Forest Monitoring – Extent Methodology

Natural Resource Commission

Report 1

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SV Contact	Stephen Farrell
Email	stephen.farrell@spatialvision.com.au

Disclaimer

Spatial Vision Innovations Pty Ltd

Level 8, 575 Bourke St, Melbourne 3000 VIC

p (03) 9691 3000

e info@spatialvision.com.au

w www.spatialvision.com.au

ABN 28 092 695 951

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1. Document Purpose

This document outlines the methodology developed and applied to generate a forest extent layer for all of NSW as part of an initiative lead by the Natural Resources Commission (NRC). This work was initially undertaken for the four Regional Forest Agreement (RFA) areas of the east coast of NSW, which has been translated across the full NSW jurisdiction.

This report is primarily focused on how existing data products can be used to develop a forest extent baseline and historical trends for key forest indicators. Given most of the existing datasets suitable for use are at the landscape scale and identify crown canopy due to their broad geographic or temporal coverage, most of the processes and derived outputs are only suitable for application and reporting at this level.

The current research and development activities being pursued by the Department of Primary Industries lead team and other agencies, including a new forest plot sampling network, is targeted at addressing key gaps in the current data products and bringing the wealth of data to a finer scale resolution.

This component of the overall program was undertaken by Spatial Vision in collaboration with the NSW Department of Primary Industries (DPI) and the NSW Department of Planning, Industry and Environment (DPIE), and focused on leveraging and aligning with existing national and state programs in terms of data, definitions and methods.

2. Background and Project Brief

This project was undertaken to assist in the implementation of the NSW Forest Monitoring and Improvement Program Framework 2019-2024 that aims to improve the management of NSW forests through the provision of relevant and timely information to meet the needs of decision makers, stakeholders, and the broader community. The Program explicitly links these needs to monitoring, evaluation and research questions that cover ecological, social, cultural, and economic outcomes. Several state-wide evaluation questions address environmental values:

1. What is the extent, condition, and health of NSW forests, and what are the predicted trajectories?
2. What is the occupancy and distribution of forest-dependent fauna and flora species, and what are the predicted trajectories?
3. Are forest water catchments healthy and what is the predicted trajectory for water availability and quality?
4. What is the health and stability of soil in forests, and what is their predicted trajectory?

The Program is state-wide and cross-tenure and will provide information for different scales, for example Regional Forest Agreement regions, Interim Biogeographic Regionalisation for Australia (IBRA) Regions and tenures. The Program will generate information to answer and report on the state-wide evaluation questions. Early tasks include analysing historical data and information to establish baselines and examine drivers of change over time. This will help identify data gaps and key metrics to track thresholds and support modelling future outcomes under different scenarios.

In addition, the Program will design a strategic cross-tenure permanent forest plot network to monitor key metrics, linked to remotely sensed information. This network will also include fauna monitoring, and is expected to be rolled out initially in RFA subregions by the end of 2022.

A key component of this initiative was the development of a conceptual framework to support the establishment of baselines and trends for environmental values related to forest extent, condition, and health for Regional Forest Agreement areas in New South Wales.

This baseline and trend information was required under two distinct NSW monitoring programs:

- The NSW Forest Monitoring and Improvement Program
- Coastal Integrated Forestry Operations Approval (Coastal IFOA) monitoring of landscape-scale trends

The project was established to focus on the first of the four key points outlined above, that is; what are the historic baselines and trends for forest extent, health, condition. This was to focus on the RFA subregion along the east coast of NSW and the Coastal IFOAs found within this region. More explicitly, the project brief was to:

- Where there is available data, propose historic baselines for the indicators of forest extent, condition and health across all tenures
- Where there is available data, propose historic baselines for the indicators of forest regeneration in Coastal IFOA state forests
- For all indicators of extent, health, condition and regeneration, identify areas or indicators where there is little or no existing data
- For those indicators where there is little or no data, propose additional baselines or data that should be established to meet other established baselines and trends
- Analyse trends in the indicators of forest extent, condition and health across all tenures
- Analyse trends in the indicators of forest regeneration in Coastal IFOA state forests
- Discuss possible drivers for these trends

The original project, methods and findings have now been applied for the full NSW jurisdiction.

3. Key Definitions

Forest Extent

For the purposes of this report forest is defined in accordance with the National State of the Forests Report which defines forests as containing as a minimum, a mature or potentially mature stand height exceeding 2 metres, stands dominated by trees usually having a single stem, where the mature or potentially mature stand component comprises 20% canopy coverage using a Crown Projective Cover (CPC) measure.

Our approach has been to assess the likelihood of an area having forest in any given year and termed this as forest extent for an identified year.

Given the focus on National Carbon Accounting System (NCAS) National Forest and Sparse Woody Vegetation Data grids for this evaluation of forest extent, it follows that the minimum mappable unit adopted for the NCAS grid program of 0.2ha (or effectively an area 50m by 50m) also apply as the minimal mappable unit adopted in this analysis of forest extent for the NSW Forest Monitoring and Improvement Program.

Hence, for the purposes of this report forest extent relates to canopy cover at a given point in time.

Forest Extent is defined as:

- containing as a minimum a mature or potentially mature stand height exceeding 2 metres
- containing stands dominated by trees usually having a single stem
- where the mature or potentially mature stand component comprises 20% canopy coverage using a Crown Projective Cover (CPC) measure
- a minimum mappable unit of 0.2ha; and
- relates to the presence of canopy cover at a given point in time.

Background

Fundamental to the process of identifying forest extent is the key definition applied to what constitutes a patch of forest. Several other key definitions and measures need to be confirmed to provide a full context and accounting of forest extent. The starting point for an initial definition of forest extent centres on a measure for and threshold applied in relation to canopy cover.

The National State of the Forests Report sets the threshold for a minimum existing or potential crown cover at 20%. The definition extends to forestry operations and plantations. Further, the report's definition identifies forest to contain, at a minimum, a mature or potentially mature stand height exceeding 2 metres and stands dominated by trees usually having a single stem.

A further definition of forest extent and canopy threshold is the metric used to capture crown cover. This is commonly captured as either Crown Projective Cover (CPC) or Foliage Projective Cover (FPC). CPC is the proportion of ground area covered by the vertical projection of tree crowns, whereas FPC relates to the proportion of ground area covered by the vertical projection of foliage of tree crowns. Differing products that capture forest extent will make use of either CPC or FPC in their estimations.

CPC is the simplest and oldest approach to assessing tree crowns, considering the entire tree crown as an opaque projection. This definition has been applied and is viewed appropriate when using coarse resolution or manual mapping approaches such as those achieved using Landsat imagery-based assessment processes.

FPC is a refined version of this approach in that it identifies tree canopy foliage and significant gaps in the crown. Typically, a CPC of 20% is comparable with an FPC of 11 to 12%, dependant on region or area of assessment.

One last key definition relates to the interpretation and usage of these forest extent products. Any product detailing forest extent is, at best, estimating canopy at a given point in time. This is particularly true for imagery-based products operating at a landscape scale resolution. Canopy cover may at a given point drop below an identified threshold due to a number of reasons. Hence, it can be left out of extent counts although the tree still is present. Therefore, an extent product reflects canopy in a given region and can be used to imply canopy vigour and recovery.

4. Available Data Products for Forest Extent

4.1. Extent

There are two main programs that can be used to help define forest extent across NSW. These are;

- **National Forest and Sparse Woody Vegetation Database**. Commonwealth of Australia, Department of the Environment and Energy – National Greenhouse Gas Inventory (NGGI). Landsat derived product to detail forest and sparse woody extent and change spatially since 1988, with annual coverage from 2004. Project run and developed in consortia with CSIRO.
- **New South Wales woody vegetation change from State-wide Landcover and Tree Survey (SLATS) Method**. NSW Department of Planning, Industry and Environment. Woody vegetation change based on analysis of multi-date satellite imagery. Uses Landsat imagery from 1988 to 2011 and SPOT5 and Sentinel 2 from 2009 to 2018. Biennial from 1988 to 2006 and annual from 2006 onwards. Product is a loss of woody vegetation database, but does have extents for static years of 2008, 2011 and 2017.

A key candidate dataset to depict forest extent in NSW is the Woody Vegetation Change Monitoring Program product generated as part of the State-wide Landcover and Trees Study (SLATS). This provides biennial tree loss monitoring data from 1988-2006 and annual data of woody vegetation loss from 2006-2018. The earlier time period was captured via Landsat imagery, whereas the more contemporary data capture is done through SPOT 5 and Sentinel 2 imagery.

This program is noted to be monitoring woody vegetation loss from clearing, rather than measuring extent directly. It measures forest loss, and any increases in the forest estate are not part of this monitoring program. However, forest extent mapping has been developed several times at static points in time for 2008, 2011 and 2017.

Most of the extent products are measuring Foliage Projective Cover (FPC) set to a threshold of 10%. This is in contrast to other programs that may be measuring Canopy Projective Cover (CPC). The relationship between these two measures is critical to understanding how SLATS data compares with products that measure CPC. In addition to its use of FPC, the SLATS forest extent approach applied in 2008, 2011 and 2017 applied a different methodology in each year. As such, a comparison between the outputs for the different time periods is not possible. The definition and approach used to measure forest extent is essential for high resolution monitoring of woody vegetation in NSW.

Another data product available at an Australia-wide scale is the National Forest and Sparse Woody Vegetation Data. This is available from 1988-2004 as annual, biennial, or longer periods and as annual products from 2004- 2018 and is derived from Landsat imagery. Resolution of the data product is at 25 m and the classification of woody vegetation is set to the 20% canopy cover level and 2 m stand height threshold. From 2016 it began using a three-class system of forest (current thresholds of ≥ 20% cover), sparse-woody (5%-19% cover) and non-woody. Prior to this it was based on a two-class system, which is no longer in use.

Due to the applied definition of canopy, extended annualised time period and consistent application, the National Forest and Sparse Woody Vegetation Database has been adopted as a base product for the derivation of forest extent in the project area.

4.2. Other Data Sources

There are several other datasets that are used in the methodological approach to determine forest extent, including tenure layers for land use application and type mapping of vegetation extents.

Land use layers are essential to identifying areas that may be woody vegetation but are not forest, such as tree crop plantations. Hence, forest extent products can identify vegetation based on the set thresholds and determinants, where the vegetation is not necessarily forest. There are three primary land use layers available for use for the three time periods of 2007, 2013 and 2017. These datasets identify land use breakdowns as per the Australian Land Use Management (ALUM) classification and broadly apply a 3-tier hierarchy with 6 broad groupings including Urban, Environment and Agriculture.

Vegetation type mapping is also used to determine woody and non-woody vegetation types across NSW. The State Vegetation Type Mapping (SVTM) product has a 3-tier classification comprising: ‘formation’; ‘class’; and ‘type’; with type being the finest resolution used in identifying plant communities. To assist the process of defining forest extent, this project uses the ‘class’ level to differentiate forest and non-forest vegetation communities across the study area.

The table below (Table 1) outlines some extra notes and details on each of these datasets.

The application of these dataset will be outlined in the following sections.

Table 1. Current operational forest extent, type and tenure layers for use in NSW as used in the forest extent method.

Dataset	Source	Time Frame	Resolution	Notes
National Forest and Sparse Woody Vegetation Data	National GHG Inventory, Department of Industry, Science, Energy and Resources	1988, 1989, 1991, 1992, 1995, 1998, 2000, 2002, 2004-2020	Landsat – 25m	Woody vegetation extent products that discriminate between forest, sparse woody and non-woody land cover.
Landsat woody extent and foliage projective cover (v2.1)	DPIE	2008	Landsat – 25m	Extent of woody vegetation at 2008 and also shows the percentage Foliage Projective Cover (FPC) for the woody areas. Generated from SLATS method.
NSW Woody Vegetation Extent 2011	DPIE	2011	SPOT 5 – 5m	State-wide binary classification of woody vegetation derived from multitemporal 5m SPOT-5 satellite imagery. Generated from SLATS method.
NSW Woody Vegetation Extent & FPC 2011	DPIE	2011	SPOT 5 – 5m	State-wide classification of woody vegetation and Foliage Projection Cover (FPC) derived from multitemporal 5m SPOT-5 satellite imagery. Generated from SLATS method.

Dataset	Source	Time Frame	Resolution	Notes
NSW Native Vegetation Extent 5m Raster	DPIE	2017	SPOT 5 – 5m	Developed under the State Vegetation Type Map program. Presents a single surface raster that combines information on native vegetation extent for NSW. The surface differentiates tree cover from candidate native grasslands, water, forestry plantations and a woodland matrix from non-native areas. Builds on NSW Woody Vegetation Extent 2011.
State Vegetation Type Map (SVTM)	DPIE	2020		Distribution of Plant Community Types across NSW.
NSW Landuse	DPIE	2007, 2013, 2017		Captures how the landscape is being used for food production, forestry, nature conservation, infrastructure and urban development.

5. Method Outline

5.1. Overview

As noted in the available data products section, the NGGI National Carbon Accounting System (NCAS) National Forest and Sparse Woody Vegetation Data grids are to be used to define historic baselines and trends in the forest extent.

This product is not without flaws due to misclassification of wooded areas and similar errors and is also a national product causing some local nuancing to be lost. The flowchart presented in Figure 1 provides the high-level approach undertaken to refine the base product into a product that is more suited to the NSW context.

