Forest Monitoring – Loss and Recovery Methodology

Natural Resource Commission

Report 2

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1. Document Purpose

This document outlines the methodology developed and applied to generate forest loss and recovery measures from a forest extent layer for all of NSW as part of an initiative lead by the Natural Resources Commission. 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 document can be read in conjunction with;

- Forest Indicators – Key Indicators, Metrics, and Data Requirements Report that outlines data products and databases that can support the establishment of a baseline and trends in relation to forest extent, condition, and health.
- Forest Monitoring – Extent Methodology (State-wide process) that outlines the process and method used to generate a state-wide forest extent layer from existing data sets and known products.

This report is primarily focused on how existing data products can be used to develop a forest baselines 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

3.1. 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.

Further outlines on this definition is provided in Report 1.

3.2. Forest Loss

The concept of forest health can be linked to all factors being investigated as part of this project, as well as other factors external to this investigation. Measures of condition such as fragmentation and habitat connectivity as well as crown recovery time are related to cover change over time and can be inputs to measurements of forest health. Similarly, ideas of drivers of change, disturbance events and key pressures are integral in understanding forest health.

The data available for application in this project at a landscape scale cannot portray an accurate or comprehensive picture of forest heath. Rather, this project addresses forest change, linked to key drivers and pressures defined in terms of forest disturbances. While these disturbances and associated loss and recovery are not directly a measure of health, they provide some of the many indicators linked to forest health. Forest disturbance and subsequent recovery is a natural process essential to healthy forest systems. The measurement and analysis of these disturbances is therefore, one essential measure of healthy forests. This approach also provides a link back to the Montreal Process Indicators for health.

For the purposes of this project and the reporting of metrics, the aspect of forest health related to canopy loss and disturbances in the forest estate has been investigated. This is related to agents or pressures that affect the capacity of forests to maintain normal ecosystem functions and sustainably provide productive capacity. The measure can be one of many variables associated with forest health.

Our approach for loss was to assess the loss of cover against each of these agents of disturbance and measure the total forest extent loss.

Background to Definition

Overall, there are a number of pressures and disturbance events that will impact the forest estate. Some are noted to be individual in occurrence, but the majority are noted to have linkages and flow on effects to other pressures and disturbances. Climate pressures, for example, can have direct impacts on the forest, but can also drive the distribution and spread of invertebrate pests and plant pathogens, increase the severity and frequency of fires, and help the spread of invasive weed species.

For the purposes of this project, forest loss will be measured by the scale, timing and impact of disturbance events. This could include, but not be limited to, where available data exists;

- Wildfire and prescribed burns
    - Frequency and severity
- Canopy dieback
    - Bell Miner Associated Dieback
    - Other causes
- Plantation and Forestry Operations
    - Native
    - Hardwood
    - Softwood
    - Mixed and Other
- Human-induced disturbances
    - Land clearance
    - Agricultural runoff and other pressures
    - In-forest grazing pressures
    - Urban pressures
- Climate change pressures
    - Drought
- Invasive species
    - Weeds - Exotic introduced species and non-local pests
    - Pest animals and insects

It is noted, of this list, the last two items – climate and invasive species – are relatively data poor for consideration in this phase of the project.

Forest disturbances are considered in this evaluation at a variety of scales based on the data available. Targeted pest control and pest distributions can be very localised actions only reported in certain areas, whereas wildfire scar data and fire severity data are more reported and spatially represented to a regional or landscape scale. A key consideration in the use of a range of disturbance data is to what scale the data is applicable to and if numerous data records can be amalgamated to a uniform and consistent database that reports at higher scales.

Fire has shaped the entire forest estate in Australia with natural fire regimes a major factor in determining the distribution of eucalypt dominated forest. It is necessary across most of the Australian landscape to maintain the condition and health of many ecosystems. Fire is also one of the most significant disturbances to forest ecosystems even if the impacts are part of a natural process.

Wildfires are a common occurrence throughout NSW and there are several key databases that spatially detail and tabulate these occurrences. Similarly, prescribed burns are also spatially recorded and detailed.

The forest extent product will only record loss in the canopy if the fire was of significant intensity to affect canopy coverage. A fire can occur across a large swathe of the forest estate. But if it was of a low enough intensity, i.e., only impacting understory and not canopy, then this will not be detected in the canopy cover product.

Human-induced pressures are observed to be one of the largest impacts on the forest estate. This can include land clearance for agricultural purposes, plantation harvesting operations and other in-forest human pressures, unsuitable or mis-managed fire practices and redirection of local hydrological systems. Clearing of land for agricultural practices, for instance, can fundamentally alter a natural ecosystem.

These disturbances can be recorded from a variety of databases, both spatial and non-spatial. Plantation activity for example, can be spatially defined and attributed by organisations, such as FCNSW, in terms of their extent, type and timing of operations. Hence, these datasets can be leveraged to attribute why canopy loss has occurred and when.

