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Environmental lands study for Cessnock LGA

A spatial database for the Cessnock LGA

Department of Climate Change, Energy, the Environment and Water

Acknowledgement of Country

Department of Climate Change, Energy, the Environment and Water acknowledges the Traditional Custodians of the lands where we work and live.

We pay our respects to Elders past, present and emerging.

This resource may contain images or names of deceased persons in photographs or historical content.

Artist and designer Nikita Ridgeway from Aboriginal design agency Boss Lady Creative Designs created the People and Community symbol.

Cover photo: Quorrobolong Scribbly Gum Threatened Ecological Community. Mark Cameron/DCCEEW

Published by:
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ISBN 978-1-923285-06-4
EH 2024/0215 July 2024

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Summary

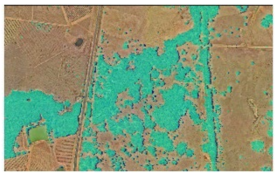
The Department of Climate Change, Energy, the Environment and Water's Biodiversity, Conservation and Science – Regional Delivery collaborated with Cessnock City Council in 2021 to 2022 to deliver a report and package of spatial data layers to inform an environmental lands study. It comprises 6 comprehensive map layers that collectively cover the entire Cessnock Local Government Area (LGA) and identify lands of environmental or ecological value.

This information can be used to enable informed landuse planning, environmental protection or conservation investment decisions, and to support local or regional environmental initiatives. This study verifies a best practice model to deliver evidence-based biodiversity data at a precise scale to fulfil stakeholder expectations and improve NSW Government service delivery outcomes for landuse planning and biodiversity conservation.

The 6 map layers, their function and a small example of each map is provided below.

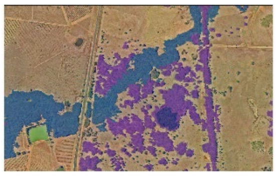
Woody vegetation

This layer is critical for accurate establishment of vegetation extent.



Vegetation

This layer provides a mosaic of 78 plant community types across the LGA.

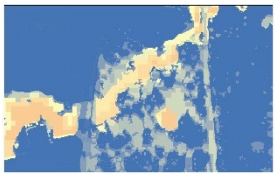


Corridors

This layer provides a landscape solution for the maintenance of connected habitat to support persistence of species.

Environment

This layer built on an Integrated Infrastructure Planning Tool used to consider ecological integrity and cost-effective urban planning.



Streambanks

This layer maps all streambanks of larger streams and applies a 40 m buffer to mitigate impacts of development too close to waterways.

Tenure

This layer shows what land is managed privately compared to publicly managed land.

Background

The Biodiversity, Conservation and Science – Regional Delivery in the Department of Climate Change, Energy, the Environment and Water (the department) is responsible for the delivery of environmental conservation programs across New South Wales (NSW), including through the Saving our Species program. The department works in partnership with other government agencies, landowners, research institutions, private organisations and the broader community to enable conservation of native animals and plants across public and private lands.

Cessnock City Council committed to undertake an environmental lands study to identify lands of high environmental value in consultation with the local community and to develop an environmental zoning framework to facilitate council's review of their local environment plan (LEP). The study identifies lands of high environmental value and develops an environmental zoning framework for the future.

In November 2020, the department and Cessnock City Council formed a partnership via a memorandum of understanding (MoU) to develop an environmental lands study to identify areas of high environmental value in consultation with the local community. The MoU agreed that the department would provide:

- spatial layers to enable informed decision-making
- content for communications supporting the study
- technical guidance supporting the study.

Cessnock Local Government Area

The Cessnock Local Government Area (LGA) is located 120 km north of Sydney and 40 km west of Newcastle in NSW (Figure 1). The population of almost 60,000 residents reside in urban, semi-urban and rural landscapes with European settlement dating from the 1820s. The LGA covers 196,468 ha and supports a variety of landuses and social and economic activity, including tourism, wineries, education, industrial areas and town centres.

Traditional Aboriginal Custodians of the land are the Wonnarua, Awabakal and Darkinjung peoples. The LGA is host to areas of culturally significant lands and sites of Aboriginal significance identified by community. NSW National Parks and Wildlife Service (NPWS) estate occupies almost a third (29%) of the LGA, including the Watagans, Werakata and Yengo national parks. Cessnock City Council, NSW Crown Land, Forestry Corporation of NSW, Department of Defence, and land under stewardship by the Biodiversity Conservation Trust occupy almost 14% of the LGA. Cessnock City Council owns and manages 0.36% of the LGA, and freehold land represents 51% of the LGA.

The Cessnock LGA is a biologically diverse region that supports over 120 threatened plants, animals and ecological communities. It lies at the convergence of several environmental and climatic influences from the north, west and east. It is bisected into 2 types of landscapes. The western half is dominated by the rugged and dissected sandstone plateau of which large parts are protected within the Greater Blue Mountains Area World Heritage property. The eastern half contains some of the largest vegetation remnants left in the Hunter Valley, including temperate dry woodlands that provide key habitat areas for woodland birds such as the critically endangered regent honeyeater (*Anthochaera phrygia*) and swift parrot (*Lathamus discolor*). Some threatened species only occur in Cessnock region, such as the North Rothbury persoonia (*Persoonia pauciflora*) and Pokolbin mallee (*Eucalyptus pumila*).

There are a number of threats to Cessnock's unique biodiversity, including:

- landuse and development pressures
- fragmentation and degradation of habitats
- high-intensity frequent fires
- weeds and pest animals
- climate change
- in some cases, a lack of awareness and stewardship by the local community.

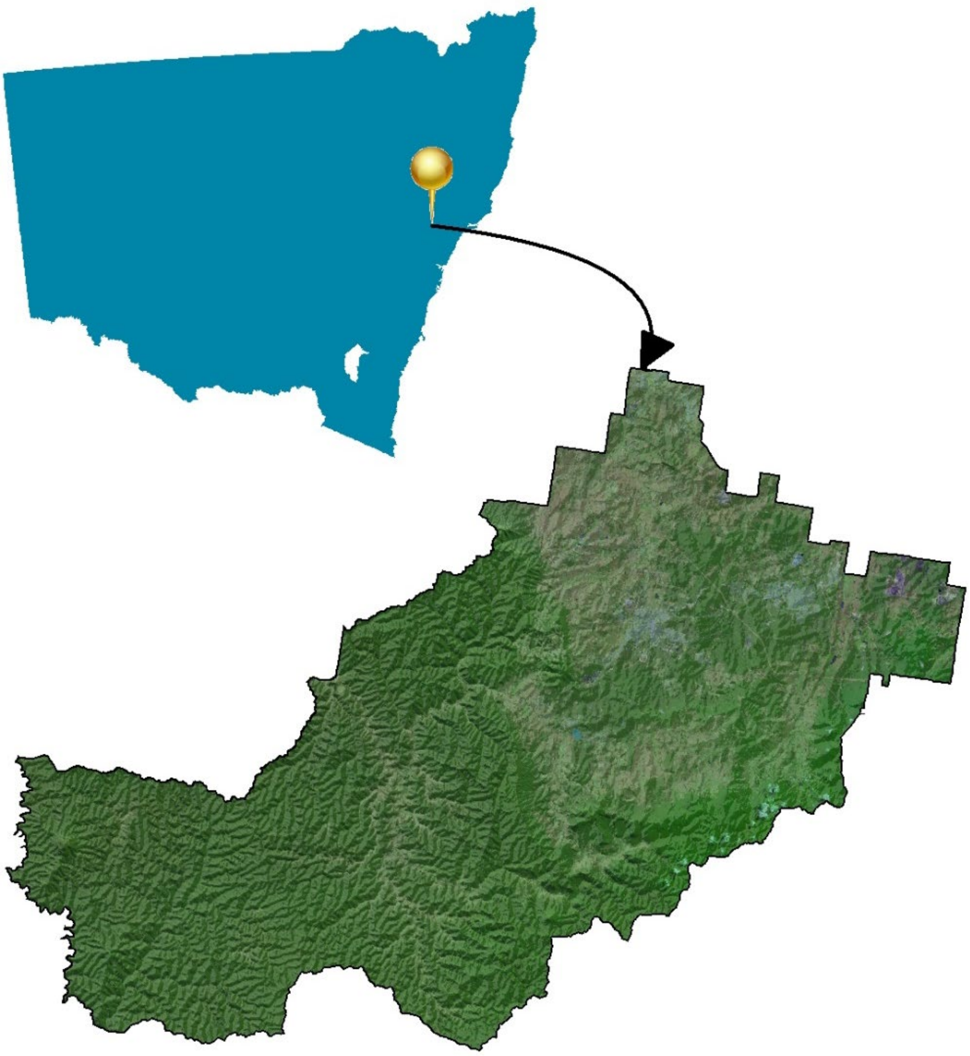


Figure 1 Location of the Cessnock Local Government Area within tNew South Wales

Statutory framework

Cessnock City Council is the authorised regulatory agency for planning and development approvals in the Cessnock LGA and maintains a local environment plan (LEP) that establishes criteria for landuse. LEPs guide planning decisions for local government areas through zoning and development controls. Environmental planning instruments such as LEPs are statutory instruments under *Environmental Planning and Assessment Act 1979* that provide a local framework for the way land can be developed and used.

Cessnock City Council committed to undertake an environmental lands study to identify lands of high environmental value in consultation with the local community and to develop an environmental zoning framework to facilitate council's review of their LEP. The study sought to identify lands of high environmental value and develop an environmental zoning framework for the future.

This report and accompanying map layers identify lands of environmental or ecological value which can be used to inform the environmental lands study and enable informed landuse planning and conservation investment decisions.

The threatened species and ecological communities mapped in the study are protected under the NSW *Biodiversity Conservation Act 2016*, and some species are also protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

A buffer of 40 m was applied to mapped streambanks to ensure that any development or other activities consider the recommended riparian corridor widths as specified under the *Water Management Act 2000*. This map layer can help meet the objectives of the controlled activities provisions of the Water Management Act to establish and preserve the integrity of riparian corridors.

Method

The development of each layer involved an initial audit of existing data and expert review to ensure outputs would be fit-for-purpose. The method for each dataset is explained in more detail in appendices A to F. The geographic information system (GIS) used for the environmental lands study was ArcGIS. ArcGIS is used to view, edit, analyse and create geospatial data and allows the user to create maps and explore data. Production of each map layer in the study required consideration of the following criteria:

- quality, accuracy and long-term application of data
- repeatability
- evidence-based data
- baseline data to inform future trends
- local-scale planning decisions that meet stakeholder needs.

The production of each map layer (or dataset) required expert ecological skills, specific expertise in spatial analysis, industry-specific and technical knowledge. A glossary of technical terms and acronyms used in the appendices is provided in Appendix G.

The woody map layer was completed first because it provides an important foundation that most other layers are built on. The vegetation layer was completed next as it provides detailed floristic information for the woody layer. The corridors layer required both the woody and vegetation layers to establish the location of quality habitats and the connectivity between. The environment layer depends on all 3 of these layers to capture significant environmental features. The streambanks layer was manually derived from high-resolution LiDAR (laser imaging detection and ranging) to accurately define streambanks. The tenure layer captures all tenures across public and private lands.

All layers were provided to Cessnock City Council in May 2022.

Map layers

The 6 layers that cover the Cessnock Local Government Area are provided in summary in this section.

Woody vegetation layer

This dataset delineates woody vegetation at a fine scale across the Cessnock LGA (Figure 2). All tenures were mapped excluding NPWS estate because it is formally reserved and protected under LEPs. Data is in vector (i.e. polygon) format and was produced to a scale range of 1:500 to 1:3,000. Production of this layer is discussed in Appendix A.

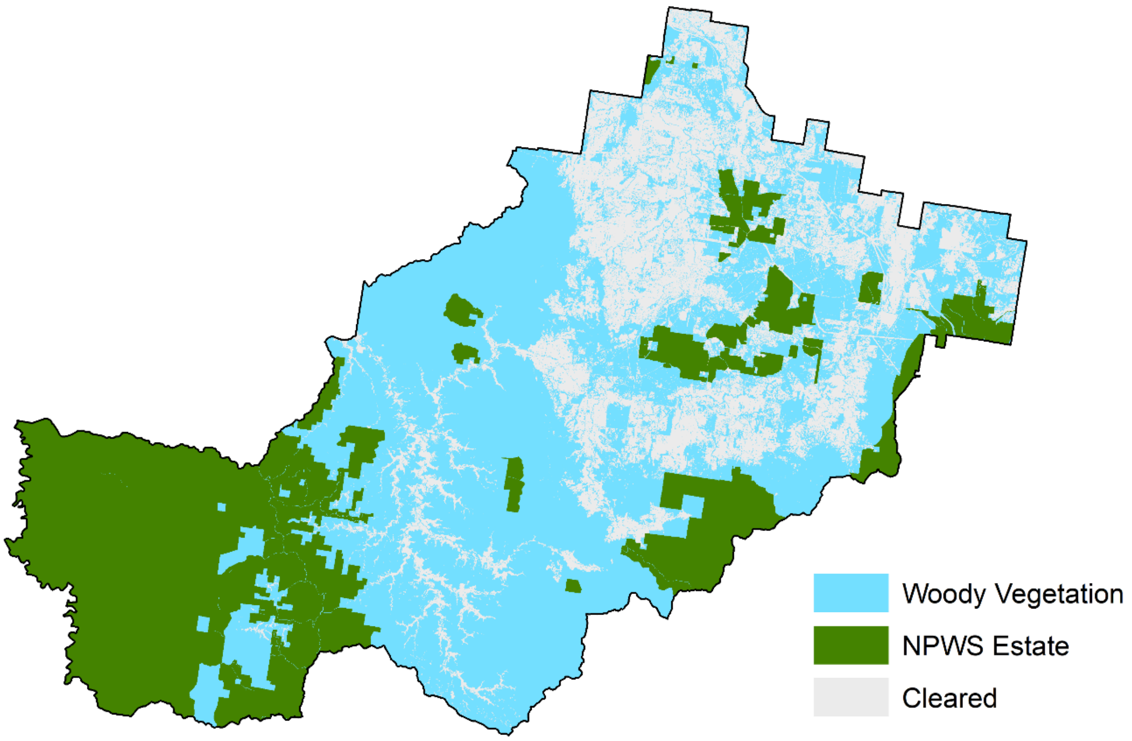


Figure 2 Woody vegetation in Cessnock Local Government Area

Vegetation layer

This dataset captures floristic vegetation mapping across all tenures in the Cessnock LGA (Figure 3). The dataset captures all 78 plant community types across the LGA. The data is in vector format and mosaiced from vegetation mapping datasets that have been audited for their fine-scale efficacy. Production of this layer is discussed in Appendix B.

