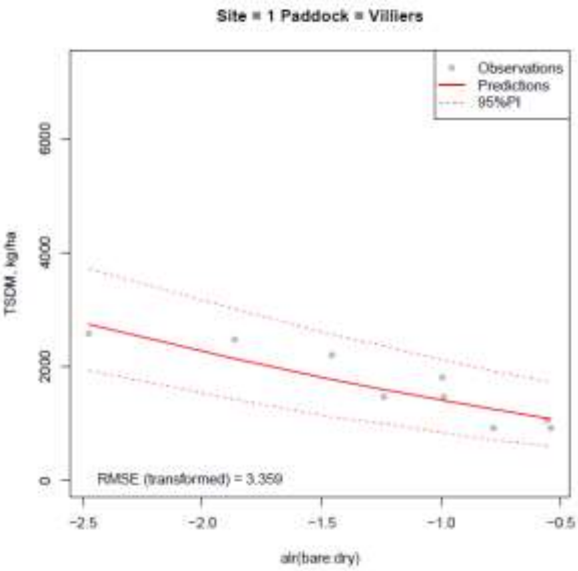
Site = 1 Paddock = No_13
Observations
Predictions
95%PI
RMSE (transformed) = 4.87
TSDM, kg/ha
alr(bare:dry)



Site = 1 Paddock = North_Stevens_Creek
Observations
Predictions
95%PI
RMSE (transformed) = 3.612
TSDM, kg/ha
alr(bare:dry)



Site = 1 Paddock = South_Stevens_Creek
Observations
Predictions
95%PI
RMSE (transformed) = 3.2
TSDM, kg/ha
alr(bare:dry)

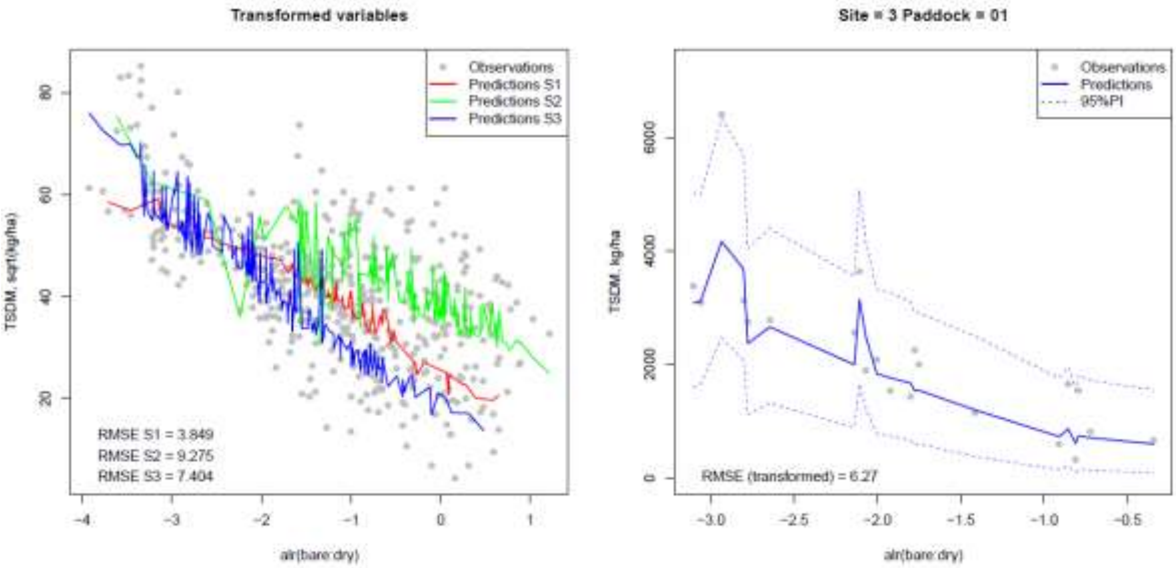


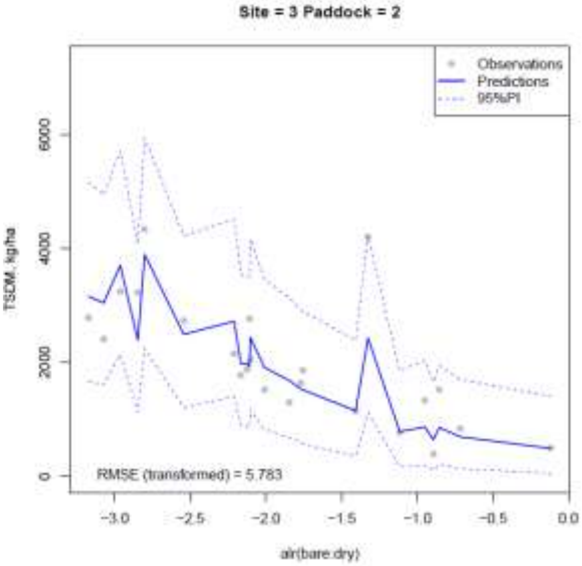
Site = 1 Paddock = Villiers
Observations
Predictions
95%PI
RMSE (transformed) = 3.359
TSDM, kg/ha
alr(bare:dry)

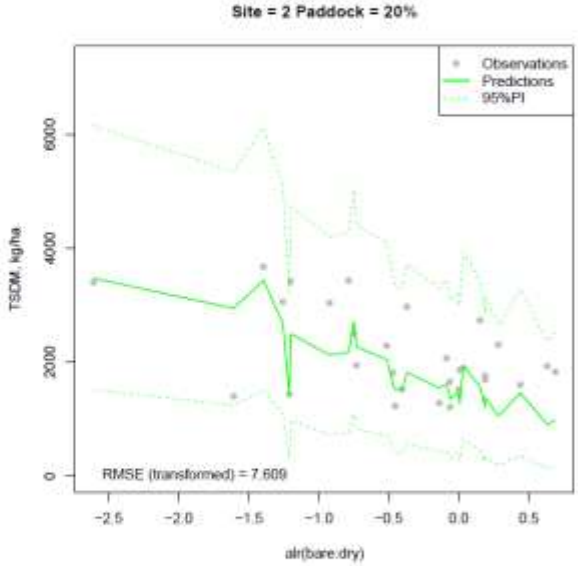
Appendix (11) Paddock performance using individual trial based complex functions.

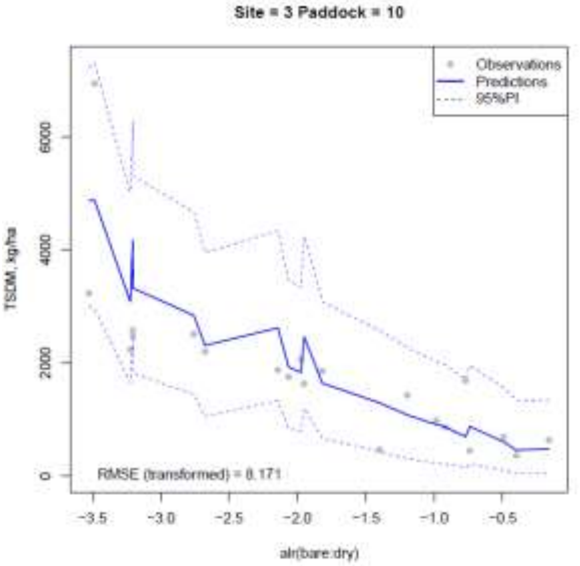
Paddock level fits of TSDM for each 3 grazing trials for a function of log (bare/dry), average greenness over last 365 days, persistent green and interaction terms (8 parameters). Site 1 = Pigeon Hole, Site 2 = Toorak and Site 3 = Wambiana.

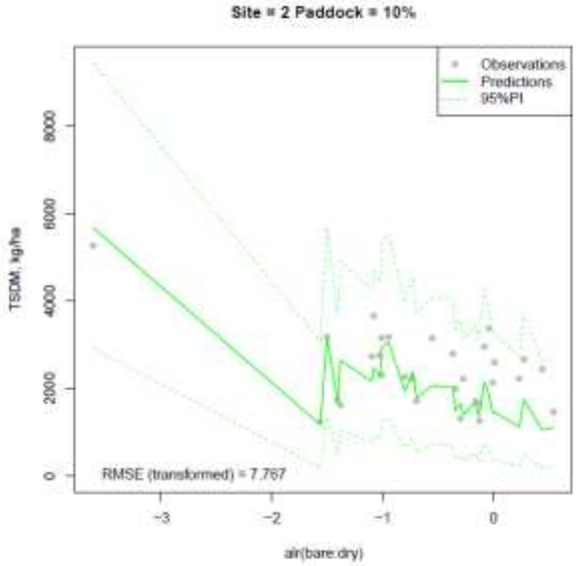
FIGURE 5 ==

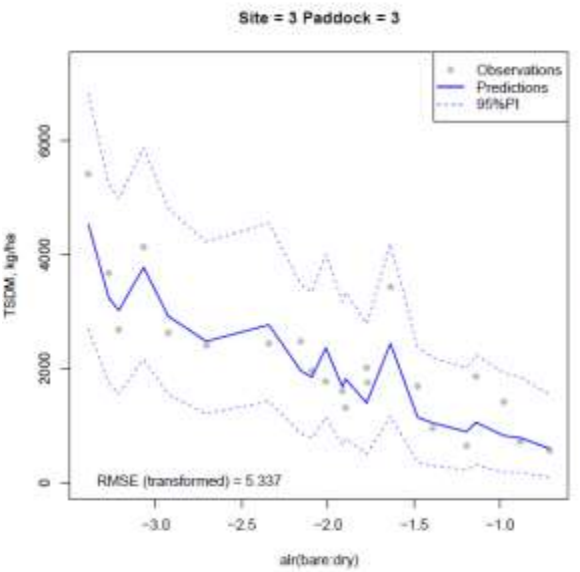


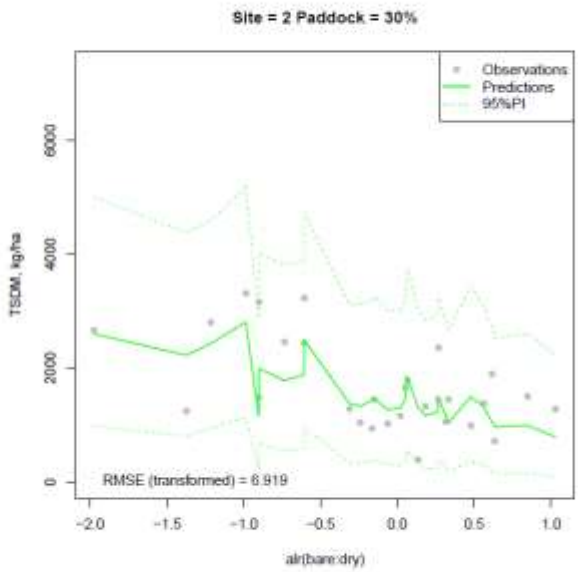

Site = 3 Paddock = 2
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 5.783
alr(bare:dry)