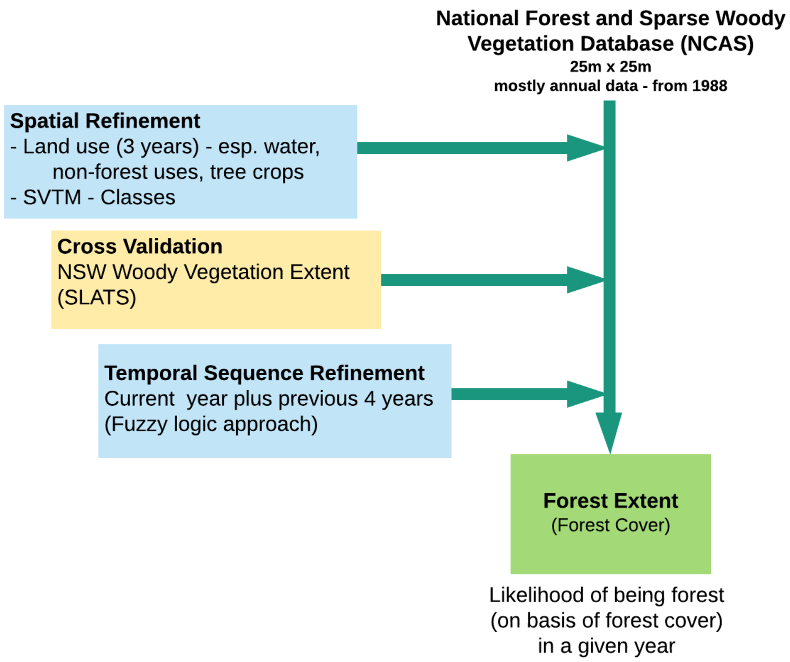

Figure 1. Forest extent method overview

The process outlined includes a three-stage process of

- Spatial Refinement,
- Cross Validation, and
- Temporal Refinement.

The spatial refinement process is a series of data-driven masking events and are undertaken to identify and exclude area extents that are incorrectly identified as forested instead of woody. The process is done by employing the use of the land use and vegetation layers, as outlined in the data products section.

The next stage involves cross validating these initial outputs against other available extent products for the same region. Products, such as the SLATS extent products, as outlined above, can be compared to these interim outputs.

An understanding of how the comparable data product is produced, and to what purpose it has been created for, is key in driving this comparison. Not all extent products are created in the same manner and each will have an intended use case. Differences may arise due to these conflicts, but it is the overall trend between year products, as well as representations of extent within a year that are essential to be analysed.

The last stage in generating a forest extent product from the National Grids data product is a temporal sequence refinement. As alluded to in the key definitions above, a forest extent product is more of a reflection on canopy coverage at a given point in time rather than true extent. To derive a higher certainty over time of areas that are very likely to be forest, and what areas are likely not to be forest, a fuzzy logic operation is applied to assign degrees of certainty on the product.

The following sections outline the Spatial Refinement and Temporal Sequence Refinement in more detail. Outcomes and some results for the cross validation will be outlined in subsequent project reports. This document intends to focus on the method of application.

The application of the outlined method on the NCAS National Forest and Sparse Woody Vegetation Database provided a consistent forest extent product on an annualised basis, aside from earlier years where NCAS is biennial.

The forest extent metrics and products derived from the approach outlined are at a landscape scale and support decision-making at this level. The process outlined is an easily repeatable process when new base extents become available, where the final output is intended to be a more nuanced and locally applicable forest extent product for NSW.

5.2. Spatial Refinement

It is assumed that any remote sensing data product that is analysis ready has a high order of reliability and integrity. For any product that falls within this scope, it is assumed that image tile quality is consistent across the entire project boundary and that all care has been applied to process cloud-free tiles with a clear image. It is also assumed that the algorithms and application is consistent across all temporal points in use for this assessment.

Use of the NGGI National Carbon Accounting System (NCAS) National Forest and Sparse Woody Vegetation Data grids (National Grids) presents several challenges that may increase uncertainty in any final processed forest extent product. Differences of existing products have been presented in the previous section, namely in relation to the National Grids vs. NSW SLATS products and how each product treats forested coverage extents.

However, within the National Grids, and other products to a large extent, key limiting factors are the underlying spectral algorithms that are employed to define measures of forest extent (Crown Projective Cover and Foliage Projective Cover). This is more in relation to either an over estimation of what could be forest in particular regions, or identification of forest extent that is not necessarily forest. The latter is more of an issue for misidentification of forest within particular land uses while the former relates more to forest being defined in non-forest vegetation classes.

Land Use Masking

In relation to land use misidentification, there are three key areas that are noted to be affected; water bodies, urban environments and agricultural zones.

Water bodies and larger river channels are generally excluded from being classified as forest. Problems can exist at water edges, shallow water bodies and wetland areas where spectral properties may either match vegetation (via algae blooms or other phenomena), or tree and vegetation cover is intermittent within the water area.

Urban environments present more of an issue in relation to trees and tree classification. National Grid products are observed to identify and classify woody vegetation in urban setting, where it meets its thresholding requirements. However, questions arise in relation to whether this should be classified as 'forest extent' or if these areas should be treated more generally as woody vegetation. This comes back to the intent of the product and what the requirements and definitions are of 'forest extent'.

Agricultural zones present issues that are similar to both water bodies and urban areas; incorrect identification of forest and/or misclassification of forest extent. A principal example of this is within horticultural enterprises where orchards are identified as woody vegetation, but by no means does this correspond to actual forest extent. Similar is misidentification of vineyards or other regularly spaced horticultural enterprises that may be identified as plantation forest rather than non-forest agriculture.

For processing and exclusion of these three factors from the NCAS Grids, a series of masks is applied against the NCAS Grids time-series of products, both with each of these three land use themes as well as against various time points where possible.

Of main use is the NSW Land Use spatial product which has been processed for the years of 2007, 2013 and 2017. This product contains classifications of NSW land use against the Australian Land Use Management Classification. The system allows for the division of the landscape into the three land use themes that are of concern down to a high detail, for example differing horticultural enterprises, such as vineyards and orchards, can be identified form this product. The three time points allow for limited processing and masking of land use changes over time.

Of main concern are four high level land use classifications. These include;

- Intensive Uses
- Water
- Production from Dryland Agriculture and Plantations
- Production from Irrigated Agriculture and Plantations

<u>Intensive Uses</u>

Under 'Intensive Uses', all classes were considered in masking and three separate time-point masking layers were created, as seen in the left panel of Figure 2. These classes included areas and uses that would not have any tree cover present. However, it was considered practical to include all classes in a masking layer independent of actual woody cover or not. These Intensive Uses include;

- Intensive horticulture
- Intensive animal production
- Manufacturing and industrial
- Residential and farm infrastructure
- Services
- Utilities
- Transport and communication
- Mining
- Waste treatment and disposal

Although all uses were considered, there were several exclusions applied where particular land uses were retained and not used with a masking layer. These primarily included the land use class 'Rural residential with agriculture' as it uses included farms on private land that may have scattered trees or retained natural bush on the property. A final masking layer is shown in the right panel of Figure 2.

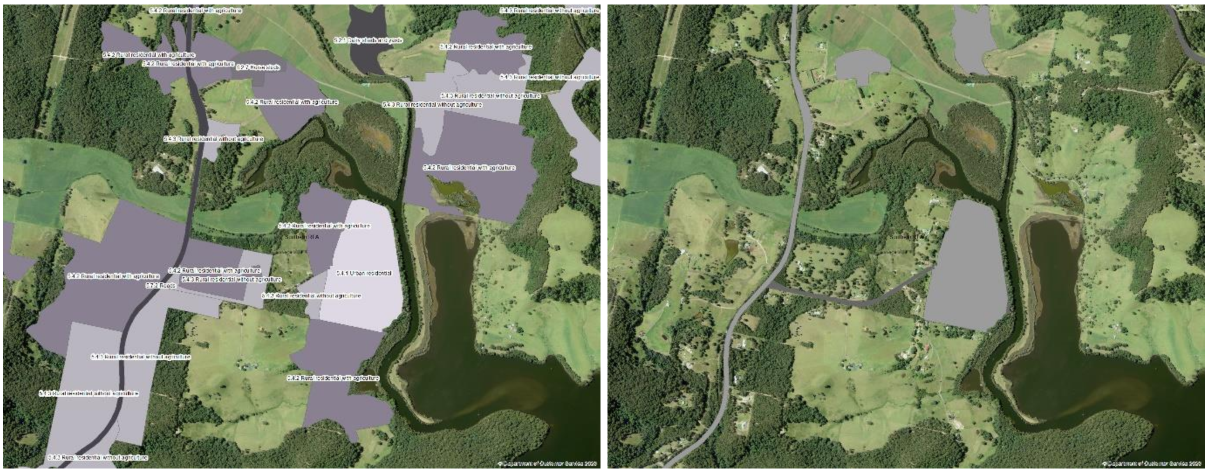

Figure 2. ***Application of Intensive Uses land use categories. Left panel; all classes included. Right panel; final mask with exclusions applied.***

<u>Water</u>

Under the ‘Water’ classification, all classes were initially considered in masking. These included;

- Lake
- Reservoir/Dam
- River
- Channel/Aqueduct
- Marsh/Wetland
- Estuary/Coastal Waters

However, on review only ‘Lake’ and ‘Reservoir/Dam’ classes were used in full. ‘Channel/Aqueduct’, ‘Marsh/Wetland’ and Estuary/Coastal Waters’ were not used at all due to potential natural forest extent in these classes. The ‘River’ class was restricted manually to major waterways where the river channel occupied a significant area. Smaller rivers, particular those that ran through National Parks and other related areas, were excluded from any masking layer.

These selected classes were then combined into a single Water masking layer, as a single point of truth, to be used in all time points. An example of a major water channel is shown in Figure 3.

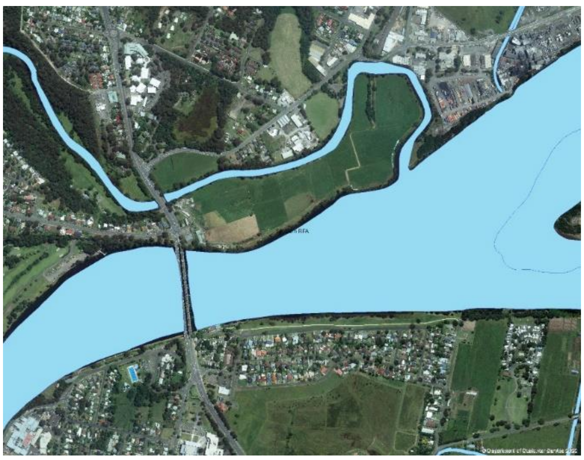

Figure 3. ***Final Water masking layer***

Agricultural Production

Under the 'Production from Dryland/Irrigated Agriculture and Plantations' only several select classes were used. This was mainly restricted to agricultural enterprises and land uses where there could be a misidentification of crops or plants as forest, and included the classes of;

- Perennial Dryland/Irrigated Horticulture
- Seasonal Dryland/Irrigated Horticulture

These classes include orchard and vineyard operations that can potentially be identified as forest. Between dryland and irrigated land uses these included;

- Tree fruits
- Olives
- Tree nuts
- Vine fruits
- Shrub berries and fruits
- Perennial flowers and bulbs
- Perennial vegetables and herbs
- Citrus
- Grapes

Other classes, including cropping and pastures were left out of exclusion masking. Pastures was excluded from any masking as any scattered trees and remnant vegetation was wanted to be retained. Land uses identified as pasture could contain such tree cover, especially along private to parkland boundaries. Cropping land was also left from any masking exclusions.

Also left in the masking process was land use designated as managed hardwood or softwood production plantations. These operations can be considered an agricultural crop and not as forest. However, for the purposes of this project plantations have been kept in account for total forest extent and have been included in the subsequent analyses. These areas can be excluded in latter stages where metrics and land divisions are applied back to the forest extent product and filtered out.

The selected classes were then combined into three unique masks for 2007, 2013 and 2017 to allow for limited processing and masking of land use changes over time. An application of this between tree nut orchards and cereal crops is shown in Figure 4. The large area to the bottom of the image is a cropping enterprise, hence it has been left out of the exclusion mask.

Figure 4. Application of agricultural masking layer. Left panel; imagery showing tree orchards and cereal cropping. Right panel; masking application of tree orchards.

Vegetation Classification Masking

During the process of identification of forest extent and cover from satellite imagery, there can be an over-representation or identification of forest in particular vegetation communities where forest extent is not present at all, or falls under a reasonable threshold. For example, heathland communities may be identified as forest even though most often comprise of medium to tall shrubs that do not necessarily fall within the 'tree' classification. The canopy cover, to an extent, can mislead classification algorithms.

To somewhat restrict and remove these communities that are not forest, the NSW State Vegetation Type Mapping (SVTM) data layer can be applied to remove misidentified areas. Under this layer there are three tiers of community classification from a high scale to a detailed level. These include;

- Formation
- Class
- Type

Vegetation classified to the 'Class' level was used in masking the forest extent out. To identify these classes a combination of two methods were applied. Of primary use was the descriptions and benchmarks for all Plant Community Types as supplied under the NSW BioNet Vegetation Classification (https://www.environment.nsw.gov.au/NSWVCA20PRapp/default.aspx). Of particular note were Tree Cover benchmarks for each SVTM vegetation class.

Once vegetation classes were identified, tree cover and general presence of forest were visually checked against aerial imagery for several key regions, and final selections checked against expert input. Each of the vegetation classes identified were classes in which forest was incorrectly identified under the National Grids forest extent data layers. It must be noted that other forest extent data products did not always correctly identify forest extent all the time. Sometimes certain non-forest vegetation classes were identified in all available forest extent products, where as other times there was inconsistency across all products. Hence other products could not be effectively used as a point of reference or validation.

The final classes identified to be included in a masking layer are listed in Table 2

Table 2. Included vegetation classes into classification masking filters

Vegetation Type	Vegetation Class
Alpine Complex	Alpine Bogs and Fens
	Alpine Fjaeldmarks
	Alpine Heaths
	Alpine Herbfields
Arid Shrublands (Acacia sub-formation)	Gibber Transition Shrublands
	North-west Plain Shrublands
	Sand Plain Mulga Shrublands
	Stony Desert Mulga Shrublands
Arid Shrublands (Chenopod sub-formation)	Aeolian Chenopod Shrublands
	Gibber Chenopod Shrublands
	Riverine Chenopod Shrublands
Freshwater Wetlands	Coastal Freshwater Lagoons
	Coastal Heath Swamps
	Inland Floodplain Shrublands

Vegetation Type	Vegetation Class
	Inland Floodplain Swamps
	Montane Bogs and Fens
	Montane Lakes
Grasslands	Maritime Grasslands
	Riverine Plain Grasslands
	Semi-arid Floodplain Grasslands
	Temperate Montane Grasslands
	Western Slopes Grasslands
Heathlands	Coastal Headland Heaths
	Northern Montane Heaths
	South Coast Heaths
	Southern Montane Heaths
	Sydney Coastal Heaths
	Sydney Montane Heaths
	Wallum Sand Heaths
Saline Wetlands	Inland Saline Lakes
	Saltmarshes
Semi-arid Woodlands (Shrubby sub-formation)	Desert Woodlands
	Semi-arid Sand Plain Woodlands

The final selection of classes were communities in which forest was incorrectly identified, as demonstrated in Figure 5. Other classes, such as grasslands, were not included. This was due to these classes, as a majority, not correctly identifying vegetation as forest. Further, scattered trees may be present in some of these classes or in transitional zones between forest and grassland classes.

