Forest Monitoring – Condition Methodology

Natural Resource Commission

Report 3

5/12/2022

Project Number SV005822

About This Document

Project Number	SV005822
Project Name	Forest Extent Condition and Health – Monitoring Program
File Name	Method Paper – Spatial Vision – Forest condition methodology
Project Client	Natural Resource Commission
Date of Issue	8/12/2022
Version Number	Final 1.1
Document Title	Forest Monitoring – Condition Methodology
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

Table of Contents

Figures

Tables

1. Document Purpose

This document outlines the methodology developed and applied to generate forest condition 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

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 Condition and Forest Connectivity

An intended use of these forest extent products is to investigate factors of forest condition, particularly connectivity and fragmentation, including trends over time. As such, 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.

Invariably, the measure of condition relies on the delineation of forest extent. Within any forest area condition can be set to measure variables such as tree stand composition, structure and age class as well as species richness and diversity. Therefore, the concept of ‘what is forest’ is linked to ‘what is in the forest’.

Condition, as it relates to composition and structure, can be linked to forest health, in particular disturbance events. Measures of condition before and after events can detail how a forest area is recovering and if it is returning to a post-disturbance condition.

In this essence, condition can be a measure of factors in a forest patch including growth stages, canopy classes and overall height. Certain vegetation communities will have standards and measures for these factors, and any deviation from these baselines can indicate a loss in condition or loss in overall health.

However, under the current usage of forest extent data inputs and how extent and cover is defined, metrics above the 20% canopy threshold and measures within forest stands cannot be adequately measured. These are factors that will require higher resolutions of data inputs and other on-ground metrics.

As an alternative for condition, measures of connectivity and fragmentation are one key metric and can easily be measured and expressed at the landscape scale. This as a metric, is a measure of how well-connected patches of forest are to one another.

This can be assessed in the forest estate by analysing the relative position of a forest patch to other forest patches across the landscape. Spatially, this process is done by assessing nearest neighbours and adjacency filtering. Those that are only showing connections or adjacency to one, or no, patches can be considered to exhibit fragmentation.

Large areas of National Park or State Forest that are relatively undisturbed will be very well connected, hence not exhibit fragmentation. At this landscape scale, these measures can be processed against the NCAS National Forest and Sparse Woody Vegetation data product. As it is suggested to be a main product detailing trends in extent and regeneration, it can similarly be used to detail connectivity measures at this scale.

The NSW Biodiversity Indicator Program (BIP) [1] has developed measures of connectivity which have been applied in combination with estimates of ecological carrying capacity and ecological condition. Through this project the measures of condition, connectivity and carrying capacity are used to define ecological integrity, with each component having a definition of;

- Condition relates to the quality of the habitat by measuring intactness (stand composition) and naturalness (richness and diversity),
- Connectivity details the contribution each patch has to linkages within and between habitats by way of condition and its relative position in the landscape,
- Carrying Capacity assesses the effectiveness of habitat patches to support native species and ecosystems by considering its condition and connectivity within the landscape.

Each of these variables are linked to one another, with condition influencing connectivity, which together can impact on carrying capacity. Overall, a loss in connectivity will increase habitat fragmentation and result in a loss in the capacity of an ecosystem to support species.

Given that the BIP has already established definitions and processes into dealing with connectivity, this baselines and trends project will adopt the same precepts and methods for detailing condition as it relates to connectivity. This project has involved adapting the BIP methods and using the BIP outputs to validate to the adapted processes. The two major differences in the approaches are:

- Levels of aggregation
- Condition dataset

[1] NSW Department of Planning, Industry and Environment, 2020. NSW Biodiversity Outlook Report, Results from the Biodiversity Indicator Program: First assessment. NSW DPIE, Sydney, Australia

How these are addressed and how condition will be implemented and adapted to this project, in relation to methods, will be expanded upon in later sections.

Overall, for the purposes of this project, condition will be concerned with canopy cover connectivity and fragmentation. This will be aligned with concepts and definitions applied in the Biodiversity Indicator Program (BIP) and the Spatial Links methodology for calculating connectivity [2]

Condition Metrics and Indicators

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

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.

[2] Love J, Drielsma MJ, Williams KJ & Thapa R 2020, Integrated model–data fusion approach to measuring habitat condition for ecological integrity reporting: Implementation for habitat condition indicators, Biodiversity Indicator Program Implementation Report, Department of Planning, Industry and Environment NSW, Sydney, Australia.