In relation to climate data, there are a number of databases available that provide daily records of temperature, rainfall and other variables. While there is no data available to support forest metrics being directly impacted as a result of climate change, there are several projects underway within NSW DPI that are looking into drought impacts on the forest estate and how to detect and record these, but this is not at a practical product ready stage as of yet.

Climate change is seen to affect a number of pressures on the forest ecosystem such as fire, drought, flood occurrences and severity, and increased heat stresses. Fire frequency and severity is influenced by climate changes in terms of increasing temperatures and reduced rainfalls. Droughts are projected to increase in their frequency, duration and severity in the mid to long term, with droughts impacting on tree dieback and mortality. Also, increases in temperature and increased heat and water stress can lead to tree mortality.

Another major pressure on forest health are invasive weed species and pest animal species. Both are noted to impact on the natural ecosystem cycles and can potentially alter forest composition, condition and subsequently forest health.

Invasive weed species, both introduced exotic and non-indigenous species can potentially out compete native indigenous plant species. This can lead to increased mortality of tree species at a juvenile stage, especially after a disturbance event where weeds can take over an environment.

Pest animals, both vertebrate and invertebrate, are noted to be more an impact on faunal species richness and diversity. Pest animals can outcompete native animals for resources and habitat and may drive out native animals from forest stands. Additionally, pest animals can have a degrading effect on the landscape, for example rabbits. This can cause erosion and other issues in the landscape, irreparably altering the land for healthy forests.

Health Metrics and Indicators

From the Montréal Process Criterion and Australian State of the Forests Report, several key indicators have been identified relating to Forest Health. These can be covered by other measures including Condition.

These include;

- 3.1 Scale and impacts of agents and processes affecting forest health and vitality
    - 3.1a Dieback area for canopy health
    - 3.1b Pest agent affected areas
    - 3.1c Bushfire affected areas
    - 3.1d Climate affected areas
- 3.2 Area and type of abiotic human-induced disturbance
    - 3.2a Area of forest burnt by planned burns
    - 3.2b Area of forest under grazing
    - 3.2c Area of forest cleared

Each indicator would have classifications, or further divisions of the measure, into refined classes including type and tenure. It is suggested for all indicators to divide the values by type and tenure, including all methods of tenure and type classification.

3.3. Forest Regeneration

As described in the project brief, this project attempted to identify a measure of landscape-scale regeneration to fulfill the requirements of the Coastal IFOA monitoring program. During the project, the available data at a landscape scale cannot adequately measure regeneration, as required under Coastal IFOA monitoring program.

As such, the project trialled an approach of landscape scale recovery through the analysis of the period that NCAS grids return back to the 20% threshold following disturbance. This measure of recovery is potentially useful to evaluate the types or scale of disturbances that cause a lasting change to the forest extent.

However, as recovery to the canopy however, does not mean that the canopy has returned to its previous condition. This measure should be used alongside other metrics collected through the on ground monitoring network to provide a richer picture of canopy health and forest condition. Therefore, this indicator will require additional monitoring data to adequately account for landscape-scale regeneration.

Forest regeneration vs Forest recovery

Regeneration refers to a particular forest growth stage that is nearly impossible to measure from landscape scale products, such as NCAS grids. At best, these products can be used to measure when after the loss of crown cover below the threshold for a forest categorisation the canopy recovers to the required thresholds indicating an area can again be classified as forest (or contributing to a forest extent measure).

In relation to forest extent and how it has been defined, the extent grids recognise when an area changes from non-forest or essentially 'bare ground' to the point at which it meets the definition of a forest (as described in the previous section). Therefore, from a data perspective this forest extent change is when a change from an absence to a presence of forest extent occurs as established from the 20% canopy coverage threshold.

Trialled measurement of recovery

The approach trialled for recovery is to assess the loss of forest extent due to a disturbance event and measure the time to which the extent recovers back to the defined threshold as stated in the extent definition. This project applies NCAS data and forest extent grids produced to the 20% canopy threshold to investigate forest recovery.

As an overall definition, recovery can be assessed through several lenses. As a starting point, a common definition of canopy cover recovery can be applied, such as: 'X' years post disturbance event. However, the relationship to forest community type and rates of recovery may further assist refine this definition across all of NSW forests for comprehensive assessment purposes. It is anticipated that different forest types will have different rates of recovery with further variation based on disturbance regime characteristics, such as fire intensity or harvesting operation type.

When relating this concept of recovery in cover to the definition of regenerative growth post disturbance, there are obvious limitations. Recovery on the ground, or in situ, does not relate directly to canopy cover, but rather to growth of vegetation and growth stage progression. For example, while forest extent uses a 20% canopy as a threshold to delineate forest from non-forest, there can be significant recovery expressed in younger forest growth stages that don't meet the 20% threshold. For these areas the estimates of forest extent, and by definition recovery are at best conservative.