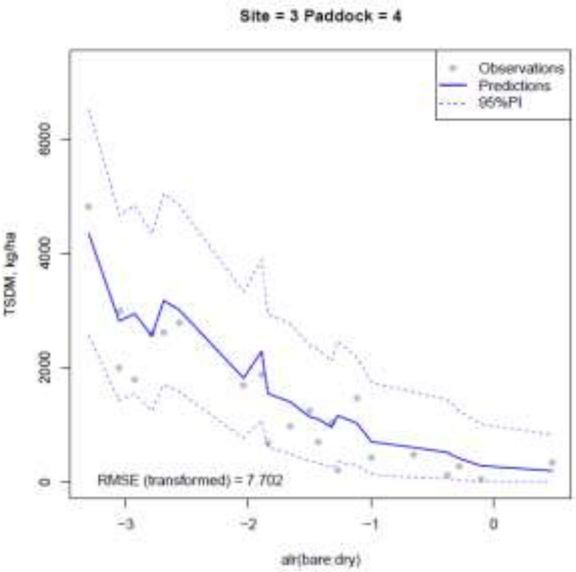

Site = 2 Paddock = 20%
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 7.609
alr(bare:dry)

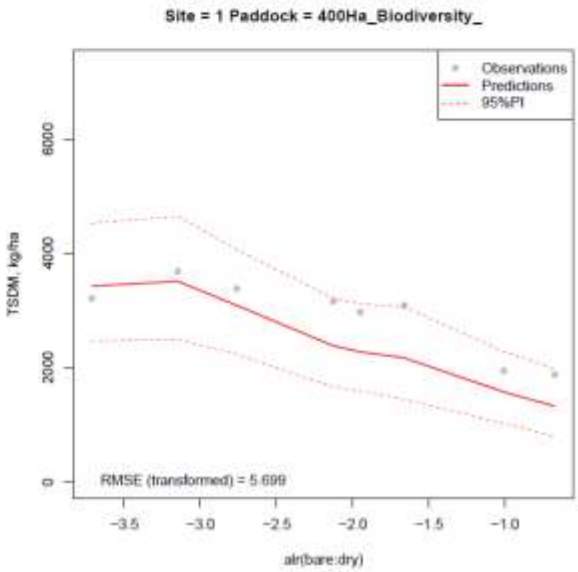

Site = 3 Paddock = 10
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 8.171
alr(bare:dry)

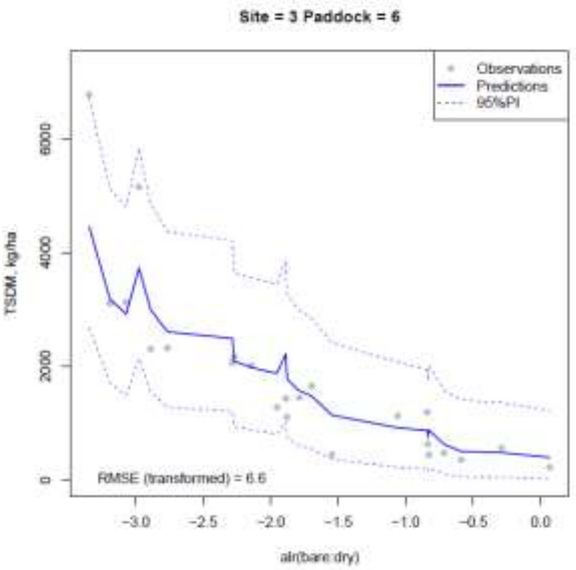

Site = 2 Paddock = 10%
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 7.767
alr(bare:dry)

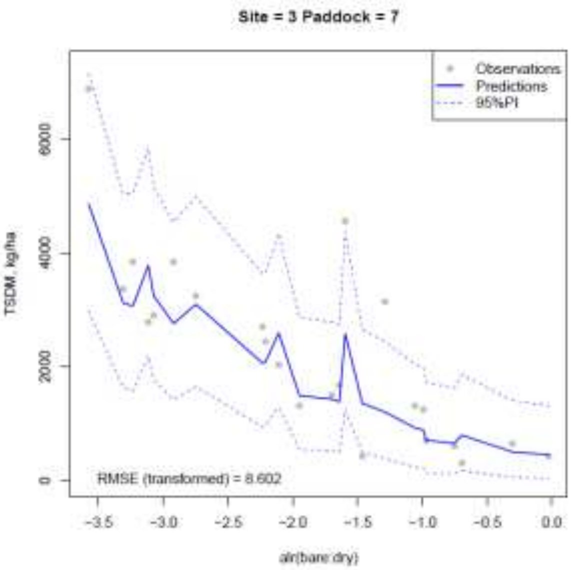

Site = 3 Paddock = 3
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 5.337
alr(bare:dry)

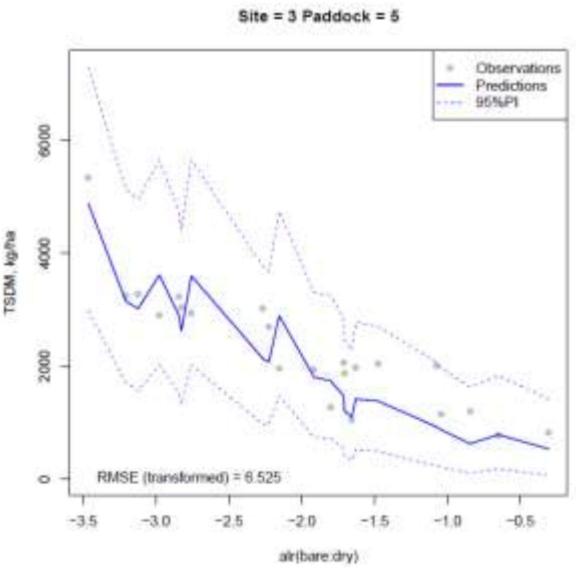

Site = 2 Paddock = 30%
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 6.919
alr(bare:dry)

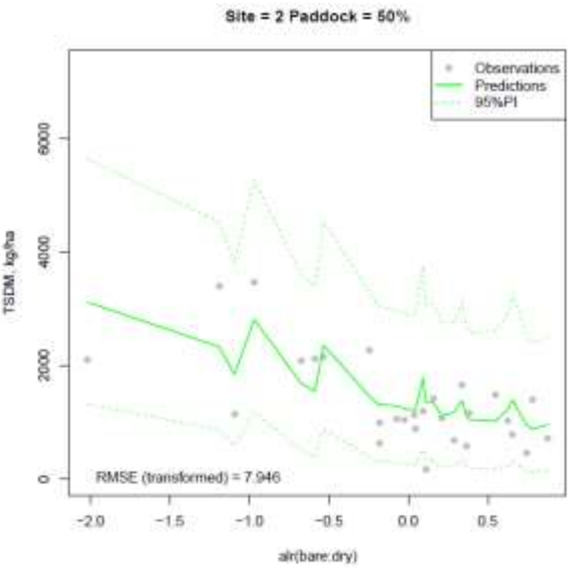

Site = 3 Paddock = 4
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 7.702
alr(bare:dry)

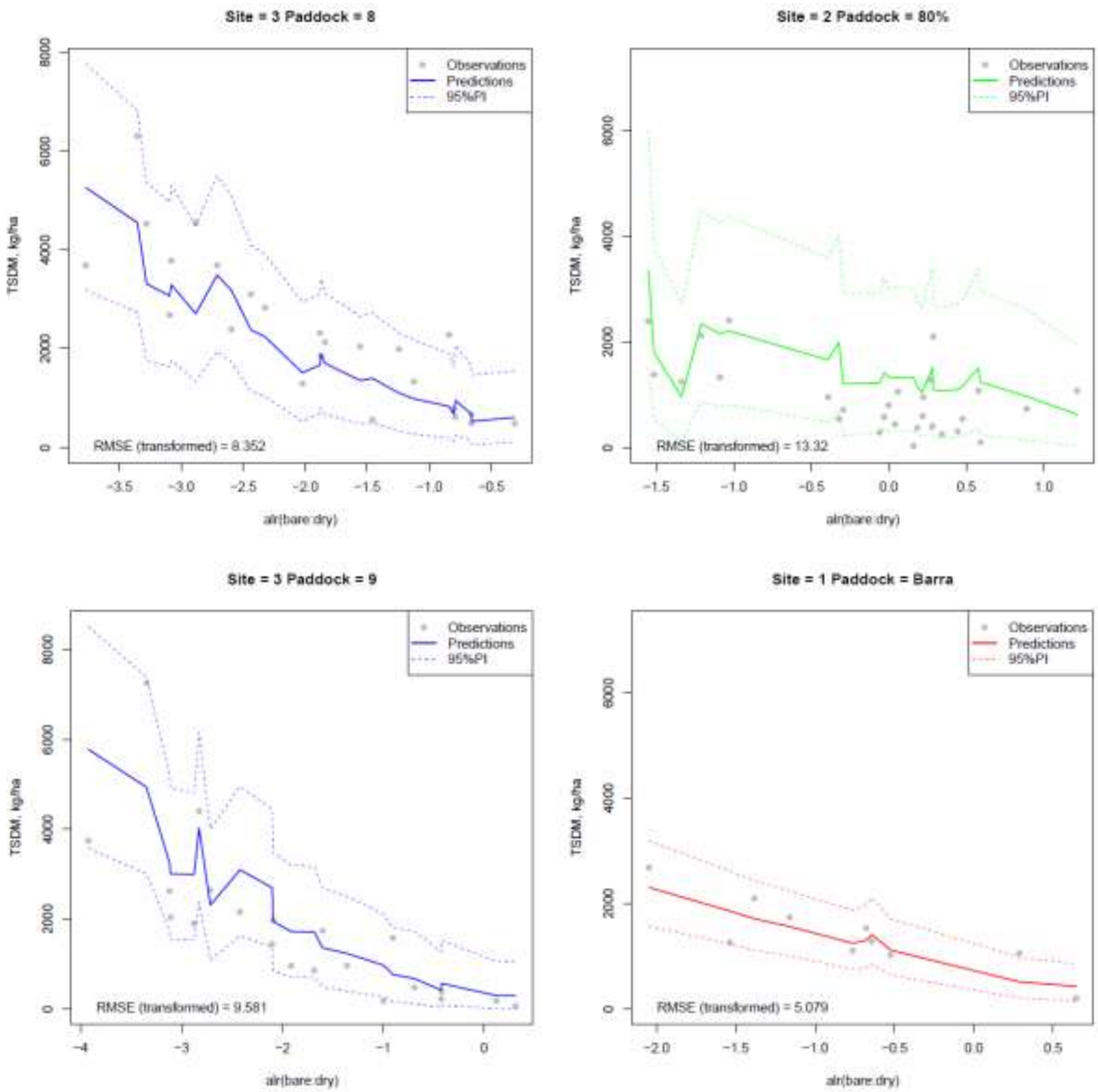

Site = 1 Paddock = 400Ha_Biodiversity_
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 5.699
alr(bare:dry)

