Gateway Regeneration Checks for Human Induced Regeneration projects

ANUE Project #1-1035 (Phase 3 part 2 for 2024)

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Summary

This report continues the series of independent reviews that began in 2023 of the process and outcomes of the Human Induced Regeneration (HIR) Regeneration Gateway Checks. The report completed in 2023 reviewed 25 projects that had passed Regeneration Gateway Checks prior to May 2023. This is the second report for 2024 and completes the review of 33 Projects that had Regeneration Checks after the guidelines had been updated to include the new s215 audit processes.

HIR Proponents are *expected to select techniques that best increase certainty in their situation for assessing pre-existing forest cover, the forest potential and its subsequent regeneration toward forest cover (collectively forest regeneration) and attainment of forest cover (Australian Government (2019), page 9[1]).* In most cases, these techniques include high resolution remotely sensed data (1 – 10 m resolution) and locally acquired algorithm training data to classify areas as non-potential, baseline forest or successfully regenerating Carbon Estimation Areas (CEAs). Independent checks by qualified auditors confirm good practice methods were used and the strata boundaries were reliable. On average, about 1,900 ha or 6.5% was removed from the CEA of each project reviewed as a consequence of improved mapping or a failure to demonstrate meeting the minimum 5-year thresholds of regeneration success. Such removals could be reasonably expected given the heterogenous nature of the original CEA areas.

Analyses of data collected from projects reviewed in this report demonstrate that national-scale models of tree cover are unreliable in substantial areas, especially in Western Australia. This lack of reliability is significant because some recent journal publications and media have been relying on national-scale models to make conclusions about the success of the HIR program. National-scale models use spatial resolution data that is 2 – 20 times poorer than the resolution used by project proponents and do not have many (or any) local data points for calibration or verification. Over 200 field measurement observation conducted by independent auditors and ecologists under expanded s215 audits confirm that proponent stratifications are significantly more accurate than the national-scale models, although some areas were identified for exclusion or follow up. Hundreds of georeferenced photographs and *in situ* measurements have been used by the Clean Energy Regulator (CER) to confirm regeneration thresholds were being met when national-scale models otherwise suggest unsuccessful regeneration.

The independent audit reports and the CER reviews continue to provide strong assurance that projects are being managed appropriately and that appropriate methods have been used by the proponents or their agents in classifying the CEA and identifying changes in regeneration cover.

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[1] Guidelines on stratification, evidence and records For projects under the Human-Induced Regeneration of a Permanent Even-Aged Native Forest and Native Forest from Managed Regrowth methods. 8 May 2019. https://cer.gov.au/document/guidelines-stratification-evidence-and-records-hir-and-nfmr.

An increased focus on objectively located, field-based measurements and georeferenced photographs is required until national-scale models of tree cover become more reliable in the areas of large HIR projects.

1.   Context

Sequestering carbon in trees and forests is a significant tool for keeping atmospheric levels of carbon dioxide within the thresholds required to avoid dangerous climate change. Under the Australian Carbon Credit Unit (ACCU) Scheme (formerly known as the Emissions Reduction Fund), the Australian Government offers landholders, communities and businesses the opportunity to run projects in Australia that avoid the release of greenhouse gas emissions or remove and sequester carbon from the atmosphere. The ACCU Scheme is legislated under the *Carbon Credits (Carbon Farming Initiative) Act 2011* and is administered by the Clean Energy Regulator (CER).

One method under the ACCU Scheme is the Human-Induced Regeneration (HIR) method. This method aims to improve the forest cover on degraded and deforested land. In essence, HIR projects identify land that has no forest cover prior to project commencement but has potential to be regenerated to forest through undertaking approved activity or activities. Successful HIR projects are awarded Australian carbon credit units (ACCUs) for each tonne of carbon dioxide equivalent sequestered by regenerating vegetation.

This report is a part of a series of reviews that began in 2023 to review the processes and outcomes of HIR Regeneration Gateway Checks. The 2023 report reviewed a representative sample of 25 projects that had completed regeneration checks prior to May 2023. Those projects had completed regeneration checks prior to the new s215 audit program and had been accepted by the CER as meeting the requirements of the HIR method. The projects were located in south-western Queensland, western New South Wales and parts of South Australia. The findings from the 2023 report included:

> *The independent audit reports and the CER reviews provide strong assurance that projects are being managed as per the legislative requirements and that appropriate methods have been used by the proponents or their agents in classifying the CEA and identifying changes in regeneration canopy cover…*

This 2024 report reviews an additional 33 projects that have completed CER processes, including the new s215 audits.

2.   2024 Review data and method

Similar to the 2023 review, CER provided details they had used to evaluate projects completing their 5-year regeneration check (Table 1).

A total of 33 projects were reviewed in 2024 (including 18 reported previously in mid-2024):
- Queensland: 14 projects, mean CEA of 17,000 ha
- New South Wales: 5 projects, mean CEA of 8,000 ha
- Western Australia: 14 projects, mean CEA of 41,000 ha

Table 1: List of data / dataset (and sources) provided for Brack 2023, 2024 review

Data, documents (and sources) for each project examined or processed in Brack 2023, 2024 reviews of HIR
Reasonable Assurance Audits of CEA establishment and meeting requirements (independent, registered auditors)
Documents including invoices, sales dockets and other material to demonstrate project proponents met their requirements to fence; trap or otherwise remove feral animals; reduce/manage grazing/browsing to demonstrably safe level; etc. (Proponents, Agents)
Maps of stratification into baseline/pre-existing forest; non-project; and carbon estimation areas including details of satellite resolution (usually 1.5 – 10 m), supervised/unsupervised techniques, training sites and *in situ* data collection (Proponent, Agents)
Confusion / error matrix of stratification accuracy, with evidence that accuracy exceeds 85% (Proponent, Agents, Independent Auditors)
Maps of CEA strata with canopy cover estimates generated by good practice methods in 100 ha cells for comparison with minimum threshold values (Proponent, Agent)
Georeferenced photographs, measurements and descriptions of Permanent Observation Points (POPs) or Temporary Observation Points (TOPs) as volunteered (Proponent, Agent)
Maps of NFSW[2] canopy cover estimates in 100 ha cells for comparison with minimum threshold values (TERN, via CER)
Maps of Persistent Green[3] (PG), (Auscover) estimates in 100 ha cells for comparison with minimum threshold values (TERN, via CER)
Mega Forest Cover Tool – a purpose built analytical spreadsheet tool tracking change in vegetation cover within CEAs and project area using multiple data sources including each version of the maps that inform the National inventory from 2015 to present (CER)
Discussion of any substantive differences between NFSW, Persistent Green and Proponent values at 100 ha scale, and requests for further evidence as required (CER)
Historic / archive remote sensing images for cells where there is concern that thresholds not being met (Wayback imagery via CER)
Georeferenced photographs and/or in-situ measurements of canopy cover / number of trees capable of achieving 2+ m height for cells identified by CER as points of interest (Proponent, Agent)
20 – 30 points / project (600 points overall) systematically examined using remotely sensed imagery [2023], 100 points of interest [2024]. Estimates of current/historic weather; soil condition; fire; social/management; environmental condition and Woody Cover Fraction[4] (WCF) (Australian Environment Explorer, data via TERN)
Estimates of woody vegetation cover, vegetation height and biomass over project and surrounding areas (*TreeChange*, ANU Water and Landscape Dynamics)
Offsets reports, with details of modelling and any changes in stratification (Proponent, Agent)
s215 audit data including georeferenced photographs, in situ measurements of tree canopy, regeneration and comments on likelihood of achieving forests status at Points of Interest (identified by CER) and Temporary or Permanent Sample Points (Independent, registered auditors, including ecologists) [2024]