The NCAS grids as a base, are best suited to detect presence or absence of forest extent at a particular point in time. This is more a measure related to recovery to a threshold rather than regeneration in terms of growth stages. Therefore, as a general measure, the NCAS grids will be used to measure forest canopy recovery. Recovery in this sense will be defined as the gain of cover at and above the defined measures of forest extent, as outlined above.

This recovery of cover, or loss of, can be assigned back to a disturbance event to provide context as to reasons behind the change in cover. Further, it can be attributed back to a vegetation type or other provision of context on which rules can be assigned.

However, where NCAS can become limited is in the finer measurements of recovery below or above the thresholds for cover detection. The threshold measure used in the NCAS grids is set to a hard limit, there is no percentage canopy above or below this limit in this Crown Projective Canopy (CPC) set measure.

If a Foliage Projective Cover (FPC) is used, it can be trained to provide a continuous percentage scale. However, it is still limited to a focus of forest extent rather than regenerative stages that are not typically defined as forest. These deeper understandings of forest growth stages would be gained from other techniques, including higher resolutions imagery including LiDAR scans and a range of on-ground assessments.

4. Available Data Products for Forest Loss and Recovery

4.1. Loss

Forest loss and disturbance is mainly linked to a variety of natural or man-made disturbances, the scale of which can affect a forest region to be able to restore to a previous or natural state. Overall, these disturbances can be broken into two main categories: natural agents of pressure and human-induced pressures.

Overall, there are a number of pressures and disturbance everts that will impact the forest estate. Some are noted to be individual in occurrence, but the majority are noted to have linkages and flow on effects to other pressures and disturbances.

From a data perspective, measurements of these disturbances can be quite limited. For example, pest animals and weeds are a noted pressure in the forest estate, but records and impacts are often reported at a local scale, if at all. A state-wide database of pest species disturbance data is not available and has not been related back to the forest estate.

Wildfires are a common occurrence throughout NSW and there are several key databases that spatially document and tabulate these occurrences. Similarly, prescribed burns are also spatially recorded. Data products are readily available for fire history including extent, severity and year. As a time-series of disturbance data that can be applied back against the forest extent, which can detail trends and recovery measures after fire events.

The NSW SLATS Woody Change data product can also be leveraged to look at disturbance events in the forest estate. As it is looking at forest loss, it details the reasons behind the loss as well as the point in time. Hence relations back to harvesting operations or agriculture pressures can be derived back against the forest extent.

Most of the assessment on disturbance trends and baselines focus on what data is available, which was mainly fire history and severity data products as well as SLATS Woody Change data products to detail human-induced forest disturbances. This can be applied back against the National Forest and Sparse Woody Vegetation data product from which extent will be derived. Other data products, as noted in Table 1, that can be investigated include any plantation databases or forestry harvesting histories.

Satellite imagery such as from Landsat data can be trained to determine the presence of trees and level of canopy cover, but not forest stand height and growth stage. Of all the measures stand height and growth stage, which can be integral for health and regeneration, are not present in the available data.

Optical satellite imagery such as from Landsat data cannot provide canopy height but numerous other satellites can be tasked to provide high swath overlap for photogrammetric canopy height measures. Measures can alternatively be derived from radar and the new LiDAR satellite products, such as GEDI. Most of these products are currently being used for landscape biomass estimation.

A combination of canopy height measurements and textural object-based image analysis may be an initial approach to mapping landscape-scale forest regeneration.

Some site-specific assessments, such as those undertaken through the Biodiversity Assessment Method (BAM), can determine these measures, but there are no reliable data sets that can presently cover these metrics at a landscape scale resolution. Even canopy coverage and classes are reliant on these on-ground assessments to correctly determine division breakdowns of the forest estate.

Table 1. Current data layers that can be operationalised and processed for forest health and disturbances for use in NSW.

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.
NPWS Fire History - Wildfires and Prescribed Burns	DPIE	1988-2020	N/A – Vector data	Final wildfire and prescribed burn boundaries for every year for which there is data
Fire Extent and Severity Mapping (FESM)	DPIE	2019-2020	Sentinel 2 – 10m	Fire extent and severity based on a semi-automated approach
Google Earth Engine Burnt Area Map (GEEBAM)	DPIE	2020	Sentinel 2 – 15m	Rapid mapping approach to find out where wildfires in NSW have affected vegetation
Bell Miner Associated Dieback (BMAD) Mapping for the Greater Blue Mountains World Heritage Area 2012	DPIE	2012	N/A	Bell Miner Associated Dieback (BMAD) mapping
Bell Miner Associated Dieback (BMAD) Mapping – North East NSW	DPIE	2015-2017		Bell Miner Associated Dieback (BMAD) mapping
NSW Landuse	DPIE	2007, 2013, 2017		Captures how the landscape is being used for food production, forestry, nature conservation, infrastructure and urban development.
Forest Management Zones	FCNSW	2018		Forestry Management Zones by operational types
Forest Harvesting and Disturbance History	FCNSW	Up to 2020		Forestry operations undertaken by FC in NSW
NSW SLATS LANDSAT Woody Change: Derived	DPIE	1988-2006 (biennial),	Landsat – 25m (1988-	Woody vegetation change (loss) based on the analysis of