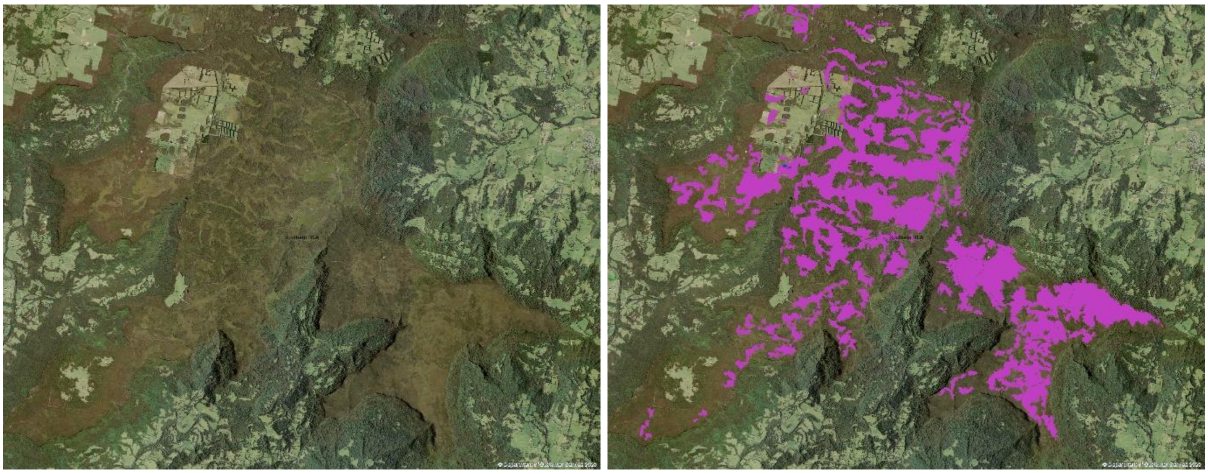

Figure 5. ***Application of State Vegetation Type Mapping masking. Left panel; aerial imagery of heath dominated National Park. Right panel; masking layer to remove Sydney Coastal Heaths.***

Final Masking

Once assembled, each of the masking layers for Urban, Water, Agriculture and Vegetation were combined into a master layer. As described, for Urban and Agriculture there were three time points in use for 2007, 2013 and 2017. Overall then for the master masking layers, there were three in use.

For final masking back against the National Grids the 2007 layer was used for any National Grid products prior to 2008. The 2013 layer was used for National Grids from 2009 to 2014 and the 2017 layer was used from National Grids from 2015 to a current time point.

The one-year overlap after the 2007, 2013 and 2017 time periods was to account for land uses that may have been in transition between time frames. The use of three time points was to create a perceived change over time of land use, but it is noted that this could result in hard or discrete cut-offs where large blocks of area may appear from one layer to another resulting in loss of forest extent. This is more so noted in urban growth zones into agricultural land.

As a general assumption, the SVTM layer was only created for one time point but applied across all National Grids data layers from 1988 to 2020. Vegetation communities can be transient and transitional in nature, and there will be changes in vegetation types over time as communities recover from disturbances, or potentially transition from one type to another. Using the SVTM as relevant to one point in time for all National Grids products means the occurrence can be disregarded.

One major assumption of the application of a masking layer against the National Grids forest extent product is the use of a discrete masking layer back against a continuous data layer. This is particularly relevant when creating and using the SVTM masking layer as it applies a hard-line boundary between vegetation types, whilst in nature this line does not occur and there is generally a smooth changeover between areas. However, the SVTM layer was the best layer to use in this masking application. The issues and assumptions are noted, but not all can easily be resolved.

5.3. Temporal Sequence Refinement

Fuzzy Logic and Probability

There are 24 annualised forest extent layers generated in the National Grids product for the period 1988 to 2010. Early in the period, up until 2004 after which the products became annualise, there were biennial and triennial updates. The time series years for these forest extent layers is 1988,1989,1991,1992,1995,1998,2000,2002,2004-2020.

On application and analysis of these layers it became apparent that the NCAS National Grids data products are more often a reflection of forest extent between years rather than that of true extent. Further, this output provides a good reflectance of canopy response to disruption. This is particularly true for forest edges and disturbed areas where ‘cover extent’ can be lost for a year then reappear the next year. For example, a fire may have occurred impacting the canopy cover which would result in loss of ‘extent’, but in reality, the tree is still present. Hence, extent is not lost, only cover.

Albeit, this output is more so required to be a view of extent rather than cover. Analysis of cover trends over time can facilitate several points of analysis, including health, but it cannot answer all trends and analyses required. To gain certainty in the National Grids and redefine the annualised forest extent to become more a forest extent product, the products were processed through a Fuzzy Logic operation.

Fuzzy Logic is a mathematical approach in which typical true or false definitions (Boolean logic) are processed or converted into multiple ranges of truths, or ‘degrees of truth’. In application back to forest extent, it takes the annualised cover products in which values are either forest extent or no forest extent (1 or 0) and looks at the state of forest extent over a range of years to determine what the likely cover is at the final given year.

For example, if we take a five-year processing window, look at the year on year trend of cover and determine if there is forest extent for all five years, then we can state that there is a definite certainty of extent. This can be repeated for all given Boolean combinations of forest to non-forest. In this way we can determine extent from forest extent and place a certainty on final extent coverage.

The NCAS product, prior to production release is known to undergo similar fuzzy logic operations for error verification processes and functions. This also uses a Conditional Probability Network (CPN) early in the processing chain. This CPN reviews previous and subsequent cover assignments to determine an eventual classification, whereas the fuzzy logic is used to clean and check the processed imagery based on certainty outputs.

The fuzzy logic process undertaken in this project has a twofold focus. One side is to introduce ranks of certainty in the output forest extent product that will range between 'definitely forest' and 'definitely not forest'. This will allow for further analysis, if required, of core or untouched forest against more disturbed or less certain determinations of forest extent.

The other focus is to reduce noise in forest extent over a series of years. Over a sequence of years, the forest extent cells in the NCAS grids can be seen to 'flicker' between presence or absence. This could be a result of cover moving back and forth between the 20% cover threshold applied in the NCAS grids in response to environmental impacts or image detection algorithms. This flickering could also be a result of error in the image detection process underlying the NCAS product. However, this would be minimal due to the error resolution process within the NCAS production cycle.

For application in the NSW project space, a five-year moving window was placed on the National Grids product from the 1988 period until the final year of 2020 and a fuzzy logic operation performed. Therefore, for a stated year (e.g., 2018), the final product would be based on the previous five years (e.g., 2014-2018). This curtailed the 24 annualised forest extent layers to 20 overall and move the baseline year from 1988 to 1995.

To provide an example of how the Boolean forest extent operators are scored and ranked into certainty classes, possible combinations in a five-year moving window are provided in Table 3. The table shows all possible true or false scores for cover in each year where 0 indicates no cover and 1 indicates cover. Also shown in the table is a calculated score for each combination and assigned rank.

Each year is weighted to calculate the score. Year 1 was given a weight of 1 and each year incremented by a value of 1. Year 5 is given a double weighting plus one to provide a score of 11. Each of these weights are multiplied against the Boolean operator and added together to give a final score. Final scores range from 0 to 21.

The purpose behind the high score on the final year is to account for abrupt changes in forest extent, such as clearance or fire disturbances, which in turn accounts for the definite presence or absence of forest, rather than the potential of forest extent. If the final year was given a weight of 5, as initially investigated, these abrupt changes could be given a lower certainty, hence potentially including them in a forested category.

Table 3. Fuzzy Logic application processing table for a five-year moving window including final scores and certainty ranking.

Year 1	Year 2	Year 3	Year 4	Year 5	Score	Rank
0	0	0	0	0	**0**	**H**
1	0	0	0	0	**1**	**G**
0	1	0	0	0	**2**	**G**
0	0	1	0	0	**3**	**G**
1	1	0	0	0	**3**	**G**
0	0	0	1	0	**4**	**F**
1	0	1	0	0	**4**	**F**
0	1	1	0	0	**5**	**F**
1	0	0	1	0	**5**	**F**
0	1	0	1	0	**6**	**F**
1	1	1	0	0	**6**	**F**
0	0	1	1	0	**7**	**E**
1	1	0	1	0	**7**	**E**
1	0	1	1	0	**8**	**E**
0	1	1	1	0	**9**	**E**
1	1	1	1	0	**10**	**E**
0	0	0	0	1	**11**	**D**
1	0	0	0	1	**12**	**D**
0	1	0	0	1	**13**	**D**
0	0	1	0	1	**14**	**D**
1	1	0	0	1	**14**	**D**
0	0	0	1	1	**15**	**C**
1	0	1	0	1	**15**	**C**
0	1	1	0	1	**16**	**C**
1	0	0	1	1	**16**	**C**
0	1	0	1	1	**17**	**C**
1	1	1	0	1	**17**	**C**
0	0	1	1	1	**18**	**B**
1	1	0	1	1	**18**	**B**
1	0	1	1	1	**19**	**B**
0	1	1	1	1	**20**	**B**
1	1	1	1	1	**21**	**A**

Each score was then assigned a rank which corresponds to a level of certainty. These ranks are further expanded upon and assigned to a certainty category are show in Table 4. As shown, there are 8 classes ranging from 'definite forest' to 'definite non-forest' with degrees of certainty between.

Of interest are the two middle categories of 'least likely' to be forest or non-forest (ranks D and E). These have the highest amount of uncertainty attached to them as a result of the pattern of presence or absence over the five-year window. In particular, the two middle sequences of a four-year forest or non-forest pattern followed by an abrupt change in the final year. Due to the final year focus this abrupt change (likely as a result of a disturbance event) can place these two categories in a state of uncertainty where for the given point of focus it could be considered forest or non-forest. For consideration and application into a forest extent deliberation, it is this final year weighting that will assign the certainty rating. However, if this changes in the subsequent year back to the prior state, then either of these will move up or down in terms of certainty.

Table 4. Fuzzy Logic forest extent ranks as organised into certainty categories.

Rank	Presence/Absence	Certainty
A	Forest	Definitely
B	Forest	Most Likely
C	Forest	Likely
D	Forest	Least Likely
E	Non-Forest	Least Likely
F	Non-Forest	Likely
G	Non-Forest	Most Likely
H	Non-Forest	Definitely

Forest extent certainty ranks were initially assigned manually primarily to ensure abrupt changes were accounted for correctly and visualised appropriately when applied back to the spatial coverage, particularly at the clear division between presence and absence of cover extent. To ensure correct selection of the intermittent categories either side of this division, a frequency distribution analysis of the weighted score occurrences was undertaken.

As the weighting metrics were applied for each year in the data range, the total hectare counts were collated and tabulated. The average hectare count, per weight score, is shown in Figure 6. Bookend scores of 0 and 21 are not displayed as they would have the largest hectare count amongst them and are assumed to be a category by themselves.

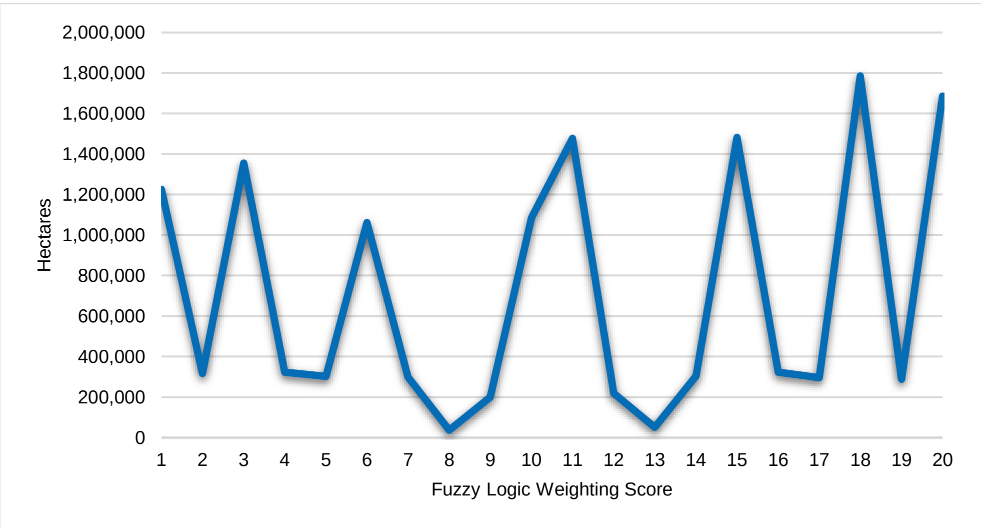

Figure 6. Fuzzy logic weighting score frequency distribution

This frequency distribution highlights the arrangement of NCAS grids that are present or absent over the five-year window and which combinations are more common than others. For example, combinations that are shown to turn from presence to absence, or flicker over the five-year moving window, are less common in occurrence compared to those that have a more solid run of years of presence or absence.

Further, this distribution details the peak values which are combinations that are more than likely to occur in the five-year window. These peaks are used as the natural break points into which the eight categories of certainty have been created.