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[2] Australian Government (2019) National Inventory Report 2017: Volume 2 [page 149]

[3] Gill, T., Johansen, K., Scarth, P., Armston, J., Trevithick, R., Flood, N. (2015). Persistent Green Vegetation Fraction. In A. Held, S. Phinn, M. Soto-Berelov, & S. Jones (Eds.), AusCover Good Practice Guidelines: A technical handbook supporting calibration and validation activities of remotely sensed data product (pp. 134-154). Version 1.1. TERN AusCover, ISBN 978-0-646-94137-0.

[4] Liao, Z., VanDijk, A.I.J.M., He, B., Larraondo, P.R and Scarth, P.F. (2020) Woody vegetation cover, height and biomass at 25-m resolution derived from multiple site, airborne and satellite observations. Int J Appl Earth Obs Geoinformation 93: 102209

Permanent Observation Points (POPs) or Temporary Observation Points (TOPs) were provided for most projects (e.g., Figure 1). There are no "HIR standardized" requirements for these observations points and the various teams use different measurement techniques and approaches. Most points collect quantitative data (tree canopy, species and height) along one or more transects at each point. The total transect area at each point is at least 0.10 ha although this can be made up from 1 – 3 transects established as a cluster. Georeferenced photographs are taken from cardinal directions or other systematic approaches. Most observation points are selected using a "restricted sampling" approach that avoids impractical travel time but still covers the heterogeneity of the CEA. Agents use a variety of measurement tools, including LiDAR and Unmanned Aerial Vehicles (UAVs).

Descriptive data	Canopy and stocking	Photographs
Plot Description: Overstory of broad leaf mulga 3-5m, fine leaf mulga 3-5m, kurara 2-2.5m, wild lemon 3m, flat leaf bowgada 2.5m, hop mulga 4-4.5m. Scattered regen broadleaf mulga 0.6-1.6m, flat leaf bowgada 0.7-1.4m, kurara 0.4-2m, needle bush 0.8m, fine leaf mulga 1m. Majority of regen captured in site under 1m in height and under existing mature canopy. Understory of Wilcox shrub, cotton bush, cottony blue bush, blue bush, warty leaf eremophila, cork screw, tall sida, occasional wooly butt grass. Located on a sandy surfaced hard pan. Regeneration Comments: Scattered regen broadleaf mulga 0.6-1.6m, flat leaf bowgada 0.7-1.4m, kurara 0.4-2m, needle bush 0.8m.	Canopy cover of woody vegetation over 2 m: 17% Regeneration stocking/ha: 489	8 photographs taken in directions: N, NE, E, SE, S, SW, W, NW E.G.,

Figure 1: Example of data collected at one POP in Western Australia

3. Results

3.1. Management actions

HIR relevant management actions included reducing stock numbers, fencing, supplementary feeding and using controlled water point management to effectively control over-grazing and other degradations caused by large numbers of (hooved) animals. Evidence of these actions included the auditors' reports and personally sighting copies of relevant bills of sale, invoices for fencing materials and water point maintenance. During a field trip, I observed damage to tree canopies caused by heavy cattle browsing in non-project areas, including canopies over 2 m in height damaged as cattle broke branches to gain access to new/young growth (Figure 2). I also observed areas where over-stocking had impacted the soil chemistry and structure – adding too much urine/nitrogen and compacting the surface into relatively impermeable layers. Independent auditors also regularly reported on the impact on soil of historical stocking levels (Table 4). A significant reduction in stocking numbers reduced the direct damage to canopies as well as allowing for natural restoration of soil chemistry and structure necessary for regeneration.

Figure 2: Example of a non-CEA location where the leading branch of a tree (originally over 2 m height) has been broken by cattle as they seek the tender, younger leaves. Note too the number of other branches broken and on the ground, and lack of any regeneration.

Other management actions included feral animal control (pigs, goats, horses and camels), again as evidenced by the auditors' reports and personally sighting of copies of invoices/sales documents.

Evidence of fire trail construction and maintenance to help ensure permanence of the carbon stock and mitigate against the risk of significant reversal, was also sighted. The controlled water point management also reduced the free availability of water across the entire project area which would help control feral animal numbers inside and outside the CEAs. Similarly, improved wildfire control or management would potentially help reduce potential carbon losses over the entire project area.

3.2. Stratification

Projects generally re-stratify their CEAs as part of their first regeneration check into forest, non-woody and areas that had reached specific canopy cover classes (e.g., the 7.5% minimum threshold). All the projects reviewed in 2024 used high resolution satellite imagery (SPOT with 1 / 1.5 m resolution or Sentinel 2 with 10 m resolution). This satellite resolution is superior to the National Forest and Sparse Woody (NFSW) and other national-scale models for these regions. Good practice techniques (mainly supervised, but occasionally unsupervised classification) were confirmed as being used to group the project areas into relevant canopy cover classes. Data used in the supervised classification or to group the unclassified classes included high resolution remote photographs, ground plots (including TOPs, POPs) and tree canopy maps (derived from LiDAR or UAVs). Classifications were only accepted if the accuracy rate was greater than 85%, but often the accuracy was greater than 90%.

Independent auditors confirmed the classification methodologies met good practice standards and that boundaries were reliable.