Vector Database 1988 - 2010		2006-2010 (annual)	2008), 30m (2008-2010)	multi-date Landsat imagery. SLATS method
SLATS - Woody Vegetation Change - NSW 2008-2014	DPIE	2008-2014	SPOT 5 – 5m	Woody vegetation change (loss) based on the analysis of multi-date SPOT5 imagery. SLATS method
SPOT Woody Change Data 2014/15	DPIE	2014-2015	SPOT 5 – 5m	Woody vegetation change (loss) based on the analysis of multi-date SPOT5 imagery. SLATS method
SLATS - Woody Vegetation Change - NSW 2015 - 2017	DPIE	2015-2017	SPOT 5 – 5m and Sentinel 2 – 10m (split by SPOT)	Woody vegetation change (loss) based on the analysis of multi-date imagery. SLATS method
SLATS - Woody Vegetation Change - NSW 2017 - 2018	DPIE	2017-2018	Sentinel 2 – 10m	Woody vegetation change (loss) based on the analysis of multi-date imagery. SLATS method

4.2. Recovery

As described previously, the project attempted to measure landscape-scale regeneration with available data. Significant data gaps exist that show that currently monitoring regeneration at the landscape scale is not possible. The project trialled a process to measure recovery using currently available data. As recovery is a measure of change in the extent over time, there is a requirement of any data product to be a multi-year assessment. This is preferably to be measured on a recurrence of either an annual or biennial time-step, but other frequencies can be considered if regular in spacing.

Also, as a side for any measure of recovery, there can be a requirement to measure why the forest extent has declined. That is, if the forest loss was a natural change such as flood or wildfire, of if the forest was removed through human intervention, such as harvesting operations or agricultural purposes. For this, measurements of disturbance events including location, scale and cause can be required.

As with Forest Extent, under Forest Recovery the two main programs that produce data layers that can be used to determine measures are;

- NCAS National Forest and Sparse Woody Vegetation Database.
- New South Wales woody vegetation change from Statewide Landcover and Tree Survey (SLATS) Method.

The NCAS data product can be utilised as a measure of extent change over time. Its biennial and annual (a two triennial points), can be used to look at a pure measure of change over time without knowing the why of the change.

The SLATS Woody Vegetation change data product is also an instrumental data product to measure recovery and context behind cover loss. In comparison to woody vegetation extent SLATS products, the change data products have been produced to measure forest loss at an annual and biennial basis. A main point of the SLATS products is to detail why a patch of forest has been cleared at a particular point in time. This can be leveraged to produce metrics for IFOA protocol measures. Potentially this can be used against the National data product as a point of reference to why the forest extent has decreased. However, a main limitation is that SLATS only considers forest loss and has no measures for forest recruitment and regrowth.

Main data gaps over each data product that can measure regeneration includes growth stage and stand height. Each product is assessing change to a set threshold of cover and height, there is no differentiation in age class, tree height and overall canopy cover. Without measures of tree age class and height, there can be no measure of age class and effective change over time. The main measure that can only be detected at the current time is when a cleared patch of land reached the threshold as under forest extent.

Table 2 presents the range of data products available to help define and measure forest recovery. As noted, the National Forest and Sparse Woody Vegetation can be used as a primary source, with validation and reference points being supplied from the NSW Woody Vegetation Change layers. There are also available other nationally based gridded data products.

Table 2. Current data layers that can be processed for forest regeneration for use in NSW.

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.
NSW SLATS LANDSAT Woody Change: Derived Vector Database 1988 - 2010	DPIE	1988-2006 (biennial), 2006-2010 (annual)	Landsat – 25m (1988-2008), 30m (2008-2010)	Woody vegetation change (loss) based on the analysis of multi-date Landsat imagery. SLATS method
SLATS - Woody Vegetation Change - NSW 2008-2014	DPIE	2008-2014	SPOT 5 – 5m	Woody vegetation change (loss) based on the analysis of multi-date SPOT5 imagery. SLATS method
SPOT Woody Change Data 2014/15	DPIE	2014-2015	SPOT 5 – 5m	Woody vegetation change (loss) based on the analysis of multi-date SPOT5 imagery. SLATS method
SLATS - Woody Vegetation Change - NSW 2015 - 2017	DPIE	2015-2017	SPOT 5 – 5m and Sentinel 2 – 10m (split by SPOT)	Woody vegetation change (loss) based on the analysis of multi-date imagery. SLATS method
SLATS - Woody Vegetation Change - NSW 2017 - 2018	DPIE	2017-2018	Sentinel 2 – 10m	Woody vegetation change (loss) based on the analysis of multi-date imagery. SLATS method

4.3. 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 orchards. There are three primary land use layers available for use for three time periods; 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 3) outlines some extra notes and details on each of these datasets.