A loose set of guiding principles were used to provide an overview of how these were assigned. These were primarily set off probability coverages or averages of cover. However, if not visually appropriate, ranks could change. The rules are set out below;

A. 100% forest for 5 years
B. 60%-80% forest extent over 5 year period
C. 40%-80% forest over 5 year period.
D. Approximately 40%-60% forest over 5 year period. Depends on placement of forested year to non-forest year
E. Approximately 40%-60% forest over 5 year period. Depends on placement of forested year to non-forest year
F. 20%-40% forest over 5 year period. Depends on placement of non-forest year to forested year
G. <20% - 40% forest over 5 year period. Usually has only 1 year of forest extent in series
H. 0% forest for 5 years

Final forest extent outputs

Final outputs from the fuzzy logic operation were then used in two principal directions. One was to analyse each of the eight classes and determine how ranks and certainties changed over the processed 20 National Grids products. A key observation of this would be how core forest areas (i.e., rank A – definite forest) has changed over the years and if there are gains or losses over time.

The other direction of analysis was to assign a Boolean score of 0 or 1 back to the processed NCAS Grids products - a score of 1 for forest certainties (rank A – D) and 0 for non-forest certainties (rank E – H). Although this did remove the certainty ranks and fuzzy logic, these products were more so a reflection of extent over cover, and hence a higher amount of veracity could be placed on these products and if they state there is extents coverage or not.

Conversion back to this absolute score of 1 or 0 of presence or absence ultimately realigns the final determination back to the base non-fuzzy NCAS grids, albeit with a few differences. If the Boolean score is used going forward, then the fuzzy logic application is more an application to filter the noise out of the NCAS grids.

On reflection, the base NCAS grids as a product are viewed as a completely valid and rigorous product to use to measure forest extent. There are a few issues seen in the product with incorrect determinations and some pattern noise. The process includes NCAS masking and fuzzy processing to clean the product for use in analysis, such that the grids provide a reliable input into forest extent or extent trend analysis.

Overall, the focus of the categories was to look at the presence or absence of forest extent rather than the potential of cover extent. By using the last year as the focal point and placing the forest to non-forest division at the point where the final year, it keeps the concept of presence or absence. The fuzzy logic application in this sense smooths out the data presenting logical groupings. However, depending on focus and intent of the final dataset for cover extent, this weighting or grouping could be altered to account for a potential cover extent focus.

Sensitivity testing and other uses of the forest extent output

The point of focus is the final year and the change experienced in cover. This emphasises the fuzzy logic and certainty ranking on the presence or absence of forest extent and any abrupt change. For example, a particular use could be to assess immediate damage post fire event. This abrupt change and output could be compared to known disturbances and then monitored into the future to record recovery of canopy post disturbance.

If the centre of focus is taken off this abrupt change by accounting for potential change into the future, then the final output product would more so reflect potential of forest extent rather than absolute presence or absence. This could be of particular use in accounting for and masking out plantation operation clearance events where the forest extent will be replanted and replaced and hence cover extent is notionally not lost.

During the course of the project while investigating the fuzzy logic approach, there was analysis done on moving the centre of focus within the five-year moving window. This was done to look into altering the output to be more potential cover based rather than presence or absence based. By moving the focus to the third or fourth year, there was an ability to look forward in the sequence to verify if an abrupt change was sustained. Also, weight alterations alongside this change in focus allowed for particular sequences (i.e., two or three sustained years of cover) to be elevated in score, hence increasing the certainty rank.

Other alterations suggested to the fuzzy logic approach can include enlarging the moving window, either looking forward or back in the sequence, or to include an outside determining factor to increase the certainty determination.

The original approach, as outlined in this section, was the primary choice for analytic and production purposes for forest extent grids. This was undertaken to;

- Reflect and measure abrupt changes or disturbances
- Retain presence or absence rather than potential
- Reduce noise, or flickering of cells, in the NCAS grids

Other methods can be used and should be investigated if the focus of the output product is wanted to be shifted. However, the final treatment of NCAS grids in this project to delineate forest extent reflects confidence in the overall NCAS approach, particularly the processing undertaken to reduce data noise.

The next section describes how these resultant tree cover extent datasets derived from the NCAS grids were evaluated against appropriate tree cover validation data that has been verified by NSW agencies.

5.4. Cross Validation

The original NCAS National Grids have been established for the purposes of detecting land cover change across landscape or regional coverages. This is principally a National product, although it does align to individual State forest extent coverages. The product is known to use a consistent methodology for each year it is run with consistent processing. The key points of difference for this time series are changes associated with different satellite input sources, where the Landsat inputs were shifted from Landsat 5, to Landsat 7, and to Landsat 8. The outputs for each annual run and overall model have been validated to the NCAS standards and purposes.

However, like all products there can be a level of error associated with the NCAS product. The level of 'error' can potentially be determined by reviewing the product in the relation to higher resolution State extent coverages, and evaluating the misalignments and areas of incorrectly identified forest extent. The other level of discrepancy, or error, can arise during the two stages of refinement, as outlined in the prior sections.

The spatial refinement and temporal sequence refinement processes seeks to reduce these National to State issues and make this product more accurate and reliable for NSW users, although it is useful at both stages in the refinement process to validate the NCAS derived product against more detailed and ground validated forest extent products already prepared for NSW (such as the SLATS product).

As detailed in Table 1, there are three NSW products available that outline forest extent coverage produced using the SLATS methodology. These include;

- 2008 Landsat woody extent and foliage projective cover (v2.1). Landsat at 25m. Extent of woody vegetation at 2008 and also shows the percentage Foliage Projective Cover (FPC) for the woody areas.
- 2011 NSW Woody Vegetation Extent. SPOT 5 at 5m. State-wide binary classification of woody vegetation derived from multitemporal 5m SPOT-5 satellite imagery.
- 2017 NSW Native Vegetation Extent 5m Raster. SPOT 5 at 5m. Developed under the State Vegetation Type Map program. Presents a single surface raster that combines information on native vegetation extent for NSW.

As noted, they are for only three time points and are for two differing resolutions. Each have been produced using different methods, and hence results in slightly different outputs between these three years. This is shown in Figure 7 where outputs for the three years are overlaid.

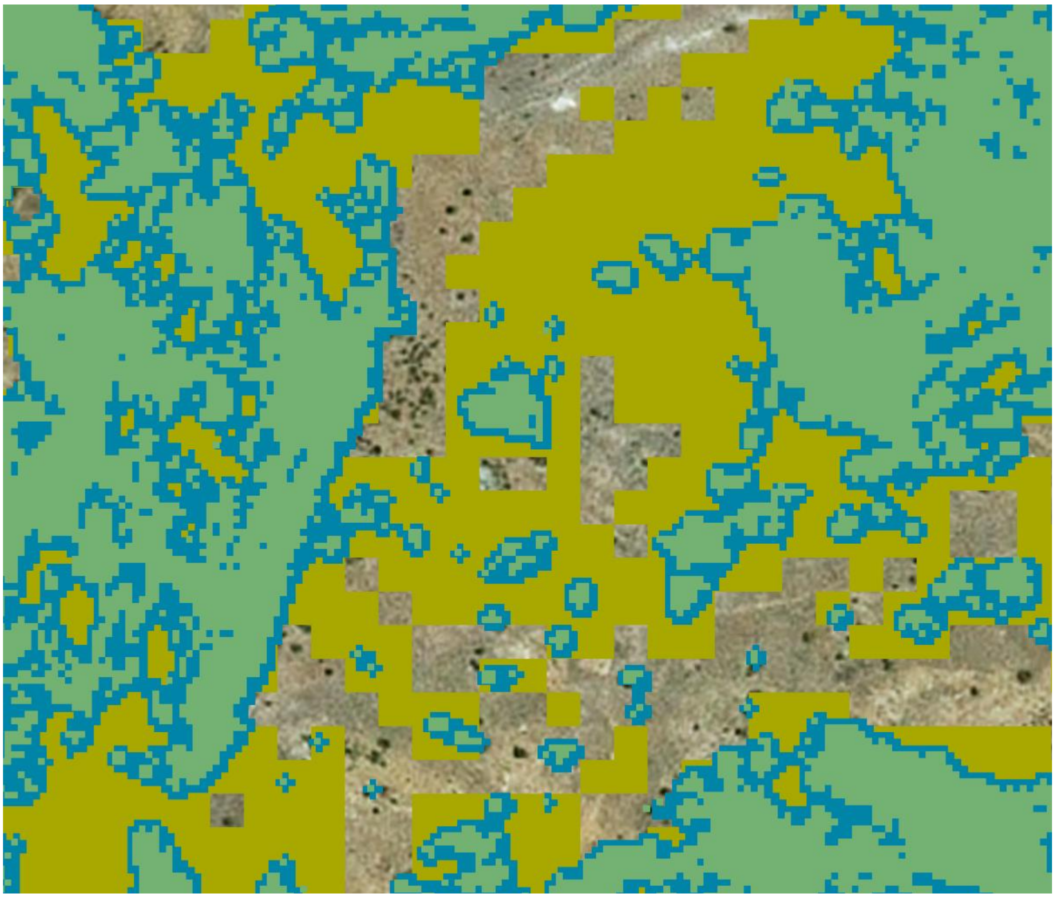

Figure 7. SLATS Forest Extent product differences between 2008 (yellow), 2011 (blue) and 2017 (green).

All products and the SLATS programs, including Woody Change outputs produced, are produced for the purpose of monitoring woody change and compliance primarily in the private realm and any land clearance. As such, the minimum mapping unit differs to NCAS and it identifies more isolated and scatted tree points not associated with contiguous forested areas. This is demonstrated in Figure 8 below.

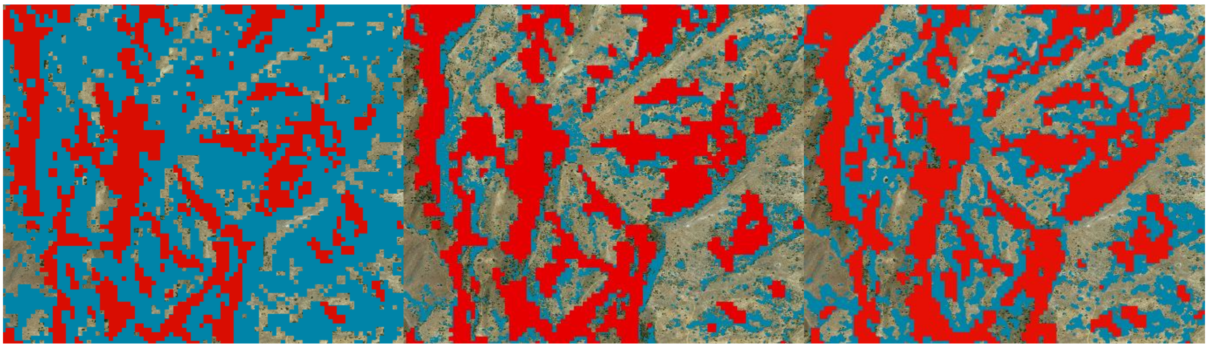

Figure 8. SLATS output, in blue, for 2008 (left), 2011 (centre) and 2017 (right) overlaid with NCAS output, in red, for corresponding year.

Despite these differences, it is useful to look at these two products and determine where similarities and differences lie. Table 5 presents a comparison between the three timepoints and the two products – SLATS and NCAS – over four Regional Forest Agreement (RFA) areas of eastern NSW. The NCAS product used is the final stage outputs from the Spatial and Temporal refinements. This comparison is presented for several different tenure types, including National Parks and Private tenures.

The NCAS product in all three points is identifying more forest extent coverage than SLATS, but this difference is reduced to near 100,000 hectares in the 2011 timepoint. Even with a similar resolution at 25m in 2008, SLATS is identifying more forest extent coverage. The main difference is in the private tenure. Each of the other categories have only minimal differences with at most a 40,000-hectare difference in National Parks in 2011, which over the full project area is not that substantial.

Table 5. SLATS outputs compared with NCAS outputs for several differing tenure type breakdowns.

Tenure	SLATS			NCAS			Difference		
	2008 (ha)	2011 (ha)	2017 (ha)	2008 (ha)	2011 (ha)	2017 (ha)	2008 (ha)	2011 (ha)	2017 (ha)
National Park	3,538,471	3,503,333	3,552,581	3,544,658	3,544,871	3,592,537	6,186	41,538	39,956
Crown Land - Other	178,504	168,857	184,600	155,113	156,336	163,092	-23,390	-12,520	-21,508
Crown Land - Leasehold	100,214	96,261	108,132	93,363	93,330	98,827	-6,851	-2,931	-9,305
Private	4,522,646	3,990,904	4,756,814	3,796,795	3,840,893	4,130,858	-725,851	-150,011	-625,956
Unresolved tenure	1,276	1,034	1,165	728	712	765	-548	-321	-400
State Forest	1,512,399	1,495,243	1,539,176	1,514,583	1,507,807	1,526,493	2,183	12,564	-12,683
Indigenous Owned	1,169	915	961	1,149	1,194	1,185	-20	279	224
Other	644	549	707	514	575	660	-131	26	-47
Total	9,855,323	9,257,096	10,144,136	9,106,902	9,145,719	9,514,418	-748,422	-111,377	-629,718

It is anticipated that SLATS will identify more forest coverage on private land than that identified by NCAS due to its use of FPC, as previously identified. However, the difference in 2008 and 2017 is larger than that seen in 2011. The 2008 extent is using 25m Landsat grids as an input, so an isolated tree will be defined with a single grid cell, which is about 625m^2. The 2017 output tends to buffer or extend tree grid cells at each of the cardinal direction, resulting in a cross or star output for an individual tree point, which is about 125m^2. The 2011 SLATS product is viewed as a more accurate depiction of actual forest extent coverage for the project area. This makes it a useful point of comparison back against the NCAS product for validation and correlation purposes.

NCAS to SLATS correlation comparisons

A correlation between the 2011 NCAS product and 2011 SLATS product was undertaken over the project areas. This was undertaken for 50,000 random sampling points for the full project boundary, which is about 12,500 points. Further to this, 5000 random points were sampled in each of the

Private Tenure, National Parks and State Forests.