Restratification occasionally found parts of a CEA that had not achieved the minimum canopy cover originally predicted as capable of being met within 5 years. For the projects reviewed to date, an average of 1,900 ha or 6.5% of original CEA areas (and any previously credited carbon) were removed due to restratification (Figure 3). Given the accuracy of the original stratification into CEA and the precision of estimating regeneration over 5 – 10 years, such a reduction is not unanticipated and procedures for changing the CEA areas and reimbursing any credits are documented. Some CEA reduction is the result of improved mapping identifying area as baseline or pre-existing forest that are not eligible CEAs.
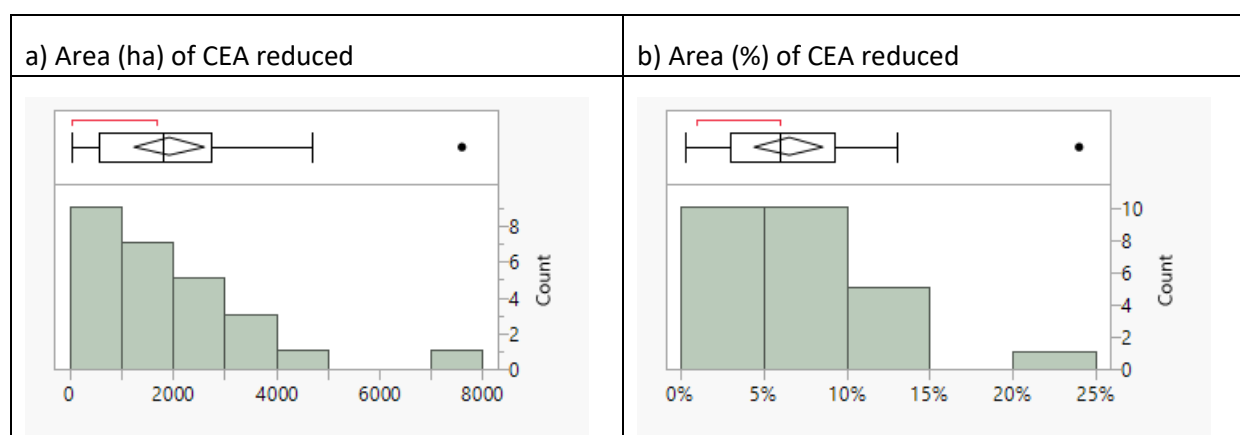

Figure 3: Whiskers diagram and histogram of the reduction in original CEA area as a result of proponent restratification to exclude non-performing areas. [The box in the center of Whiskers plot contains 50% of the data – from the 25th percentile to the 75th percentile and is divided by a vertical line at the 50th percentile or median value. The diamond is centered on the mean with a width of ± standard error of the mean. The "whiskers" extend to the furthest observation that is not assumed to be an outlier. The ● is a potential outlier]

3.3.   Regeneration checks

The 5– year regeneration checks require proponents to demonstrate that the CEAs have increased canopy cover by at least 5%; achieved a canopy cover of at least 7.5%; or have sufficient stems of appropriate species that they will be at least 2 m in height and achieve a canopy cover of 20%.

As a cross-check, CER compares proponent stratification of successfully regenerating CEAs with several national-scale models and databases. The area in the (updated) CEA stratification are intersected with cover estimates generated by the national-scale model at a 100-ha cell level to confirm the cover is at least 7.5%. However, the national-scale models have different levels of precision, different relative biases, and in some cases are estimating different things. Persistent Green, for example, estimates the cover of persistent (non-annual) vegetation cover, regardless of height, but Gill et al (2017)[5] warn that it may not be reliable when cover is in the range of 3% - 17%. NFSW on the other hand, identifies three classes based on the canopy cover of trees greater than 2 m height: non-woody (less than 5%, nominally 2.5% average cover); sparse-woody (5% - 20%, nominally 12.5%); and woody (greater than 20%, nominally 20%). The accuracy rates for correctly identifying non-woody and woody in NFSW are high (95% or greater), but there is much poorer accuracy reported[6] for identifying sparse-woody (only 66%). Notably, most of the CEAs could be expected to be in the 3% - 17% cover or sparse-woody class during the 5 – 10 year regeneration check period.

The national-scale model differences and the heterogeneous nature of the areas often meant that results were not consistent across models or States (Table 2). Where there were major inconsistencies or it appeared likely that there were substantive areas without adequate regeneration, CER examined time series of remotely sensed images (Wayback[7]). Animated gifs of these images allowed CER to observe whether regeneration was happening. In locations where the national-scale models suggested a lack of regeneration or stagnation of growth, studies of Wayback images found evidence of positive regeneration trends in about 75% of cases in Queensland; 50% in NSW; and 85% in Western Australia. Proponents usually also provided georeferenced photographs[8] of "representative" areas of the CEA which CER could use to identify trees and regeneration success contrary to national-scale estimates.

If substantial concerns remained after these cross-checks, CER required an expanded s215 audit and professional teams of auditors with ecologists/foresters collected field data at points of interest (POI) to clarify regeneration success and forest potential (e.g., Figure 1).

Field data, collected voluntarily or as a requirement of an expanded s215 audit, includes georeferenced photographs, descriptions by qualified ecologists (Figure 1) and extensive measurements of trees, shrubs and regeneration along one or more transects. Transects were established at POI selected by CER, or at Temporary and Permanent Observation Points (TOPs, POPs) established as part of an audit processes. The POIs are often located at parts of the CEA where CER has identified potential issues with proponent stratification or other issues.

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[5] Tony Gill, Kasper Johansen, Stuart Phinn, Rebecca Trevithick, Peter Scarth and John Armston (2017) A method for mapping Australian woody vegetation cover by linking continental-scale field data and long-term Landsat time series, International Journal of Remote Sensing, 38:3, 679-705, DOI: 10.1080/01431161.2016.1266112

[6] Australian Government Department of the Environment and Energy (2019) National Inventory Report 2017 Volume 2. Figure 6.A.7

[7] https://livingatlas.arcgis.com/wayback/

[8] Some proponents/agents provided over 100 such photographs

Table 2: Results from example CER checks where national-scale models resulted in inconsistent predictions about meeting regeneration thresholds at 100 ha scale

State and nominal project number	CER analysis (sighted) summary		
	Persistent Green / AUSCOVER at 100 ha grid cells	NFSW at 100 ha grid cells	MegaForest tool
NSW #1	Positive trend with all cells > 7.5%	All fail at 7.5%	CEA woody cover increased from almost 0% to 12%
NSW #2	All cells pass in northern CEA, but southern part 50% fail	Increase in cover but most cells fail at 7.5%	CEA woody cover increased over 6%
NSW #3	Positive trend with all cells > 7.5%	94% of cells pass 7.5% check.	Small positive trend with increase 6%-9%
NSW #4	Positive trend with all cells > 7.5%	87% of cells pass 7.5% check. Cover increased by 26%	Positive trend with non-woody decreasing from 48% to 38%
QLD #1	Negative trend with only 5% of cells > 7.5%	50% of cells pass (but failures appear related to changes in soil colour)	Positive trend with 5% increase QLD SLATS database concludes 100% pass 7.5% cover
QLD #2	Positive trends with 70% of cells over 7.5%	90% pass 7.5% check Cover increases by 6.4%	Positive trend with 4.5% increase QLD SLATS database concludes 100% pass 7.5% cover
QLD#3	No change. Majority of cell < 7.5%.	27% of cells pass 7.5% check Cover increased by 7.7%	Positive trend with cover increasing from 6% to 11%
QLD #4	50% of cells over 7.5% Regeneration evidence and positive trend towards regeneration over the last five years	Most pass 7.5% check, minor areas of concern Regeneration evidence Positive trend towards regeneration over the last five years	woody vegetation increasing from 13% at project start to 25%
WA #1	20% of grids > 7.5%;	80% of cells pass 7.5% check	Positive trend with woody cover increasing 9%
WA #2	No regeneration (stagnant trend)	All except partial boundaries pass at 7.5%	Positive trend with woody cover increasing 10%
WA #3	15% of cells over 7.5% Negative trend	43% of cells pass 7.5% check	positive trend with woody cover increasing 6%
WA #4	10% of cells over 7.5%	80% of cells pass 7.5% check	positive trend with woody cover increasing 6%

Field measurements allow direct comparison of canopy statistics with national-scale model estimates. The inclusion of POI as well as systematically collected POP and TOP ensured these field

measurements will have an emphasis on CEAs around the important threshold levels of canopy cover (i.e., 7.5%) while still covering the range of canopy cover across the CEAs.