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

Table 3. 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

The National Forest glossary, defines forest health as "*the effect of the sum of the ecosystem processes that together maintain the vitality of a forest ecosystem*". The NCAS grids for forest extent cannot be directly leveraged to account for this full scope of forest health. However, aspects of health that contribute to this whole picture can be investigated. Forest health was therefore not investigated directly as a measure in this project, but rather the approach focused on one aspect of health related to the loss of canopy cover against each agent of disturbance. The key measure pursued was therefore the total forest extent loss per given year per disturbance event type.

Due to the consistent method used in the acquisition and processing of the NCAS National Grid series and refinements, historical baselines and trends can be reliably derived to ascertain changes over time. This forest extent dataset for individual years was 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. The flowchart presented in Figure 1, to the left-hand side provides the high-level approach undertaken to refine the base product into a product that is more suited to the NSW context.

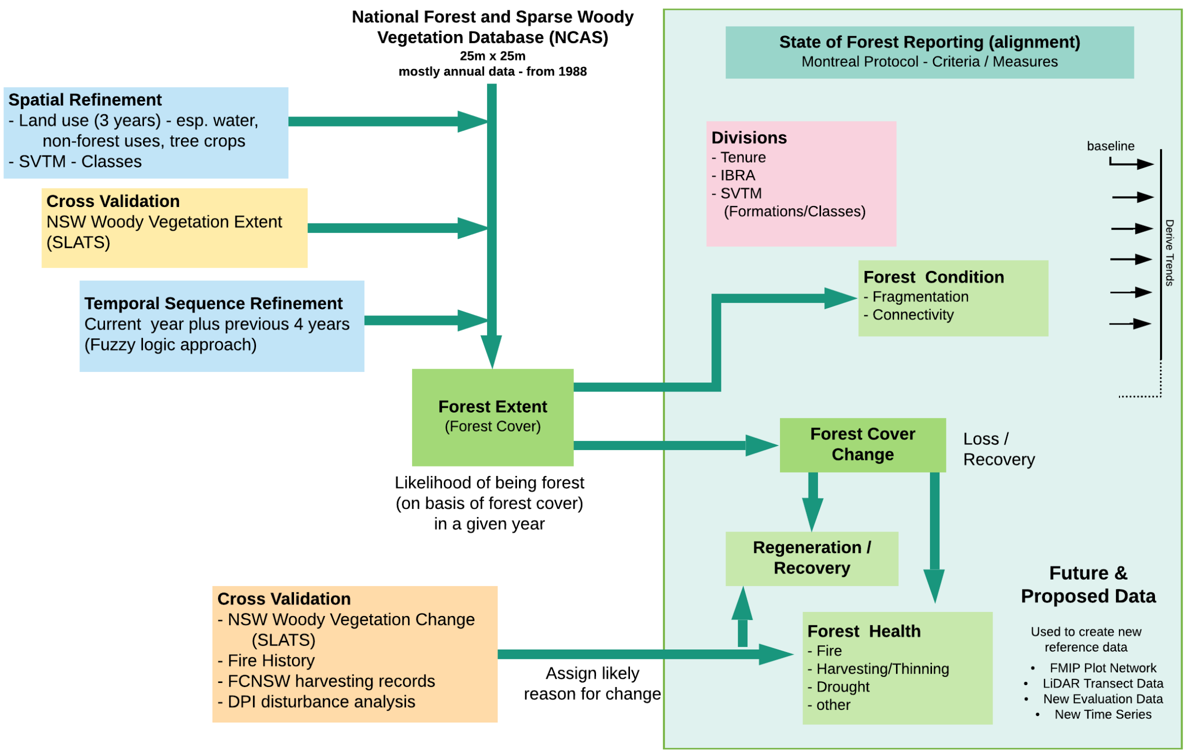

Figure 1. Forest extent method overview

The forest extent product, alongside metrics and extents of forest disturbances, helps 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 was generated. This information was then 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 disturbance drivers of change, as a potential indicator of forest health, can be potentially assigned, or at the very least, investigated.

The below methods section will focus on aspects of regeneration and health as defined to loss or disturbance.

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 interpreted 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.

As previously stated, regeneration is a difficult variable to measure from landscape scale products, such as NCAS grids. As these products are measuring forest extent to set thresholds, forest extent below the limit will not be recorded, or vegetation that is not technically forest yet is not recorded. Regeneration is typically a measure to certain growth stages and can differ across regions, boundaries or forest uses. Hence, there are limitations in the products used to determine overall forest extent in providing a measure of regeneration, particularly when dealing with growth stages.

Regeneration from a commercial standpoint is generally driven by a requirement to assess if there are sufficient trees per hectare to meet future harvesting needs. From an environmental view, regeneration can be used to assess if there is a diverse forest ecosystem post disturbance. Although there is a data deficiency in regeneration above and below a 20% threshold, at minimum, a measurement to assess recovery back to this point can inform if forest extent has not been removed, at least permanently, and if it has the potential to provide to ecosystem services or commercial needs in the future.