For correlation purposes the NCAS and SLATS products were sampled in several different breakdowns at differing stages of processing, for NCAS, and several resolutions for SLATS. This included:

- NCAS pre-processed inputs before refinements, this will include the full non-woody, scattered woody (cover 5% to 19%) and woody definitions employed in the original input.
  - NCAS RAW Full – 0, 1, 2. Non-woody, Scattered Woody, Woody
  - NCAS RAW – 0, 1. Non-woody, Woody
- NCAS Spatial Refinement processed.
  - NCAS Masked Full – 0, 1, 2. Non-woody, Scattered Woody, Woody
  - NCAS Masked – 0, 1. Non-woody, Woody
- NCAS Spatial and Temporal processed.
  - NCAS Fuzzy Full – 0, 1, 2. Non-woody, Scattered Woody, Woody
  - NCAS Fuzzy – 0, 1. Non-woody, Woody
- SLATS base product for 2011.
  - SLATS RAW – 0, 1. Non-woody, Woody
- SLATS resampled to 25m for 2011.
  - SLATS RAW 25m – 0, 1. Non-woody, Woody
- SLATS processed with spatial refinement masking layer
  - SLATS Masked – 0, 1. Non-woody, Woody
- SLATS processed with spatial refinement masking layer and resampled to 25m
  - SLATS Masked 25m – 0, 1. Non-woody, Woody

For each random sampling point, the presence or absence of woody vegetation were tested for differing combinations between the NCAS and SLATS products. This was for the full extent under investigation, which included both non-woody and woody vegetation.

Full Project Area

There are 50,000 random sample points for the evaluation area that incorporated four Regional Forest Agreement (RFA) areas of eastern NSW. These sample points are used both in woody and non-woody areas and had roughly a 60-40 sampling split between woody and non-woody regions for each random sampling permutation.

The first comparison shown in Figure 9 is between the original pre-processed NCAS grids for 2011 and the base SLATS product for 2011. The NCAS is sampled both as woody extent only and including scattered woody forest. Overall there are four methods of correlation presented. For each method there is over a 90% correlation between NCAS and SLATS products. However, in the comparison of NCAS without scattered woody vegetation back to SLATS, there is a higher degree of correlation. When scattered woody forest is included there is a lowering of correlation indicating that the NCAS scattered woody forest is over represented in the NSW compared to SLATS.

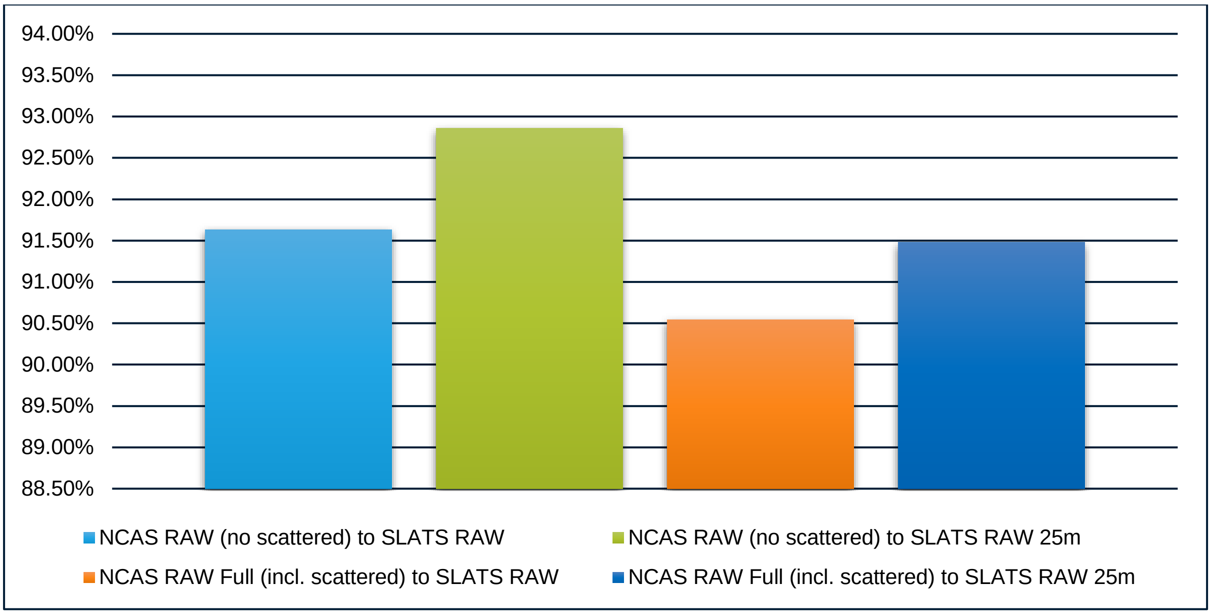

Figure 9. Correlation graph for full project area between NCAS pre-processed products and SLATS products

The output correlations in Figure 10 are between several different comparison permutations. The first set of four outputs are between NCAS grids processed only with a Spatial Refinement correlated to SLATS base products and SLATS with a masking layer applied. The second set of four outputs are between the final NCAS processing step with a Temporal Refinement run correlated to SLATS base products and SLATS with a masking layer applied.

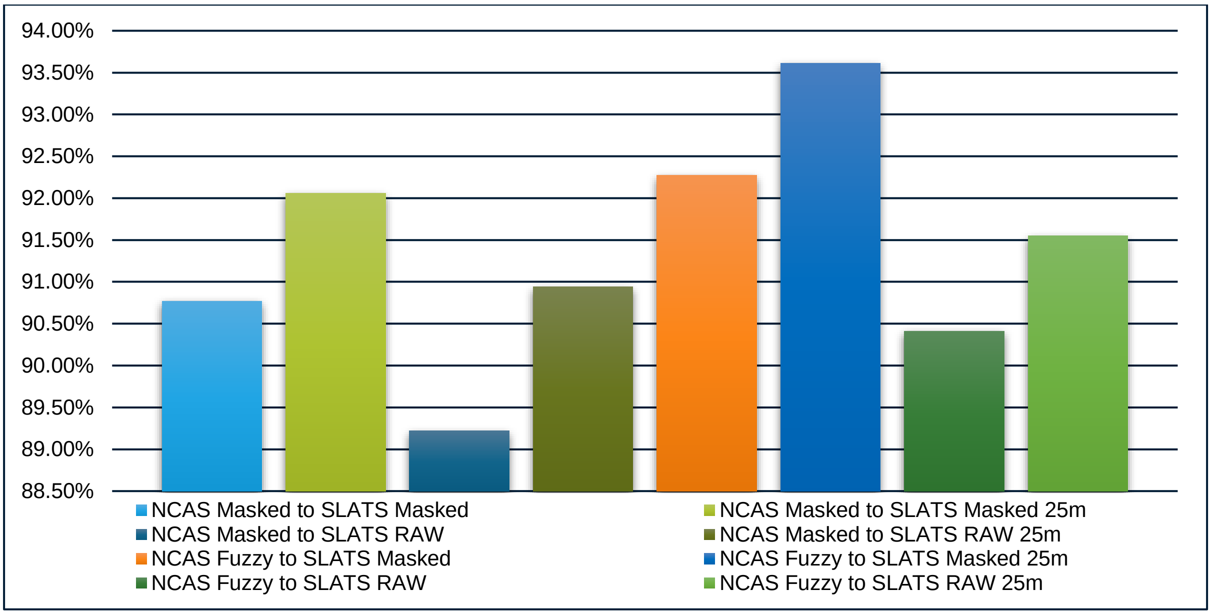

Figure 10. Correlation graph for full project area between NCAS processed products and SLATS products

The main comparison of NCAS masked to SLATS masked presents a very similar correlation to that of the un-processed products. However, the correlation between the final forest extent coverage product developed by the project back to a similar SLATS product with a masking layer applied presents the highest high correlation above 92% for both the 5m and 25m comparisons.

The final correlation outputs presented in Figure 11 compares this final NCAS correlated with the SLATS product with a masking layer applied back to an NCAS refined output that includes scattered woody vegetation. The inclusion of scattered woody forest into the refinement stages in NCAS do not add any extra level of correlation between NCAS and SLATS.

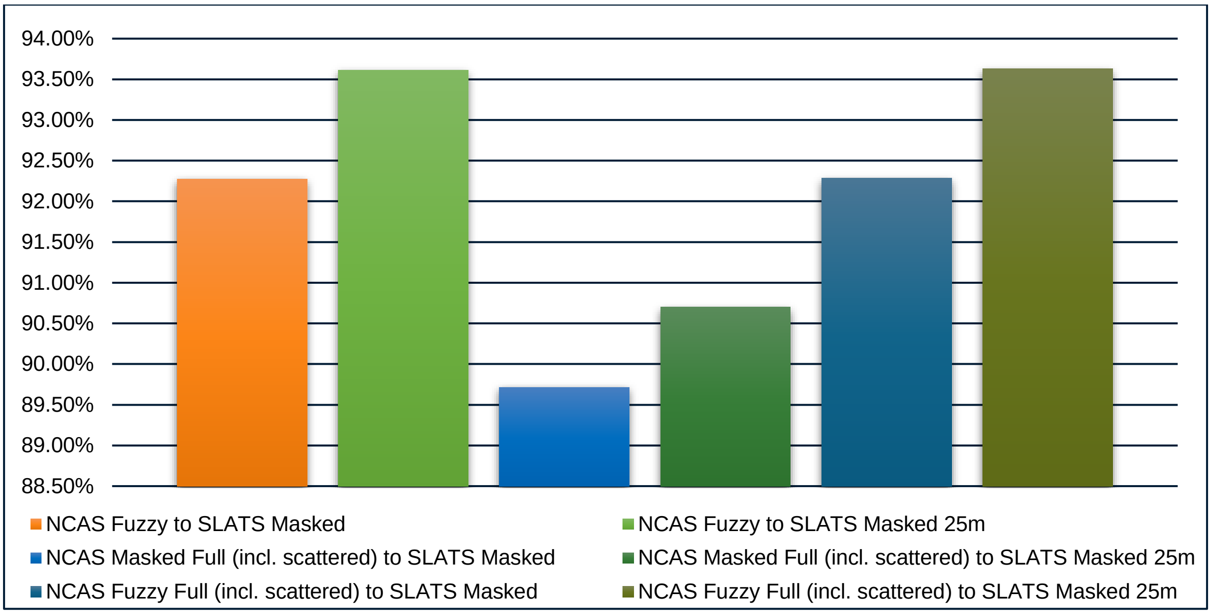

Figure 11. ***Correlation graph for full project area between NCAS processed products with scattered woody vegetation and SLATS products***

Overall, between each correlation permutation over NSW there is about a 90% and above correlation. The highest levels are seen in the correlation of the final NCAS product processed with both spatial and temporal refinements back to SLATS.

Private Tenure

For private tenure, there were 5,000 random sample points used. These sample points are used both in woody and non-woody areas and has roughly a 50-50 sampling split between woody and non-woody regions for each random sampling permutation.

The first comparison shown in Figure 12 is between the original pre-processed NCAS grids for 2011 and the base SLATS product for 2011. The NCAS is sampled both as woody extent only and including scattered woody forest. Overall there are four methods of correlation presented, and for each method there is over an 88% correlation between NCAS and SLATS products. However, in the comparison of NCAS without scattered woody vegetation back to SLATS, there is a higher degree of correlation. When scattered woody forest is included there is a lowering of correlation indicating that the NCAS scattered woody forest is over represented compared to SLATS.

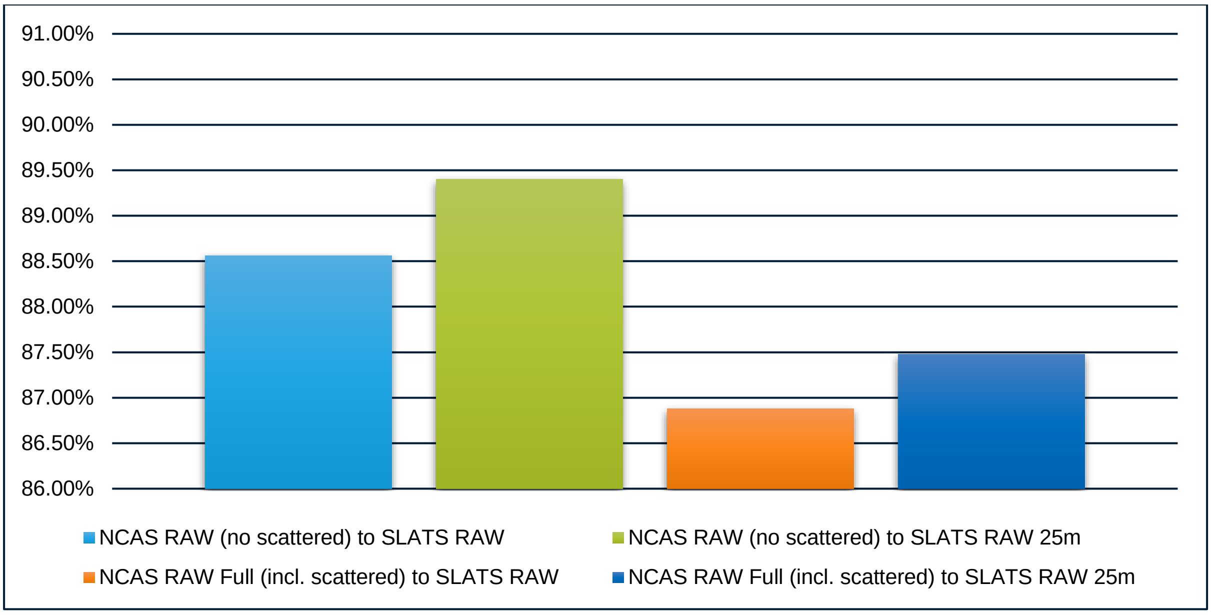

Figure 12. Correlation graph for private tenure between NCAS pre-processed products and SLATS products

The output correlations in Figure 13 are between several different private tenure comparison permutations. The first set of four outputs are between NCAS grids processed only with a Spatial Refinement correlated to SLATS base products and SLATS with a masking layer applied. The second set of four outputs are between the final NCAS processing step with a Temporal Refinement run correlated to SLATS base products and SLATS with a masking layer applied.