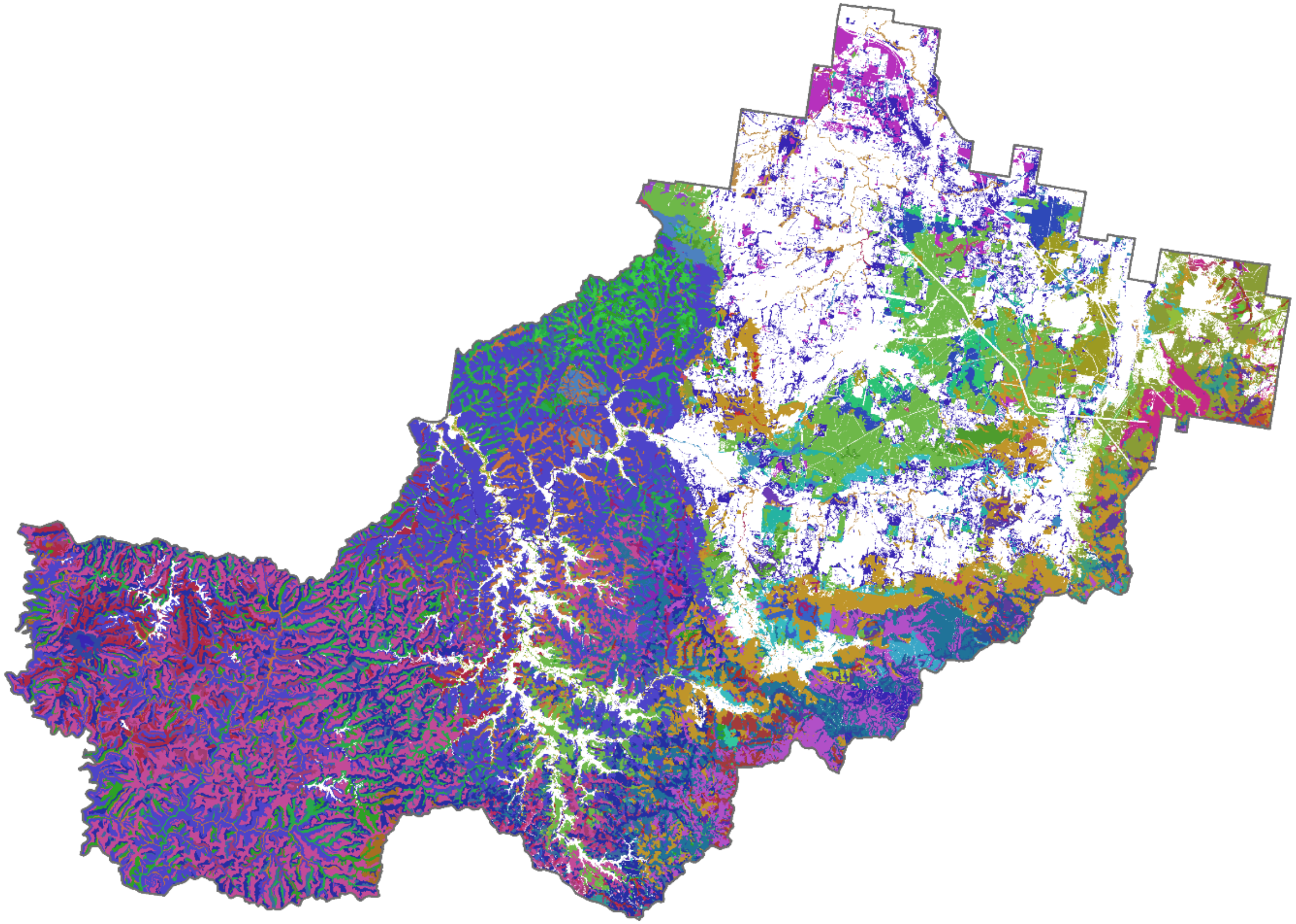


Figure 3 **Vegetation types in Cessnock Local Government Area**

Note: A legend is not shown on the map because space does not allow all 78 categories to be illustrated

Corridors layer

The connectivity analysis was conducted at multiple raster (i.e. grid) scales then combined into a final vector format with accuracy commensurate to a scale range of 1:500 to 1:1,000 (Figure 4). This connectivity analysis is one aspect of biodiversity information that maps the current state of biodiversity movement at a scale that can inform local planning decisions. Production of this layer is discussed in Appendix C.

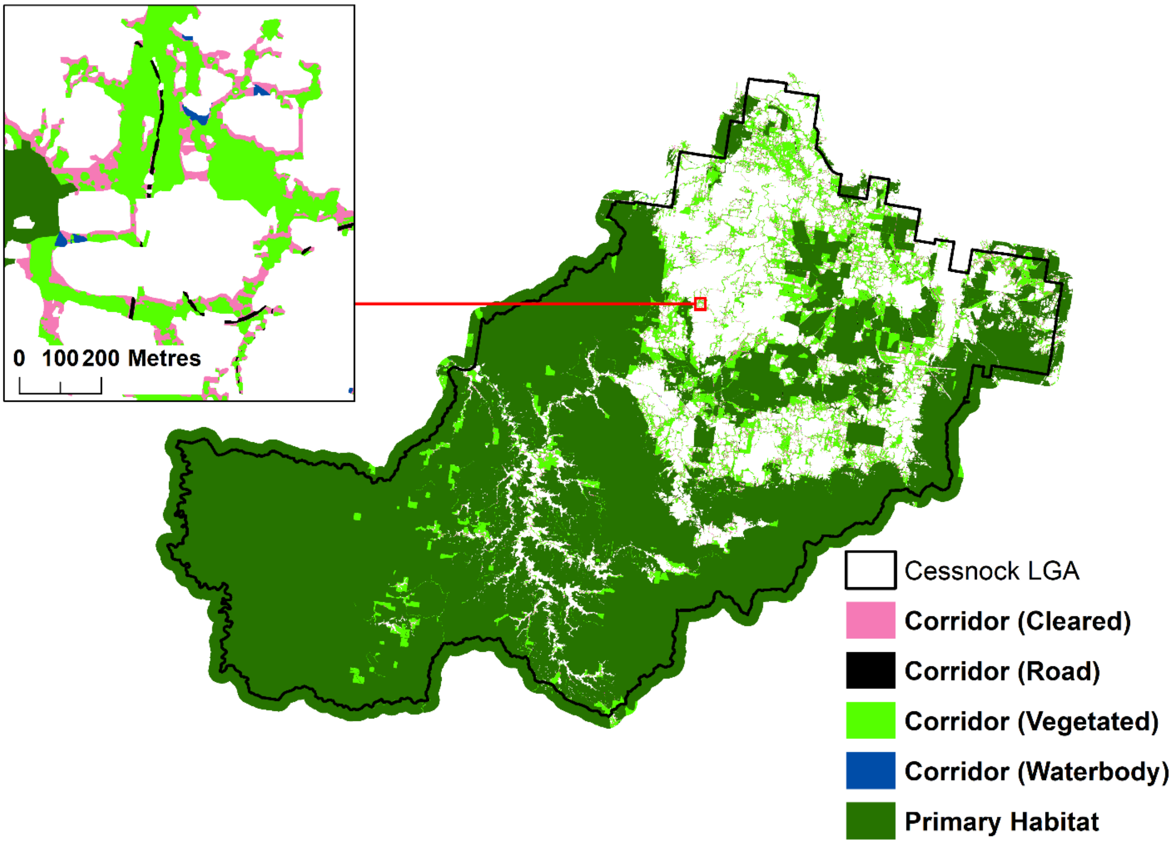


Figure 4 **The final structural connectivity/corridors layer for Cessnock Local Government Area**

Inset highlights the corridor categories, that is, vegetation in lime green, non-vegetated in pink, waterbodies in blue and roads in black.

Environment layer

This dataset provides a single layer capturing significant environmental features and biodiversity persistence (Figure 5). The environment layer is in raster format with a 2 × 2 m cell size, and is the result of consolidating multiple environmental layers that capture all aspects of biodiversity. Those consolidated layers contributed species composition information, structure/condition of habitat and ecological function attributes at the same scale and a common scoring system using a peer-reviewed scientific methodology. Production of this layer is discussed in Appendix D.

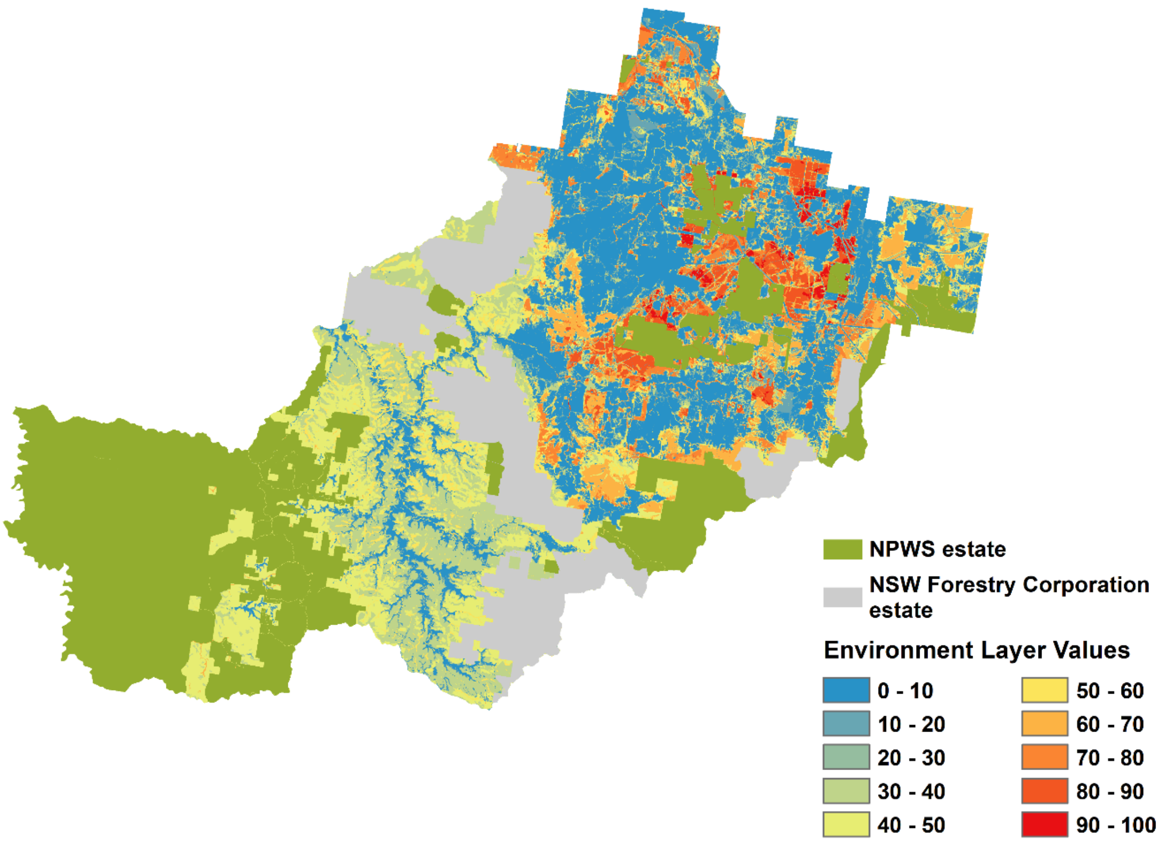


Figure 5 **Significant environmental features in Cessnock Local Government Area**

The value range from blue to red shows low to high environmental value respectively.

Streambank layer

This dataset maps all streambanks of larger streams using the Strahler system to identify stream type (Figure 6). All tenures were mapped excluding NPWS estate because it is formally reserved and protected under LEPs. Data is in vector format and was produced to a scale range of 1:500 to 1:3,000. Production of this layer is discussed in Appendix E.

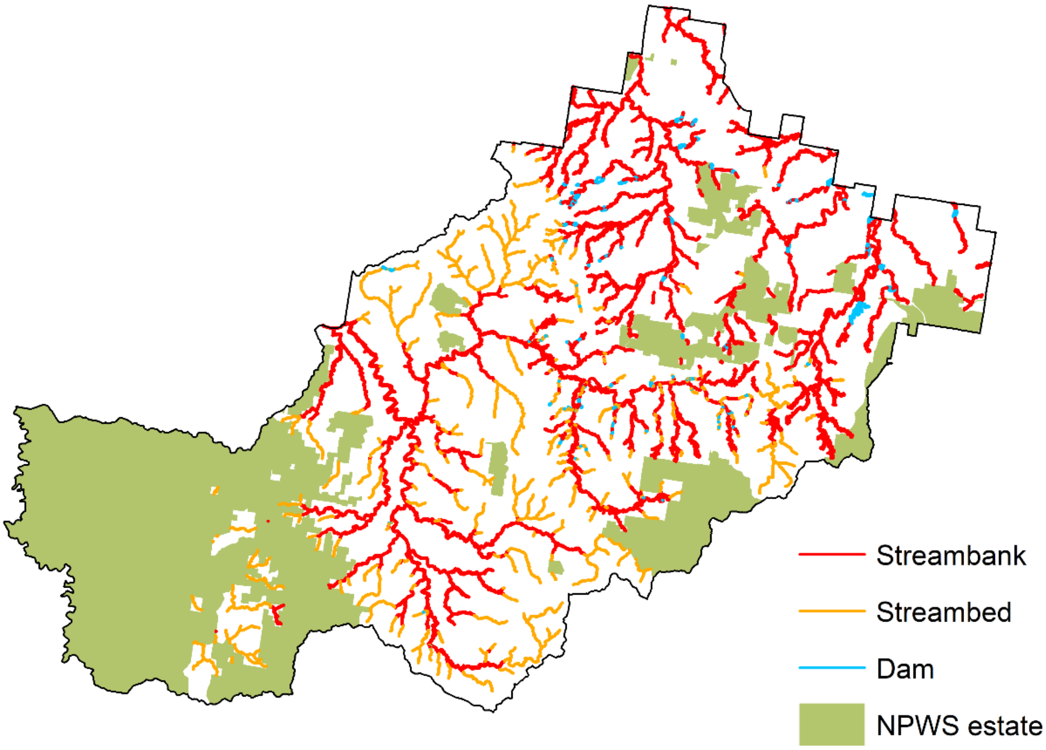


Figure 6 Streambanks in Cessnock Local Government Area

Tenure layer

This dataset includes NPWS estate, Biodiversity Conservation Trust properties, Forestry Corporation of NSW estate, Crown lands, Commonwealth of Australia estate (namely Department of Defence lands), Cessnock City Council lands and Aboriginal-owned lands (Figure 7). By default, all other land outside of these categories is assumed to be freehold. The data is in vector format and is combined from datasets sourced from respective landowners and land managers. Production of this layer is discussed in Appendix F.