The recovery data trialled looking at 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.

5.2. Data Preparation

Regional Analysis

This initial processing of the extent cover grids to calculate recovery is an optional step.

When looking at changes between years, there can be a lot of ‘noise’ in the canopy cover change. This usually presents as single cell canopy loss and edge effects around large contiguous forest estates.

Although the spatial and temporal refinements undertaken in determining forest extent can remove a lot of year-on-year noise, there can be some remaining when looking at differences. Also, it is noted with a portion of these noise cells that they can re-appear in subsequent years. This can be described as a cell ‘flickering’.

This flickering of cover cells can be present if the canopy is right at the 20% threshold, therefore between years it can dip to 18% or 19% in overall cover and then not be counted. This will depend on the environment on which a forest extent cell is located.

To remove some of these cells, a region analysis can be undertaken on the forest extent to group and then remove regions below a threshold. A region analysis groups cells into unique regions by looking at each of the neighbouring cells and their associated value. Large contiguous forest estate areas will be identified as a unique 'region' and smaller groupings down to single cell canopies will also be uniquely identified as a 'region'. The number of cells per unique region will also be recorded.

By applying a threshold or minimum unit of two to four cells per region to be considered 'noise' (i.e., an eighth to a quarter of a hectare), this 'flickering' of cells can be removed. Hence, only larger areas of canopy loss will be counted and measured in subsequent metrics and analysis.

This regionalisation can also be used at later stages and in other processes to identify patches and classify forest area groupings.

Calculation of Loss

The calculation of forest extent canopy cover loss is done between two immediate years in the temporal sequence of cover data, e.g., 2004-2005. This is done to measure an immediate disturbance in the forest canopy cover. The only exceptions in this is if the gap between temporal sequence outputs extends great than a year. This is principally seen in the beginning of the forest extent canopy cover series from 1995 to 1998 to 2000 to 2002 to 2004. Here, the measurement of loss and recovery will be a factor larger, but with no supporting data between years it can only be reported as two- or three-year loss values.

A difference model is employed to calculate loss. That is, between two time points the more contemporary year is subtracted from the older year. The main input into this process is a presence or absence forest extent canopy cover grid. Values are recorded as 0 or 1, therefore there are four possible permutations between these values and three possible scoring outcomes after a subtraction is done:

- 1 – 0 = 1 → Loss
- 1 – 1 = 0 → No Change
- 0 – 0 = 0 → No Change
- 0 – 1 = -1 → Recovery

As is seen, if there is no change between years, the difference also indicates no change. If there is a loss, i.e., the 1 becomes a 0, there is no change in the initial value. If there is a recovery, i.e., the 0 becomes a 1, there initial value becomes negative.

These combinations can be used in this measurement and in the subsequent measurement of recovery.

The difference output is then filtered to exclude out all values that do not indicate a loss. The final output is then saved and the value of 1 is revalued to reflect the year of change. For example, if the difference is done between 2004 and 2005, the loss value is re-scored to 2005. This is then used as a base year on which measurements of recovery can be measured.

5.3. Disturbance Identification – Multiple Lines of Evidence

To measure recovery the increase, or change, in forest extent from non-forest to forest can be measured. This can be done without disturbance events acting as a baseline. It would simply use the existing forest extent dataset and detect where a cell has changed from non-forest to forest.

To measure recovery or change from an actual disturbance event, there is a requirement for an attribution layer to provide evidence for this disturbance. This can include event data including fire extent data or land clearance data, or forest extent loss data. This concept would apply a disturbance dataset, for example fire history data, back against the forest extent dataset and the recovery dataset, as outlined previous. This will attribute a reason behind a cover loss and provide context to the subsequent recovery, or lack thereof.

Through NSW there are a number of data layers and databases that can provide this disturbance context. This includes, but is not limited to;

1. SLATS Woody Change database
2. Fire history
3. Harvesting disturbance history (including Plantation and Native Forestry)
4. Landuse
5. Forestry Management Zones
6. Natural disturbances (including die back)
7. Tenure classifications

Multiple Lines of Evidence Approach

All relevant sources of disturbance attribution are combined in a Multiple Lines of Evidence (MLE) approach, which examines and combines disturbance history data from multiple sources into a logical and consistent disturbance history attribution layer. This is done in order to assign a reason to a disturbance based on the best know data to hand.

The MLE approach employs a hierarchical system where differing sources take precedence over other sources. This is due to higher levels of confidence placed in some data sources over others, or a higher relevance or scale in disturbance type. This can be either entire datasets as a whole, or parts thereof.

For this construction of an MLE disturbance attribution layer, the above noted datasets are used, in whole or in part, to determine a single point of truth for a disturbance. This is done in the 1 to 6 order as outline above.