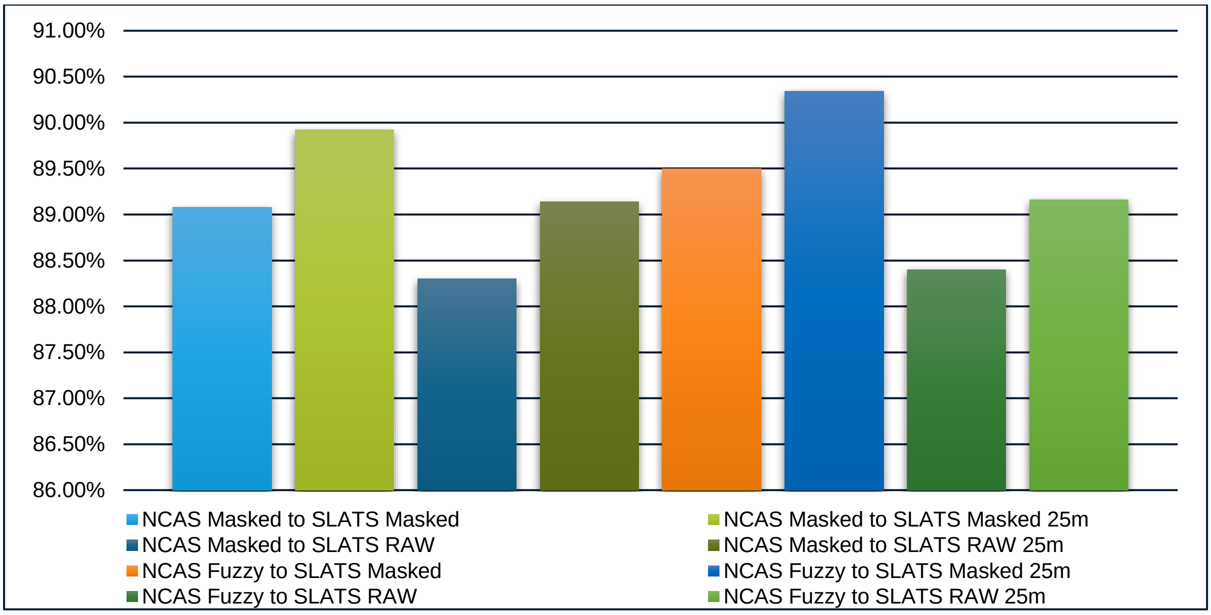

Figure 13. Correlation graph for private tenure between NCAS processed products and SLATS products

The main comparison of NCAS masked to SLATS masked presents a very similar correlation to that of the un-processed products. However, the correlation between the final NCAS forest extent coverage product back to a similar SLATS product with a masking layer applied presents a very high correlation above 89% for both the 5m and 25m comparisons.

The final correlation outputs presented in Figure 14 compares this final NCAS correlated with the SLATS product with a masking layer applied back to an NCAS refined output that includes scattered woody vegetation. The inclusion of scattered woody forest into the refinement stages in NCAS do not add any extra level of correlation between NCAS and SLATS.

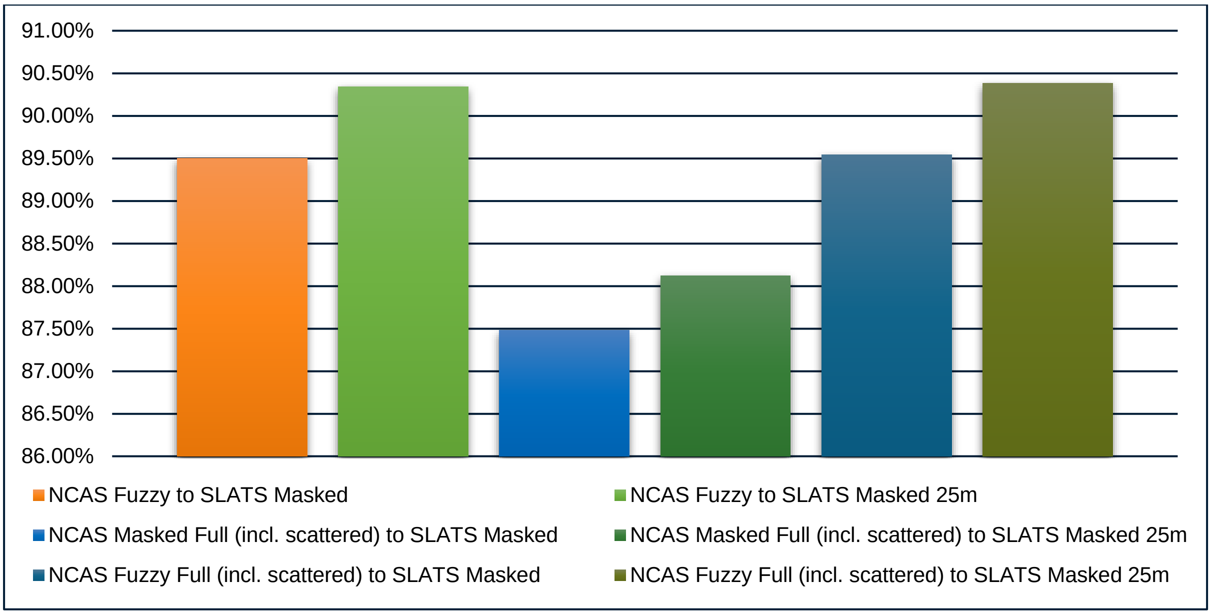

Figure 14. Correlation graph for private tenure between NCAS processed products with scattered woody vegetation and SLATS products

Overall, between each correlation permutation there is about an 88% and above correlation. The highest levels are seen in the correlation of the final NCAS product processed with both spatial and temporal refinements back to SLATS.

National Park

For National Parks, there are 5,000 random sample points used. These sample points are used both in woody and non-woody areas and has roughly a 90-10 sampling split between woody and non-woody regions for each random sampling permutation.

The first comparison shown in Figure 15 is between the original pre-processed NCAS grids for 2011 and the base SLATS product for 2011. The NCAS is sampled both as woody extent only and including scattered woody forest. Overall there are four methods of correlation presented, and for each method there is over a 94% correlation between NCAS and SLATS products. In the comparison of NCAS with scattered woody vegetation back to SLATS, there is a higher degree of correlation. However, there is only a 1% difference back to NCAS without scattered woody vegetation. This indicates that the NCAS scattered woody forest adds a small increase of correlation between NCAS and SLATS, possibly around forest edges, but not by a large degree.

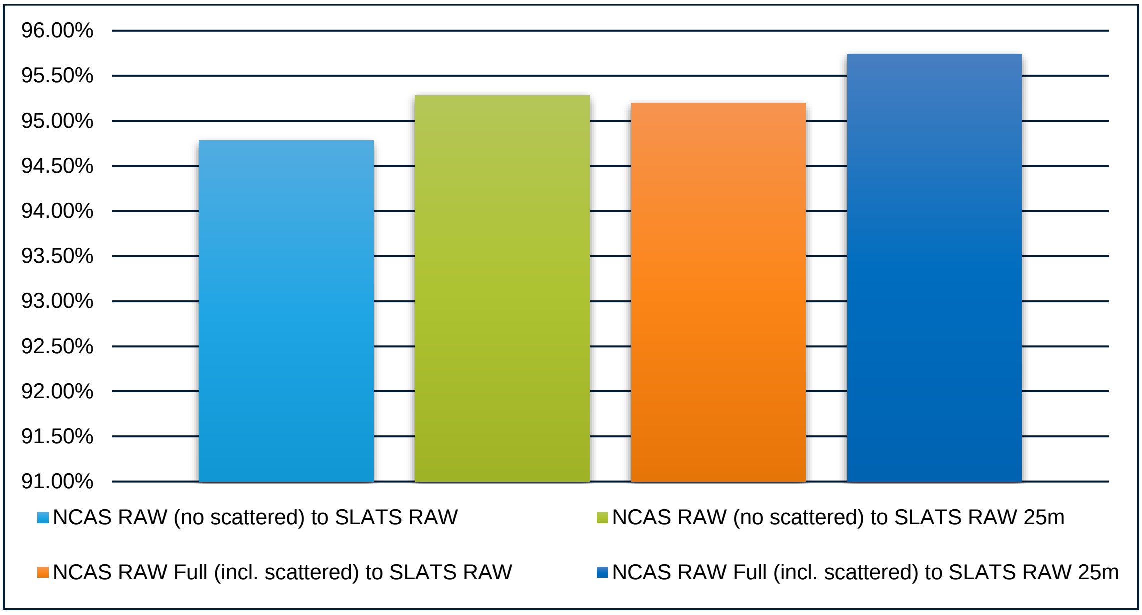

Figure 15. Correlation graph for National Park tenure between NCAS pre-processed products and SLATS products

The output correlations in Figure 16 are between several different National Park comparison permutations. The first set of four outputs are between NCAS grids processed only with a Spatial Refinement correlated to SLATS base products and SLATS with a masking layer applied. The second set of four outputs are between the final NCAS processing step with a Temporal Refinement run correlated to SLATS base products and SLATS with a masking layer applied.

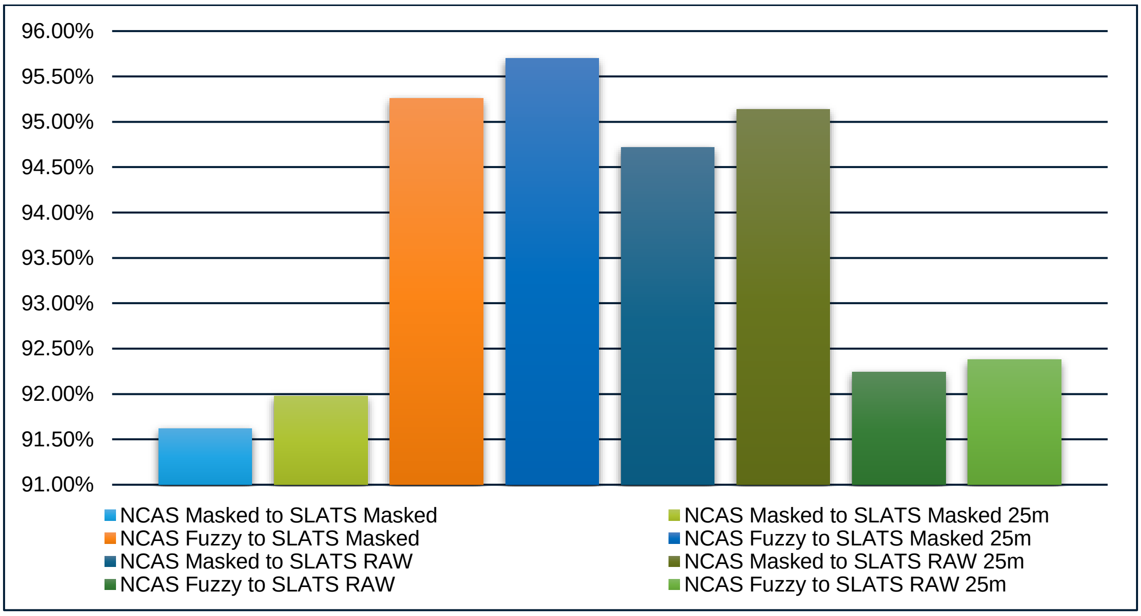

Figure 16. Correlation graph for National Park tenure between NCAS processed products and SLATS products

The main comparison of NCAS masked to SLATS masked presents a lower correlation to that of the un-processed products. However, the correlation between the final NCAS forest extent coverage product back to a similar SLATS product with a masking layer applied presents a very high correlation above 95% for both the 5m and 25m comparisons.

The final correlation outputs presented in Figure 17 compares this final NCAS correlated with the SLATS product with a masking layer applied back to an NCAS refined output that includes scattered woody vegetation. The inclusion of scattered woody forest into the refinement stages in NCAS do not add any extra level of correlation between NCAS and SLATS.

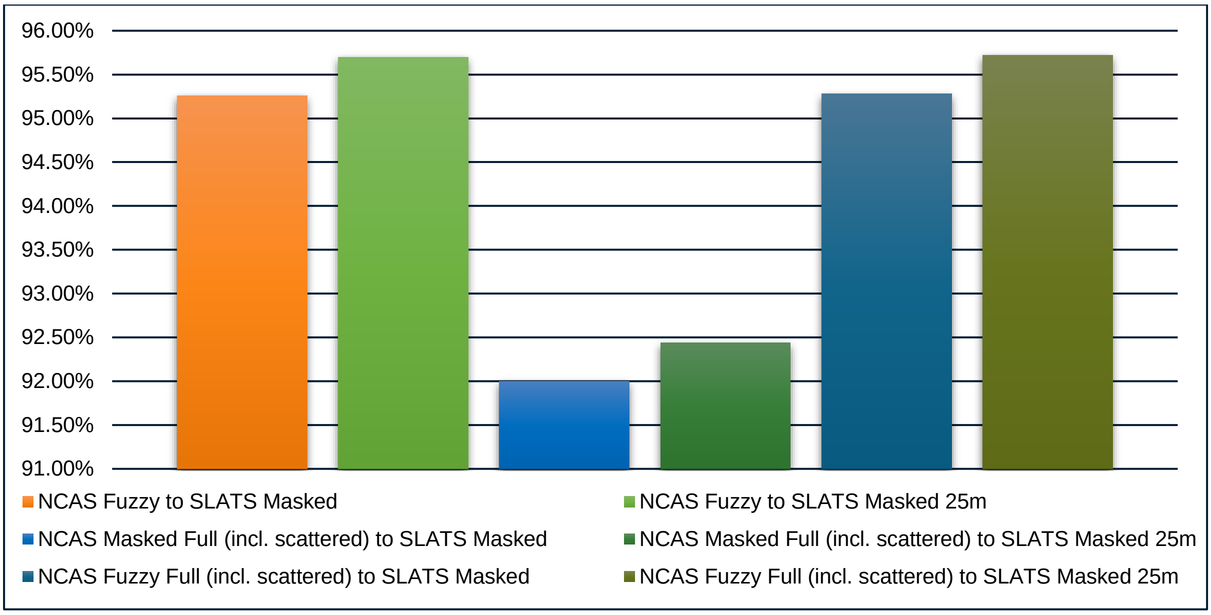

Figure 17. Correlation graph for National Park tenure between NCAS processed products with scattered woody vegetation and SLATS products

Overall, between each correlation permutation there is about a 91% and above correlation. The highest levels are seen in the correlation of the final NCAS product processed with both spatial and temporal refinements back to SLATS.