Over 200 field measurement points were provided for the 2024 analyses. The location for each point was identified in Australia's Environment Explorer and the associated remotely sensed imagery and model predictions (Table 1) were examined to check whether the point was in a relatively homogeneous area (Figure 4). If the location was too close to changes in vegetation type or other boundaries it was excluded from this analysis.
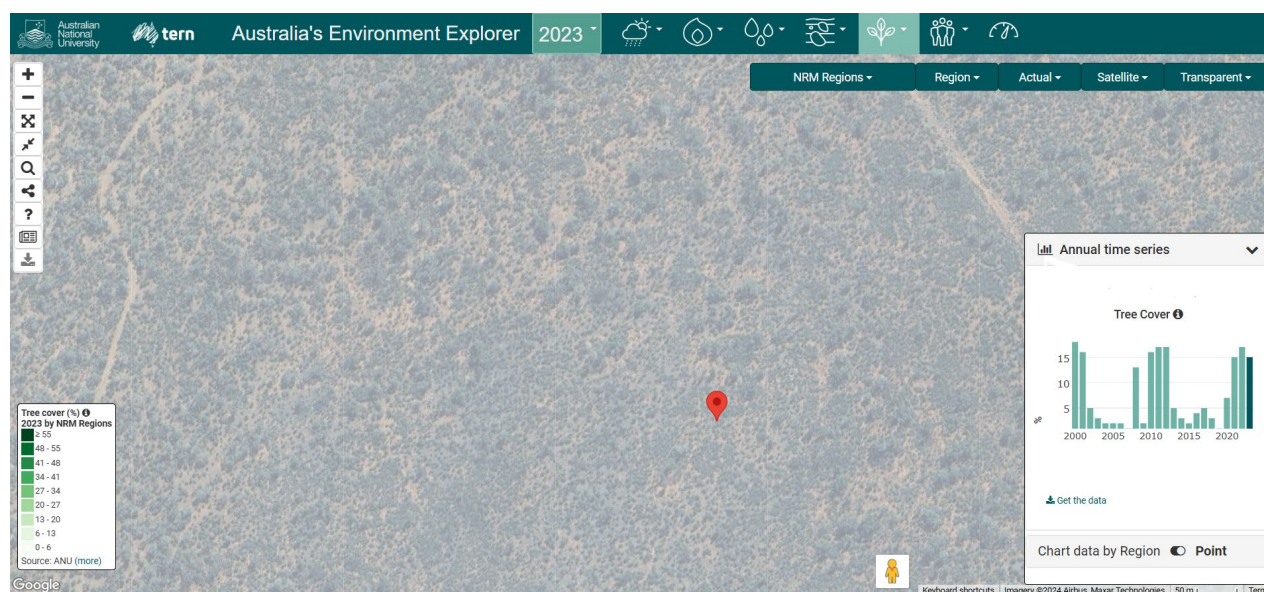
Figure 4: Example of a field measurement site displayed in Australia's Environmental Explorer showing WCF trends, recent remote sensing image and options for other model outputs. The 2023 mean WCF for this Natural Resource Management Region is 8%

The NFSW class for each sample point was identified and an ANOVA[9] tested for significant differences between the three classes (Table 3). Each State was tested separately as there was a significant interaction between classes and States ($p < 0.05$). The accuracy of NFSW in classifying points into their correct canopy cover class was substantially poorer than reported in the literature, and the mean canopy cover was not significantly different between classes ($p > 0.05$). Except for woody/forest, the mean canopy cover for each cell was significantly greater ($p < 0.05$) than the nominal canopy cover for each NFSW class.

The relatively poor accuracy of NFSW may in part be due to POIs making up a disproportionally large portion of the sample. These POIs were selected as "potential problem" areas by CER and therefore may also be "potential outliers" for NFSW. In contrast to the poor NFSW accuracy, 71% of the samples were correctly mapped by proponent/agents as being within the "successful CEA" strata – i.e., more than the 7.5% canopy cover required threshold level. Of the remaining samples (29%) with less than 7.5% measured canopy cover, ecologists undertaking the s215 audits concluded that just under half (47%) had a medium or better chance of achieving forest cover based on the number and species observed on site but currently less than 2 m (Table 4). Overall, the proponent/agent stratification maps had an accuracy of 84% classifying areas as having at least 7.5% canopy cover or enough stems of appropriate species to produce a forest.

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[9] Analysis of Variance (ANOVA) is a statistical test of differences of the mean between more than two groups. The variation within at least one group (variance) must be less that the variation between groups for a finding of significant difference between the groups.

These findings indicate that NFSW is not a useful estimator of current canopy cover in these POI and representative POPs or TOPs and that the stratification by proponents using higher resolution and locally calibrated data is far superior. Even moving between NFSW classes may be more likely to reflect inaccuracies in the NFSW classifier than changes in canopy cover.

Table 3: ANOVA for field measurements of canopy copy against NFSW classes (Version 8.0 - 2023 Release). The diamonds represent ANOVA means and error ranges. Classification accuracy = number of samples within correct canopy cover range / total number classified in that NFSW class.

Queensland					New South Wales					Western Australia				

Source	DF	Sum of Squares	Mean Square	Prob > F
NFSW	2	0.0857	0.0428	0.107
Error	64	1.187	0.0185	
Total	66	1.273		

Source	DF	Sum of Squares	Mean Square	Prob > F
NFSW	2	0.0156	0.0078	0.8552
Error	18	0.8918	0.0495	
Total	20	0.9074		

Source	DF	Sum of Squares	Mean Square	Prob > F
NFSW	2	0.0255	0.0127	0.1663
Error	84	0.5844	0.0069	
Total	86	0.6099		

Queensland

Classification accuracy:
Non-woody: 51%
Sparse-woody: 55%
Woody/Forest: 33%

Canopy Cover (class mean):
Non-woody: 12%
Sparse-woody: 18%
Woody/Forest: 22%

New South Wales

Classification accuracy:
Non-woody: 13%
Sparse-woody: 20%
Woody/Forest: 75%

Canopy Cover (class mean):
Non-woody: 31%
Sparse-woody: 26%
Woody/Forest: 25%

Western Australia

Classification accuracy:
Non-woody: 0%
Sparse-woody: 57%
Woody/Forest: 33%

Canopy Cover (class mean):
Non-woody: 14%
Sparse-woody: 18%
Woody/Forest: 18%

Similarly, Persistent Green estimates of vegetation cover for each sample point were plotted against the field measurements of canopy cover (Figure 5). There was no significant correlation between field measurement and Persistent Green in Western Australia, although most of the field measurements of canopy cover were well above Persistent Green estimates. There were significant correlations for Queensland and NSW[10] ($p<0.05$) although the relationships were relatively weak (r^2 0.16 and 0.22 respectively, with both having RMSE of about 0.13). Again, the field measurements of canopy cover were usually greater than the Persistent Green estimates. The slope of the best fit line for Queensland and NSW was not significantly different to 1.0 but in both cases the intercept was about 8% indicating that, on average, Persistent Green underestimated canopy cover by 8%. This bias was unexpected as Gill et al[11] (2015) found that estimates of Persistent Green were higher than precisely measured canopy cover at low cover levels. Given the 5-year threshold was only 7.5%, the lack of significant correlation in Western Australia and the underestimates in Queensland and NSW means the Persistent Green has little value for testing regeneration levels at the 100-ha scale.