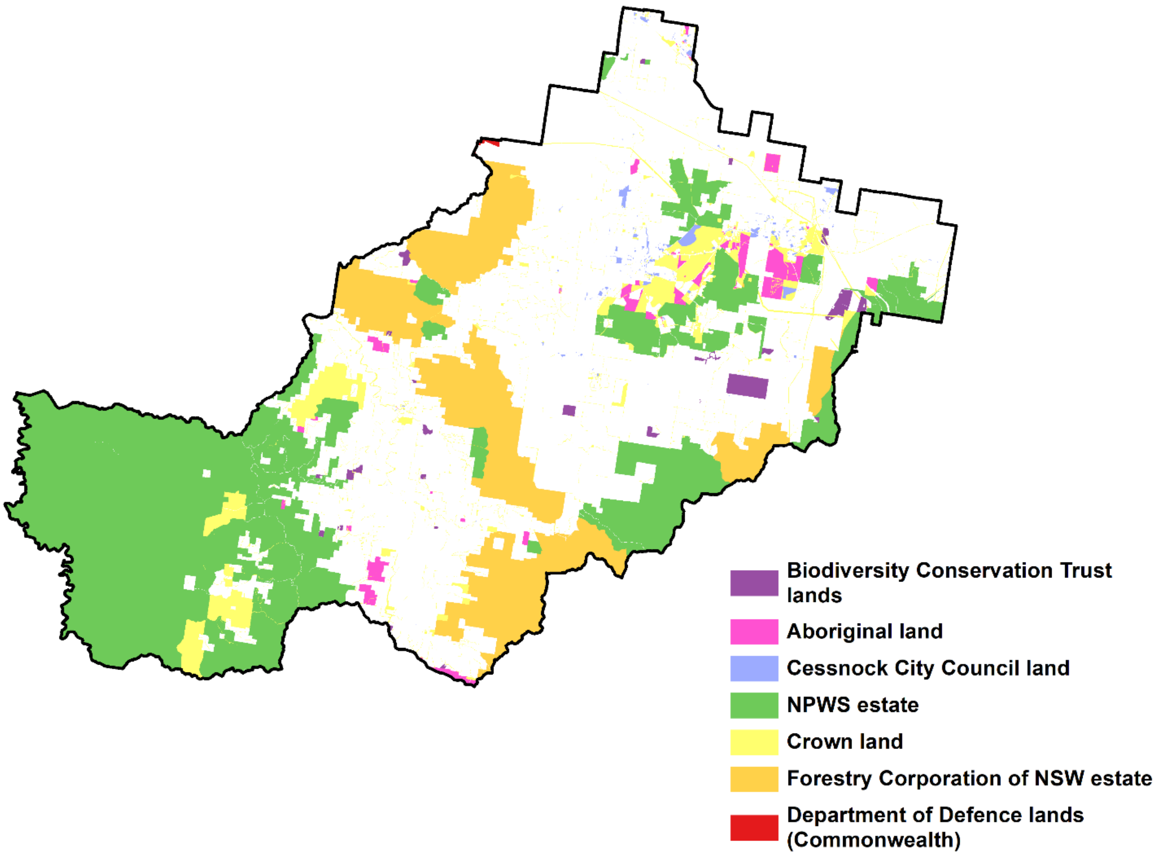


Figure 7 **Land tenure in Cessnock Local Government Area**

Spatial assets and intellectual property

All parties agreed to apply open data principles to enable sharing and re-use by the department, Cessnock City Council, their partners and the community. Where confidential information is provided, no parties will disclose confidential information without consent. The department provided final products to Cessnock City Council in May of 2022 and data is used by both parties. Products are stored in their respective corporate spatial repositories.

Resourcing and review

The department delivered this project with Biodiversity, Conservation and Science – Regional Delivery – Hunter Central Coast in-kind resourcing. The partnership with Cessnock City Council enabled prioritisation and delegation of elements of the project as relevant to expertise and availability. The department acknowledges contributions of Cessnock City Council, Lake Macquarie City Council, Central Coast Council, NPWS and non-agency subject matter experts. The department would like to acknowledge the contribution of partners, and Appendix H outlines individuals' contributions toward relevant elements of the project.

The datasets for this project were prepared in 2022 and are therefore representative of data available at the time. As new information becomes available, the datasets will be reviewed, updated and redistributed.

All datasets were subject to expert botanical and ecological review, and partners collaborated to ensure map layers represent the latest available information.

Appendix A. Woody layer metadata

This layer (or dataset) delineates woody vegetation at a fine scale across the Cessnock Local Government Area (LGA) which covers 196,468 ha. All tenures were mapped, excluding National Parks and Wildlife Service (NPWS) estate because it is formally reserved and protected under local environment plans. Data is in vector (i.e. polygon) format and was produced to a scale range of 1:500 to 1:3,000.

Background

A map of the extent, condition and floristic composition of vegetation is an important data source that captures many aspects of biodiversity. Vegetation mapping is used as a surrogate for biodiversity and has many added applications such as mapping flora/fauna habitat, wildlife corridors, distribution of threatened entities and the status of vegetation communities across the landscape. Therefore, it is critical that the spatial accuracy of vegetation extent is established in the first instance to avoid any unnecessary investment in regenerating vegetation maps that were not accurately captured in the first instance.

An accurate extant woody vegetation map underpins vegetation mapping and other biodiversity data generated in the environmental lands study. It is the critical first step for a vegetation map because it forms a baseline that propagates accuracy and user confidence through all subsequent biodiversity data. The advent of high spatial resolution imagery (i.e. less than 1 × 1 m pixel size) permits the capture of woody vegetation extent at very high levels of accuracy. The woody vegetation map generated in this study uses very high-resolution imagery to capture individual trees and shrubs while excluding shadow effects.

Production of this layer required highly technical expertise and explanation of the methodology uses technical language. The glossary of technical terms and acronyms in Appendix G provides explanations.

Audit of existing layers

Existing layers that capture woody vegetation are limited to either vegetation maps or mapping which supports programs that monitor land clearing across the state. The NSW Department of Climate Change, Energy, the Environment and Water (the department) produces annual woody extant layers for monitoring that are derived from 5 × 5 m SPOT satellite imagery (OEH 2011). This data is 1:15,000 scale and used primarily for detecting large paddock trees, woodlands and expansive areas of woody vegetation.

However, the scale requirements for the Cessnock environmental lands study are set to 1:500 to capture individual trees and shrubs with diameters down to 2 m, while excluding and eliminating shadow effects. Prior to this study, no such layers existed or were known to exist. The woody layer developed as part of this project forms the base for improving vegetation maps of the Cessnock LGA as existing maps were not of high enough accuracy.

Method

All analyses were undertaken in the ArcMap geographic information system (GIS). The mapping involved 2 procedures which are detailed below:

1. Automated procedure: Automated GIS analyses were used to develop an initial woody vegetation mask using 3 remotely sensed datasets (ADS40, LiDAR intensity and building footprint). This generated a woody vegetation mask as a 1-bit raster with 2 classes: 0 for cleared and 1 for woody vegetation.
2. Manual procedure: The initial woody vegetation mask was manually edited and refined using high-resolution Nearmap and ADS40 imagery. Most of the editing for the LGA was conducted against Nearmap imagery with a 6 cm resolution. A small area in the western section used 50 cm resolution ADS40 imagery where Nearmap imagery was unavailable. Figure 8 shows these Nearmap and ADS40 image extents and the date the image was captured. Manual desktop editing of the initial masks used the ArcScan raster editing tool, a module within the ESRI ArcMap software. The high-resolution imagery allowed mapping of patches of woody vegetation down to 12 m^2 (0.00012 ha) and trees and shrubs with crowns 2 m in diameter.

Production of the final woody vegetation map involved conversion of the refined raster data to vector polygon using ArcScan's vectorising and line smoothing functionality.

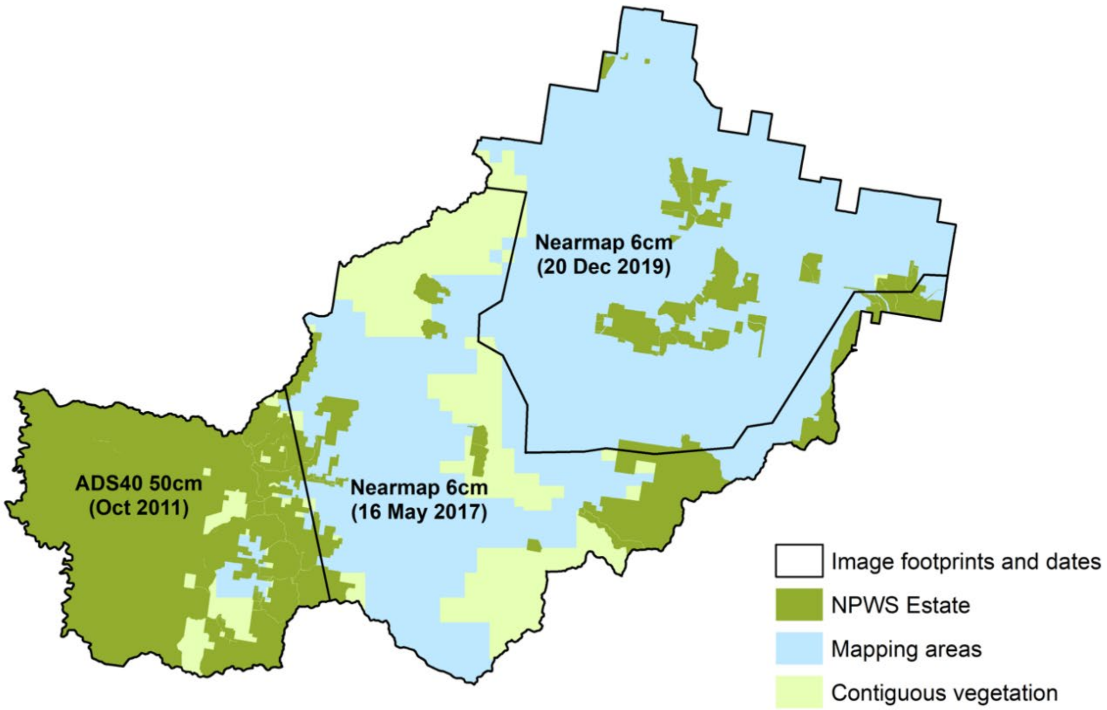


Figure 8 **Name and date of satellite imagery used to edit and refine woody vegetation in Cessnock Local Government Area**

The mapping made no distinction between native and exotic vegetation due to the floristic diversity within urban and rural zones. Remote sensing is very limited in detecting individual tree species, even with the benefit of hyperspectral data. With only 4 bands of multispectral imagery, classification of individual species is near impossible because high spatial resolution results in an exponential increase of similar spectral signatures with little or no spectral power to discriminate between them. Species classification may be inferred from auxiliary data or accurately recorded from in situ data collection. However, due to the size of Cessnock LGA and the scale of data capture this would require significant resources and was beyond the scope of this analysis.

Automated and manual procedures are explained in further detail below.

Automated procedure

The 3 layers used for generating the initial woody vegetation masks are:

- ADS40 imagery with 50 cm spatial resolution and blue (B), green (G), red (R) and near infrared (NIR) bands – including the 1:100 mapsheet mosaics of Newcastle (16 December 2012), Cessnock (21 October 2011), Gosford (24 October 2011) and St Albans (12 April 2010)
- LiDAR intensity with 0.5 m spatial resolution supplied by Cessnock City Council
- Geoscape building footprint – the horizontal positional accuracy of imagery used for the extraction of urban buildings range from +/−0.2 m to +/−2.5 m (Geoscape 2018).

Nearmap imagery was not used in the automated procedure due to only having the 3 RGB bands and differing levels of radiometric processing that negated consistent spectral classification. Also, tree canopy LiDAR was not available to the project but would have provided a significant improvement to the accuracy of the initial masks.

Strengths of each layer were used to offset limitations of others. As a result, analysis was structured in sequence so that classification errors were negated and errors resulting from data limitations would not be reintroduced during the sequence. The process is provided stepwise below with background theory and technical details.

Step 1 – Mapped area and tiling

The mapped area was defined as the contiguous area the LGA that did not include NPWS estate or areas of contiguous vegetation. As shown in Figure 9, the mapped area was subdivided into 1,436 square 1 × 1 km tiles for processing efficiency and systematic guidance for manual editing.