Concluding Comments

Between the NCAS product and SLATS product there is a high level of correlation. Across the four Regional Forest Agreement (RFA) areas this can be in excess of a 90% correlation at various combinations of NCAS and SLATS. This is indicating that even though the two products employ differing methodologies and are designed for differing purposes, what they are detecting in terms of woody or forested areas in comparison to non-woody or non-forested areas is very similar.

This high level of correlation is seen to remain even when switching between the original 5m SLATS resolution to a resampled 25m resolution. Figure 18 below shows this final comparison between the final NCAS product employing a spatial and temporal refinement against SLATS, both at 5m and 25m, for a full project area and the two tenure types compared. As discussed, it indicates at the full project area there is a high level of correlation between products.

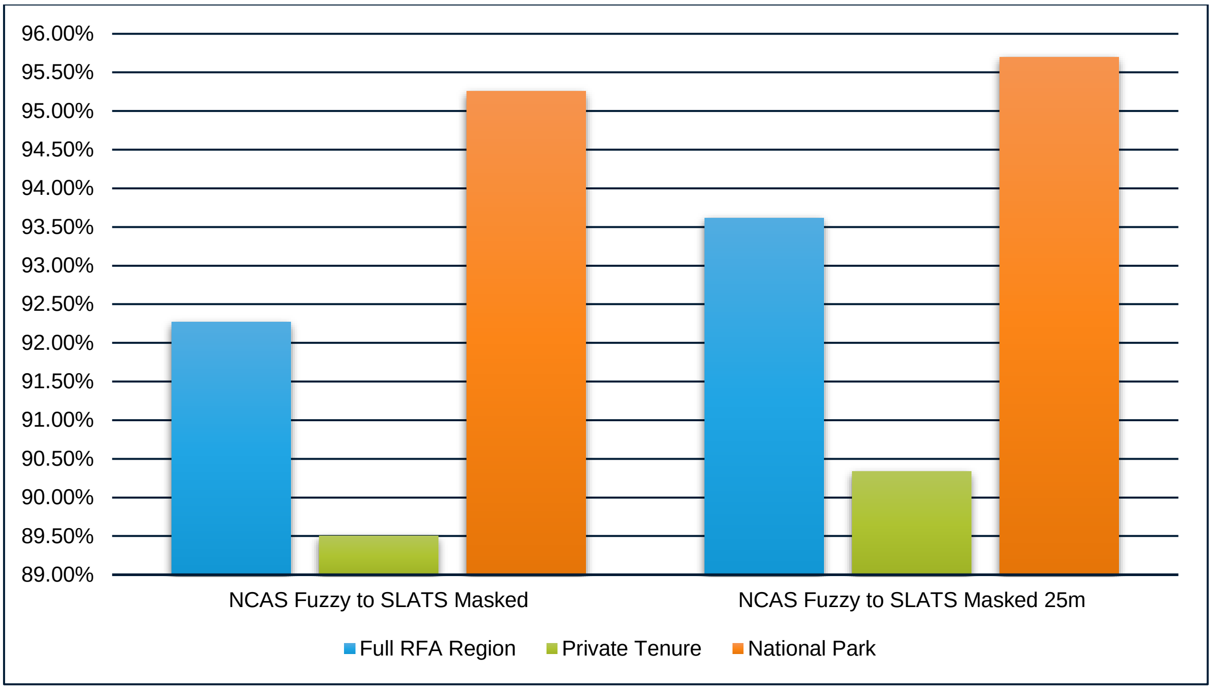

Figure 18. Correlation graph between NCAS processed products and SLATS products for full project area, private tenure and National Parks.

When comparing private tenure to National Parks and the relation of NCAS to SLATS, there is a noted difference. As a main point there is a higher correlation in National Parks as compared to private tenure. This is largely expected between the two products for a number of reasons.

The main point of difference, as discussed prior, is the purpose behind SLATS as compared to NCAS. SLATS have an objective of detecting woody change in private landholdings and compliance in these areas to NSW regulations. As such this product has differing standards and parameters for woody detection and will result in a higher rate of woody detection in private areas, in particular isolated trees.

Therefore, a difference between NCAS and SLATS in this tenure type is expected. What is supportive of NCAS is the high correlation, even with the noted differences in product and purpose of product.

The high correlation in National Parks is largely expected as these areas are typically defined by large contiguous areas of wooded vegetation with very little clearing or isolated/scattered forested regions. With the restriction to only these areas both products are expected to be picking up a similar forested to non-forested detection.

The main purpose behind this correlation and cross validation is to determine the accuracy of the NCAS refined products back against a product designed explicitly for the NSW region. SLATS only have a few time-points available for forest extent, hence there is limited availability to define baselines and trends over a significant amount of time. NCAS provides this opportunity, however the refinement process to an NSW centric product can increase uncertainty.

This correlation indicates that the refined NCAS product is producing an output that is useful and applicable for the NSW project region.

5.5. Categorisation of Outputs for Analysis

In addition to assigning the results of the forest extent analysis process to a grid cell, every grid cell is also linked to, or assigned, other thematic attributes.

For example, a grid cell for which forest extent has been assigned can be linked to a tenure, a land use, an RFA subregion, along with other divisions. For classification of all of the NSW forest extent areas, a wall to wall classification system was established using multiple layers of divisions. This allows any cell with forest extent to be linked back to any number of divisions.

These divisional data layers or themes included:

- Regional Forest Agreement subregions
- Integrated Forestry Operations Approval regions
- Local Government Areas
- Tenure Type
- Landuse
- National Parks and Wildlife Service
- State Forests
- Forestry Management Zones
- IBRA Bioregions
  - Region
  - Subregion
- State Vegetation Type Mapping
  - Formation
  - Class

Each data layer used as a point of classification is to be considered independently of one another. That is, there is no assumed or created hierarchy of data use or categorisation. Some data layers or geographic divisions can sit within one another or provide a higher level of classification. For example, tenure can define if something is public or private, but the National Parks and Wildlife Service layer will define further what public land is divided into. It was not the intention for one layer or input to dictate the grouping of another, hence a level of independence was introduced.

Within a GIS process, each data layer was converted to a grid format, aligned to the forest extent output and processed to the same resolution. Each data layer is then combined into a singular division layer where each unique combination between every input is assigned a unique ID link. In this manner each forest extent grid cell could then be linked back to this unique ID.

Once a unique link for every grid cell is assigned, then the output can be filtered between a desired combination of input layers, along with counts of corresponding grid cells and assumed area metrics. For example, combinations between RFAs, FMZs, and SVTM classes can be quickly filtered and summated based on areas and grid cell counts.

This can be facilitated within a Microsoft Excel pivot table where potentially large datasets can be filtered down into a tailored set of metrics for particular useful combination of divisions.

5.6. Application to the 2019-20 Black Summer Bushfires

As a final step the updated National Forest and Sparse Woody Vegetation grids for the year 2020 were incorporated into the forest extent analysis across all of NSW. Prior analysis for the FMIP project RFA subregions only went up to 2019 as this was the latest data product available from NCAS at initiation of the project.

This new year of 2020 includes the 2019-2020 fire season which captures the impact of the Black Summer wildfires that impacted a large area of the eastern NSW. As input into the assessment of forest extent across NSW, this fire season will have a large impact on forest extent metrics and overall canopy cover.

Prior to applying the pre-processing stages of spatial and temporal refinement, as outlined in Section 5 Method Outline, an assessment was undertaken to determine what the impact of the 2019/2020 fires may potentially be, and if any extra considerations should be given in processing. Through this pre-assessment there were a few noted anomalies in the 2020 NCAS output in fire impacted areas. This included canopy still being present in areas where there was known complete canopy consumption, and artefacts and boundary issues in the output.

To better understand these anomalies in the 2020 NCAS grids, two products were used;

- Fire History Extent for the 2019/20 fire season
- Fire Extent and Severity Mapping (FESM)

The fire extent database was used to narrow the scope of assessment to know fire areas. The FESM product was used as it ranks fire severity from Low - burnt understory with unburnt canopy to Extreme - full canopy consumption. The product is bounded to a spatial boundary, such as known fire extents, so it can exclude some fire impacted areas. It does however provide an assessment of impacted canopy in fire events.

Figure 19 shows the extent and FESM product for eastern NSW. In the FESM panel on the right, the full range of ratings is shown where the black colouration is indicating areas where there was complete canopy consumption.

To assess whether the NCAS forest extent product was providing a full accounting of the 2019/2020 fires, the difference between 2019 and 2020 base products was undertaken to determine areas where there was potential forest extent loss. This output then was used as an exclusion mask against FESM to look at areas impacted by fire that were potentially not assessed correctly in the NCAS layer. Figure 20 provides these mapping views for eastern NSW. The right panel displays the FESM differences, and shows where complete canopy consumption is shown as a deep burgundy. This view suggests there are significant areas of potential canopy loss that is not been covered by the NCAS product. This is particularly noticeable in the Southern and Eden RFA subregions.

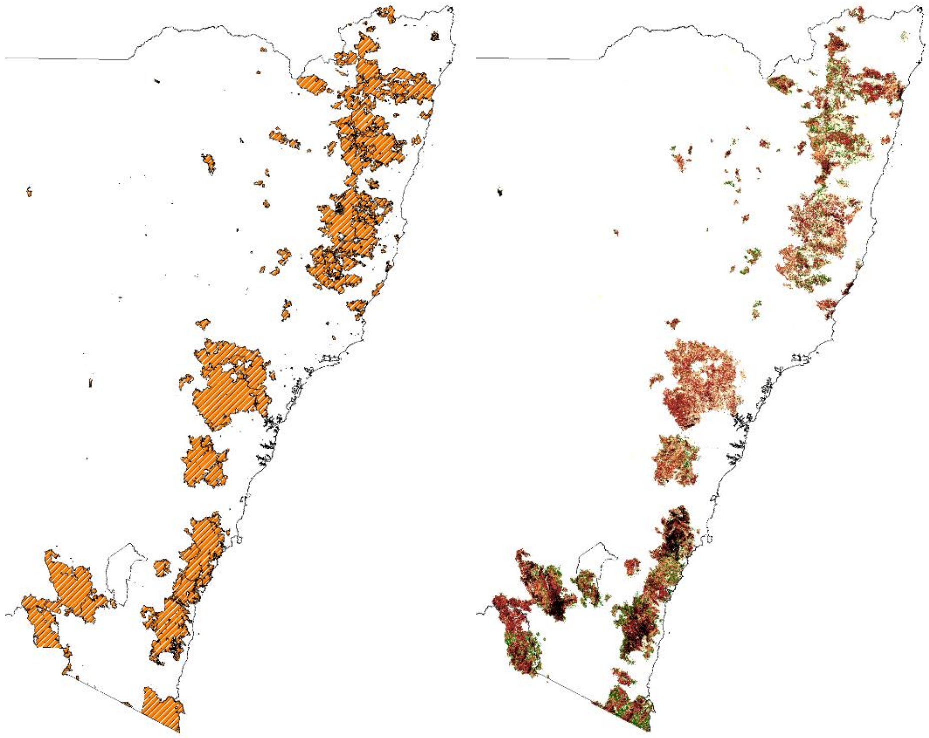

Figure 19. ***Fire extent mapping (left panel) and Fire Extent and Severity Mapping (right panel) for eastern NSW.***

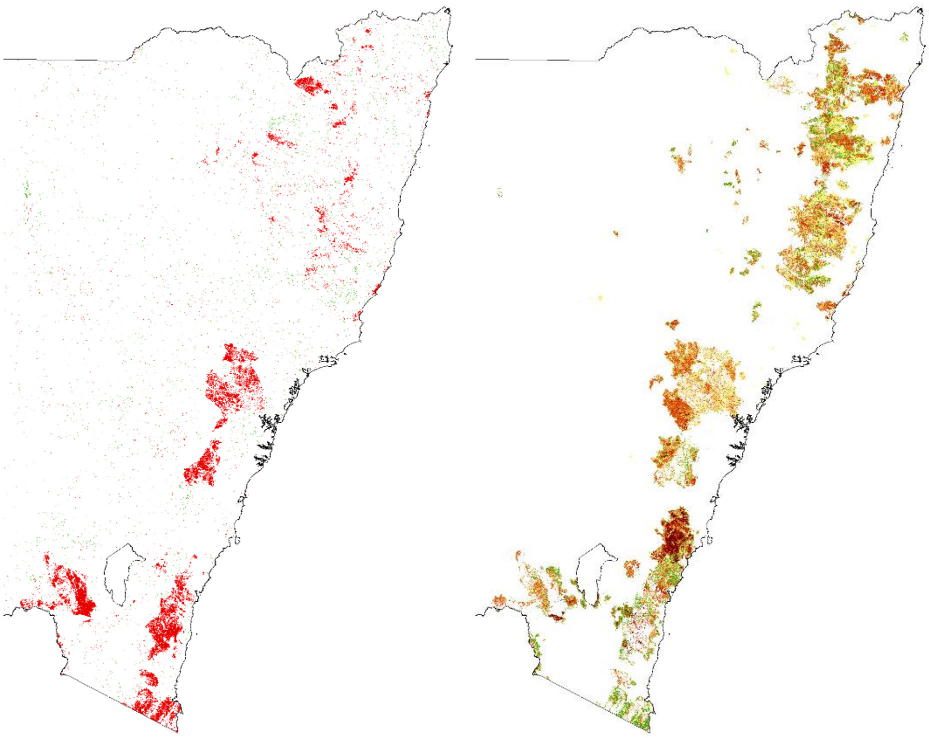

Figure 20. ***Forest extent loss between 2019 and 2020 in the NCAS product (left panel) and potential missed regions according to the FESM product (right panel)***

If a closer review is taken of these potentially missed complete canopy consumption areas, a few anomalies in the NCAS product can be noted, as shown below in Figure 21. Presented are the 2019 and 2020 base NCAS product for forest extent (shown in green) that fall within areas of full canopy consumption indicated under FESM. While there is noted forest extent loss, there are several artefacts noted in the 2020 product. These include clear circular or straight-line boundary issues between forest and non-forest. These appear as hard-line boundaries which do not appear to be a natural occurrence.