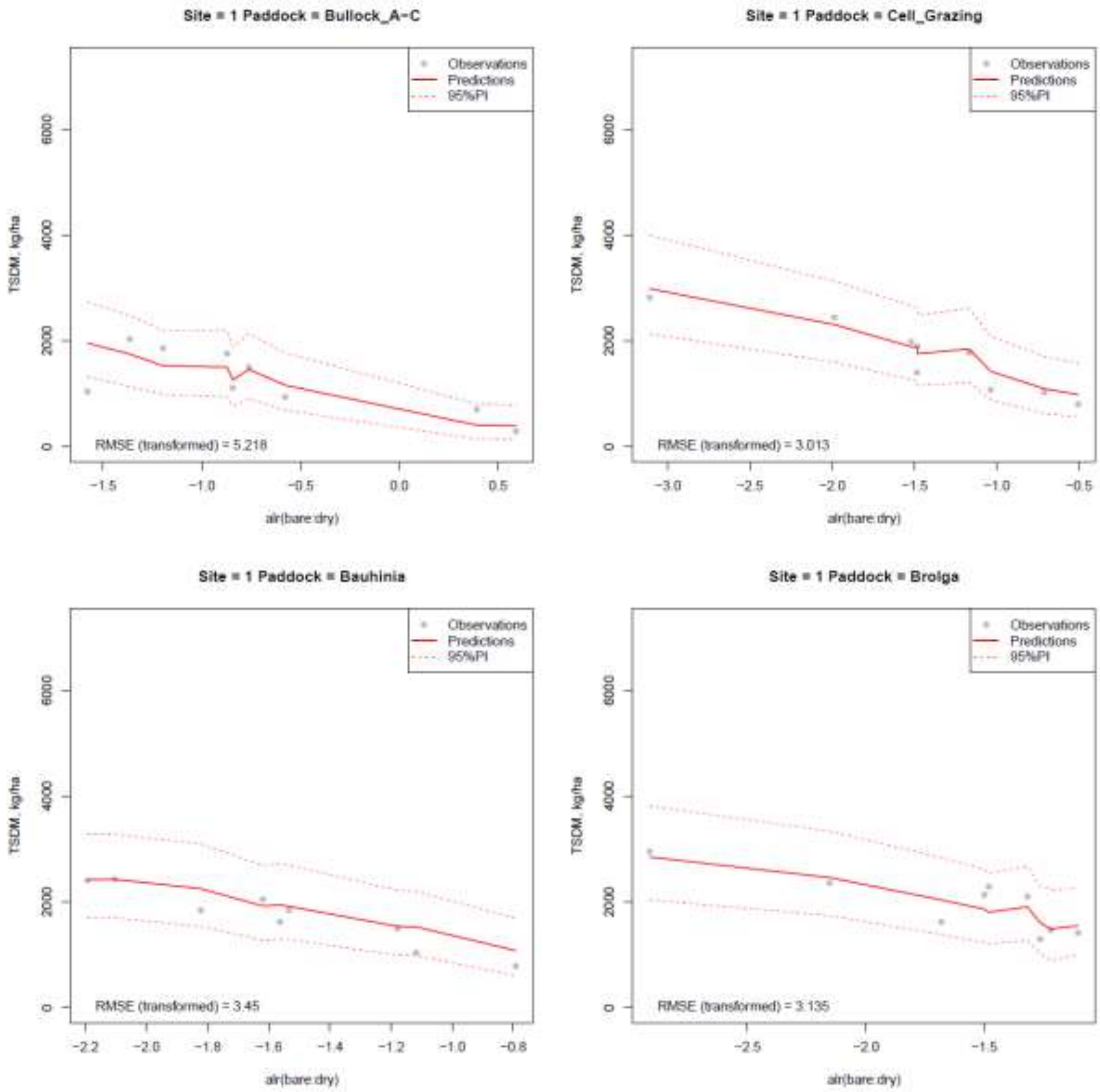

Site = 3 Paddock = 6
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 6.6
alr(bare:dry)

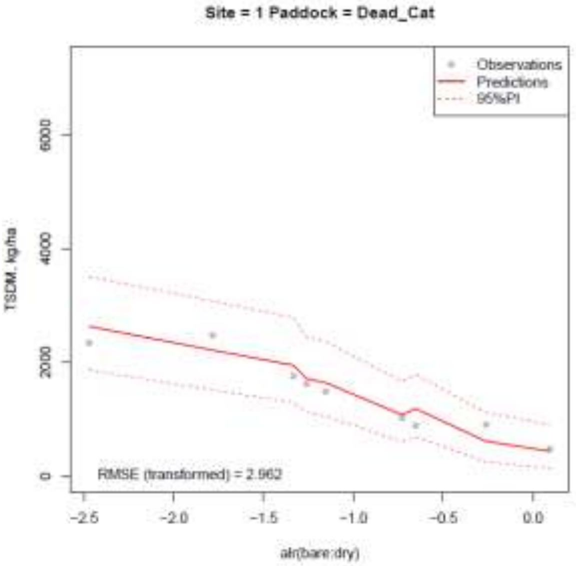

Site = 3 Paddock = 7
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 8.602
alr(bare:dry)

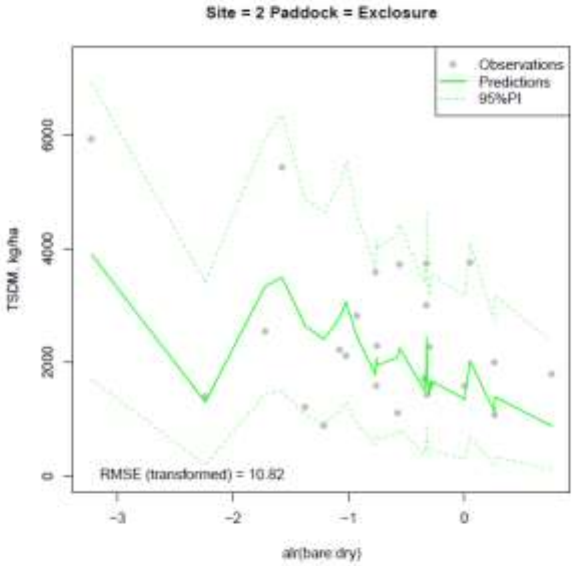

Site = 3 Paddock = 5
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 6.525
alr(bare:dry)

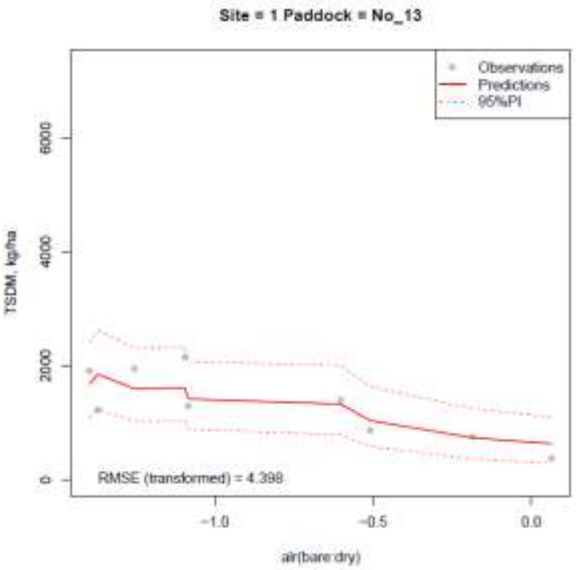

Site = 2 Paddock = 50%
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 7.946
alr(bare:dry)

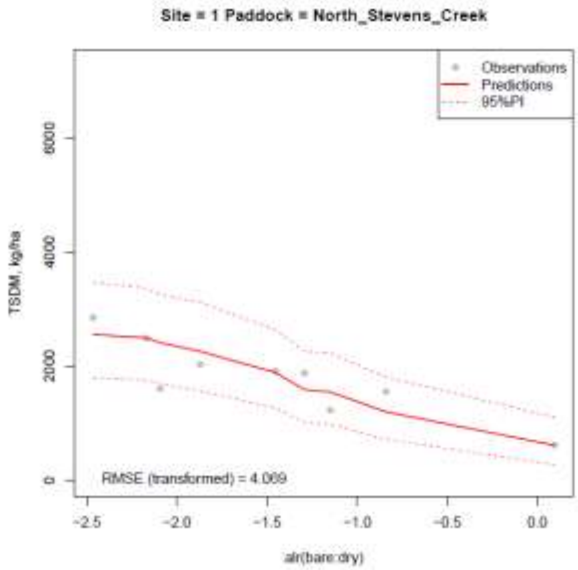

Site = 3 Paddock = 8
Observations
Predictions
95%PI
RMSE (transformed) = 8.352
TSDM, kg/ha
alr(bare:dry)
Site = 2 Paddock = 80%
Observations
Predictions
95%PI
RMSE (transformed) = 13.32
TSDM, kg/ha
alr(bare:dry)
Site = 3 Paddock = 9
Observations
Predictions
95%PI
RMSE (transformed) = 9.581
TSDM, kg/ha
alr(bare:dry)
Site = 1 Paddock = Barra
Observations
Predictions
95%PI
RMSE (transformed) = 5.079
TSDM, kg/ha
alr(bare:dry)

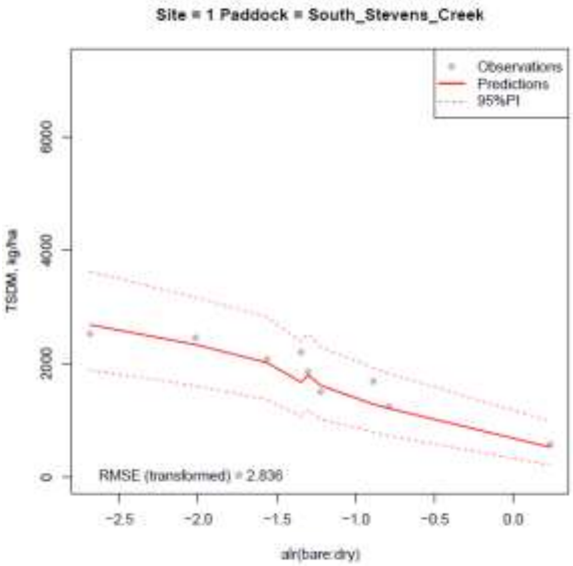

Site = 1 Paddock = Bullock_A−C
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 5.218
alr(bare:dry)
Site = 1 Paddock = Cell_Grazing
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 3.013
alr(bare:dry)
Site = 1 Paddock = Bauhinia
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 3.45
alr(bare:dry)
Site = 1 Paddock = Brolga
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 3.135
alr(bare:dry)