4. Available Data Products for Forest Condition

4.1. Condition – Connectivity

The Biodiversity Indicator Program (BIP) also contains measures of connectivity which has been applied in the program report alongside notions of ecological carrying capacity and ecological condition. As noted, the BIP measure is also linked back to ideas of condition and carrying capacity. Condition relates to the quality of the habitat by measuring intactness (stand composition) and naturalness (richness and diversity) and carrying capacity assesses the effectiveness of habitat patches to support native species and ecosystems by considering its condition and connectivity within the landscape.

The outputs under the BIP are limited in application. They are noted to be only for a single year, 2013, and are only applied and reported within the BIP report. Outputs are only now being applied across NSW in other forest-based applications. However, with ongoing refinements and validations, as well as creation of time series or multiple static time points, this product could be of use. Within this project, it is suggested to adapt the BIP methods and use the BIP outputs as validations to the adapted processes.

This measure of condition can be covered off by local assessments such as Vegetation Integrity (VI) scores as determined by the Biodiversity Assessment Method (BAM). VI scores and assessments are undertaken to ascertain the structural composition of vegetation communities. A series of assessments undertaken on various components, including an assessment of tree and shrub cover and number of large trees per unit area, and scores are compared against a Vegetation Condition Benchmark.

A limitation of these assessments is that they are done to a plot or local area. Relations back up to Plant Community Types, Vegetation Formations or IBRA Bioregions could present a large amount of uncertainty. Also, a number of these VI scores are done for private organisations, hence releasing of data to form a consistent network of scores can be problematic. However, benchmarks for PCTs and IBRA Bioregions could be investigated to, at least, form a minimum standard of condition to measure against.

Overall, there is a limited collection of data to determine condition in the forest estate. Landscape scale metrics derived from satellite imagery are limited to canopy-based analysis. Older imagery and lower resolution imagery, such as Landsat, are at best used to determine issues at the canopy level. Even newer and higher resolution imagery are best used to the landscape and canopy scale. Traditional remote sensing techniques, such as measurements of Vegetation Indices and biomass calculations can help in assessing condition but are more used in health-based analysis. Disturbance data can also be leveraged to ascertain the why of forest condition. A full listing of disturbance data products is provided under the Forest Health section.

Table 1 presents the range of data products available to help define and measure forest condition. As noted, the National Forest and Sparse Woody Vegetation can be used as a primary source, principally in measuring fragmentation. The Biodiversity Indicator Program data products, as noted, are static in nature and are best leveraged to test out their use for future monitoring programs and act as a validation to derived products from the NCAS grids.

Table 1. Current data layers that can be operationalised and processed for forest condition 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.
Data packages for the Biodiversity Indicator Program: First assessment – Ecological Connectivity	DPIE	2013	90m	Measures the value that each location contributes to the connectivity of habitat in a region
Data packages for the Biodiversity Indicator Program: First assessment – Ecological Carrying Capacity	DPIE	2013	90m	Measures effectiveness of habitat at each location to support native species and ecosystems.
Data packages for the Biodiversity Indicator Program: First assessment – Ecological Condition	DPIE	2013	90m	Measures quality of habitat estimating intactness and naturalness.
Vegetation Condition Benchmarks V1.2	DPIE	2019	N/A	Describe the reference state to which sites are compared to score their site-scale biodiversity values or set goals for management or restoration
Ecosystem Disturbance Index - MODIS, Australia and New Zealand coverage	University of Technology Sydney (UTS)	2000-2013	MODIS Terra and Aqua - 500m	Used to detect the timing, location and magnitude of major ecosystem disturbances such as wildfire, flooding, climate change and human-triggered land use

4.2. Other Data Sources

There are several other datasets that are used in the methodological approach to determine forest extent. These include 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, tree-nuts and vine-fruits. 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 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 2) outlines some extra notes and details on each of these datasets.

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

Table 2. 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 canopy cover and subsequently metrics on condition as connectivity.

This product is not without flaws due to misclassification of wooded areas and similar errors. This database is also a national product, and hence some local nuancing may be lost. The process in which to improve and align this national product to more local NSW conditions is outlined in detail in Report 3. At a high level, the process involved a three-stage process of Spatial Refinement, Cross Validation and Temporal Refinement. 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.