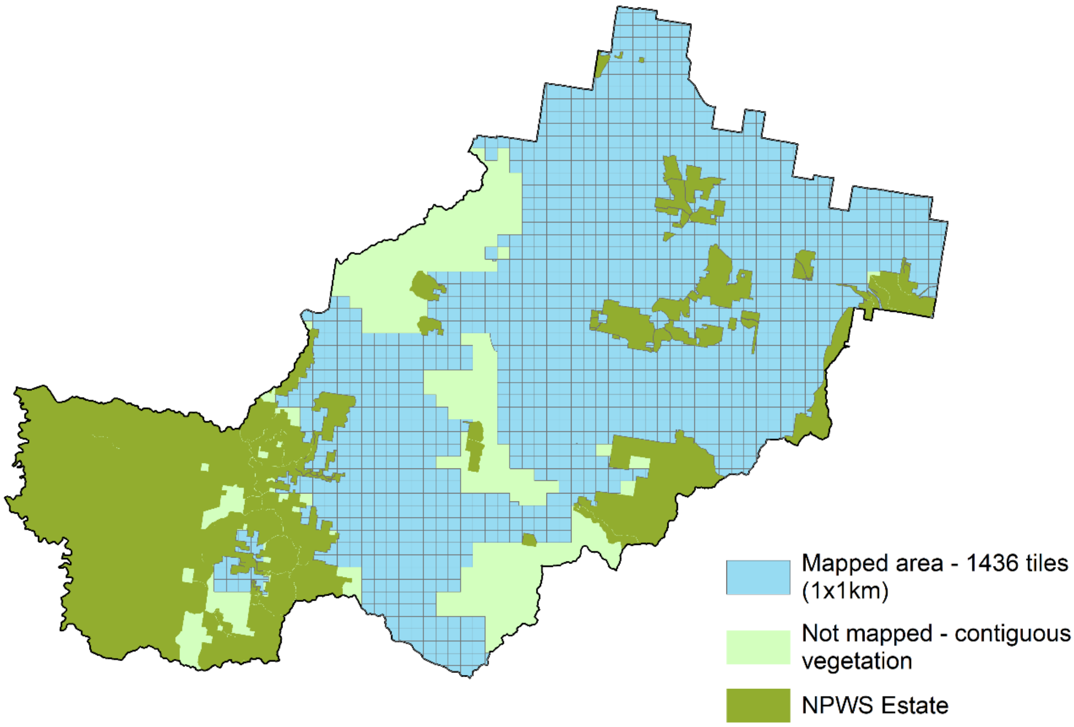


Figure 9 **Mapped areas in Cessnock Local Government Area shown in blue with 1,436 square 1 × 1 km tiles**

Step 2 – Data and formatting

The ADS40 image mosaics were 4 band (R-G-B-NIR) and supplied in jp2 format with radiometric format of unsigned 8-bit integer. Spatial Services (part of the NSW Department of Finance, Services and Innovation) pre-processed the data using a simplified atmospheric correction using dark object subtraction as per Chavez (1988). Further colour rebalancing was performed to assist merging image tiles into 1:100 map tile mosaics. For inclusion in the analysis, the ADS40 image mosaics were clipped to the 1,436 individual tiles and converted to TIF image format with LZW compression, resampled to 1 m spatial resolution and formatted to unsigned 8-bit radiometric depth.

LiDAR intensity for the LGA was captured by the NSW Department of Finance, Services and Innovation over the period 2012 to 2017 for Cessnock City Council. The data was supplied as compressed ECW format with 0.5 m spatial resolution and radiometric format of 8-bit unsigned integer. All intensity layers from the different date ranges were seamlessly mosaiced in ERDAS imagine format with unchanged spatial resolution and radiometric format. For inclusion in the analysis, the intensity mosaic was clipped to the 1,436 individual tiles and converted to TIF image format with LZW compression, 0.5 m spatial resolution and unsigned 8-bit radiometric depth.

Geoscape building footprints were provided by the department as ESRI vector data (feature class) in file geodatabase format. For inclusion in the analysis, the data was converted to TIF image format with LZW compression, 0.5 m spatial resolution and 1-bit radiometric depth.

All data pre-processing and formatting was performed using ArcGIS, ERDAS imagine and multiple Python scripts to automate clipping data to the 1,436 tiles. Once pre-processed, the data was then run through a final Python script that produced a preliminary vegetation mask as outlined below. The output vegetation masks were resampled to 1 m spatial resolution with 1-bit radiometric format. The resampling was required to reduce virtual memory problems with ArcScan's editing cache during the manual editing stage.

Step 3 – Vegetation mask processing using Python code and NumPy

The derivation of an initial vegetation mask was performed in Python code using the NumPy module for mathematical and algebraic functions. The ADS40 images, LiDAR intensity and Geoscape buildings were converted to NumPy arrays for the analysis and the final output array was converted back to 1-bit TIF format. The Python script is shown as a flowchart in Figure 10 and the equation references are discussed in further detail below.

The aim of the Python process is to create an accurate vegetation mask so that manual editing is minimised. The process was designed to eliminate non-vegetation responses such as shadows, false vegetation responses, roof buildings, waterbodies, roads and high-reflectance objects. Indices were developed to minimise non-vegetation response, and these are summarised below with key equations explained.

Shadow is characterised by diffuse skylight and that is explained by Rayleigh scattering principles (Slater et al. 1983). Equation 1 creates a Rayleigh scattering reference as a pixel vector and used as independent shadow reference that helps classify shadow pixels in image. Bold typing in the text below the equations denotes pixel vector.

1. $$\widehat{\boldsymbol{SV}}(\lambda)_i = \frac{{\lambda_i}^{-4}}{\sum_{i=1}^{n} {\lambda_i}^{-4}}$$

where $\widehat{\boldsymbol{SV}}$ is the Rayleigh scatter vector value for band *i* in unit form, *n* is the number of bands and λ is the centre wavelength of each image band.

All image pixels were spectrally compared to the reference using an inner product and the resulting index is called the scattering index (**SI**) from Cameron and Kumar (2018). Derivation of the **SI** requires image pixels be converted to unit vector form as shown below in Equation 2 where bold type denotes vector format.

2. $$\boldsymbol{SI} = \hat{\boldsymbol{p}}^{T} . \widehat{\boldsymbol{SV}}$$

where $\boldsymbol{SI}$ is the scattering index, $\hat{\boldsymbol{p}}$ is the unit vector form of an image pixel and $\widehat{\boldsymbol{SV}}$ is the Rayleigh scatter vector in unit form.

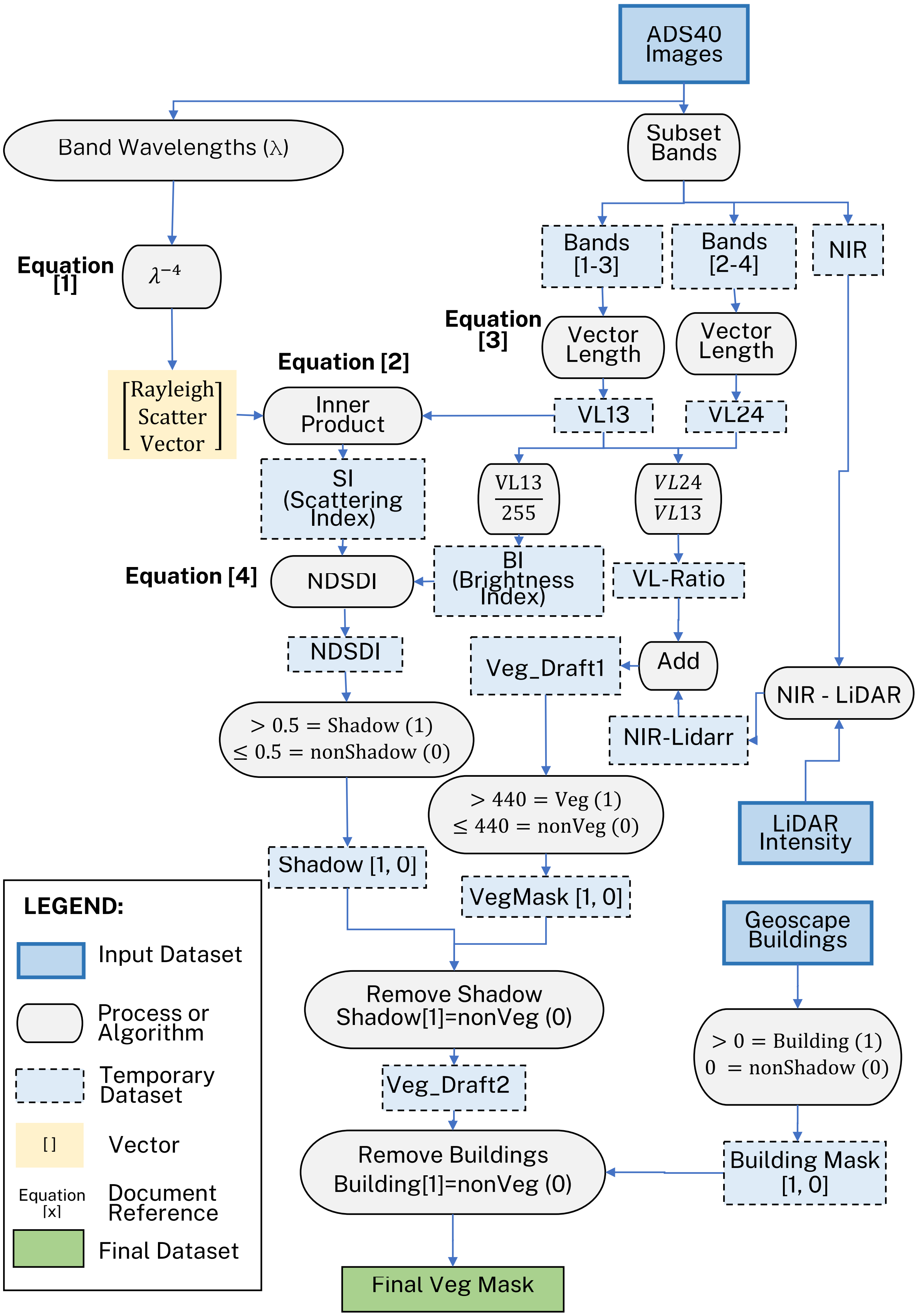


Figure 10 Python script for creating initial vegetation mask for each of the 1,436 mapped tiles

From Figure 10, vector magnitude indices are derived using 2 subsets of bands from the ADS40 image as per Equation 3.

3. $$||\mathbf{p}|| = \sqrt{\sum_{i=1}^{n} \mathbf{p}^2}$$

where $||\mathbf{p}||$ is magnitude of the image pixel vector, *i* is the *i*th band of *n* bands and **p** is the image pixel.

The SI is derived from the orientation of pixel vectors and that equates to the colour or chromaticity of the pixel. Shadow is also characterised by low brightness where pixel magnitude equates to brightness. So, a further index is derived to utilise the low brightness response of shadow pixels. A shadow index called normalised-difference shadow depth index (NSDSI) from Cameron (2021) improves the SI scattering index by using both vector orientation and magnitude to quantify shadow depth.

4. $$NDSDI = \frac{(\hat{\boldsymbol{p}}^T . \widehat{\boldsymbol{SV}}) - (\frac{\|\boldsymbol{p}\|}{MaxBitDepth})}{(\hat{\boldsymbol{p}}^T . \widehat{\boldsymbol{SV}}) + (\frac{\|\boldsymbol{p}\|}{MaxBitDepth})}$$

where NDSDI is the shadow index, $\hat{\boldsymbol{p}}$ is the unit vector form of an image pixel, $\widehat{\boldsymbol{SV}}$ is the Rayleigh scatter vector in unit form, $\|\boldsymbol{p}\|$ is the magnitude of the pixel vector and *MaxBitDepth* is the maximum radiometric depth of the image pixel.

From Figure 10, the blue, green and red bands are used because the Rayleigh scattering effect lies within the visible range of wavelengths and weakens exponentially towards longer wavelengths, that is, near infrared (NIR). The resulting NDSDI index is a unitless ratio so a user-defined threshold of > 0.5 was chosen to delineate shadowed pixels and derive a binary mask (Shadow) of shadow (value 1) and non-shadow (value 0).

The remaining steps in the process at Figure 10 are summarised below:

Subtracting NIR from the LiDAR (NIR_Lidarr) exploits the high response of vegetation in NIR and the low response of vegetation in LiDAR intensity. High index values represent vegetated pixels and this index supresses shadow because LiDAR ignores shadow and NIR shadow responses are low. However, LiDAR responses for roads and houses are also low and may present as vegetated pixels, so subsequent steps eliminated these ambiguities.

For vegetation pixels, the vector magnitude of optical bands (VL13) is low whereas the vector magnitude is larger when NIR (VL24) is included because of vegetation's high NIR response. For roads and houses the converse is true, optical band response (VL13) is higher than NIR (VL24). So, the ratio of VL24 to VL13 (VL_ratio) separates vegetation from roads and houses, that is, high ratio values represent vegetation pixels and low values represent roads and houses.

To further isolate vegetated pixels, the VL_ratio was rescaled from 0–1 to 0–255, and then added to the NIR_Lidarr index to produce Veg_draft1. This addition increased vegetated pixel responses by adding 2 high values whereas roads and houses are further separated because addition of 2 small values produces a much smaller response. Like the NDSDI, the Veg_draft1 index required a user-defined threshold to delineate vegetation and this was selected as > 440 for vegetated pixels to derive a binary mask (Veg_mask) of vegetation (value 1) and non-vegetation (value 0).

The remaining steps in the process were to apply the Shadow mask and Veg_mask to Veg_Draft1 and then remove definitive building footprints using the Geoscape building layer. The resulting quality of the binary vegetation mask outputs varied across the whole LGA but in general they were accurate and significantly reduced manual editing time. For the outputs, removal of shadows using the Shadow mask produced holes within contiguous vegetation canopies due to self-cast tree shadow and canopy gaps. However, these gaps were rapidly filled in the subsequent editing process using ArcScan's tools as outlined below.

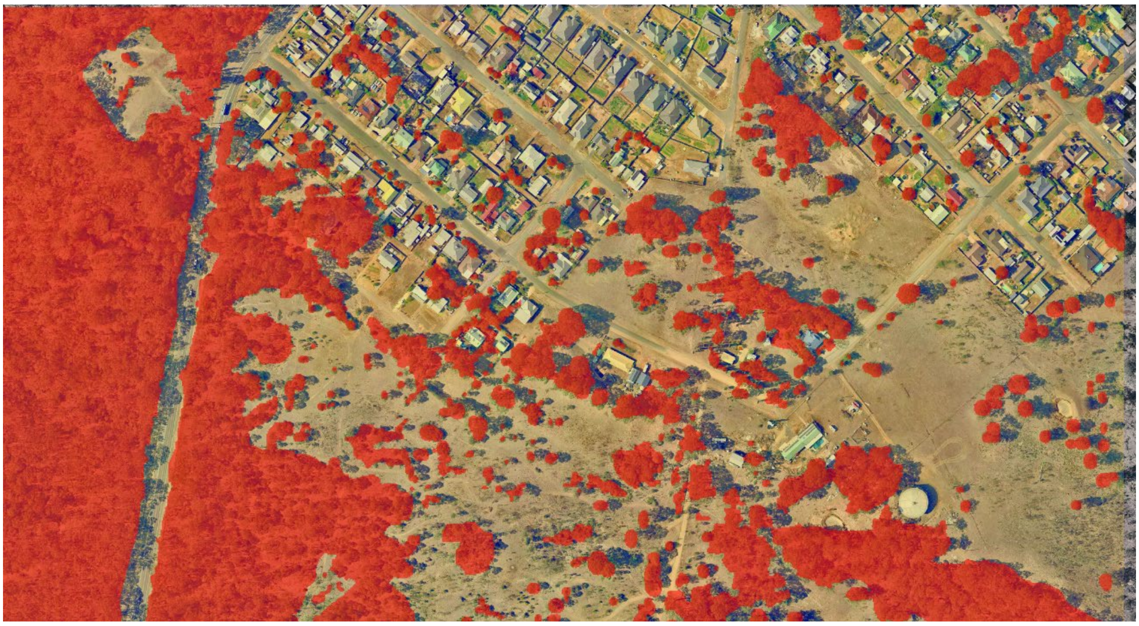
Manual procedure

Step 1 – Manual refinement and line smoothing

The initial vegetation mask for each tile was manually refined using ESRI's ArcScan extension. The extension was designed to vectorise hardcopy maps and has very efficient raster editing tools. Editing in ArcScan is a 2-step process, first is to manually refine raster edges/boundaries and the last step is vectorisation with comprehensive parameters to control the degree of line smoothing.