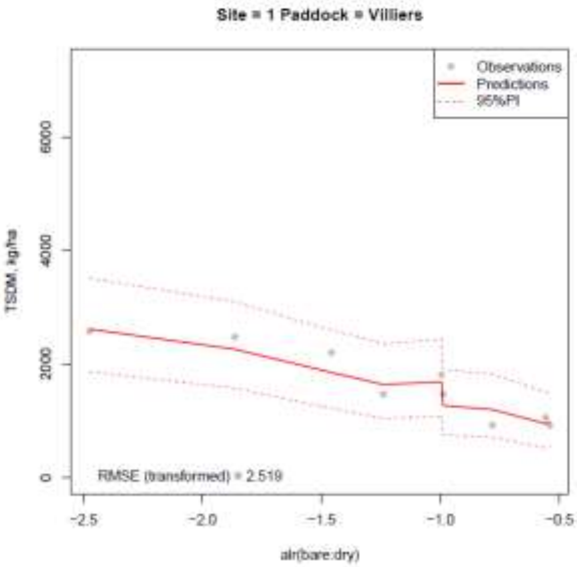

Site = 1 Paddock = Dead_Cat
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 2.962
alr(bare:dry)

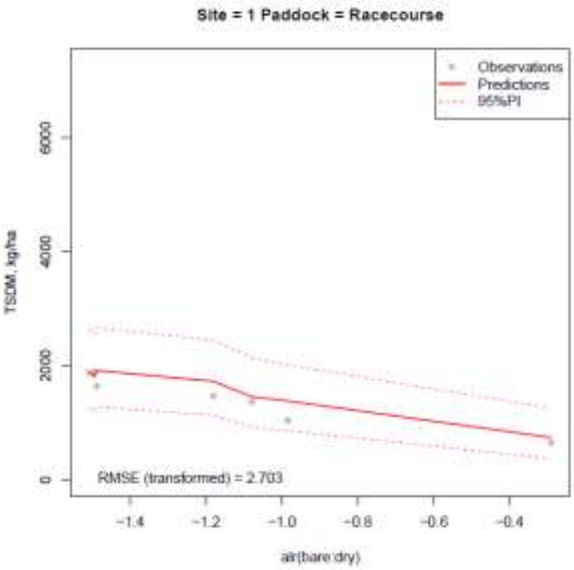

Site = 2 Paddock = Exclosure
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 10.82
alr(bare:dry)

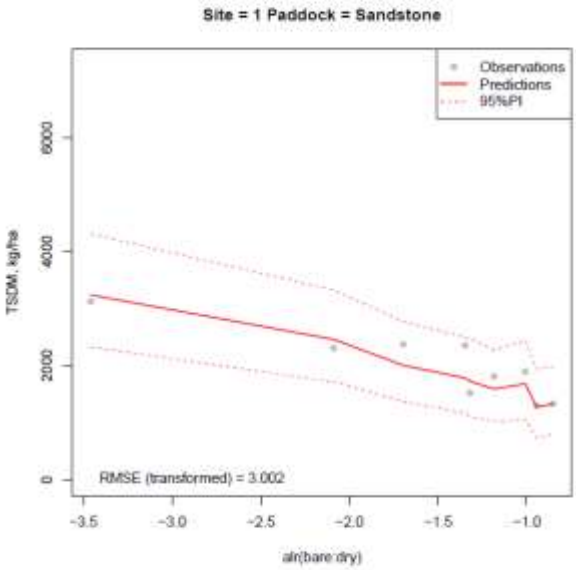

Site = 1 Paddock = No_13
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 4.398
alr(bare:dry)


Site = 1 Paddock = North_Stevens_Creek
Observations
Predictions
95%PI
TSDM, kg/ha
RMSE (transformed) = 4.069
alr(bare:dry)


Site = 1 Paddock = South_Stevens_Creek
Observations
Predictions
95%PI
RMSE (transformed) = 2.836
TSDM, kg/ha
alr(bare:dry)

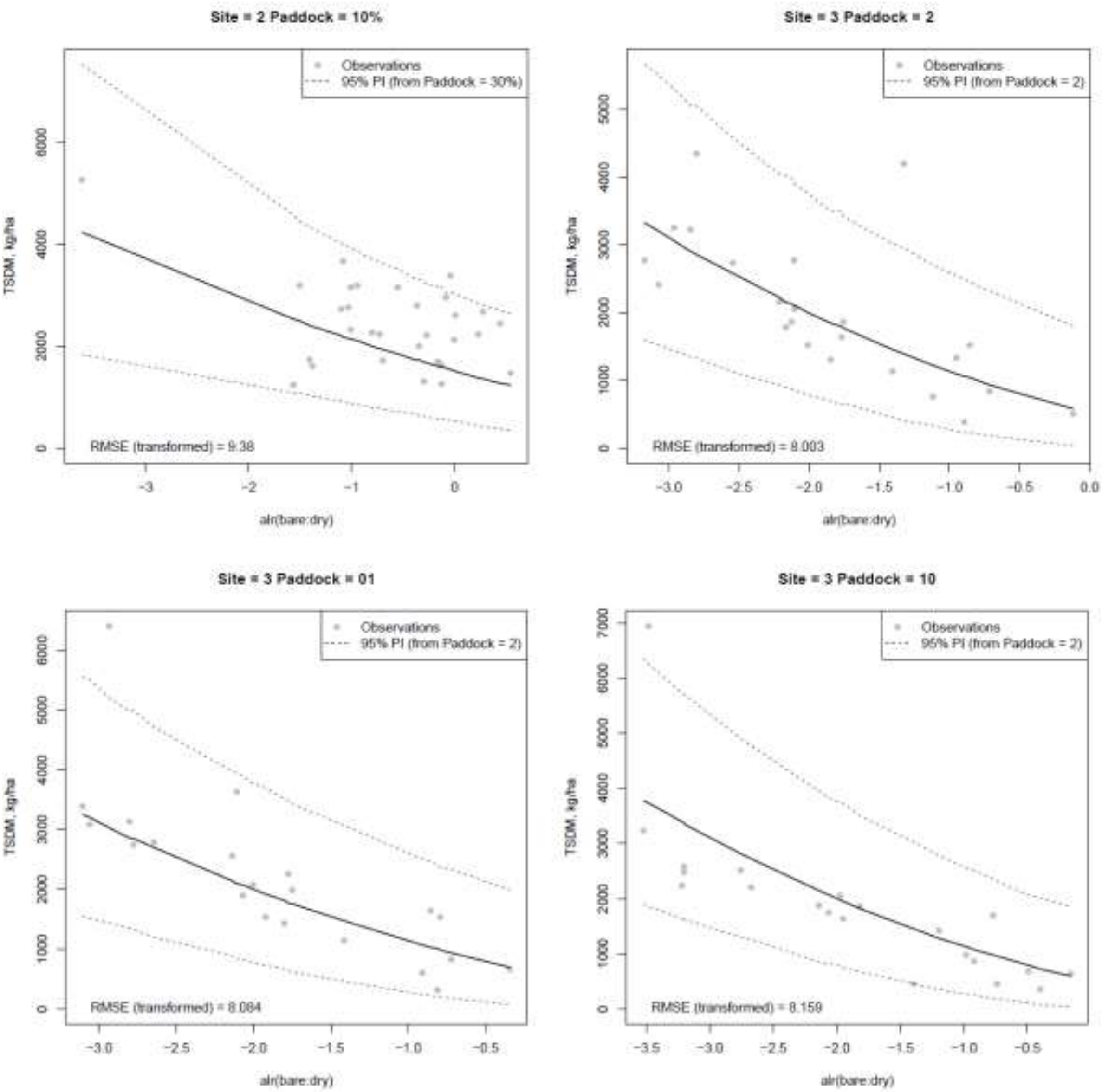

Site = 1 Paddock = Villiers
Observations
Predictions
95%PI
RMSE (transformed) = 2.519
TSDM, kg/ha
alr(bare:dry)

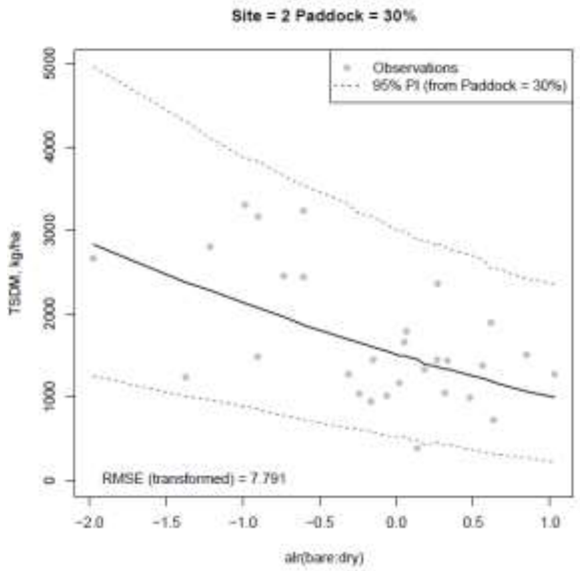

Site = 1 Paddock = Racecourse
Observations
Predictions
95%PI
RMSE (transformed) = 2.703
TSDM, kg/ha
alr(bare:dry)

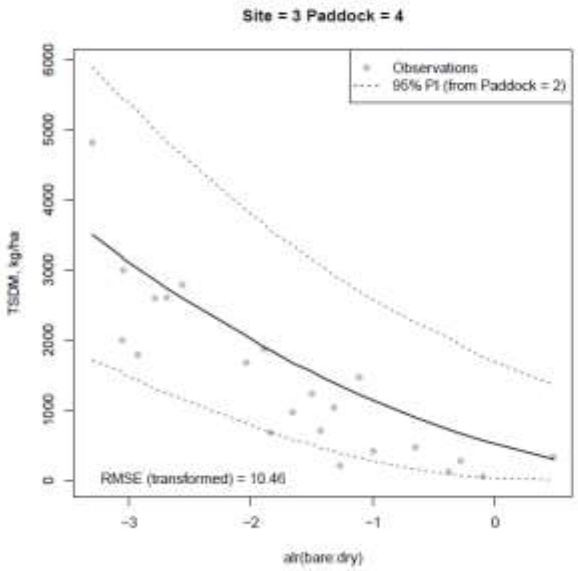

Site = 1 Paddock = Sandstone
Observations
Predictions
95%PI
RMSE (transformed) = 3.002
TSDM, kg/ha
alr(bare:dry)

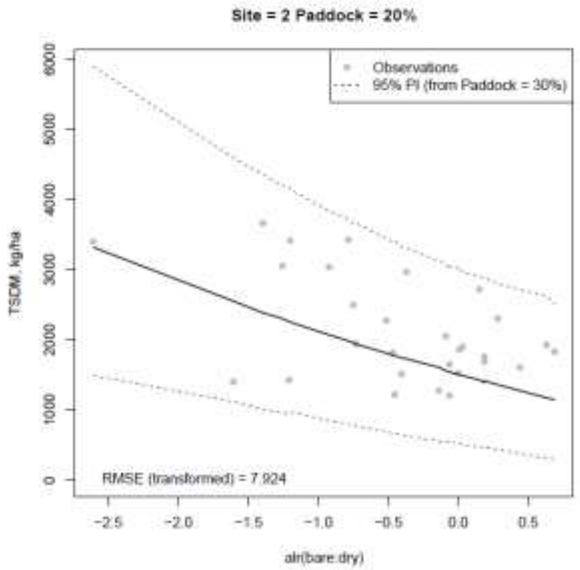
Appendix (12) Calibration using a representative paddock from each grazing trial.