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[10] One highly influential outlier was removed from the NSW samples for this analysis

[11] Gill, T., Johansen, K., Scarth, P., Armston, J., Trevithick, R., Flood, N. (2015). Persistent Green Vegetation Fraction. In A. Held, S. Phinn, M. Soto-Berelov, & S. Jones (Eds.), AusCover Good Practice Guidelines: A technical handbook supporting calibration and validation activities of remotely sensed data product (pp. 134-154). Version 1.1. TERN AusCover, ISBN 978-0-646-94137-0.

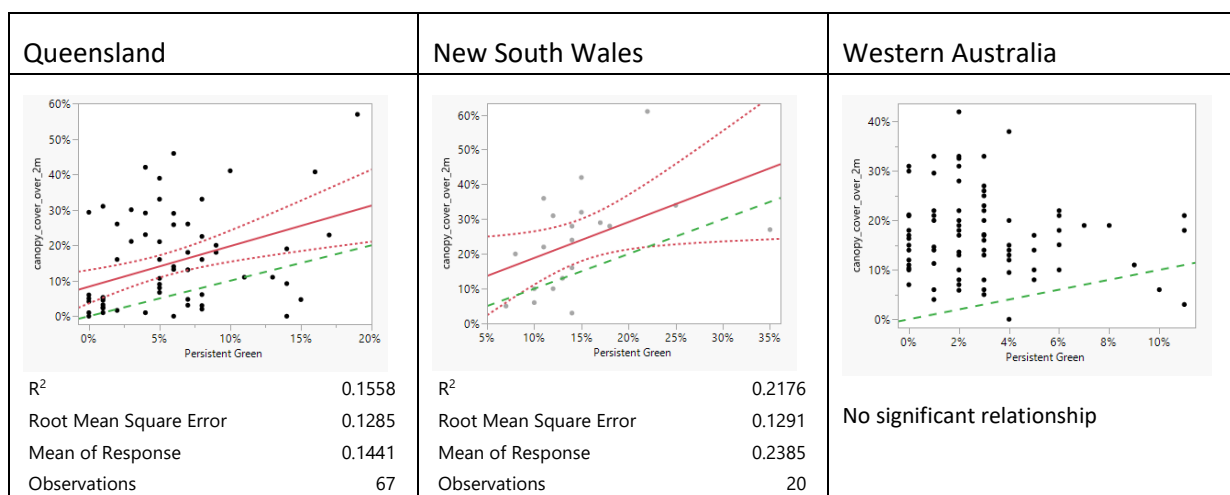| Queensland	New South Wales	Western Australia
R^2 0.1558	R^2 0.2176	No significant relationship
Root Mean Square Error 0.1285	Root Mean Square Error 0.1291	
Mean of Response 0.1441	Mean of Response 0.2385	
Observations 67	Observations 20	

Figure 5: Plot of Persistent Green estimates (Landsat, JRSRP Algorithm Version 3.0, Australia Coverage) against in situ measurements of canopy cover. Dashed line is 1:1. Where present, solid line represents the line of best fit (if p<0.05) and dotted lines are the prediction intervals for the best fit

Finally, the WCF estimates from Australia's Environmental Explorer were transformed[12] into canopy cover estimates (CPC) and plotted against the field measurements of canopy cover (Figure 6). Similar to Persistent Green, there was no significant correlation between field measurement and CPC estimates in Western Australia, and most of the field measurements of canopy cover were well above the model estimates. There were significant correlations for Queensland and NSW (p<0.05) although the relationships were relatively weak (r^2 0.07 and 0.13 respectively, with RMSE of 0.13 and 0.19 respectively). The slope of the relationship for Queensland was 0.51 (significantly less than 1.0, p<0.05) and the intercept was 0.11. This indicates that the Queensland measured canopy cover was greater than the model estimates until the CPC estimates were above 20%. Extrapolation of this trend beyond 20% should be avoided as there is little data.

The slope of the relationship for NSW was 0.69 (not significantly different to 1.0, p<0.05) while the intercept was 0.12, but this relationship is significantly influenced by three points with CPC between 20% – 30% and measured canopy less than 5%. Expected canopy cover is likely to be about 12% greater than the CPC estimates with very low cover, with the difference reducing to 0% as the CPC estimates approach 30%. Again, extrapolation of this trend should be avoided and further data is required. The canopy cover estimates based on WCF may therefore be useful beyond the very low canopy cover areas.

These national-scale models were developed from a range of satellites with different footprints and wavelengths, underpinning assumptions, use of annual (or other) mean data inputs and classification approaches. The scales of the national-scale models (ranging from 25 m pixel to 250 m) are also different to the 100 m transects used in the field measurements. It is therefore not unexpected that there is no precise or strong correlation between field estimates collected using a variety of methods and the national-scale models. However, it is surprising that in a number of cases there is no significant correlation at all (e.g., Table 3 and Western Australia Figure 5 or Figure 6).

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[12] Fisher, A., Scarth, P., Armston, J. and Danaher, T. (2018) Relating foliage and crown projective cover in Australian tree stands. Agricultural and Forest Meteorology 259; 39 – 47