Data Considerations

The Statewide Landcover and Tree Study (SLATS) woody change database is a primary point of reference, mainly due to the scope of changes it takes note of. In general, it does look at Fire and Plantation changes, but also defines agricultural and urban clearing and natural processes where applicable. Disturbances, such as pest and disease disturbances, are not recorded under SLATS.

The Fire History dataset presents fire extent polygons for recorded fires across NSW and includes both wildfires and prescribed burns. These are presented on an annual basis and presents the full area burnt, including low lying vegetation, as well as large forested areas. Intensity of fire is not recorded. The SLATS database does have records of disturbance in forest by fires, but the Fire History dataset provides a higher degree of confidence.

Locations of Plantations are covered over several data sources. The SLATS woody change does include disturbance history as a result of forestry operations as part of their change reasoning. This can include both for softwood or hardwood harvesting or thinning operations. However, a majority of plantation locations and operation types data attributions come from information sourced from the Forest Corporation of NSW. This includes plantation disturbance history, plantation locations, as well as harvest amount and other such information.

Secondary to these two data sources, landuse layers can indicate broadly where plantations are known to occur. This will break land uses by operation type or use of land, including hardwood, softwood, grazing of native vegetation, amongst other classifications.

Lastly, for plantations and forestry operations, the Forestry Management Zone (FMZ) data layer is used to pick up operational disturbances within FMZs that are unknown in nature. This allows for any disturbance in a forestry area to be recorded and attributed at minimum to the relevant zone, which is more applicable for disturbances of an unknown origin that occur in softwood or hardwood plantation zones. However, this can be overwritten if there is more reliable data describing a higher order disturbance type.

Natural disturbances are an underrepresented database and are only covered by Bell Miner Associated Dieback (BMAD) extent polygons. This is only for a few select years and largely only cover the northern regions of the RFAs in the east of NSW.

The last level of disturbance history used is a general tenure layer. This is used to broadly define where a disturbance occurs if it has not been attributed to another higher order disturbance type. This can be described as a 'catch-all' data layer as it, at minimum, indicates where a disturbance occurs. From this, associations or linkages can be made.

Data Not Included

Two major core disturbance types not covered in this approach include pest and pathogen disturbances and climate related disturbances.

BMAD as a disturbance type is covered, as outlined above. But other pest or pathogen related disturbances that may impact canopy cover are not included in this MLE approach. These types of disturbances have not been covered, or data has not been sourced, for this MLE approach.

Treatment of pest and pathogens may be recorded in non-spatial tabular formats or other logs and records. However, there was no spatial representation of affected area or treatment areas sourced for the project region.

This is a consideration for later updates to this process, if spatial representations can be sourced. This will allow for reporting under indicator 3 under the Montreal Process Indicators.

Climate related disturbances that may impact on canopy cover have not been included in this application of an MLE disturbance attribution layer. This disturbance type is currently under investigation in a separate stream under this project by Christine Stone and Sam Hislop in the NSW DPI.

The DPI project team is investigating how climate related impacts, primarily drought, impacts forest extent canopy cover, how this presents and is detected in the underlying Landsat products and how to attribute this to a disturbance analysis. Although drought is of primary concern, other disturbance types will be bought into this analysis, including fire and forestry operation disturbances.

Although no usable data product that can be incorporated into the MLE process has been produced for this project looking at recovery and loss, this will be a future dataset inclusion and consideration.

This project looking at recovery and loss (Extent, Health, Condition and Regeneration) has been able to receive initial outputs, as a series of validation points, for correlation purposes, from the DPI project team. Some results from the correlation are presented in the next section.

5.4. Correlation

As part of a validation and correlation process to align and assess the outputs from this project to currently underway research projects, a series of sample points was taken from various time points and locations from the outputs and provided to the DPI project team investigating disturbances and drought impacts.

What was provided was about thirty sample points where there was canopy cover loss. This was for areas that were identified to have a large or notable disturbance at a given point in time. There was not set area for the scale of forest extent loss to use as a validation area. The only criteria was whether the disturbance or change in forest canopy cover was evident in the forest extent product.

The identified disturbances as per the MLE was assigned to the point and the year of canopy loss. Similar disturbance years were chosen for a few types, but these were located in various locales. Also, a few unknown disturbances were provided in these sample points to assess what is potentially causing canopy cover loss and disturbance.

The DPI project team took these sample points and ran this against their disturbance database over the whole time period they have available (1988 to 2020). Table 4 details these correlations, with the first two columns provided through this project and the last two columns the identified disturbance from the DPI project team. The purpose was to determine if the MLE approach was identifying and describing a disturbance to the same degree of accuracy as the DPI assessment and if the disturbances of unknown origin could be attributed to some identified factor.

Overall, for each row entry there is a reasonable alignment between the two disturbance databases, with a few notable differences. It should be noted that the DPI analysis on disturbance is a higher magnitude of accuracy over the MLE approach used in this project. The DPI process uses a seasonal change analysis using over 5000 points of reference that were visually attributed back to a disturbance, where disturbance is assessed for a 1ha circular plot at each sampling point.