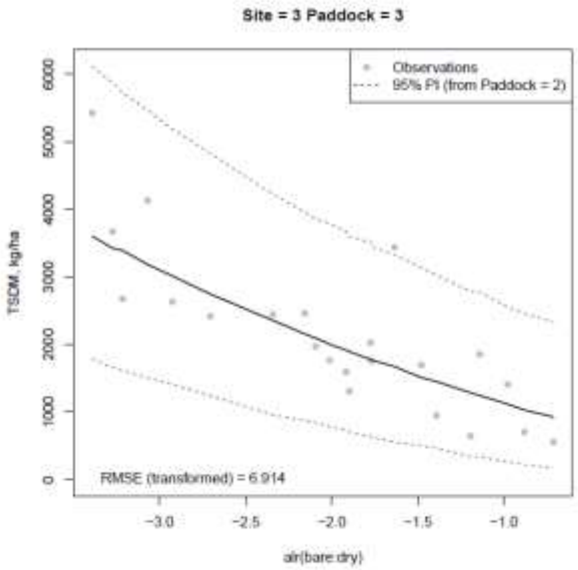
A single representative paddock (close to trial average TSDM) from was selected from each grazing trial. The log (bare/dead) model was fitted each of the three paddocks and the parameterisation was checked on each of the remaining paddocks in the grazing trial. The simpler form of model was used as there was less data available than for the whole trial and the data range particularly for persistent green was much reduced. Note significant increases in RMSE (transformed) and instances of bias

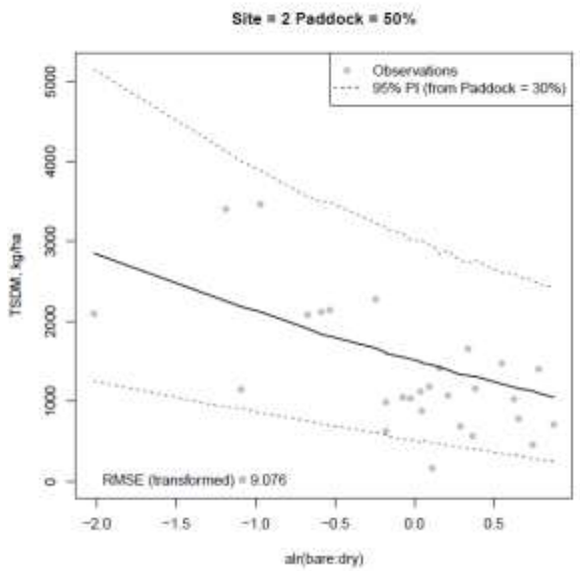


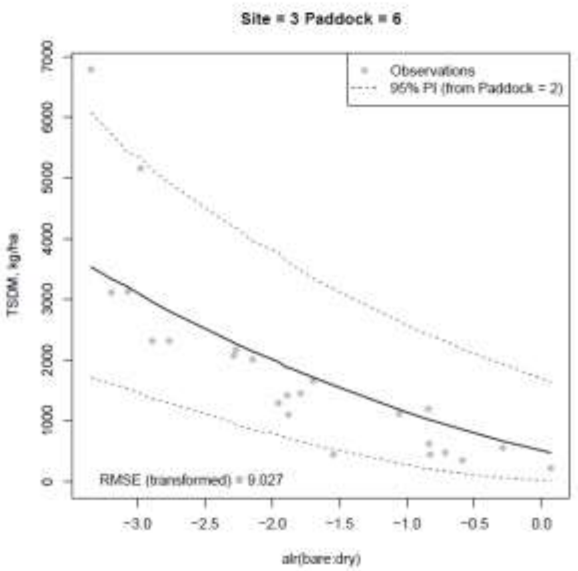

Site = 2 Paddock = 30%
Observations
95% PI (from Paddock = 30%)
RMSE (transformed) = 7.791
TSDM, kg/ha
alr(bare:dry)

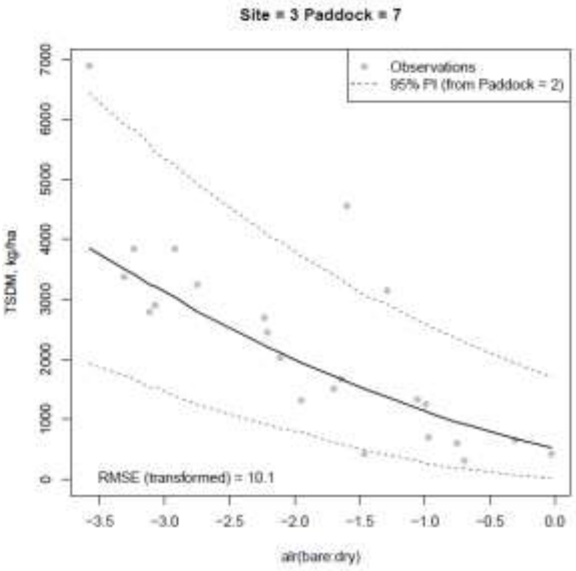

Site = 3 Paddock = 4
Observations
95% PI (from Paddock = 2)
RMSE (transformed) = 10.46
TSDM, kg/ha
alr(bare:dry)

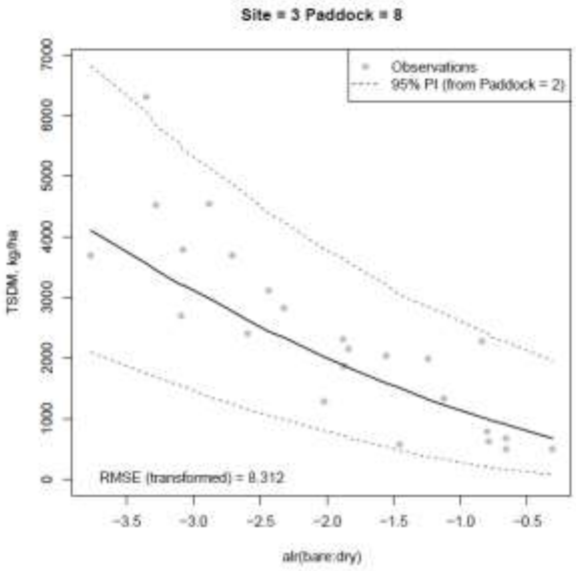

Site = 2 Paddock = 20%
Observations
95% PI (from Paddock = 30%)
RMSE (transformed) = 7.924
TSDM, kg/ha
alr(bare:dry)

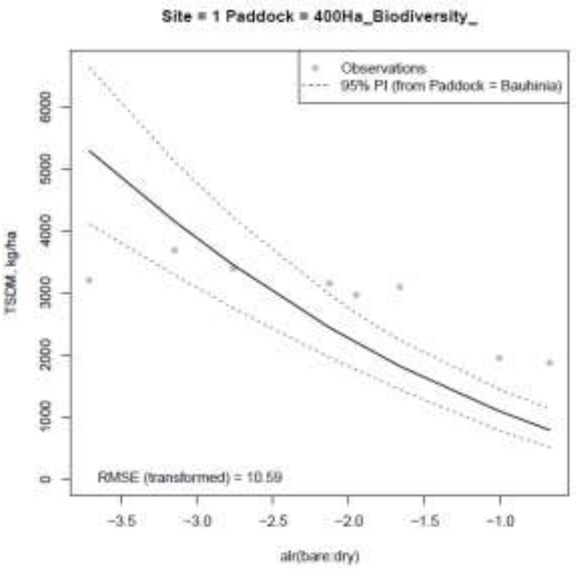

Site = 3 Paddock = 3
Observations
95% PI (from Paddock = 2)
RMSE (transformed) = 6.914
TSDM, kg/ha
alr(bare:dry)

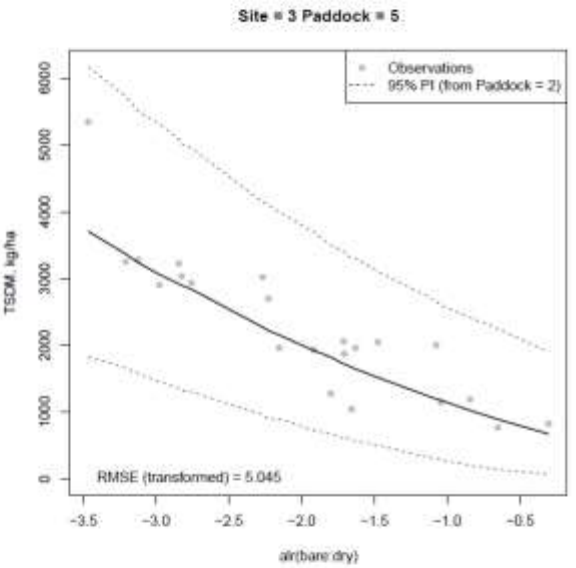

Site = 2 Paddock = 50%
Observations
95% PI (from Paddock = 30%)
RMSE (transformed) = 9.076
TSDM, kg/ha
alr(bare:dry)

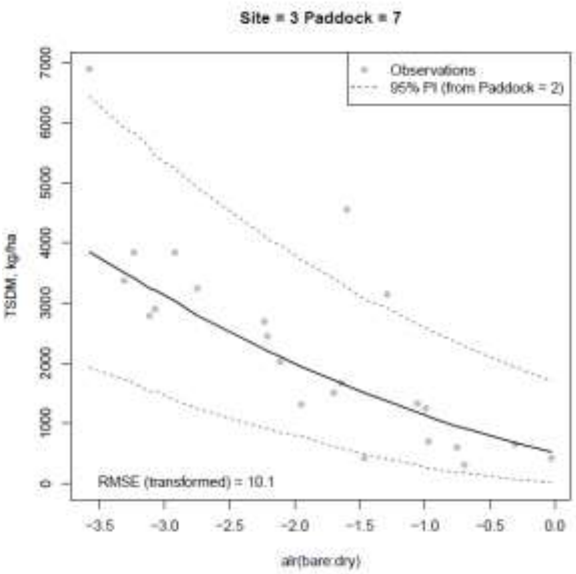

Site = 3 Paddock = 6
Observations
95% PI (from Paddock = 2)
RMSE (transformed) = 9.027
TSDM, kg/ha
alr(bare:dry)