Queensland	New South Wales	Western Australia

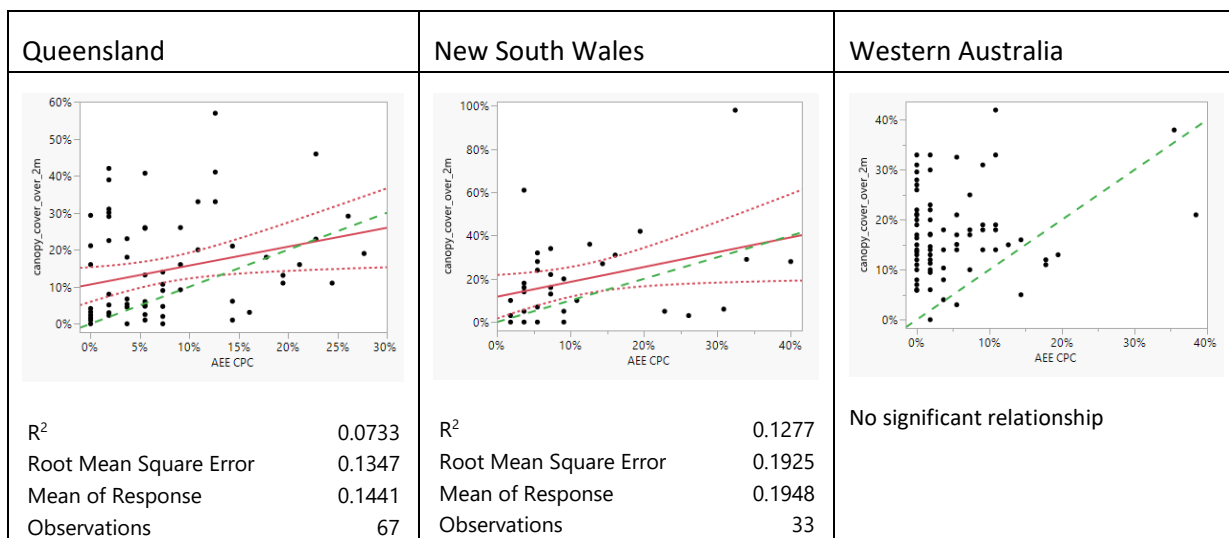|						
R²	0.0733	R²	0.1277	No significant relationship		
Root Mean Square Error	0.1347	Root Mean Square Error	0.1925			
Mean of Response	0.1441	Mean of Response	0.1948			
Observations	67	Observations	33			

Figure 6: Plot of Canopy Cover estimates (transformed from WCF estimated by Australia's Environment Explorer) against in situ measurements of canopy cover. Dashed line is 1:1. Where present, solid line represents the line of best fit (if p<0.05) and dotted lines are the prediction intervals for the best fit

For completeness, the national scale models at each point were compared with each other (Figure 7). NFSW non-woody and sparse-woody classes correlated well with Persistent Green and CPC estimates of canopy for Queensland, with Persistent Green and CPC class means being significantly different and relatively close to the nominal NFSW class means. The NFSW woody/forest class was not significantly different to sparse-woody and mean canopy cover estimates were significantly less than expected for this NFSW class. NFSW did not correlate with Persistent Green or CPC estimates of canopy for NSW and there were no significant differences between the mean canopy cover estimates. Almost all the Persistent Green and CPC estimates of canopy cover for NFSW non-woody in Western Australia were less than 5%, but so too were most of the estimates for NFSW sparse-woody and even woody/forest classes.

There were significant (p<0.05) but weak relationships between Persistent Green and CPC estimates of canopy for both Queensland and Western Australia (r² of 0.26 and 0.18 respectively) (Figure 7). The relationship for Western Australian was not different to a 1:1 line. There was no significant correlation for NSW estimates.

There were 65 samples points where all three national-scale models estimated that the area was non-woody (less than 5% cover) but only 14 of these points (21%) found the field measurement of canopy cover was within the anticipated range. There were 18 points where all three national-scale models estimated an area was sparse-woody (5 – 20% canopy cover) and 13 points (72%) of these points had field measurements within the relevant range. There were no points where all three national-scale models estimated an area as woody/forest (greater than 20% canopy cover) despite field measurements finding a number of sites with canopy cover well about 20%.

Further analysis of the relative bias of the national-scale models found that some land systems were significantly more biased than others. These land systems have different soil colours and trees may be growing with different canopy architecture than areas where the national-scale models were calibrated and verified. CER observations that national-scale model estimates changed substantially across soils with different colours even though georeferenced photographs and Wayback suggested no differences in canopy cover, supports the conclusion that not all the land systems or growth habits have been well represented in the model calibrations.

The weak relationships between the different national-scale models and localized biases explains

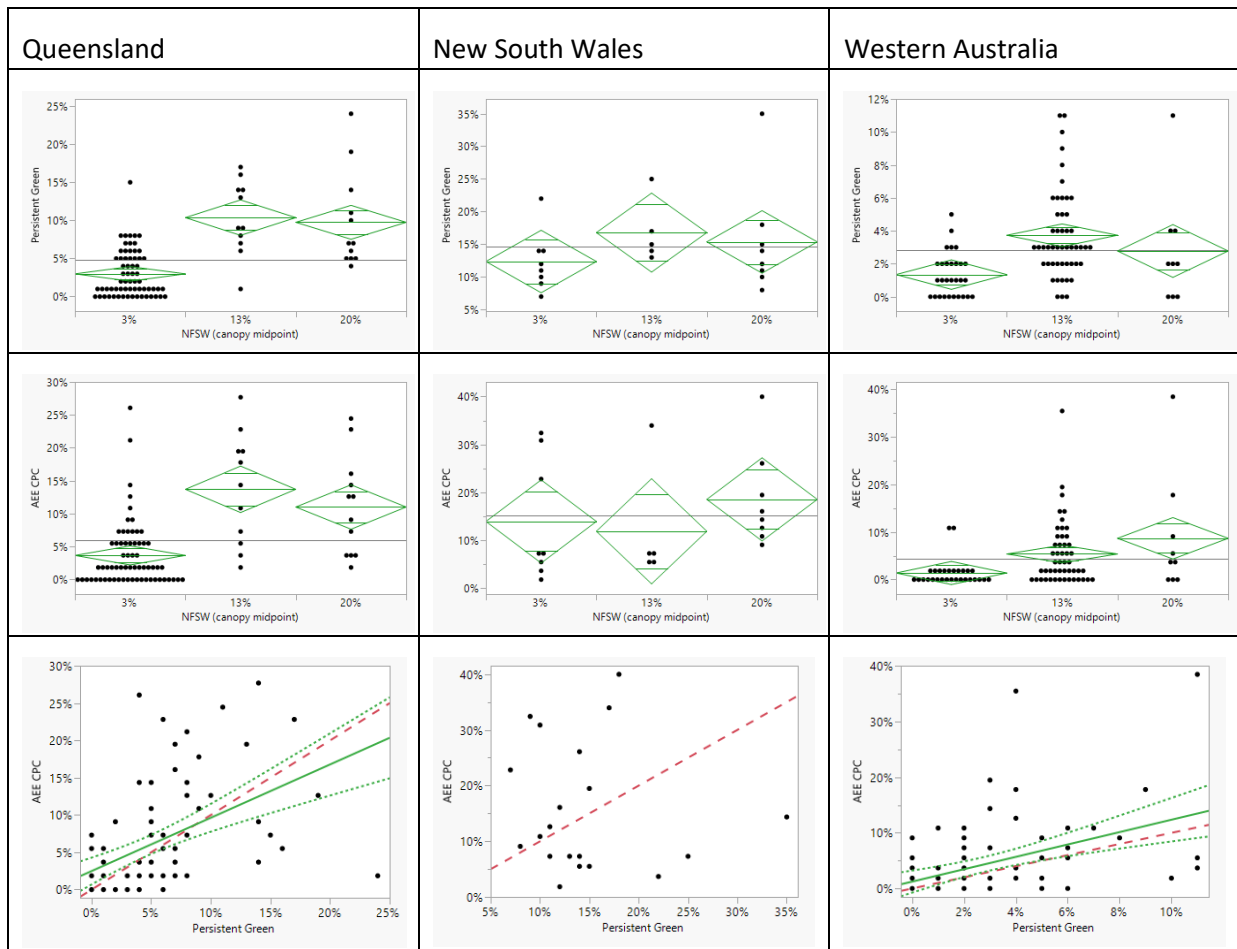the discrepancies in the 100-ha threshold tests undertaken by CER (Table 2).