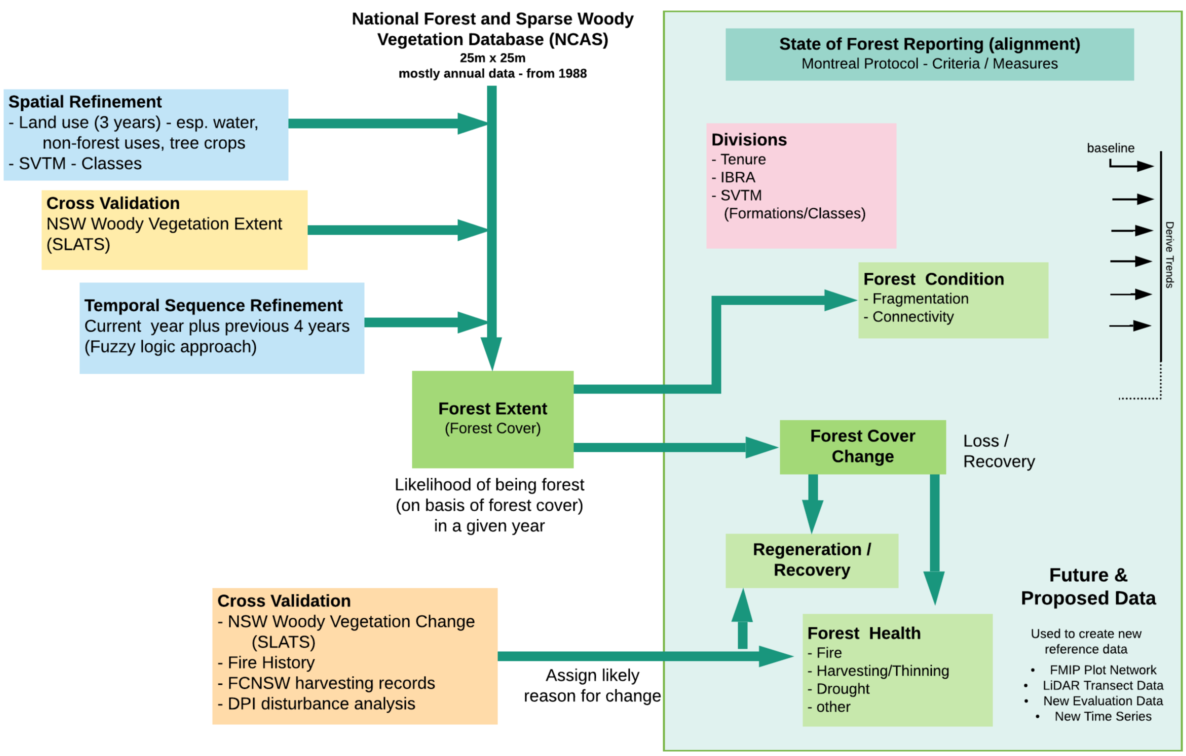

Figure 1. Forest extent method overview

The forest extent product, alongside metrics and extents of forest condition, can help provide an insight into likely drivers of forest extent change over time. The continuation of the diagram in Figure 1 shows how the forest extent product can be leveraged to produce views and metrics for loss and recovery and forest condition.

The below methods section will focus on aspects of condition as defined to connectivity.

By applying existing methods as applied under the Biodiversity Indicators Program (BIP) for Ecological Connectivity, there can be alignment between existing programs and this analysis of baselines and trends.

However, there are a few fundamental differences to the process that will be outlined below. The following sections outline the stages for procuring these views and metrics in more detail.

5.2. Methodology

As discussed, the definitions to connectivity and the applied methodology are to be aligned to the Biodiversity Indicator Program and the associated Ecological Integrity indicators, which covers condition and connectivity. As defined through this program, measures of condition and connectivity relate to:

- Condition relates to the quality of the habitat by measuring intactness (stand composition) and naturalness (richness and diversity),
- Connectivity details the contribution each patch has to linkages within and between habitats by way of condition and its relative position in the landscape.

To undertake an assessment of connectivity across the project area, the methodology outlined in the below reports will be used.