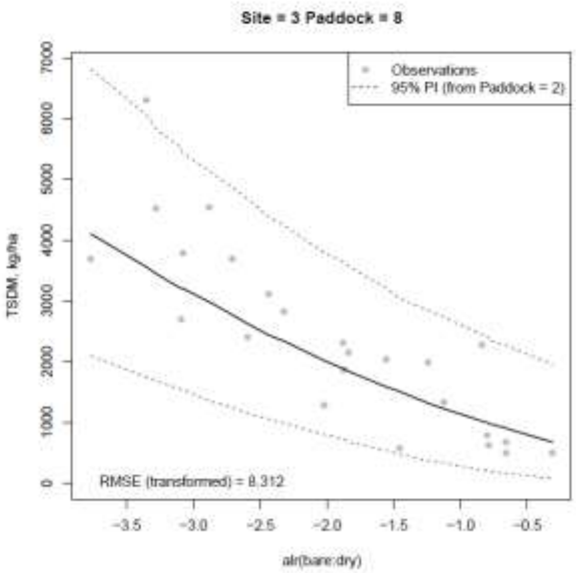

Site = 3 Paddock = 7
Observations
95% PI (from Paddock = 2)
RMSE (transformed) = 10.1
TSDM, kg/ha
alr(bare:dry)

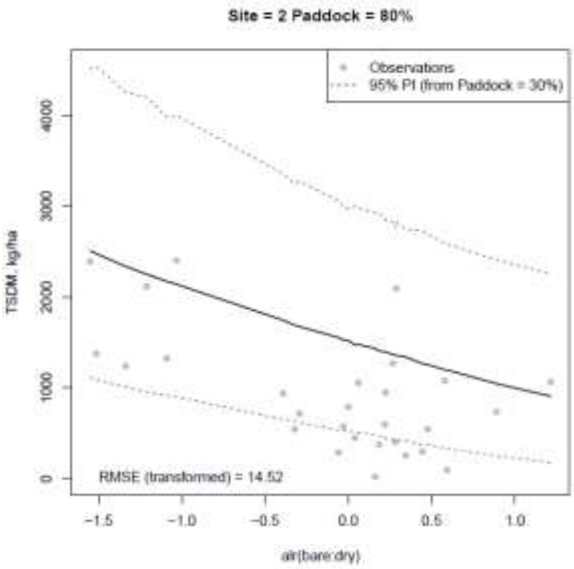

Site = 3 Paddock = 8
Observations
95% PI (from Paddock = 2)
RMSE (transformed) = 8.312
TSDM, kg/ha
alr(bare:dry)

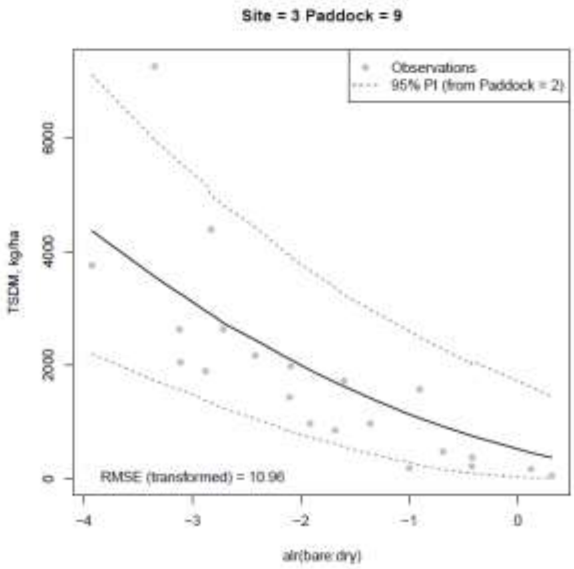

Site = 1 Paddock = 400Ha_Biodiversity_
Observations
95% PI (from Paddock = Bauhinia)
RMSE (transformed) = 10.59
TSDM, kg/ha
alr(bare:dry)

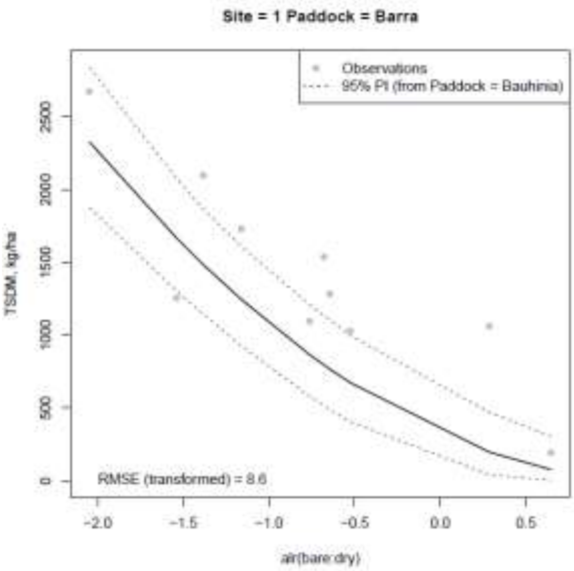

Site = 3 Paddock = 5
Observations
95% PI (from Paddock = 2)
RMSE (transformed) = 5.045
TSDM, kg/ha
alr(bare:dry)

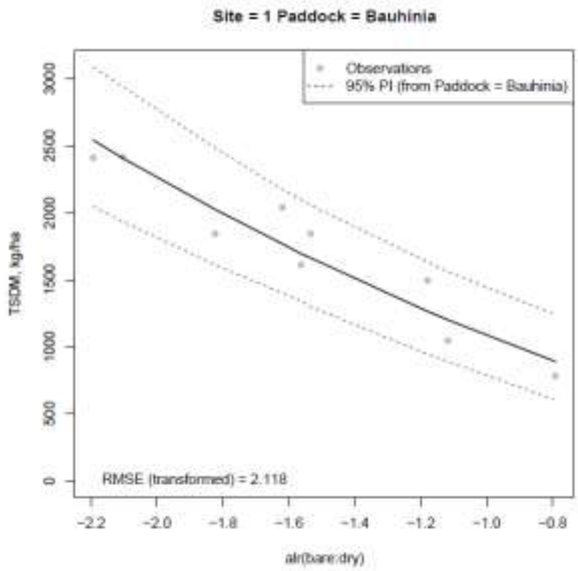

Site = 3 Paddock = 7
Observations
95% PI (from Paddock = 2)
RMSE (transformed) = 10.1
TSDM, kg/ha
alr(bare:dry)

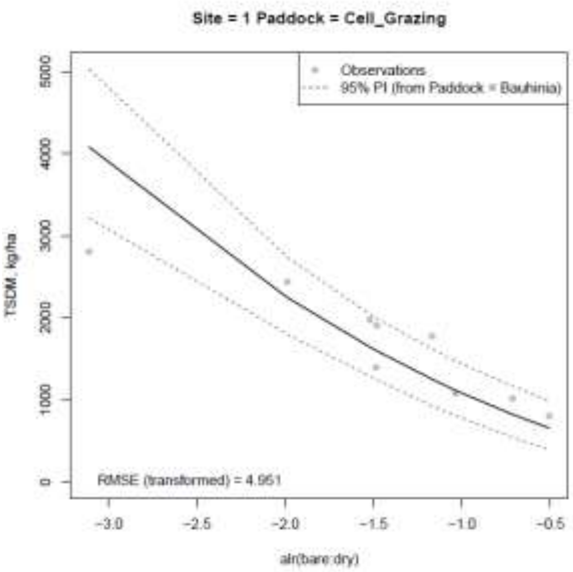

Site = 3 Paddock = 8
Observations
95% PI (from Paddock = 2)
RMSE (transformed) = 8.312
TSDM, kg/ha
alr(bare:dry)

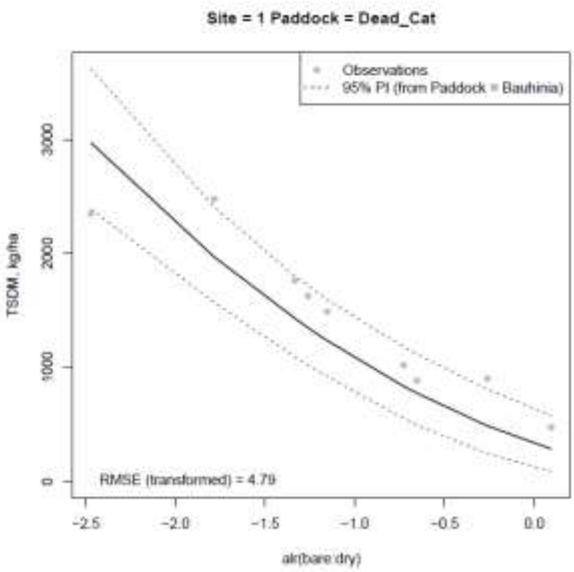

Site = 2 Paddock = 80%
Observations
95% PI (from Paddock = 30%)
RMSE (transformed) = 14.52
TSDM, kg/ha
alr(bare:dry)

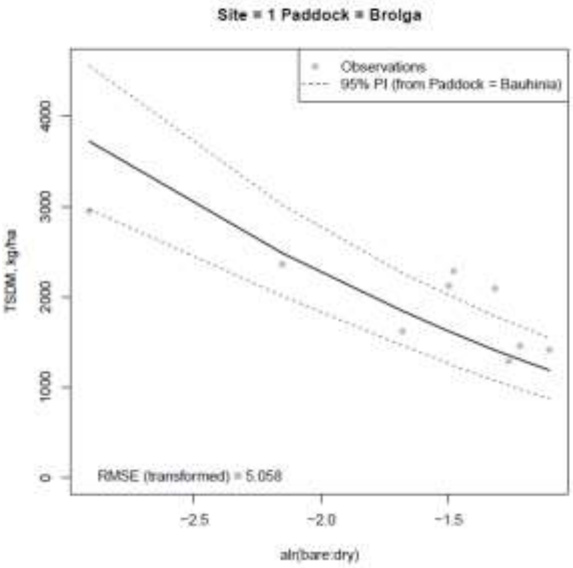

Site = 3 Paddock = 9
Observations
95% PI (from Paddock = 2)
RMSE (transformed) = 10.96
TSDM, kg/ha
alr(bare:dry)

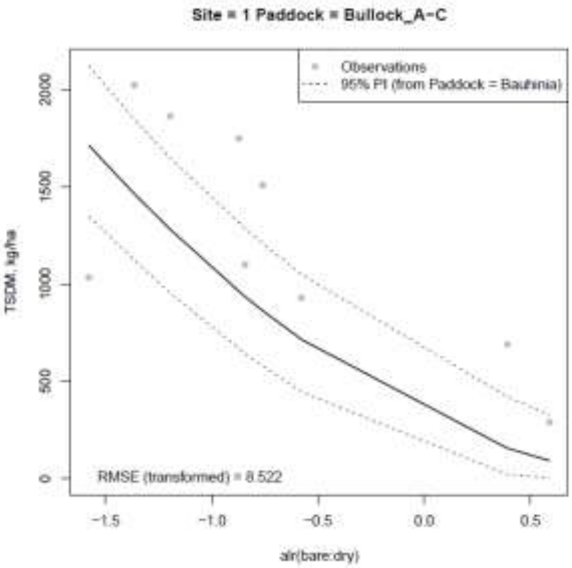

Site = 1 Paddock = Barra
Observations
95% PI (from Paddock = Bauhinia)
RMSE (transformed) = 8.6
TSDM, kg/ha
alr(bare:dry)