Figure 7: ANOVA and XY plots comparing national-scale estimates for each plot. For XY plots, dashed line is 1:1. Where present, solid line represents the line of best fit (if p<0.05) and dotted lines are the prediction intervals for the best fit

Despite the bias and imprecision of the national-scale models identified above, some of the POIs identified by CER on the basis of these models were justified for expanded s215 audits. As described above, field measurements by independent auditor confirmed that most of the sample points exceeded the minimum canopy cover threshold despite the national-scale model estimates. Registered ecologists or foresters described the POIs and provided their expert opinions on the likelihood of the sites that had not yet reached 7.5% achieving forest cover in time (Table 4). These s215 audits concluded that just under half of the sites where the 7.5% canopy cover had not been reached still had a medium to high chance of achieving forest cover within the timeframe due to the presence of sufficient stems that were currently too short.

Auditors/ecologists also described POIs, TOPs and POPs that had exceeded the 7.5% minimum threshold. Most commonly, these descriptions were of the species present and the likely history of the site and did not note any concerns about reaching forest thresholds or inclusion of ineligible land. A fraction of the reports however did draw attention to potential inclusion of baseline forest or concerns that the site may be too slow to reach the 20% minimum cover within the next 10 years

Table 4: Example extracts from s215 audit reports by ecologists with descriptions of sites and comments on likelihood of meeting forest cover in time (subset from POIs with canopy cover measured at less than 7.5%)

Likelihood of achieving forest cover	Description
LOW	*Open low Acacia aneura – Eremophila sp. Woodland. A previously cleared area with more than 80% bare and compacted soil with a sparse shrub and tree cover. Only two woody plant species occurred on this site, Acacia aneura and Acacia brachystachya.*
HIGH	*Dodonaea viscosa (Hopbush) Eremophila clarkei (Turpentine bush) Acacia sibirica (Bastard mulga) Acacia incurvaneura (Narrow leaf wattle) Geijera parviflora (Wilga) Acacia ramulosa (Horse Mulga) correctly mapped as CEA and has the potential to reach 20% based on the number of stems.*
LOW	*only Bloodbush (Senna artemisiodes subsp. oligophylla) that may have the potential to reach 2 m in height, however no species was measuring >1 m at time of survey. With this limitation and the slow growth represented in each of the identified canopy species, it is considered a low likelihood that this zone would reach required future forest cover*
HIGH	*strong native coverage and is considered a high likelihood that this zone would reach required future forest cover*
LOW	*limited native coverage due to most of the present canopy species being dead without any evident regeneration. It is considered a low likelihood that this zone would reach required future forest cover*
MEDIUM	*Fail now, but potential forest. Open low Acacia aneura Woodland. The soil in the area was observed to be much compacted and trampled by livestock in the past. Dieback was present as a result of drought of at least 50% of the Acacia aneura (Mulga) shrubs and nearly all the Eremophila (Emu bushes) shrubs in the area.*
NO POTENTIAL	*NOT potential forest. very sparse tall Acacia aneura Woodland. A previously overgrazed area with less than 10% bare and compacted soil with an open shrub and tree cover. Only one woody plant species occurred on this site, Acacia aneura (Mulga) as the dominant species, with an Eremophila sp. as the subshrub dominant species. Many of these subshrubs were dead as a result of past drought periods.*
HIGH	*Likely to achieve forest in 10 years. appear to have been affected by drought dieback that was approximately 10 years or more old. It is comprised of a mulga open shrubland and low open woodland with emergent poplar box trees*
LOW	*Ecological assessment indicates that it is doubtful that forest cover will be achieved in the next 10 years, transect data suggests there may be potential for forest to be achieved in the next 10-20 years at this site based on stem density data.*
LOW	*Open acacia woodland, sandy surfaced. Overstory of sparse mature jam and naked lady. Understorey of cassia, salt bush, jam, naked lady, kurara, broom bush.*
HIGH	*Sparse over storey of eucalyptus mallee at 3-5m, bottle brush hakea at 2.5m, sugar brother at 2-2.5m. Good regen of sugar brother 0.5-2m, eucalypt mallee at 1.5m, needle leaf bowgada at 1m - 1.5m. Understory dominated by thryptomeme shrub, sparse spinifex. Located on a light red sandy loam in fire scar. Occasional standing dead wood. No drone flight conducted as too windy.*
MEDIUM	*Shrub vegetation abundant and dense but below 2 m height. Mature canopy expected to reach forest cover.*
MEDIUM	*Only one stem > 2m height, does not meet canopy cover threshold. Ok density of stems below 2m height, mature canopy expected to reach forest cover.*

These results confirm that no single national-scale model is well suited to making estimates of canopy cover or cover change for these projects. These national-scale models rarely agree with each other and appear to be underestimating the canopy cover of areas in the sparse-woody or even lower classes.

The independent assessments at POIs and other locations indicates that the proponent maps of successful regeneration (achieving threshold levels of canopy cover or number of regenerating species) are much more reliable than the national-scale models and are achieving an accuracy of 80+%.

However, s215 audits and field inspections have identified a small percentage of locations where regeneration does not appear to be reaching successful levels (Table 4) or where the ecologists conclude part of the canopy may be made up of trees that predate project commencement (Table 5). CER will request that, before the next reporting period, proponents remove areas from their CEA or justify the continuing inclusion of areas with low likelihood of attaining forest thresholds. CER will also ask proponents to detail how they will ensure pre-existing trees will not substantially impact on

abatement calculations.

Table 5: Example extracts from reports by ecologists with descriptions of sites and potential issues (subset from POIs, TOPs and POPs where measured canopy cover above the minimum threshold). Note, not representative of all sample points. Example includes reports from different ecologists and audit teams.