- **Integrated model–data fusion approach to measuring habitat condition for ecological integrity reporting: Implementation for habitat condition indicators** (Love, J., Drielsma, M., Williams, K., Thapa, R. 2020. *Integrated model–data fusion approach to measuring habitat condition for ecological integrity reporting: Implementation for habitat condition indicators*. Biodiversity Indicator Program Implementation Report, Department of Planning, Industry and Environment NSW, Sydney, Australia.)
- **Measuring Biodiversity and Ecological Integrity in New South Wales: Method for the Biodiversity Indicator Program.** (OEH & CSIRO 2019, *Measuring Biodiversity and Ecological Integrity in New South Wales: Method for the Biodiversity Indicator Program*, Office of Environment and Heritage NSW and Commonwealth Scientific and Industrial Research Organisation, NSW Government, Sydney.)
- **NSW Biodiversity Outlook Report: Results from the Biodiversity Indicator Program – First Assessment**. (Department of Planning, Industry and Environment, 2020. *NSW Biodiversity Outlook Report: Results from the Biodiversity Indicator Program – First Assessment.* Department of Planning, Industry and Environment NSW, Sydney, Australia.)
- **NSW Native Vegetation Management Benefits Analyses: Technical report.** (Drielsma, MJ, Howling, G and Love, J 2012, *NSW Native Vegetation Management Benefits Analyses: Technical report*, NSW Office of Environment and Heritage, Sydney.)

Each reference as listed from oldest to more recent, builds on the employed methodology as applied by Love and Drielsma, with the latest application into the BIP being the most developed in terms of defining condition, connectivity and carrying capacity across a landscape.

As defined in Love et. al., (2020) "*Ecological connectivity measures the effectiveness of each location as a connector of contemporary habitat across ecological scales. It estimates each location's contribution to the ecological carrying capacity of surrounding habitat and is determined for each location by its ecological condition, as well as 'least cost path' connections between habitats that traverse that location*".

To undertake all the processing and analysis used to create these concepts, Love and Drielsma have built the process into an executable application run off a computer. This program is called the Spatial Links Toolkit which is currently in version 4.0 (Love, J., Drielsma, M., 2021).

This process calculates these 'least cost paths' between two points across a landscape, accumulating the value of connectivity at every location of transversal. In this manner of accumulation, locations that are more frequently travelled, are traversed by a connection with a higher connectivity values, or connect two areas with a higher condition score, will have a higher connectivity value.

This process has an ability to consider and run across any ecological scale. As part of the process, it employs a multi-scale analysis approach where inputs are scaled up or down in order to reflect differing ecological scales (Love et. al., 2020). For each analysis scale being considered, the raster input resolution is scaled appropriately, and the connectivity analysis run. All outputs are merged back into a final output which is processed at the highest, or base, resolution.

Within the BIP project, this multi-scale approach is run over seven levels. That is, the base raster resolution of 90m is doubled in resolution seven times up to a maximum 5,760m. For each level, the connectivity analysis is run and the least cost paths determined.

Further discussion on these concepts applied within the Spatial Links Toolkit and the overall methodology are found in Love et. al., (2020).

Data Differences and Considerations

Between the Biodiversity Indicator Program output and the NCAS connectivity output there are a number of notable differences. As input into the Links Toolkit to calculate connectivity, a condition dataset is required. As per the BIP definition for condition, the data represents the quality of the habitat by measuring intactness (stand composition) and naturalness (richness and diversity).

This condition dataset, for the Links Toolkit, is meant to indicate a presence or absence of vegetation. This can be a binary input, as present or absent, or this can be a continuous value scale with values indicating condition or habitat intactness.

For the BIP input, this data is represented on a continuous scale of 0 to 1, where values closer to 1 indicate a higher condition value, as seen in Figure 2. This condition dataset for the BIP project is one of the three indicators used to define ecological integrity and by itself can provide some indication of condition. The layer provides condition for all vegetation, both forested and non-forested areas. Hence, this can provide values between forested areas.

In relation, the NCAS input is only presented as a binary input, as seen in Figure 2. Values are either presence or absence as it relates to forest extent and is tied back to the overarching definition for extent cover.

An important note here is that the BIP input provides value between large vegetation bodies, whereas the NCAS input will only indicate these areas as non-forested. Hence, any subsequent connectivity will reflect this difference or absence in value.

Conversely, within large vegetation bodies, the continuous scaling for condition in the BIP input will continue, i.e., not all contiguous vegetated areas will have a high condition score. Mainly the values increase from the edges into the interior of vegetated areas. In comparison, the NCAS forest extent grids will only present a binary view, present or absent.