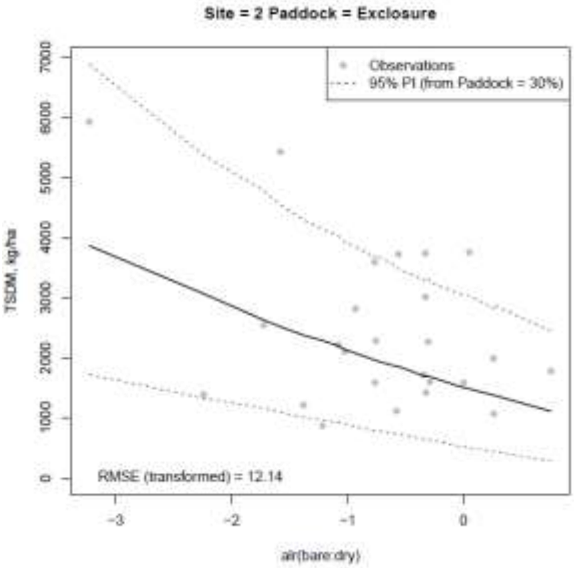

Site = 1 Paddock = Bauhinia
Observations
95% PI (from Paddock = Bauhinia)
RMSE (transformed) = 2.118
TSDM, kg/ha
alr(bare:dry)

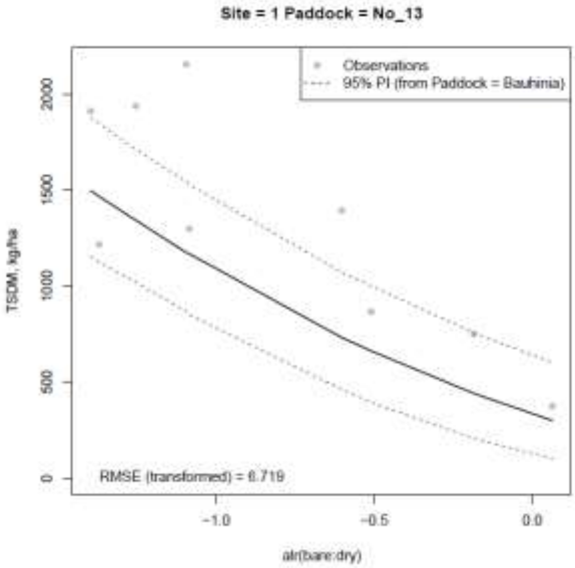

Site = 1 Paddock = Cell_Grazing
Observations
95% PI (from Paddock = Bauhinia)
RMSE (transformed) = 4.951
TSDM, kg/ha
alr(bare:dry)

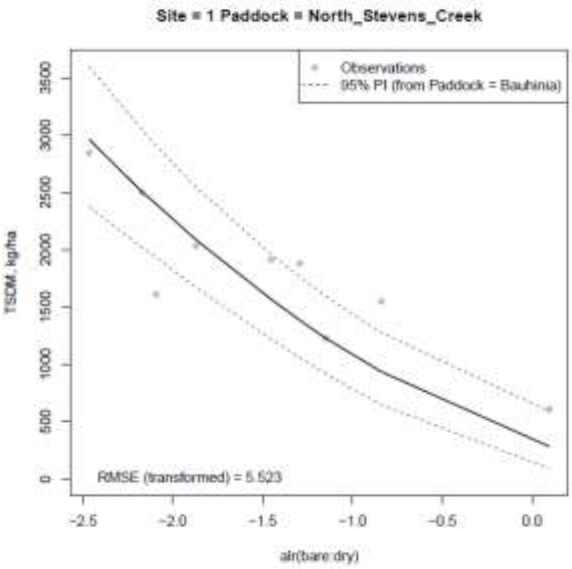

Site = 1 Paddock = Dead_Cat
Observations
95% PI (from Paddock = Bauhinia)
RMSE (transformed) = 4.79
TSDM, kg/ha
alr(bare:dry)

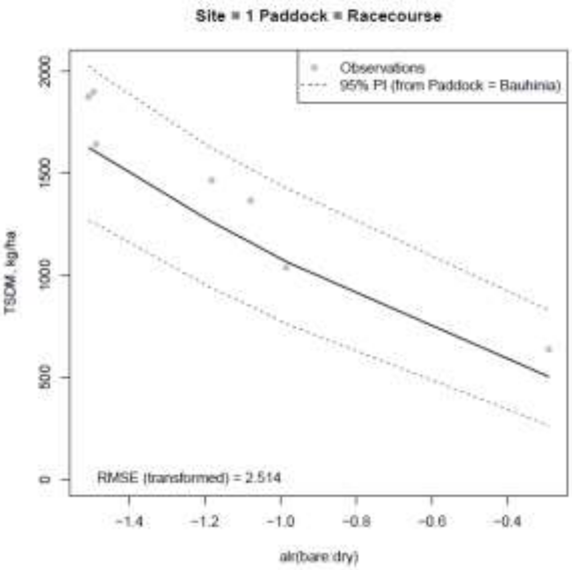

Site = 1 Paddock = Brolga
Observations
95% PI (from Paddock = Bauhinia)
RMSE (transformed) = 5.058
TSDM, kg/ha
alr(bare:dry)

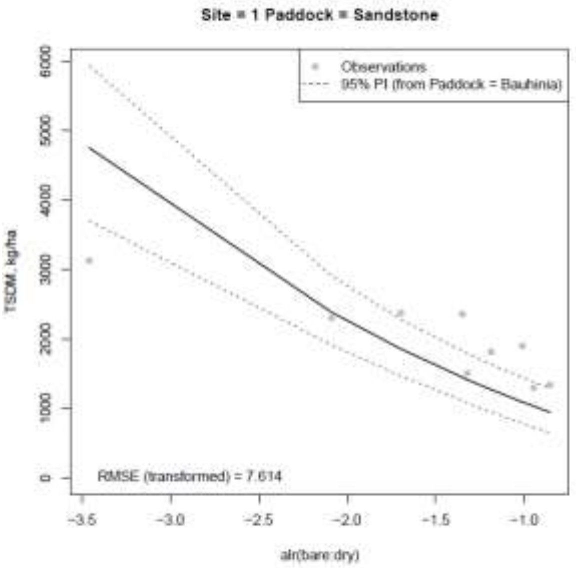

Site = 1 Paddock = Bullock_A−C
Observations
95% PI (from Paddock = Bauhinia)
RMSE (transformed) = 8.522
TSDM, kg/ha
alr(bare:dry)

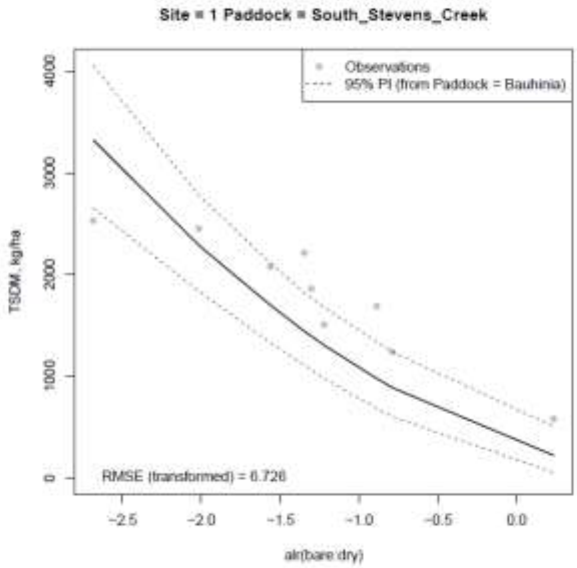

Site = 2 Paddock = Exclosure
Observations
95% PI (from Paddock = 30%)
RMSE (transformed) = 12.14
TSDM, kg/ha
alr(bare:dry)

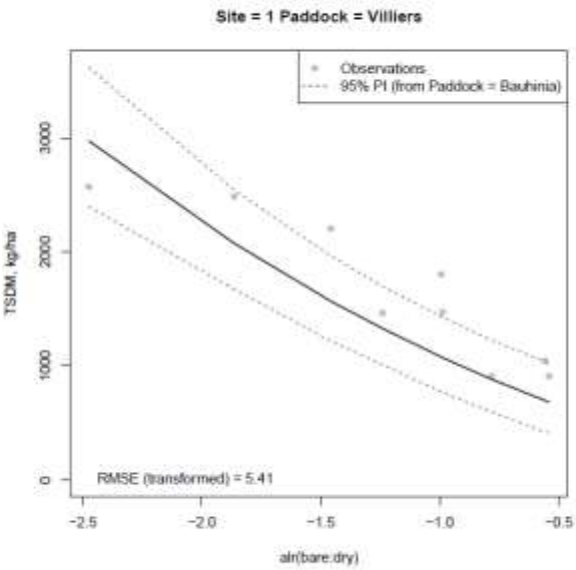

Site = 1 Paddock = No_13
Observations
95% PI (from Paddock = Bauhinia)
RMSE (transformed) = 6.719
TSDM, kg/ha
alr(bare:dry)


Site = 1 Paddock = North_Stevens_Creek
Observations
95% PI (from Paddock = Bauhinia)
RMSE (transformed) = 5.523
TSDM, kg/ha
alr(bare:dry)


Site = 1 Paddock = Racecourse
Observations
95% PI (from Paddock = Bauhinia)
RMSE (transformed) = 2.514
TSDM, kg/ha
alr(bare:dry)