For the manual refinement step, ArcScan provides a raster painting toolbar that includes cell/s selection, painting, filling, erasing, shrinking and growing routines. Manual editing requires the raster data to have only 2 unique values/classes with one value classified as 'foreground' and the other as 'background'. Foreground and background cells can be switched at any time to focus editing on either value. These tools were used to refine edges, fill gaps, delete misclassifications and apply growing/shrinking routines to smooth raster edges. Manual refinements were implemented with a pen and mouse tablet to reduce repetitive strain injury and speed up the editing process. Figure 11 shows an example of the 2-step process with the Nearmap backdrop, a completed raster (foreground red and background transparent) and the resulting vectorised linework.

(a)



(b)

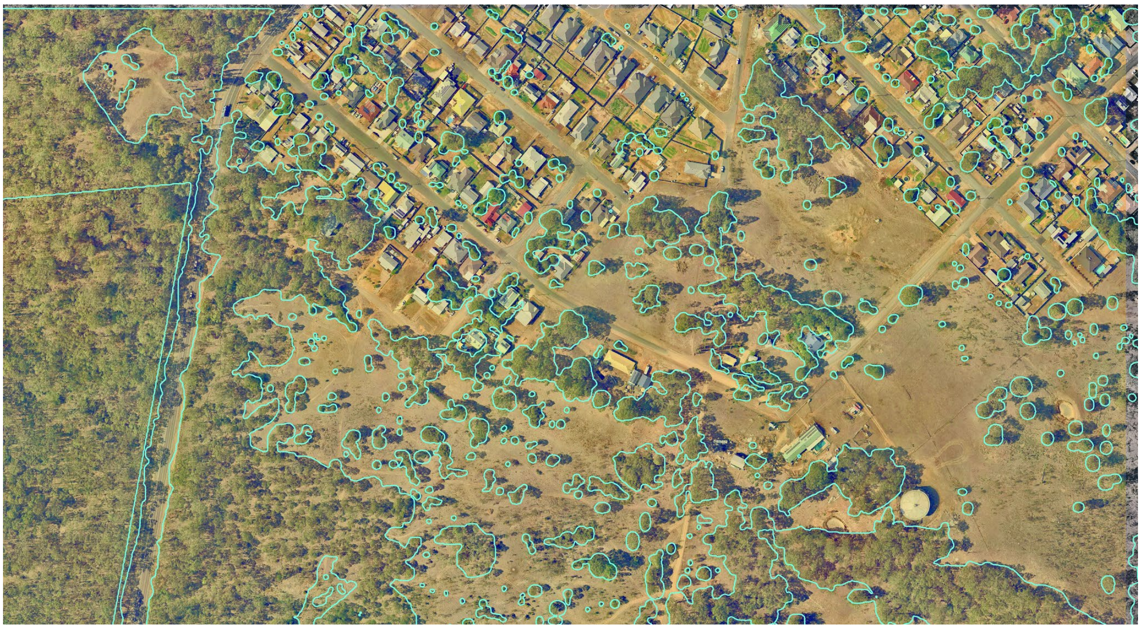


Figure 11 **An example of the 2-step manual refinement process using ArcScan**

Inset (a) is a finalised tile in raster format with foreground (value = 1) red and background (value = 0) transparent. Inset (b) shows the resulting vectorisation and line smoothing result in blue

Step 2 – Merging, review and finalisation

The last step in the process was to review and merge all tiles so that the mapped areas became a complete singular vector layer. This process is outlined stepwise below.

1. Each horizontal row of edited raster tiles was merged into a single raster.
2. Each row was reviewed and edge matched.
3. The row was vectorised and saved as an ESRI polygon feature class.
4. All row feature classes were merged into one final feature class with the internal tile edge boundaries dissolved.
5. The final feature class was unioned with all NPWS estate boundaries and the Cessnock LGA boundary. Note: All NPWS estate that had been purchased but not yet gazetted at the time of this report were included.
6. The last step was to manually review and edit any errors that resulted from edge effects to produce the final woody vegetation layer with 3 classes: woody vegetation, NPWS estate and cleared.

Due to an excessive number of vertices, the final layer had to be tiled with a square fishnet to overcome storage limitations. The tiling does not affect data quality or change any vegetation boundaries.

Review

The manual editing component of the woody vegetation layer's construction was inherently a form of review. Calibration and independent cross-checking of mapping was conducted weekly throughout the editing process. Refer to contributor acknowledgements in Appendix H.

This layer was prepared in 2022 and is therefore representative of data available at the time. As new information becomes available, the layer will be reviewed, updated and redistributed.

Final layer

The final layer is an accurate fine-scale baseline woody vegetation layer for the Cessnock LGA that is current with the image dates shown in Figure 8, that is, 2017 to 2019 in the east and 2011 in the far west. From here on the layer will require maintenance and updating as landuse and landcover change over time. However, the layer's accuracy means that maintenance and update requirements are minimal in terms of mapping expertise and resources. Either field-verified data or newer high-resolution imagery can be used to perform maintenance and updating of the layer.

Figure 12 demonstrates the accuracy and scale of the woody extent layer compared to the departments' statewide woody extent layer.

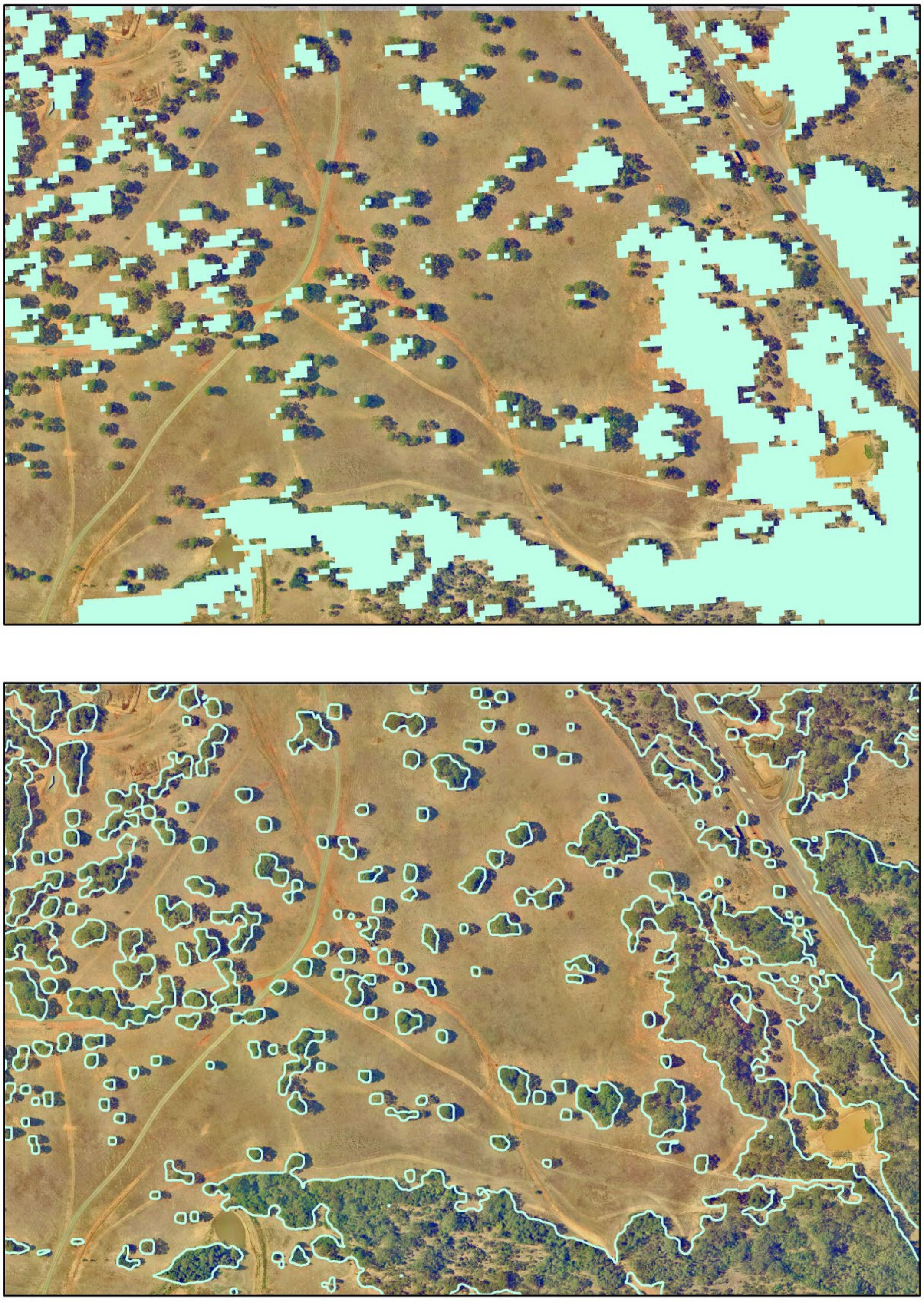


Figure 12 **Comparison of the department's 5 × 5 m raster woody extent layer in green (top) and the final Cessnock woody vegetation extent layer polygons (bottom). The backdrop is the Nearmap 6 cm resolution imagery used in this study.**

The final layer for the whole LGA is shown in Figure 13 where blue represents woody vegetation, green represents NPWS estate and grey represents cleared areas.

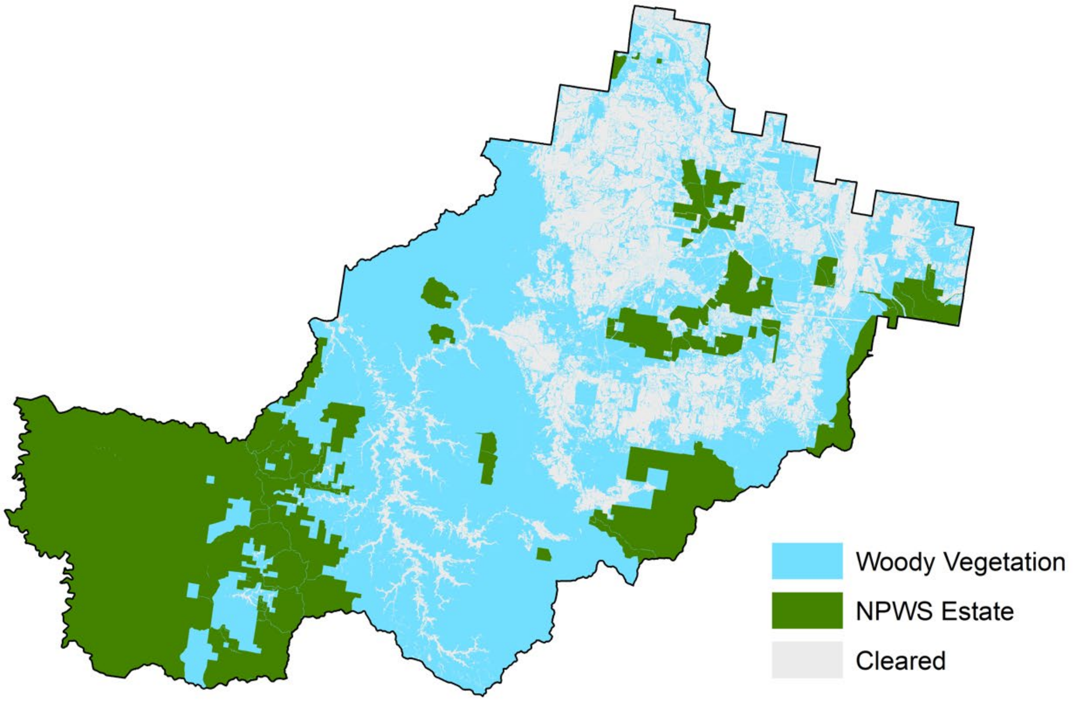


Figure 13 **Final woody vegetation layer for Cessnock Local Government Area showing the 3 classes: woody vegetation, NPWS estate and cleared**

Appendix B. Vegetation layer metadata

This layer captures floristic vegetation mapping across all tenures in the Cessnock Local Government Area (LGA) which covers an area of 196,468 ha. The layer captures all 78 plant community types across the LGA. The data is in vector format and mosaiced from vegetation mapping layers that have been audited for their fine-scale efficacy.

Background

The Lower Hunter vegetation mapping mosaic produced by Parsons Brinckerhoff in 2013 was recognised as the best starting point for the Cessnock vegetation mapping layer as it provided a comprehensive audit of existing vegetation layers at that time (Cockerill et al. 2013). Their mapping mosaic covered 5 local government areas – Cessnock, Newcastle, Lake Macquarie, Port Stephens and Maitland – and the audit resulted in the mosaic containing the most accurate vegetation mapping layers. In addition to the audit, Parsons Brinckerhoff translated all their individual mapping classifications to the NSW Government plant community type (PCT) classification. This achieved consistency and alignment with NSW environmental legislation. Officers in Regional Delivery – Hunter Central Coast of the Department of Climate Change, Energy, the Environment and Water (the department) integrated higher quality vegetation mapping layers that were in construction at the time (2013) and translated these into the PCT classification.

Additional mapping layers available in 2021 were incorporated into the Cessnock vegetation mapping mosaic including the department's Science, Insights and Economics Division NSW State Vegetation Type Map raster modelling of plant community types (DPIE 2021) and fine-scale reserve mapping layers by Stephen Bell for Corrobare, Sweetwater, Warrawalong and Cedar Creek (Bell 2017, 2018a, 2018b, 2018c).