The development of this condition layer for the BIP project was derived using an approach to estimate the intactness and naturalness of vegetation. It combined direct remotely sensed values of cover with inferred values from a range of relevant sources and expert interpretation of relationships of vegetation to condition. The approach was based off a statewide vegetation condition model from 2010 for NSW that was designed to infer biodiversity benefits of native vegetation management. Full details can be found within the methodology report *Integrated model–data fusion approach to measuring habitat condition for ecological integrity reporting: Implementation for habitat condition indicators* (Love et. al., 2020).

In itself, this condition layer was a derived product combining woody, non-woody and ground assessments into a unified output. This is similar to other applications of a continuous condition raster created by the BIP team, as applied within other baseline projects in the FMIP program. Other applications have seen a *relative intactness* condition layer created using a similar method with sample validation points rather than a range of relevant sources.

However, for application into this FMIP baselines and trends project, condition will be related back to the BIP concept of connectivity. A major reason for this was the relation of the concept of connectivity, and conversely fragmentation, back to the Montréal Process Criterion, under indicators of ecosystem diversity– 1.5: Fragmentation. This also links back to National and NSW State of the Forest reporting indicators.

The other main reason behind using connectivity as a measure of forest condition was the translation of forest presence or absence back to a condition rating. As input into a connectivity analysis under the BIP methodology, condition is a necessary input. However, this can be a simple presence or absence input rather than a continuous scale input.

Hence, in comparison to the BIP input, the NCAS input does not provide a nuanced condition input. However, it is still a reasonable input to the Links Toolkit (pers comm. Love & Drielsma, 2021) and these binary inputs for other projects have been applied post BIP.

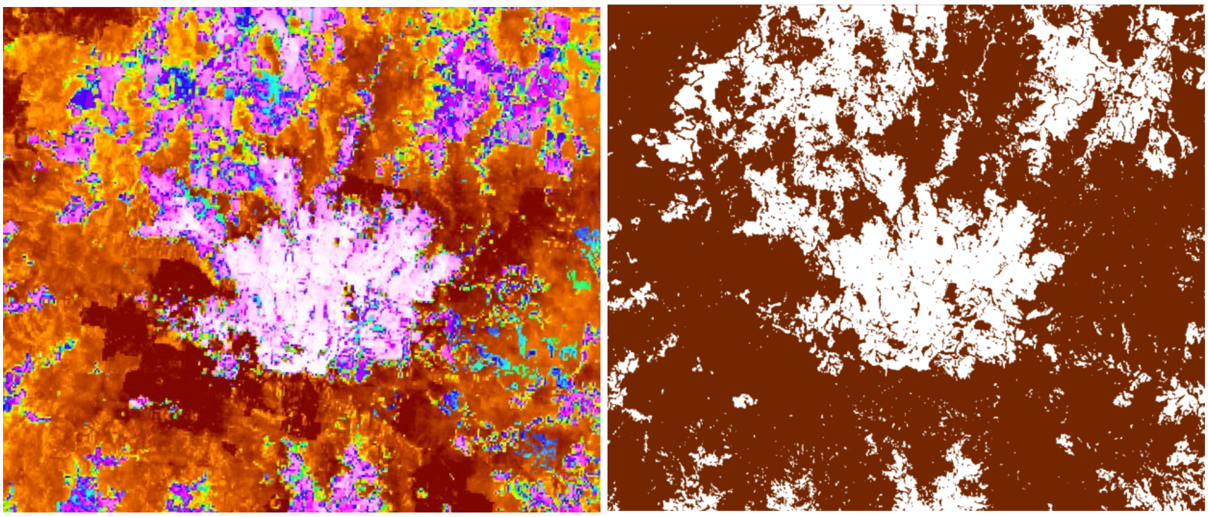

Figure 2. Condition comparisons between Biodiversity Indicator Program inputs (left panel) and NCAS forest extent inputs (right panel).

The other key difference between the NCAS approach and BIP approach is how the methodology has been adapted for this application in the baselines and trends project. As outlined in the previous methods section, the BIP connectivity is run across multiple levels of resolutions, or multiple aggregation levels. This is done up to eight levels from the base 90m resolution to 5.760m. All these outputs are then merged together back to the native resolution to provide a final connectivity output, as seen in Figure 3.