Canopy cover as measured in field	Description or concern
13%	Acacia ramulosa (Horse Mulga) Eremophila clarkei (Turpentine bush) Dodonaea viscosa (Hopbush) Geijera parviflora (Wilga) …. In field site observations noted generally well spread out stands of Horse Mulga and Turpentine Bush within the belt transect. However, it was noted that the general area had either stands of large mature trees or individuals – see photography labelled 'XXXX' (which were >8 m in height and 20 m+ in canopy cover). These are likely part of previous remnant forest but is not considered to be baseline forest.
13% (mapped as non-woody < 5%)	Acacia ramulosa (Horse Mulga) Eremophila clarkei (Turpentine bush) Dodonaea viscosa (Hopbush) Acacia excelsa (Ironwood Wattle) This area was relatively sparse with large patches of grass cover. Acacia ramulosa (Horse Mulga) known to have a crown diameter between 2 – 5 m at maturity (Ward et al., 2018). Therefore, whilst this area could reach 20% potential forest based on the upper limit of the crown diameter, it does not have the potential to reach forest cover based on the lower limit. Noting the low stem count when compared to other transects conducted at this property, hence this area is noted as may not having forest potential and should be monitored. This area is categorised as <5% per the crown cover and does not have forest potential.
29%	Large number of pre-existing trees (not CEA). numerous wildflowers and annuals. Species include Acacia and Eremophila including two large Pixie Bush specimens. Significant Wilcox Bush (Eremophila forrestii) understorey.
15%	Likely to achieve [forest]. is [s]parse and rocky, with the last 11m of the transect bare. Small shrubs include Eremophila and larger shrubs include Acacias (Mulga and Hop Mulga)
10%	Doubtful that there is the potential for forest cover to be achieved within the next 10 years. However, the site shows particularly strong recruitment of juvenile vegetation in height cohorts 1 to 4
17%	Potential to reach [forest] with many < 2m regeneration, However, the site contains a large portion of mature vegetation [not considered baseline forest]
32%	older Horse Mulga and dominant pink Eremophila (Wilcox). Old cattle tracks cross the site. high proportion of mature trees which exceed the age of the project. This ecological finding indicates a risk of non-conformance with Section 16 4(a) of the methodology determination…
16%	Forest Cover has not been achieved at this site, and it is doubtful that the site will attain forest cover in the next 10 years. Site is sparse with high density of dead timber, sheltering sparse understorey including bluebush and sida. The soils are mainly bare with scattered quartz
21%	High proportion of mature trees which exceed the age of the project [not baseline forest]. Compacted [soil] (could not get peg in), sparse and had substantial bare ground. Evidence of Grevillea seedlings self-sowing from tree outside transect. Lots of Mulga leaf litter, Mulla Mulla, crowsfoot and bluebush understorey. Old evidence of cattle.
24%	12 trees comprising of Wilga, Turpentine and Brigalow with an average height of 4.0 m within 1,000 m2 area. Along the 100 m transect, five trees approximating 5 m height were found and contributed to 23.6% crown cover. Based on our observations and experience, all five trees appeared to be [predate project]. Hence for this AOI, we refer to our tree count in the 1,000 m² plot to assess whether the 7.5% crown cover would be met based on stocking density. We counted 26 young regeneration trees under 2 m in height within the 1,000 m² area. This stocking density translates to 320 stems per ha, that will eventually achieve forest cover at maturity. We counted 26 young regeneration trees under 2 m height in 1,000 m² area

3.4.   Net abatement

After the independent auditors confirm the reliability of the CEA stratification and FullCAM modelling, they confirm the net abatement calculations for each project. On average, the net abatement is about 1.2 tC year^{-1} ha^{-1} for the CEA (Figure 8a). This abatement is reduced by buffer and permanence deductions before carbon credits are issued.

However, the proponents manage the entire project area, including non-project and baseline forests, to control feral animals, fencing and fire control even though they only receive credit for the abatements on the CEA. The net abatement when considering the entire project then is about 0.5 tC year^{-1} ha^{-1} (Figure 8b). The potential outlier in Figure 8b denotes a revised Project where the CEA covers the entire 6,000 ha Project (i.e., no non-project or baseline forest exclusions).
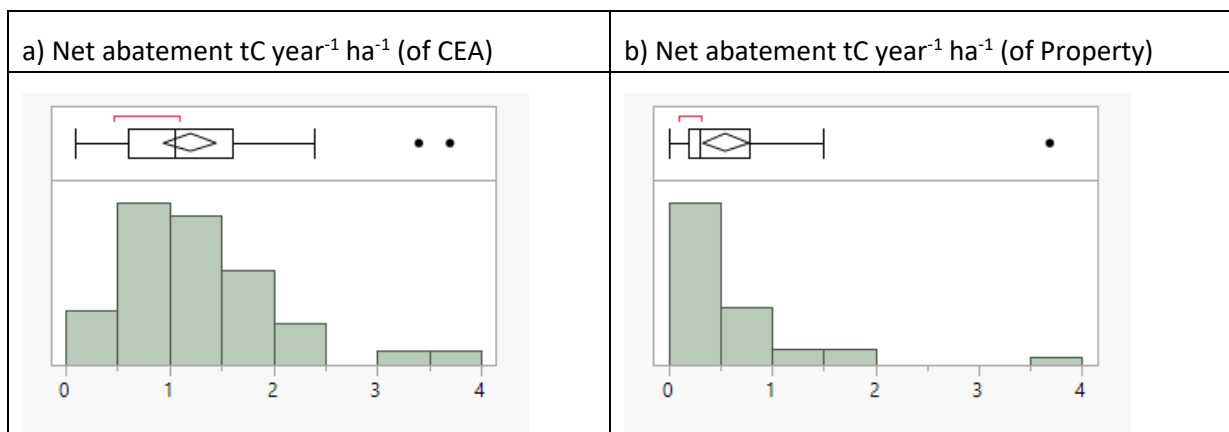
a) Net abatement tC year^{-1} ha^{-1} (of CEA)	b) Net abatement tC year^{-1} ha^{-1} (of Property)

Figure 8: Whiskers diagram and histogram of the net abatement of carbon per year in (a) per CEA ha; (b) per Project ha. [The box in the center of Whiskers plot contains 50% of the data – from the 25th percentile to the 75th percentile and is divided by a vertical line at the 50th percentile or median value. The diamond is centered on the mean with a width of ± standard error of the mean. The "whiskers" extend to the furthest observation that is not assumed to be an outlier. The ● is a potential outlier]

4. Conclusions

The independent audit reports, CER reviews and new s215 audits continue to provide strong assurance that projects are being managed as per the HIR requirements and that appropriate methods have been used by the proponents or their agents in classifying the CEA and confirming regeneration canopy cover is meeting threshold levels. Minor areas of potential regeneration issues identified by ecologists/foresters during the expanded S215 audits appear to be within the guidelines for stratification accuracy but will still be reviewed and potentially removed by the next reporting period.

The CER reviews continue to utilize multiple sources of data, including national-scale models, to check whether regeneration thresholds at project and 100 ha scales are being met. However, independent field measurements indicate that the national-scale models are not well calibrated or reliable for cross-checking proponent mapping. Substantive discrepancies between the models and the high-resolution data being used by proponents in stratification led to further information being required by CER before the regeneration check is accepted. Many proponents are now providing this additional data as a routine part of their regeneration checks and have formal methods to establish POPs, TOPs and FOPs.

On average, stratification into CEA that are regenerating is reliable with an acceptable accuracy rate and accords with good practice.

HIR appears to be a useful method of providing carbon credits to industries as they move to "decarbonize" their manufacturing and other processes.