The consolidated vegetation mosaic was refined using the fine-scale woody vegetation layer produced as part of this study (see Appendix A) to enhance the spatial accuracy of the data. Vegetation units from all included layers were translated to the new and updated PCT classification for the east coast of NSW, that is, the eastern NSW PCT classification (Connolly et al. 2021) which is publicly available. The vegetation mosaic contains the original translations to the PCTs in Cockerill et al. (2013) and translations to the new eastern NSW PCT classification. Both classifications are now linked to the department's full floristic survey data (734 plots) that occur within the Cessnock LGA. These are referenced to ground-truth data that also have associated threatened ecological communities assigned.

Production of this layer required highly technical expertise and explanation of the methodology uses technical language. See Appendix G for a glossary of technical terms and acronyms.

Audit of existing layers

The Lower Hunter vegetation mosaic by Cockerill et al. (2013) was used as an initial reference for the audit, and any additional or more recent layers were then considered.

Layers were assessed on the count and density of validation/floristics sites, currency, linework quality and robustness of methodology.

The count and density of sites (validation or full floristic) was the most critical of all criteria given Cessnock City Council's requirement for evidence-based data. Using the density assessment criteria, 2 layers from Cockerill et al. (2013) were not selected for the final mosaic. These were the *Lower Hunter and Central Coast regional environment management strategy* (House 2003) and refinements were made to the Lower Hunter mosaic by Cockerill et al. (2013) as part of that process. These were replaced by the department's State Vegetation Type Map (DPIE 2021) as it was more current and accurate where full floristic plots existed in the landscape. Table 1 lists the areas of contributing layers, and the spatial distribution of these source layers is shown in Figure 14.

Table 1 Final selected layers used to construct the Cessnock Local Government Area vegetation mosaic

Vegetation layer	Density (no. of sites per km^2)	No. of validation/floristic sites	Area (ha^2)
Vegetation and floristics of the Huntlee offset lands, Hunter Valley, NSW: 4. Warrawalong (Bell 2018b)	70.06	71	101.34
Pambalong vegetation (Ecological 2003)	57.07	5	8.76
Cessnock-Kurri region vegetation (Bell and Driscoll 2007)	48.97	14,107	28,808.77
Vegetation and floristics of the Huntlee offset lands, Hunter Valley, NSW: Sweetwater North Rothbury (Bell 2018c)	47.64	78	163.74
Vegetation and floristics of the Huntlee offset lands, Hunter Valley, NSW: 3. Corrabare (Bell 2018a)	44.20	198	447.99
Vegetation and floristics of the Huntlee offset lands, Hunter Valley, NSW: 1. Cedar Creek (Bell 2017)	38.93	249	639.67
Vegetation mapping of the Singleton Military Area (SKM and Bell 2012)	16.11	76	471.78
Maitland LGA vegetation (Hill 2003)	7.08	2	28.23

Watagans & Jilliby vegetation (Bell and Driscoll 2006)	6.11	335	5,478.64
State Vegetation Type Map (DPIE 2021)	0.52	350	67,250.48
Yengo vegetation (DECC 2008)	0.17	76	45,904.89

Note: Layers are sorted from highest to lowest density of floristic sites.

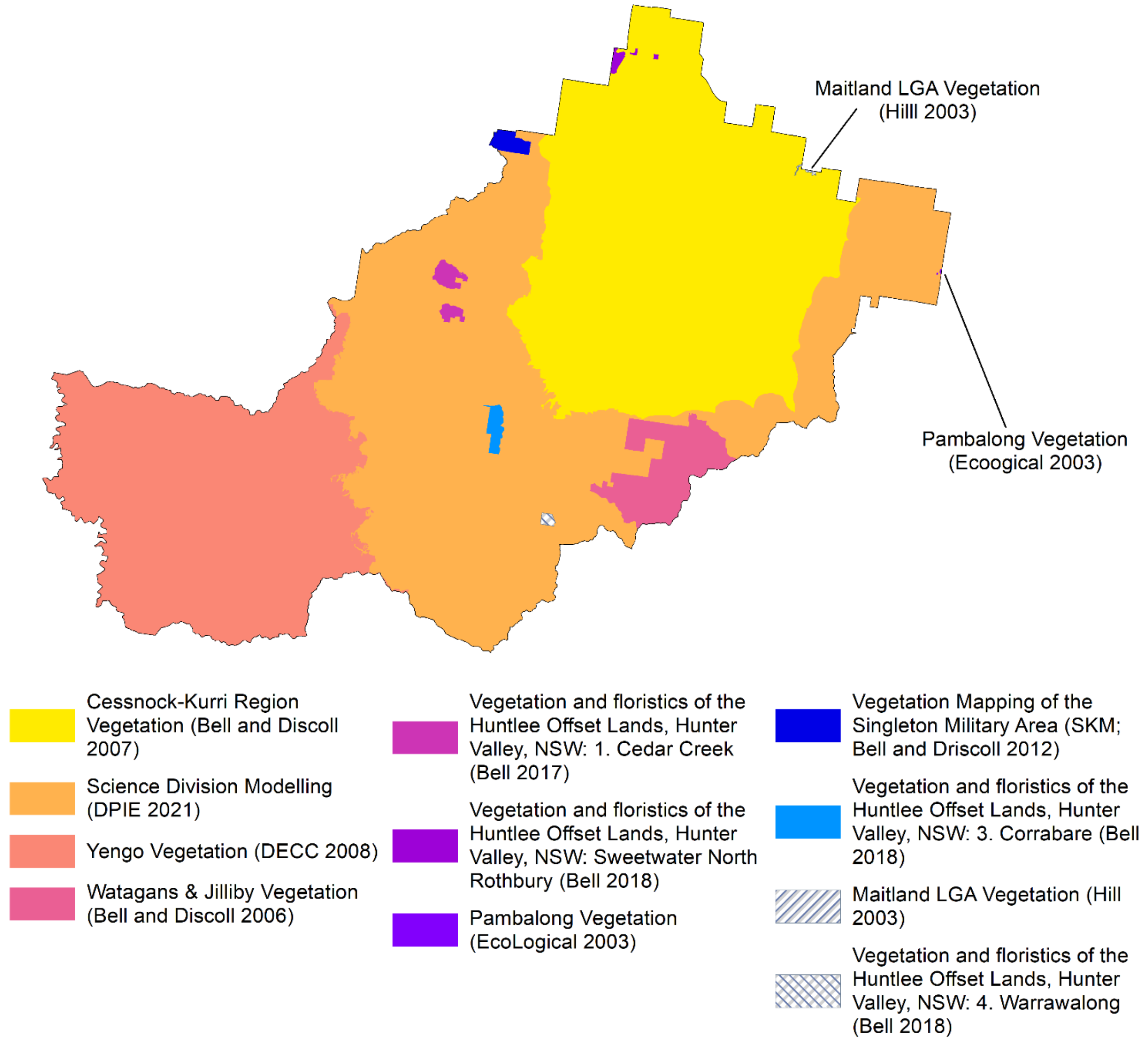


Figure 14 **Source layers included in the final vegetation mosaic for Cessnock Local Government Area**

The validation/floristic site count and densities from Table 1 are shown graphically in Figure 15 to help illustrate the spatial distribution and density of both full floristic plots and validation sites.

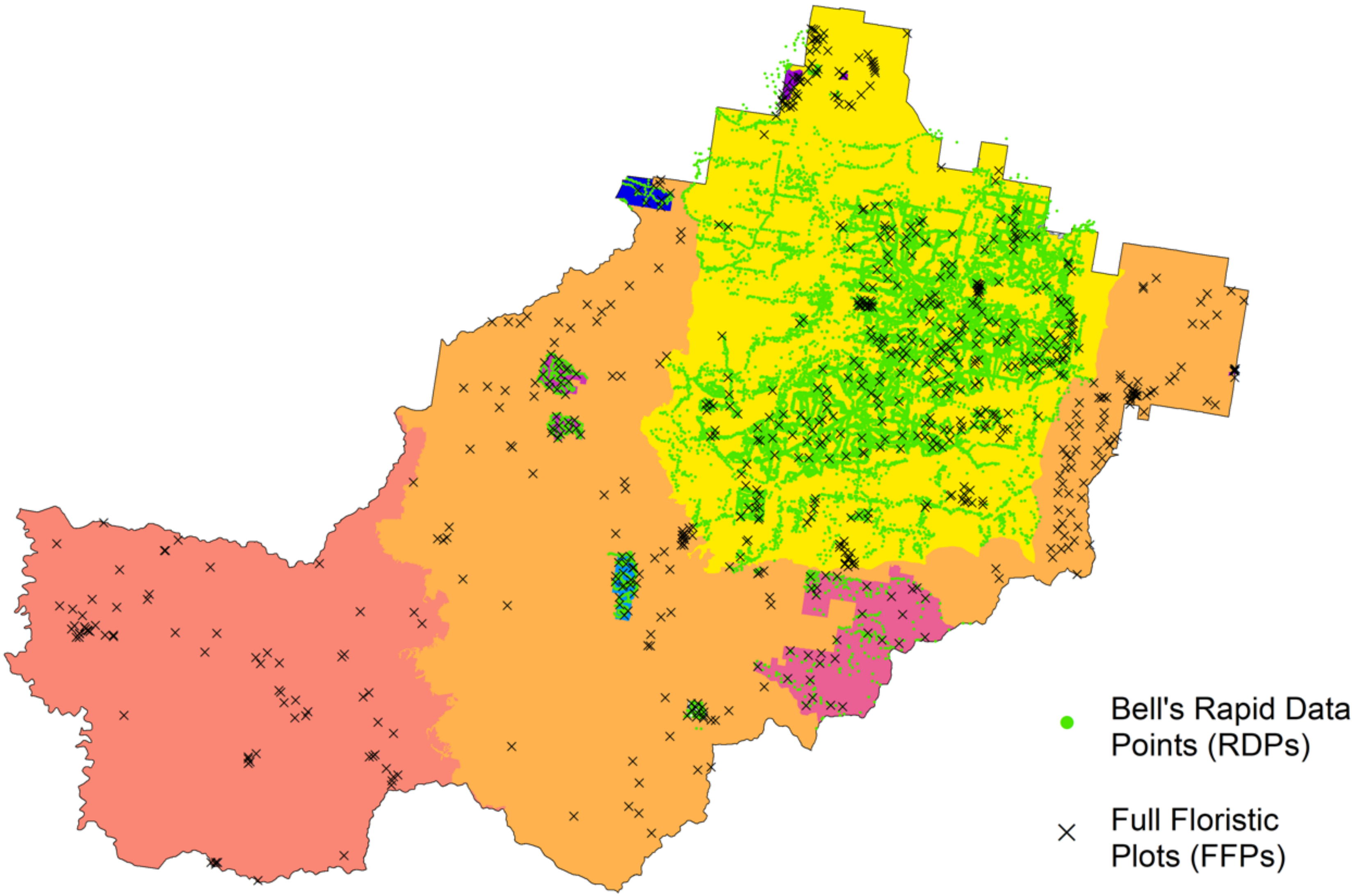


Figure 15 **Spatial distribution and density of full floristic plots and validation sites**

Full floristic plots (FFPs) shown as black crosses with rapid data point (RDPs) validation sites shown as green dots. Refer to Figure 14 map legend to explain mapping data sources. **Note:** Only Bell's mapping layers (Bell 2017, 2018a, 2018b, 2018c; Bell and Driscoll 2006, 2007; SKM and Bell 2012) contain RDPsSwitch map to landscape using Section Breaks.

Method

The aim of the method was to enhance the quality of existing vegetation mapping, to ensure the layer was evidence-based and fit-for-purpose. The environmental lands study supports Cessnock City Council's goal to utilise accurate spatial information in the review of their local environment plan (LEP). Quality enhancement of the vegetation mosaic was achieved by improving accuracy of its spatial extent. Steps in the method were:

1. Woody vegetation refinement – the woody vegetation dataset developed for the study (see Appendix A) was used to refine woody extent
2. Eastern NSW plant community type (ENSW PCT) translation – translation of map units to ENSW PCT classification to align existing layers with all ground-truth data embedded in NSW Government flora databases and the ENSW PCT classification
3. Allocation of threatened ecological community (TEC) status – NSW and Australian government determinations and listing advice was qualified by the ENSW PCT map unit.

These 3 steps are explained in more detail below.

Woody layer refinement

The woody vegetation layer (Appendix A) is an accurate extant vegetation layer produced at a very fine-scale range of 1:500 to 1:3,000 across the LGA. The layer's efficacy is characterised by containing no shadowing effects and aligning to 6 cm resolution Nearmap imagery. This layer was used to refine all final contributing layers listed in Table 1, that is, it was used to clip the vegetation mosaic described above to extant woody vegetation derived for the study (see Appendix A).

The method is outlined stepwise below.

1. All polygons in the woody vegetation layer less than 100 m^2 were considered to be single paddock trees and were removed from the layer. This equated to 127,760 trees/shrubs with canopy diameter of less than 11.2 m. Figure 16 is a histogram of the removed trees and shows a left-skewed distribution meaning that the trees removed were much smaller than 100 m^2.