For application to the forest extent grids as developed for this project, only three levels of aggregation have been run before merging back into a singular data layer, 25m, 50m and 100m, as seen in Figure 3. This does provide a detailed connectivity output, however, some of the higher-level connectivity that is calculated at the larger levels of aggregation can be lost.

This modified application to levels of aggregation is still a valid approach and was suggested by the original authors of this method (pers comm. Love & Drielsma, 2021) in order to cut back on processing times and resources.

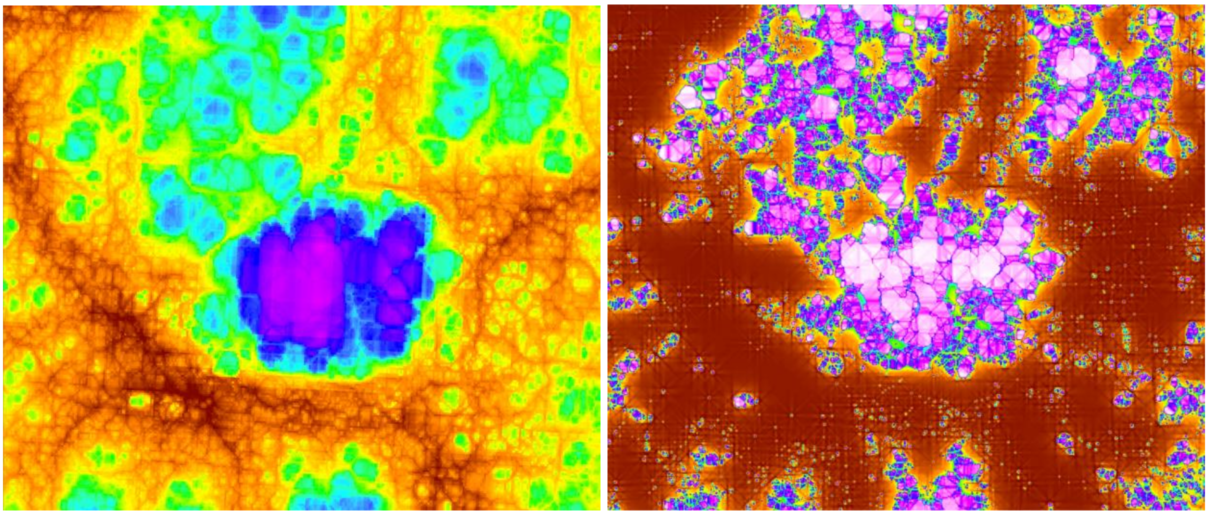

Figure 3. Connectivity comparisons between Biodiversity Indicator Program inputs (left panel) and NCAS forest extent inputs (right panel).

5.3. Validation of Outputs

To provide a level of confidence in the NCAS connectivity outputs, as derived from the Links Toolkit developed for the BIP project, comparisons will be drawn between the known and validated BIP output and equivalent NCAS outputs.

For the Biodiversity Indicators Program, the Links Toolkit was run for one static year time point of 2013. This was done to a 90m resolution across all of NSW. For this validation process, an equivalent year will be used from the processed NCAS connectivity grids. Further, validations will be run both at the native NCAS 25m resolution and at the comparable 90m resolution, as used in the BIP outputs.

A. BIP connectivity output, 2013 at 90m resolution
B. NCAS connectivity output, 2013 at 25m resolution
C. NCAS connectivity output, 2013 at 90m resolution

Another point of validation and comparison will be to look at both what happens within forested areas and also what happens between forested areas. The measure of connectivity is concerned with connections between forest fragments and the linkages that may exist. Therefore, validations should be run to look at only these areas as well. Overall, there will be four points of validation to be run.

The relevant grid products will be randomly sampled over 5,000 points across all the project area. This is both done for the whole extent area, including forested and non-forested areas, and also constrained only to the non-forested areas. Of the random sample points generated for both forested and non-forested areas, the majority of points at about 95% were generated within forested areas.

To run the comparisons and validations, a Pearson's Correlation coefficient will be determined for each of the four differing points of comparison. These results will be presented below.

Results

The four points of comparison for validation purposes and the randomly sampled data points across the project extent was run through a Pearson's Correlation Coefficient. This test is a measure of linear correlation between two sets of data and provides a value range output between -1 and 1. Values that exhibit higher positive values towards the value of 1 indicate a strong positive correlation, lower negative values towards -1 show a strong negative correlation and values closer to 0 indicate no correlation at all.