A few of the nonaligned disturbances from the correlation exercise are presented in the first few rows of the correlation table. The first two rows refer to a recorded wildfire, as per the Rural Fire Service and fire history inputs. The DPI team also identified these sampling points to contain wildfire, but also identified prescribed burns for the second, which is not too much a difference. However, the second point is also noted to correspond with a possible harvesting operation.

The next three rows in the table were provided from unknown disturbances in National Parks, hence the line of evidence for this project was a little tenuous. But spatially, the cover change presented as very sporadic and scattered. It is assumed that this disturbance is due to unidentified environmental impacts within these forested areas that are reducing canopy cover below the 20% threshold.

From the DPI team, there was no identified change or loss during the period indicated, but it was identified as sparse woodland, which does indicate a changeable landscape in terms of cover.

Most of the other sampling points do have a similar disturbance type between this project’s outputs and the DPI disturbance database.

Table 4. ***Correlation table between project sample points and identified disturbances as per DPI project team.***

Year(s) of Disturbance	Disturbance Type	Identified DPI Disturbance	DPI Comments
2017-2018	Fire	Wildfires 1989, 2003, 2020. Prescribed burn 2018	Always
2017-2018	Fire	Wildfires 1989, 2003, 2020. Possibly harvest 2018	Cover temporarily drops below threshold
2005-2006	Unknown in National Park	Wildfires 1995, 2001, 2014, 2020, impacts minor	Always, sparse woodland
2005-2006	Unknown in National Park	Wildfires 2009, 2014 and 2020, prescribed burn 2003, impacts minor	Always
2005-2006	Unknown in National Park	Wildfire 2020, possibly also 2002 and 2016. Possible drought 1995, 2003	Very sparse woodland, possibly not forest
2003-2004	Fire	Wildfire 2003	Cover temporarily drops below threshold 2003
2003-2004	Fire	Wildfire 2003	Cover temporarily drops below threshold 2003
2003-2004	Fire	Wildfire 2003	Cover temporarily drops below threshold 2003
2003-2004	Fire	Wildfire 2003, drought 2007	Cover temporarily drops below threshold 2003
2007-2008	Softwood Plantation	Wildfire 2007, followed directly by clearfell harvest	Temporarily non-forest 2007-2012
2007-2008	Softwood Plantation	Clearfell 2004, followed by burn	Temporarily non-forest 2004-2012
2011-2012	Hardwood Plantation	Clearfell 2012, replanted 2015, wildfire 2020	Temporarily non-forest 2012-2015
2011-2012	Hardwood Plantation	Harvest around 2013	Forest between 2003 and 2012 only
2005-2006	Possible Agricultural Activity	Cleared 2006	No longer forest
2005-2006	Possible Agricultural Activity	Sparse, disturbance 2006	Not really forest, possibly was prior to 2006
2005-2006	Unknown in Private Tenure	Cleared 2006	No longer forest
2005-2006	Unknown in Private Tenure	Cleared 2006	Woody veg cleared 2006, now grass
2017-2018	Fire	Wildfires 1989, 2003 and 2020, possibly prescribed burn or thinning 2018	Cover temporarily drops below threshold following fires

Year(s) of Disturbance	Disturbance Type	Identified DPI Disturbance	DPI Comments
2017-2018	Fire	Wildfire 2002, prescribed burn 2017	Cover temporarily drops below threshold following fires
2008-2009	Unknown in National Park	No major disturbances, possible drought 2004 and 2010	Forest, dry
2008-2009	Unknown in National Park	Wildfires 1991 and 2003, delayed recovery after 2003 fire	Forest, sparse. Possibly below cover threshold from 2003-2011
2013-2014	Softwood Plantation	Planted 2008, wildfire 2014, cleared 2017	Non forest
2013-2014	Softwood Plantation	Clearfell 2014, wildfire 2020	Looks like plantation replanted 2018, not yet above cover threshold
2013-2014	Fire	Wildfires 1994, 2002, 2014 and 2020	Swampy heathland, only just forest
2013-2014	Fire	Wildfires 2001, 2014 and 2020, possible prescribed burn 2011	sparse, probably drops below cover threshold following fires
2007-2008	Hardwood Plantation	Clearfell harvest 2008, replanted 2011	Temporarily non forest 2008-2011
2007-2008	Hardwood Plantation	Clearfell harvest 2008, possible fire after harvest, replanted 2011	Temporarily non forest 2008-2012
2010-2011	Possible Agricultural Activity	Cleared 2010	No longer forest
2010-2011	Possible Agricultural Activity	Cleared 2010	No longer forest
2010-2011	Unknown in Private Tenure	Cleared 2011	No longer forest
2010-2011	Unknown in Private Tenure	Partial harvest around 2012, looks to be revegetating	Borderline forest

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