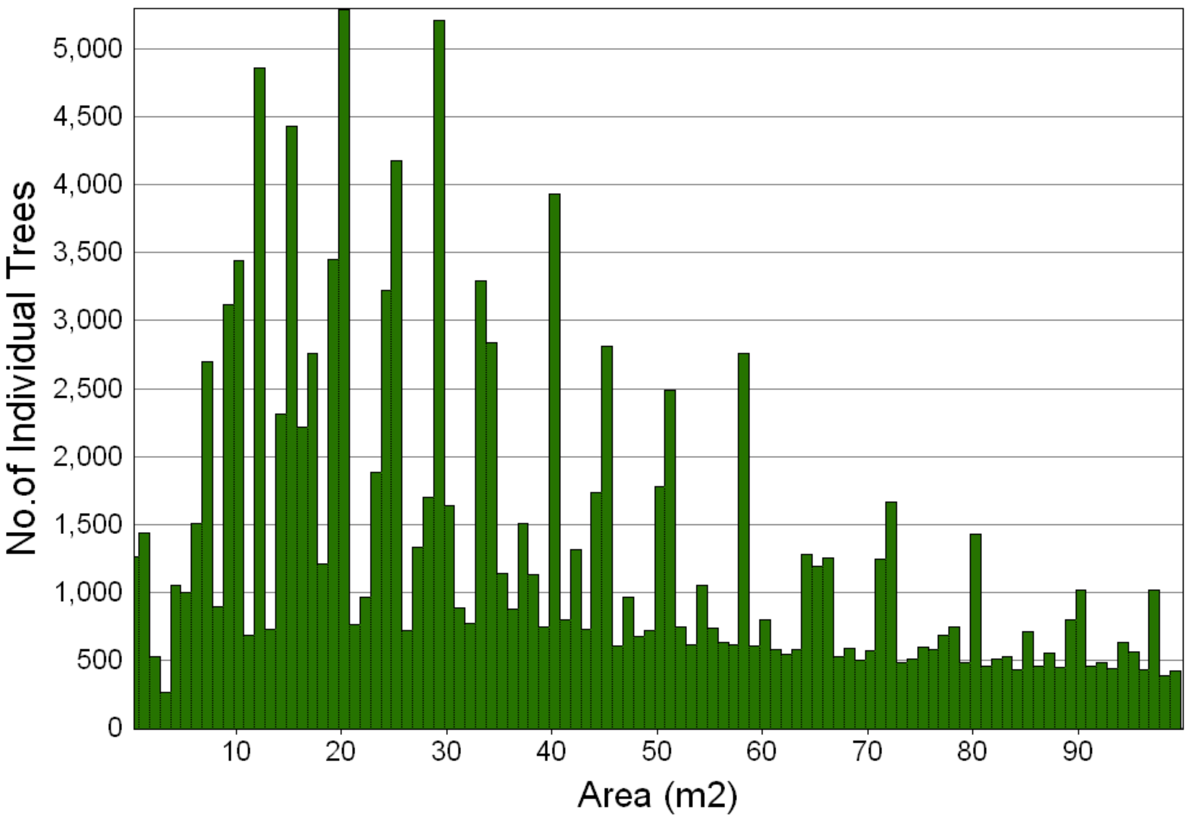


Figure 16 **Histogram of the 127,760 paddock trees with canopy areas less than 100 m^2 that were removed from the woody vegetation layer**

Using ArcMap's Identity function, the vegetation mosaic (Figure 14) was clipped with the refined woody vegetation layer so that polygons of the vegetation mosaic that occur on cleared lands (outside of the woody extent) were removed. The resulting vegetation mosaic contained only woody polygons > 100 m^2. As the vegetation mosaic and woody vegetation boundaries did not match perfectly, 3 types of issues occurred:

a. The woody layer captured vegetation that the vegetation mosaic did not map. This resulted in small polygons containing null vegetation types.
b. The refinement produced small 'sliver' polygons. These small polygons result from the original polygon being spatially reduced because it either mapped vegetation that had since been cleared or was spatially inaccurate.
c. The refinement of the woody layer resulted in small polygons with more than one PCT. An example is where clearing has occurred across 2 adjacent mapped types and the resultant refinement using the woody layer retains only a small section where the 2 map types were adjacent.

2. Corrective actions for these 3 issues required reviewing small remnant polygons that resulted from refinement of the woody layer. Hereafter, the term 'woody polygon' is used to describe these polygons. Where one woody polygon contained only one unique vegetation type, 3 simple steps were required as follows.
   a. All woody polygons that contained only one valid vegetation type were retained.

b. All woody polygons that contained only one type that was a disturbance class were retained. This situation was exclusive to mapping layers that mapped disturbance units. For example, in the Cessnock – Kurri Kurri mapping, Bell and Driscoll (2007) mapped 'Xr' which is a 'Disturbed – Canopy Only' unit.
c. All woody polygons that contained no vegetation type or disturbance class (null) were removed. These were typically very small polygons and would require intensive resources to allocate to any vegetation or disturbance category, an exercise that is beyond the scope of this study.

3. Slivers resulted where a single vegetation type polygon was reduced to less than 100 m^2 by the woody layer refinement. These situations occurred when the original mapping either covered cleared land due to spatial inaccuracy or had mapped vegetation that had since been cleared. An area-to-perimeter ratio in conjunction with the < 100 m^2 threshold were applied to identify these sliver polygons. The area-to-perimeter helped confirm that the shape of a sliver was both long and thin and thus an artefact that needed to be removed. The solution was to merge the slivers into the adjacent polygon with the longest shared edge using ArcMap's Eliminate function.
4. Review all small remnant woody polygons that contained only 2 vegetation types or only 2 disturbance classes, then apply the following rules:
   a. Reclassify both to the type with the largest area IF that larger type area is > 75% and the smaller type is < 100 m^2
   b. If the larger type area is ≤ 75% and the small PCT is ≥ 100 m^2 then do nothing and retain original plant community typing.
5. Most woody polygons that contained 3 or more types were typically above the 100 m^2 threshold and left untreated. The small number of polygons below the threshold were manually edited.
6. The woody vegetation coverage for NPWS estate was not completed because it was beyond the scope of the Cessnock City Council's LEP review. Therefore, woody refinement within these areas was not possible and thus the extant vegetation status remained the same as the mapping layers that cover NPWS estate.

Eastern NSW plant community type translation

With the exception of the department's State Vegetation Type Map (DPIE 2021), all other layers within the vegetation mosaic had current or legacy PCT classifications assigned in the Lower Hunter mosaic by Cockerill et al. (2013). As such, these layers required an upgraded translation to the ENSW PCT classification of Connolly et al. (2021).

The process of upgrading these layers to the ENSW PCT classification involved intensive review by botanical and ecological experts. Data to support this review included:

- A spatial data extract from the ENSW PCT database of full floristic plots with the ENSW PCT classification. These were regarded as empirical in situ references.

- A lineage table that translated the current (legacy PCT) allocation to the new ENSW PCT classification. The lineage is a one-to-many table meaning that a legacy PCT may equate to one or more ENSW PCTs. This table relies on the original legacy PCT allocation being applied accurately to the original mapping unit of the source data. Nonetheless, the table was a valuable tool in assisting with upgrading the PCT classification.

The method involved translating the original layer map units to the ENSW PCT classification based on all information in layer reports. These were typically vegetation community profiles with detailed information of mapping methodology, floristic composition, descriptive landscape context, diagnostic species and cover score metrics.

Full floristic plots (if present) and lineage table translations were used as starting points for each vegetation map unit to exclude invalid ENSW PCTs and to develop a shortlist of potentially suitable ENSW PCTs. The process for reviewing each individual map unit and allocating an ENSW PCT was:

1. Collate the ENSW PCT plots (if present) for each map unit, noting that there may be more than one plot in a polygon. Importantly, there were many instances where there was more than one ENSW PCT assigned to plots within a map unit and even within a single polygon. Visual inspection of the dataset was required to determine if the plots were on the boundaries of polygons or more centrally located. Plots located on boundaries meant their allocation to a polygon had lower reliability compared to those less ambiguous and more centrally located within polygons. Additionally, some ENSW PCT plot allocations are tagged as ‘Secondary’ and have low reliability compared to plot allocations tagged as ‘Primary’ (Connolly et al. 2021).
2. Review the original legacy PCT allocation to the map unit and collate the subsequent translated ENSW PCTs from the lineage table.
3. Review the map unit community profile for all information that describes the map unit.
4. Review and combine all the above information to assign the best fit ENSW PCT to each map unit. Plot data was prioritised because it is empirical and when combined with community profiles the result is the most reliable fit for ENSW PCTs. Where a map unit is dominated by a single ENSW PCT according to plots and they match the community profile, then that map unit is assigned to the ENSW PCT. In cases where the ENSW PCT plot allocations of a map unit are mixed, expert review of all data was used to assign the final ENSW PCT allocation.

Disturbance and non-vegetation codes

As mentioned previously, some mapping layers included disturbance and non-vegetation codes. Knowledge of disturbed vegetation and other features is valuable, thus, the disturbance codes were retained as an ENSW PCT value of 0. Table 2 lists these features along with their source layers and areas within the Cessnock LGA.

Table 2 **Mapping layers that used disturbance and non-vegetation codes**

Map unit	Map unit name	Layer source	Area (ha)
Xr	Disturbed - Canopy only	Cessnock-Kurri region vegetation (Bell and Driscoll 2007)	6,729.97
Xs	Disturbed - Regrowth	Cessnock-Kurri region vegetation (Bell and Driscoll 2007)	730.47
Xx	Exotic/ Plantation	Cessnock-Kurri region vegetation (Bell and Driscoll 2007)	24.88
W	Water Body/ Dam	Cessnock-Kurri region vegetation (Bell and Driscoll 2007)	13.23
R	Rocky Outcrop	Cessnock-Kurri region vegetation (Bell and Driscoll 2007)	1.93
X	Plantation Eucalypt Forest	Watagans and Jilliby vegetation (Bell and Driscoll 2006)	16.62
R	Rock	Vegetation and floristics of the Huntlee offset lands, Hunter Valley, NSW: 1. Cedar Creek (Bell 2017)	0.32
D	Dam	Vegetation and floristics of the Huntlee offset lands, Hunter Valley, NSW: 1. Cedar Creek (Bell 2017)	0.05
12	Anthropogenic Wetlands	Vegetation and floristics of the Huntlee offset lands, Hunter Valley, NSW: Sweetwater North Rothbury (Bell 2018c)	0.23
P	Plantation Eucalypt Forest	Watagans and Jilliby vegetation (Bell and Driscoll 2006)	331.34
44	Acacia Regeneration	Yengo vegetation (DECC 2008)	250.55
		Total	**8,099.59**

Note: The area (ha) column reflects total extent of these codes within the Cessnock LGA. These codes were allocated an ENSW PCT of 0.

In the case of the Cessnock – Kurri Kurri mapping of Bell and Driscoll (2007), they also produced a pre-1750 map of their study area. This allowed the inclusion of 2 attributes into the final vegetation mosaic, pre1750_ENSW_PCT and Legacy_pre1750_PCT (see 'Attributes' section below). These 2 attributes are populated with the pre-1750 map units that have been translated to ENSW PCTs and legacy PCTs respectively.

Allocation of threatened ecological community status

Assigning a map unit or PCT to a threatened ecological community (TEC) is a critically important step when deriving vegetation map products. Vegetation maps are the primary data to spatially delineate TEC determinations and approved conservation advice that define the TECs. Other spatial data is incorporated to match determination criteria such as elevation thresholds, Interim Biogeographical Regions of Australia (IBRA) constraints and substrate.

This vegetation mosaic contains TECs listed on both the NSW *Biodiversity Conservation Act 2016* (BC Act) and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Identification of TECs was achieved by reviewing the criteria in the respective determinations (see 'More information' section for link to final determinations) and matching that to all available information from the vegetation mosaic and other data, for example IBRA region, elevation data and substrate.

Allocation of TEC status required departmental modelling of the mosaic using existing vegetation mapping data sources with consideration of EPBC Act TEC listings and elevation criteria as described below.

NSW State Vegetation Type Map

Assignment of TEC status to the department's (DPIE 2021) State Vegetation Type Map modelling portion of the mosaic relied on information stored in the ENSW PCT classification database (Connolly et al. 2021). For each ENSW PCT profile in the database that has a TEC association, a relevant TEC is assigned. However, the challenge with TEC associations in the classification database is that they are rarely singular. It is common for one PCT to have more than one TEC association.

Within the Cessnock LGA only one ENSW PCT profile had a definitive single TEC associated with it, while other profiles had more than one TEC association whereby the PCT is considered 'part of' each of those TECs. These multiple TEC associations cause difficulty when trying to incorporate TEC legislation into local government scale planning decisions. To mitigate this lack of clarity, expert ecological and botanical review of these multiple associations was conducted to select the most appropriate TEC for the department's modelling data.

Vegetation mapping data sources

Layers other than the department's State Vegetation Type Map had some form of supporting information or pre-existing allocations to TECs to help support final allocations. Supporting information did not preclude layers from expert botanical and ecological review and as a result their pre-existing allocations to TECs were reviewed.

This was particularly important for older layers where new TECs have since been listed, and where more recent amendments have been made to the final determinations or listing advice of some TECs. This altered the criteria used to define these TECs. Additionally, these reviewed TEC allocations were cross-checked against the ENSW PCT classification database allocations for compliance. The compliance check was possible because each polygon has an ENSW PCT allocation and therefore associated TECs in the ENSW PCT classification database.

EPBC Act threatened ecological communities

Allocation of EPBC Act TECs was uncomplicated because the EPBC listing advice nominates NSW TEC equivalencies. However, allocation of EPBC Act TECs requires assessment against relevant EPBC Act TEC listing criteria. This is because translation from Commonwealth EPBC Act status to NSW BC Act status is not always identical and requires assessment to identify any discrepancies.

TEC polygons split by elevation criteria

Some BC Act TEC determinations have distinct thresholds based on elevation or height above sea level (ASL). An example is the river-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions TEC where the determination states that is '...generally occurs below 50 m elevation but may occur on localised river flats up to 250 m above sea level...'.

In all cases where this applies, an accurate 1 m LiDAR digital elevation model (DEM) was used to partition the LGA into areas above and below such thresholds. All polygons assigned to a TEC that were wholly above the relevant upper elevation limit do not meet the TEC definition and the TEC attribution was removed. However, there were instances where the LiDAR threshold data split a polygon so that part of the polygon fell above the threshold, but the remainder qualified as TEC. This is illustrated in the example provided in Figure 17.