Pearson's was used here as we are directly comparing two similar outputs that were run under similar methods. The only major difference is the condition input to the Links Toolkit. Higher positive outputs to a Pearson's would indicate that there are correlations between the two outputs and that the forest extent woody grids, as produced in this baselines and trends project, are suitable for connectivity analysis and outputs are useable for analysis.

Table 3 presents the outputs to the Pearson's Correlation over the four methods of comparison. All resultant values in each of the four tests are sitting at about 0.50. This, while not a highly positive correlation closer to 1, still does indicate a positive correlation and a degree of similarity between the original BIP outputs and the outputs as generated for this project.

Table 3. Pearson's correlation results between each points of comparison.

Comparison	Across whole Extent	Within Non-Forest Areas
A vs. B	0.482092	0.505829
A vs. C	0.486969	0.482474

Further lines of comparison can be drawn in

Figure ***4*** and

Figure ***5*** where scatter plots are presented comparing the randomly sampled forest extent connectivity outputs with the BIP outputs for points between vegetation bodies (

Figure ***4***) and for points over the whole project extent (

Figure ***5***). With all plots, the positive correlation can be noted from the line of best fit presented. This, as from the Pearson's Correlation results, is not the strongest relationship. However, given the differences both in the condition inputs into these connectivity outputs, as well as the adaptation of the method for this baselines and trends project. Both the Pearson's results and the trends exhibited in the scatter plots show a strong relationship and point to the connectivity results being fit for use.

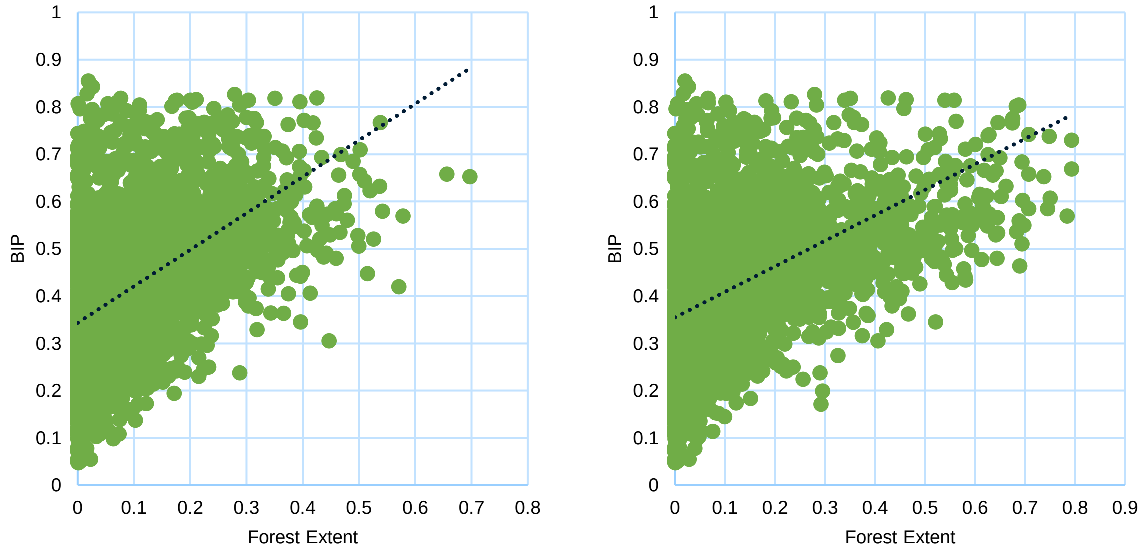

Figure 4. Scatter plot comparison for connectivity within non-forested areas, 90m NCAS c.f. 90m BIP (left panel), 25m NCAS c.f. 90m BIP (right panel).