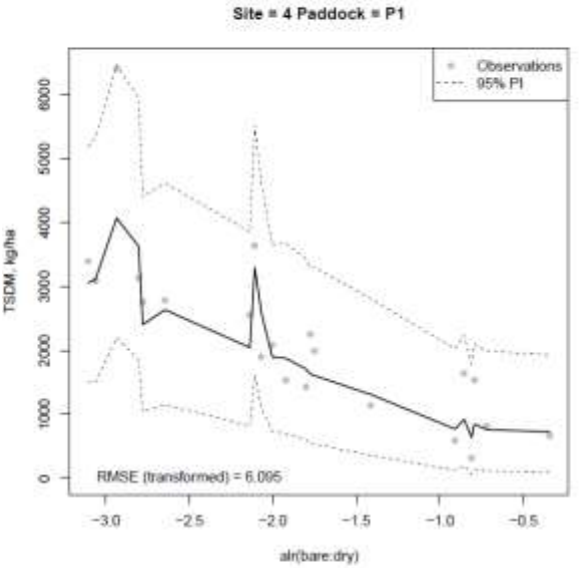


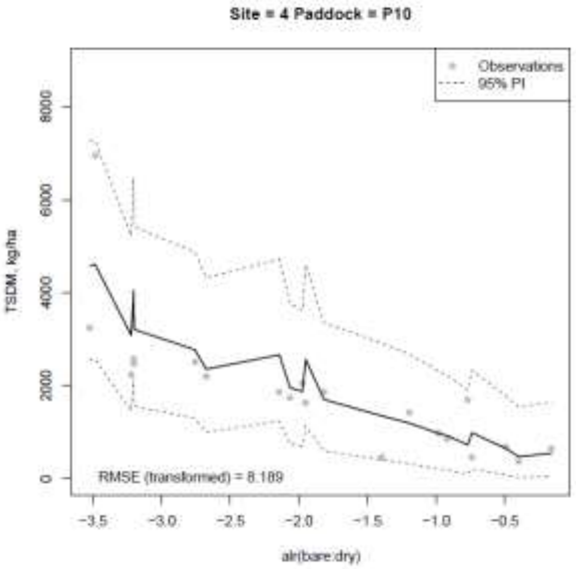


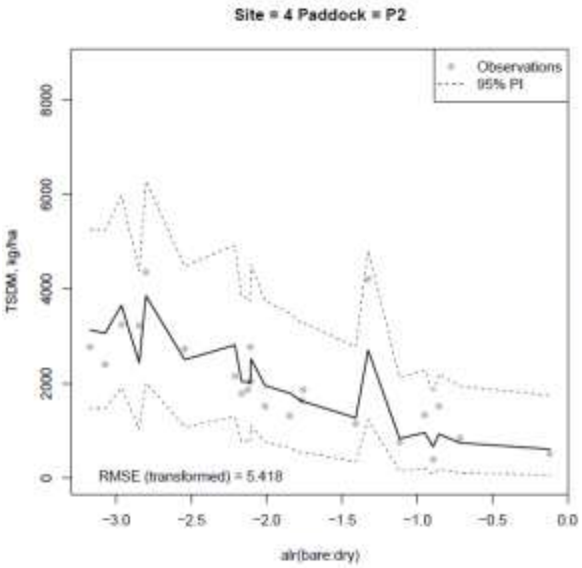


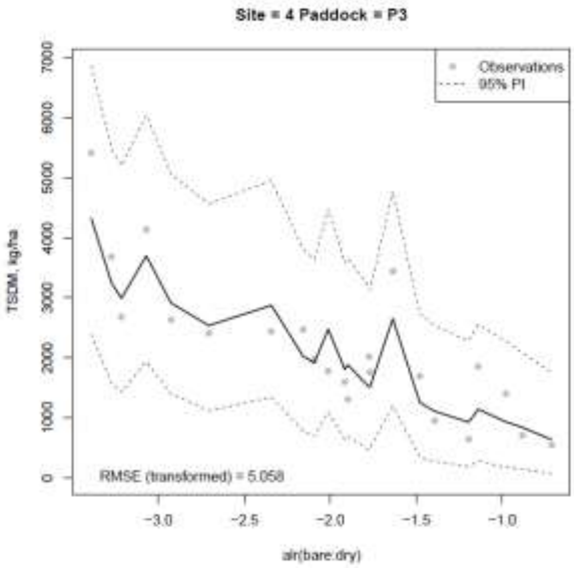
Appendix (13) Paddock performance at Wambiana using calibration by land type.

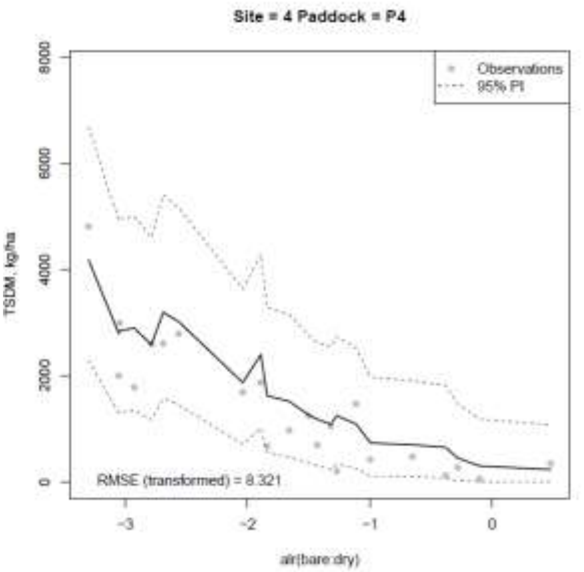
Functions were established for each of three land types at Wambiana (labelled as Site 4) for a function of log (bare/dry), average greenness over last 365 days, persistent green and interaction terms. Paddock TSDM was reconstituted using proportions of each of the three land types (Appendix 4). These plots should be compared to those for Wambiana (Site 3) in Appendix 11.

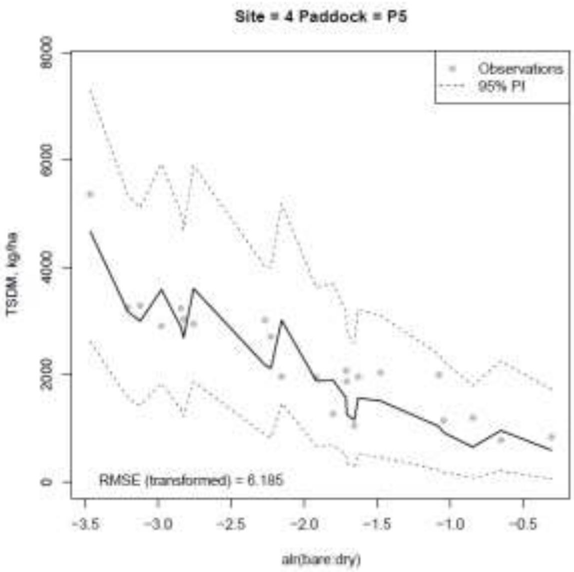


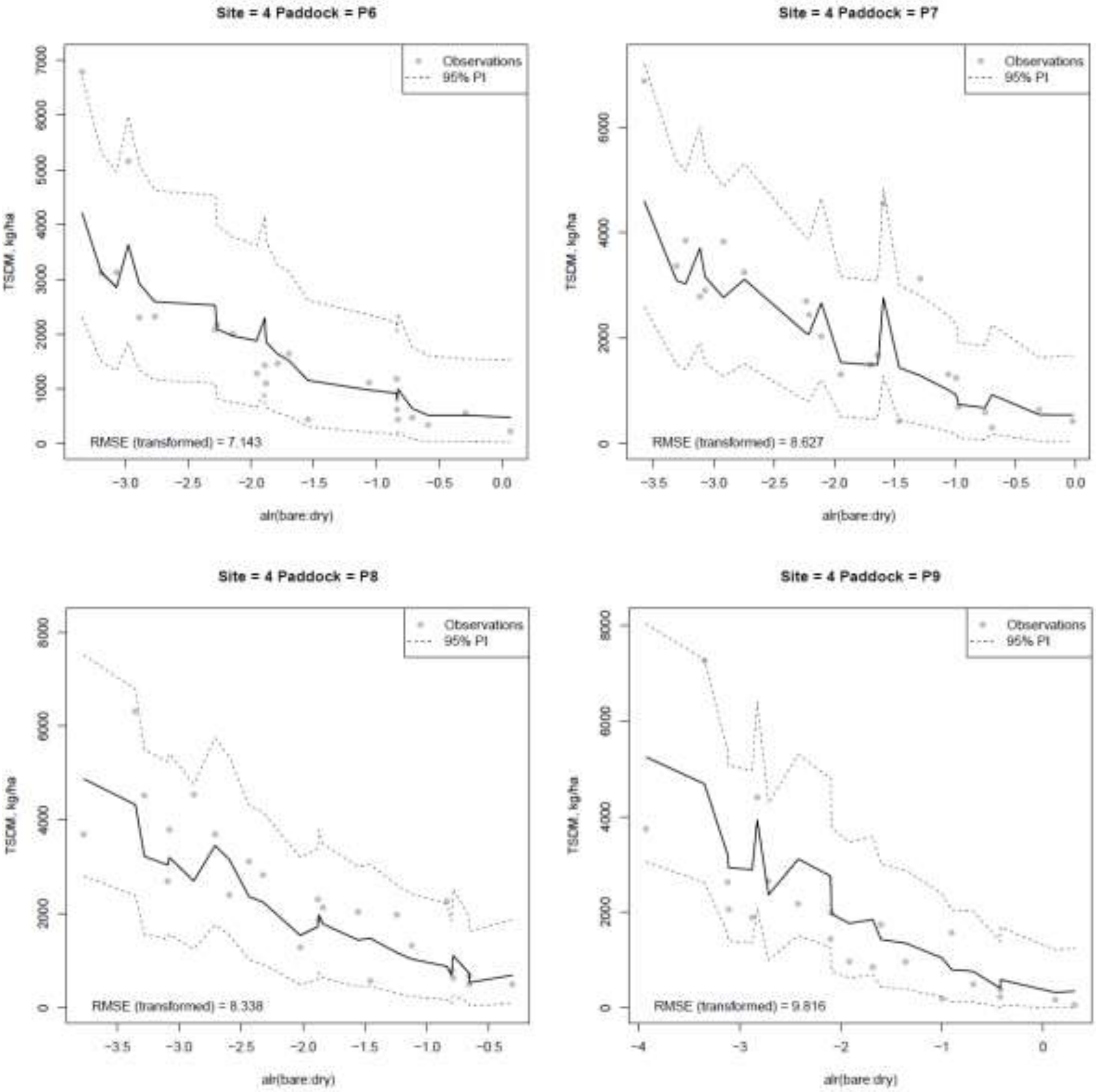



Site = 4 Paddock = P2
Observations
95% PI
RMSE (transformed) = 5.418
TSDM, kg/ha
alr(bare:dry)


Site = 4 Paddock = P3
Observations
95% PI
RMSE (transformed) = 5.058
TSDM, kg/ha
alr(bare:dry)


Site = 4 Paddock = P4
Observations
95% PI
RMSE (transformed) = 8.321
TSDM, kg/ha
alr(bare:dry)


Site = 4 Paddock = P5
Observations
95% PI
RMSE (transformed) = 6.185
TSDM, kg/ha
alr(bare:dry)



Site = 4 Paddock = P6
Observations
95% PI
RMSE (transformed) = 7.143
TSDM, kg/ha
alr(bare:dry)
Site = 4 Paddock = P7
Observations
95% PI
RMSE (transformed) = 8.627
TSDM, kg/ha
alr(bare:dry)
Site = 4 Paddock = P8
Observations
95% PI
RMSE (transformed) = 8.338
TSDM, kg/ha
alr(bare:dry)
Site = 4 Paddock = P9
Observations
95% PI
RMSE (transformed) = 9.816
TSDM, kg/ha
alr(bare:dry)