Straight line boundaries can be an artefact of differing imagery capture tiles. However, circular boundaries indicate an underlying secondary process that has updated the NCAS product after the fact. This could be due to imagery quality issues such as smoke haze or cloud cover obscuring areas, imagery acquisition dates, or a combination of both.

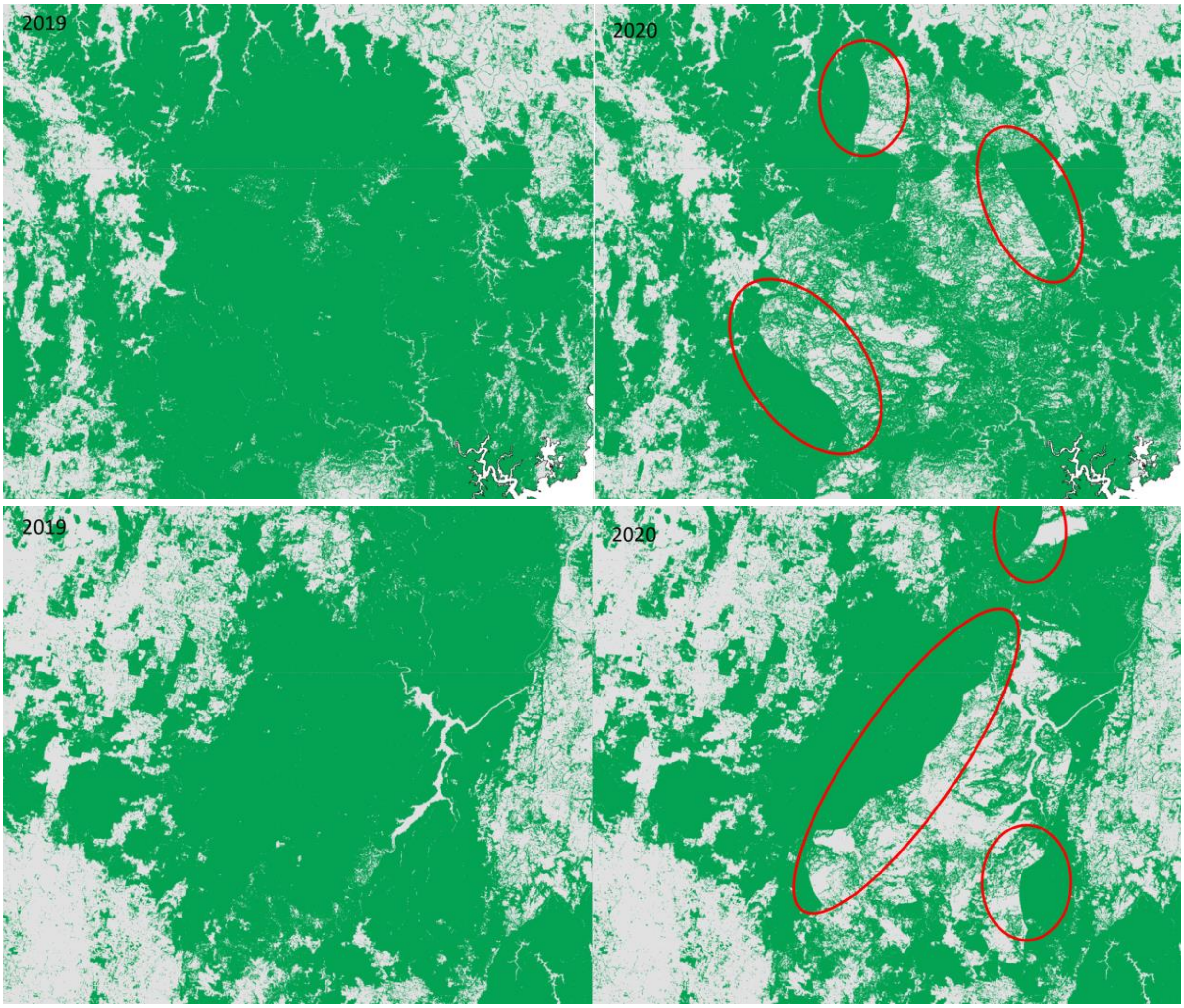

Figure 21. NCAS product outputs for 2019 (left panels) and 2020 (right panels) indicating areas of forest extent loss and areas of interest.

For inclusion in ongoing processing for the full NSW coverage and for the 2020 year, the use of FESM and the full canopy consumption category was integrated into the NCAS product. This was done to address some of the missing fire impacted regions and to clear up some of the noted boundary issues that are NCAS artefacts, as presented in Figure 21.

To integrate the two products, the FESM extreme category was selected as an exclusion mask to use on the NCAS product. Areas that intersected the FESM layer that were indicated as forest were changed to non-forest. This process is shown spatially in Figure 22 where the FESM extreme category, shown in black in the left panels, is used to select out intersecting areas before they are changed to non-forest (and which are shown as green in the right panel).

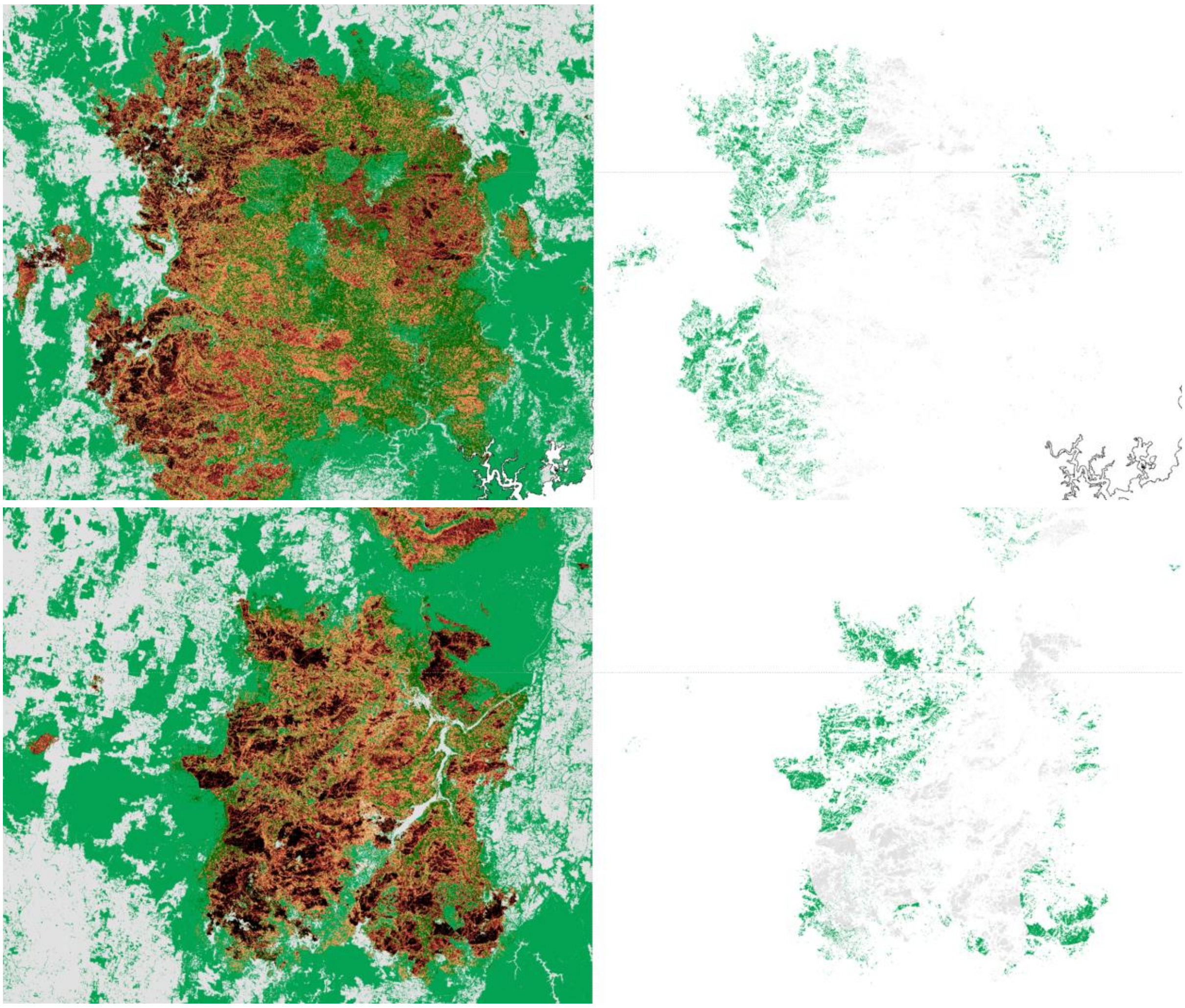

Figure 22. Inclusion of FESM products into the NCAS products in full canopy consumption areas.

6. Application of Outputs

The application of the outlined method on the NCAS National Forest and Sparse Woody Vegetation Database provides a consistent forest extent product on an annualised basis, aside from earlier years where NCAS is biennial.

The products derived from the method outlined above are intended for a number of audiences, including researchers or land managers wanting to apply landscape scale forest extent metrics in a decision-making framework.

As noted in the definitions, the product derived is best applied at the landscape scale for canopy coverage 20% and above. It cannot determine finer scale measures, such as canopy coverage breakdowns or stand heights. It is best used at the large context scale when determining metrics on forest extent or prioritising decisions in a region.

The process outlined is an easily repeatable process when new base extents become available, where the final output is intended to be a more nuanced and locally applicable forest extent product for NSW.

Due to the consistent method application in both the base NCAS National Grids and the refinement of such, historical baselines and trends can be reliably derived to ascertain changes over time. A main intended use of these extent products will be to apply them back against administration and tenure boundaries, as well as IBRA and vegetation types, to derive trends over time in each of these themes.

It is intended that this forest extent dataset for individual years be used in determining metrics and assessing forest extent over time against indicators such as those in the Montreal Process or in National State of the Forest reporting.

Figure 23 presents a diagrammatic representation of the data flow of how forest extent datasets for individual years generated using the process outlined in Figure 1 can be used to derive forest extent change outputs.

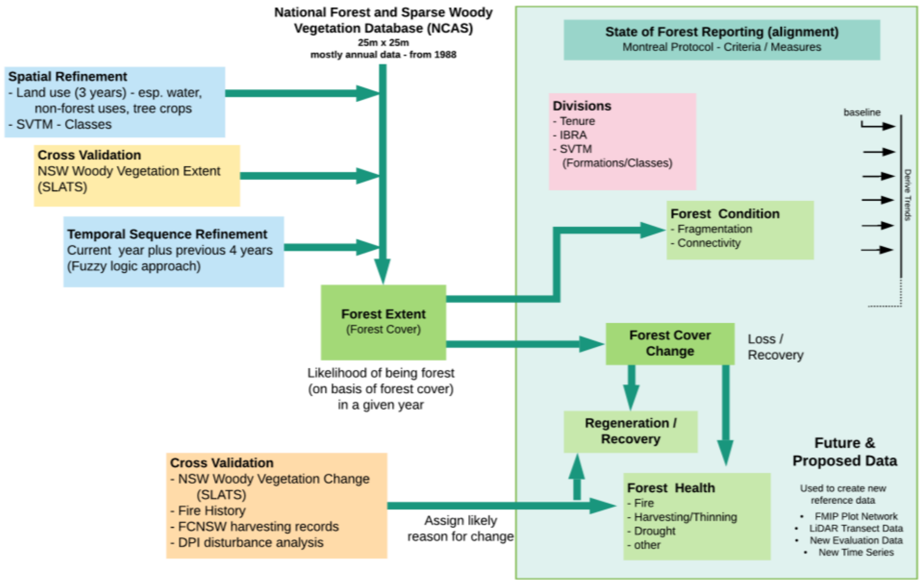

Figure 23. Forest extent product application back into the larger baseline program

The forest extent product, alongside metrics and extents of forest disturbances, can help provide an insight into likely drivers of forest extent change over time. By applying a Multiple Lines of Evidence (MLE) approach that uses available spatial datasets, a project-wide disturbance and disturbance context layer can be generated. This information can be linked back against forest extent change outputs, in particular the differences between individual years, to identify the areas of change and the likely reasons why. Therefore, landscape trends in forest health can be potentially assigned or at the very least investigated.

The time taken, in terms of years, for areas to recover from losses in forest extent can also be determined. This process identifies the time taken for a patch of forest to return to the 20% canopy cover threshold, and other characteristics such as the forest type and likely disturbance or loss event.

Another intended use of these forest extent products is to investigate factors of forest condition, particularly connectivity and fragmentation, including tends over time.

In summary, the forest extent product is viewed as the key input into the development and assessment of a broad number of key forest measures, in addition to generic forest extent over time metrics. This further reinforces the importance of this product being not only consistent, but also ensuring its generation is readily repeatable.

Appendix 1: Acronyms

ABARES	Australian Bureau of Agricultural and Resource Economics
ALS	Airborne Laser Scanner
BAM	Biodiversity Assessment Method
BIP	Biodiversity Indicator Program
CIFOA	Coastal Integrated Forestry Operations Approval
CPC	Crown Projective Cover
DPI	Department of Primary Industries
DPIE	Department of Planning, Industry and Environment
FCNSW	Forestry Corporation NSW
FMIP	Forest Monitoring and Improvement Program
FPC	Foliage Projective Cover
GIS	Geographic Information System
IBRA	Interim Biogeographic Regionalisation for Australia
NCAS	National Carbon Accounting System
NFI	National Forest Inventory
NGGI	National Greenhouse Gas Inventory
NRC	Natural Resource Commission
NRM	natural resource management
OEH	Office of Environment and Heritage
PCT	Plant Community Type
RFA	Regional Forest Agreement
SLATS	State-wide Landcover and Trees Study
SoF	State of Forests
SVTM	State Vegetation Type Map