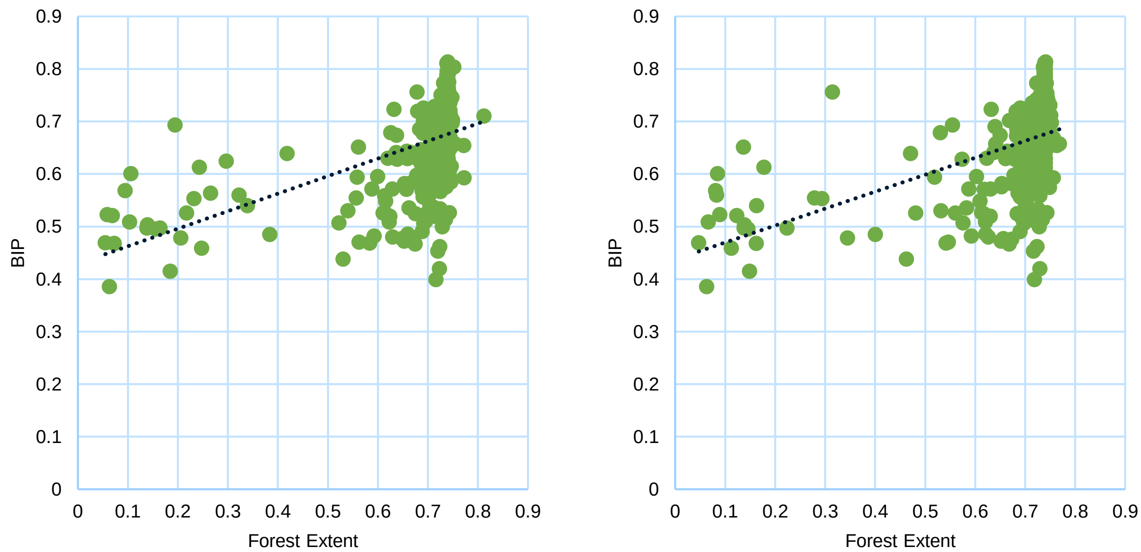

Figure 5. Scatter plot comparison for connectivity within forested areas, 90m NCAS c.f. 90m BIP (left panel), 25m NCAS c.f. 90m BIP (right panel).

6. Application of Outputs

For each of the years in the Forest Extent outputs, the connectivity analysis was run. This was done on the full project area and included both the areas with forest and the areas in between. As discussed, outputs into the connectivity are for both the interior of forest estates as well as the connections between these areas.

To develop a series of metrics and begin to understand the baselines and trends over time, each of the year on year outputs were assessed for two key metrics;

- average connectivity, and
- maximum connectivity

The average connectivity for an area should detail the general terms of connectivity and hence fragmentation over time. Changes in connectivity year-on-year or between reference periods will give a general notion of increased condition. Greater connectivity means greater dispersal and movement of species, better cover and habitat for faunal species and more connectivity indicates larger canopies which may point to larger trees within an area. This ideally should align to key disturbance events and other shifts in the forest estate. It is a good reflection back to forest extent metrics, as outlined in previous sections, more extent indicates greater connectivity. But also, invariably links back to health or loss metrics relating to disturbances.

The maximum connectivity metrics for an area should detail how the interior forest patches, or those patches in good condition, are behaving or responding to external influences. This will depend on the types or uses of forest as well as external disturbances. But conceptually a continual high value would indicate that the forest patch is stable and in good condition, any declines from a normal trend would indicate an area being disturbed or falling in condition. Changes or dips in maximum connectivity should return back to a stable stage rather quickly, if not there could be a more serious problem within the forest estate pointing to a decline in condition.

Maximum connectivity metrics relate back to the forest estate and the connections within a patch of forest, whereas average connectivity relates back to connections between forest patches. A change in maximum is a driving metric for considering the condition in forest estates. But average is also important as a factor of condition as it indicates good dispersal and connection for genetic diversity and seed dispersal.

Minimum connectivity was also considered as a metric. But after a review, values for this were always at 0. So, they were determined to be of not much use.

These measures of average or maximum connectivity, can be applied against several differing divisions, including;

- RFA Subregions
- Tenure
- State Vegetation Types
- IBRA Bioregions

Linkages to other measures, including loss and recovery (health and regeneration), are not made directly between the connectivity outputs and prior work. However, inferences and linkages gleaned from prior work can be made. For example, changes in connectivity may be linked to fire disturbances or plantation operations, which in turn can be assigned to loss and recovery metrics and divisions by type and tenure.

Overall, these metrics are presenting a landscape scale of connectivity measures for the monitoring of trends. These are not able to produce the local or ground-plot scale of connectivity or condition metrics associated with growth stage or canopy composition. However, the landscape trends can highlight and prioritise these on-round local issues and allow for pointing out locations where a deeper-dive may be required.

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