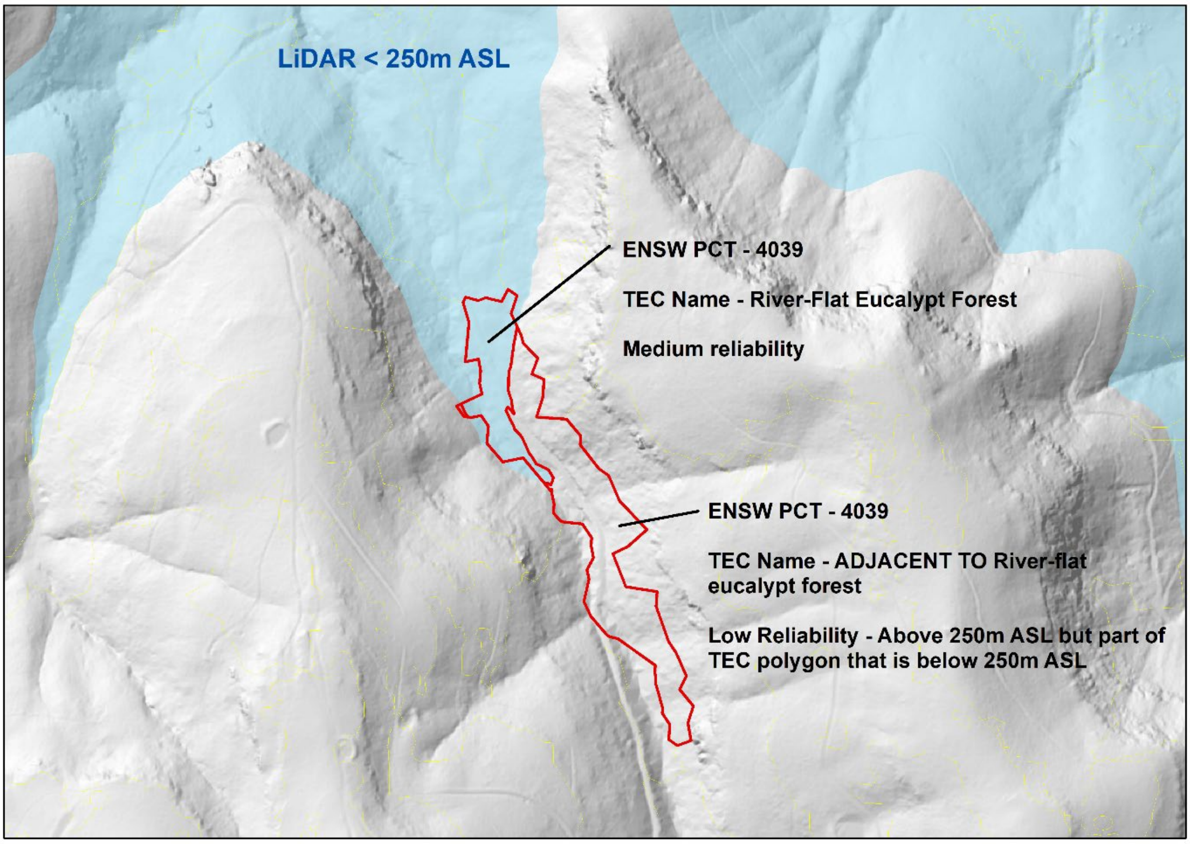


Figure 17 **Example of the State Vegetation Type Map ENSW_PCT 4039 split by elevation criteria of below 250 m above sea level for the river-flat eucalypt forest on coastal floodplains threatened ecological community (TEC)**

LiDAR elevation threshold is shown in blue with the polygon split by that threshold shown in red. The 'TEC Reliability' attribution is intuitive in explaining the split polygon.

In these instances, the part of the polygon that fell outside the threshold was allocated partial TEC status by prefixing the TEC name with 'ADJACENT TO…' and attributing the allocation as 'Low reliability' with explanatory notes (see 'Attributes' section below). An example of this from the previously mentioned river-flat eucalypt forest on coastal floodplains TEC is provided in Figure 17.

TECs (BC Act) in Cessnock LGA where an elevation threshold applies are:

- lower Hunter Valley dry rainforest in the Sydney Basin and NSW North Coast bioregions
- lowland rainforest in the NSW North Coast and Sydney Basin Bioregions
- freshwater wetlands on coastal floodplains of the NSW North Coast, Sydney Basin and Southeast Corner bioregions. **Note** that the determination threshold is not prescriptive whereby the TEC is described to 'generally occur below 20 m elevation' yet Ellalong lagoon at approximately 110 m ASL is stated as part of the TEC. As a result, the threshold was not applied because only 21 polygons (39.14 ha) out of 49 eligible polygons were above 20 m ASL and therefore included under a precautionary principle
- river-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and Southeast Corner bioregions
- swamp oak floodplain forest of the NSW North Coast, Sydney Basin and Southeast Corner bioregions
- swamp sclerophyll forest on coastal floodplains of the NSW North Coast, Sydney Basin and Southeast Corner bioregions.

Attributes

The design of vegetation mapping attributes is user-focussed so interpretation and use of data is both intuitive and clear. The original map units of source layers are maintained for review and verification. The main ENSW PCT allocations are provided first in the list and the original or 'legacy' PCT allocations are also maintained for historical purposes.

Descriptions of reliability have been provided for both NSW and Commonwealth listed TECs so that end users are provided with guidance as to how well a PCT or map unit aligns with a TEC. To aid in this reliability, every polygon is tagged with the number of full floristic plots and validation sites present. Explanation and structure of attributes is provided in Table 3.

Table 3 Final attribute structure of the Cessnock Local Government Area vegetation mapping mosaic

Attribute	Type	Description
ENSW_PCT	Integer	Eastern NSW plant community type (ENSW_PCT) number. Valid ENSW_PCT numbers range from 3029 to 4127. A non-valid ENSW_PCT value of 0 represents disturbed polygons within the Cessnock – Kurri Kurri mapping extent of Bell and Driscoll (2007). See pre1750_ENSW_PCT below for further details on these polygons.
ENSW_PCT_CommonName	Text	Eastern NSW plant community type name
No_of_Validation_Sites	Integer	Number of validation sites present in polygon
ValidationType	Text	Type of validation sites present in polygon. The 2 types are: • FFP – full floristic plot (systematic survey site) • RDP – rapid data point
pre1750_ENSW_PCT	Integer	Only applies to Bell and Driscoll (2007) Cessnock – Kurri Kurri vegetation mapping where the mapping includes disturbance codes. Process as follows: 1. Allocate all disturbance coded polygons to 0 in the main ENSW_PCT attribute 2. For all disturbance coded polygons, a pre1750_ENSW_PCT type was allocated, these were translated from pre-1750 map units. Note: This field provides user with some insight into pre-disturbance conditions and current regeneration status.
Formation	Text	Keith (2004) formation
Class	Text	Keith (2004) class
TEC_Name	Text	Name of NSW BC Act threatened ecological community (TEC)
TEC_Source	Text	Source of allocation as a BC Act TEC
TEC_Reliability	Text	Reliability of allocation to a TEC. Ranks are Low, Medium and High with explanatory notes where required. Note: A high reliability occurs wherever one or more validation sites exist in a polygon
EPBC_TEC_Name	Text	Name of Commonwealth EPBC Act TEC
EPBC_TEC_Source	Text	Source of allocation as an EPBC TEC
EPBC_TEC_Reliability	Text	Reliability of allocation to a TEC.

Attribute	Type	Description
		Ranks are Low, Medium and High with explanatory notes where required. Note: A high reliability occurs wherever one or more validation sites exist in a polygon
SourceVegID	Text	Vegetation mapping community code of source layer
SourceVegCommName	Text	Vegetation mapping community name of source layer
SourceReport	Text	Reference of source layer used
Legacy_PCT	Integer	NSW plant community type number that pre-dates eastern NSW plant community type
PCT_Source	Text	Organisation/group that was responsible for allocating the eastern NSW plant community type to the original source mapping unit
Legacy_pre1750_PCT	Integer	This field is the same as pre1750_ENSW_PCT above except Bell and Driscoll (2007) pre-1750 units have been translated to the legacy plant community type number that pre-dates eastern NSW plant community type.
Shape_Length	Double	Polygon perimeter length in metres
Shape_Area	Double	Polygon area in metres squared

Review

As the last step in TEC allocations, each TEC was displayed individually, and spatial distribution was cross-checked against the determination and all other available information. Where errors were found, the solution was to remove TEC status from the subject polygon without changing any other attributes in the data. No spatial adjustments were made in these instances. The areas and mapped distributions of the resulting NSW and Commonwealth TECs that occur in Cessnock LGA are shown in Table 4 and Figure 18 respectively.

Table 4 All NSW (BC Act 2016) and Commonwealth (EPBC Act 1999) threatened ecological communities (TEC) that occur within the Cessnock Local Government Area

TEC name (BC Act 2016)	TEC name (EPBC Act 1999)	Area (ha)
Central Hunter grey box-ironbark woodland in the NSW North Coast and Sydney Basin Bioregions	Central Hunter Valley eucalypt forest and woodland	5.06
Central Hunter ironbark - spotted gum - grey box forest in the NSW North Coast and Sydney Basin Bioregions	Central Hunter Valley eucalypt forest and woodland	1,348
Freshwater wetlands on coastal floodplains of the NSW North Coast, Sydney Basin and Southeast Corner bioregions		126
Hunter lowland redgum forest in the Sydney Basin and NSW North Coast Bioregions		135
Kurri sand swamp woodland in the Sydney Basin Bioregion		2,860
Lower Hunter spotted gum ironbark forest in the Sydney Basin and NSW North Coast Bioregions		15,613
Lower Hunter Valley dry rainforest in the Sydney Basin and NSW North Coast Bioregions		63
Lowland rainforest in the NSW North Coast and Sydney Basin Bioregions		1,549
ADJACENT TO Lowland rainforest in the NSW North Coast and Sydney Basin Bioregions		737
Quorrobolong scribbly gum woodland in the Sydney Basin Bioregion		122
River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and Southeast Corner bioregions	River-flat eucalypt forest on coastal floodplains of southern New South Wales and eastern Victoria	4,204
ADJACENT TO River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and Southeast Corner bioregions	ADJACENT TO River-flat eucalypt forest on coastal floodplains of southern New South Wales and eastern Victoria	7

TEC name (BC Act 2016)	TEC name (EPBC Act 1999)	Area (ha)
Swamp oak floodplain forest of the NSW North Coast, Sydney Basin and Southeast Corner bioregions	Coastal swamp oak (*Casuarina glauca*) forest of New South Wales and Southeast Queensland	<1
Swamp sclerophyll forest on coastal floodplains of the NSW North Coast, Sydney Basin and Southeast Corner bioregions		126

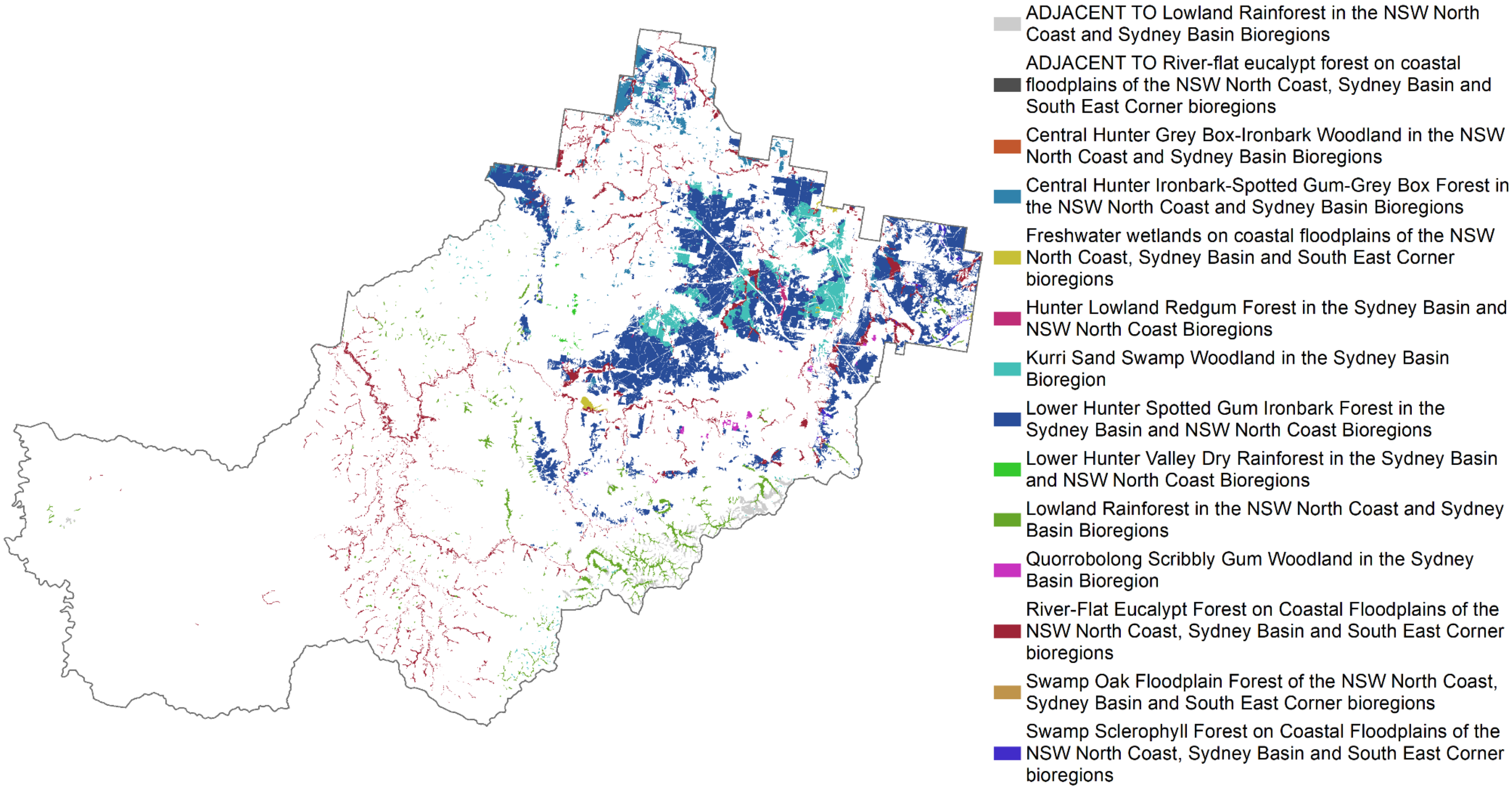


Figure 18 **NSW listed (Biodiversity Conservation Act) threatened ecological communities for Cessnock Local Government Area**

This layer was prepared in 2022 and is therefore representative of data available at the time. As new information becomes available, the layer will be reviewed, updated and redistributed. Refer to contributor acknowledgements in Appendix H.

Final layer

The final vegetation mapping mosaic has been constructed so that the most reliable and accurate biodiversity information can be applied at local scale for the user. The data will form the basis of many other biodiversity themes such as wildlife corridors and key habitats for species. With such an accurate woody vegetation footprint and fully reviewed floristics, the layer can now be properly regarded as a local-scale baseline so that any future data can be implemented as an update or maintenance.

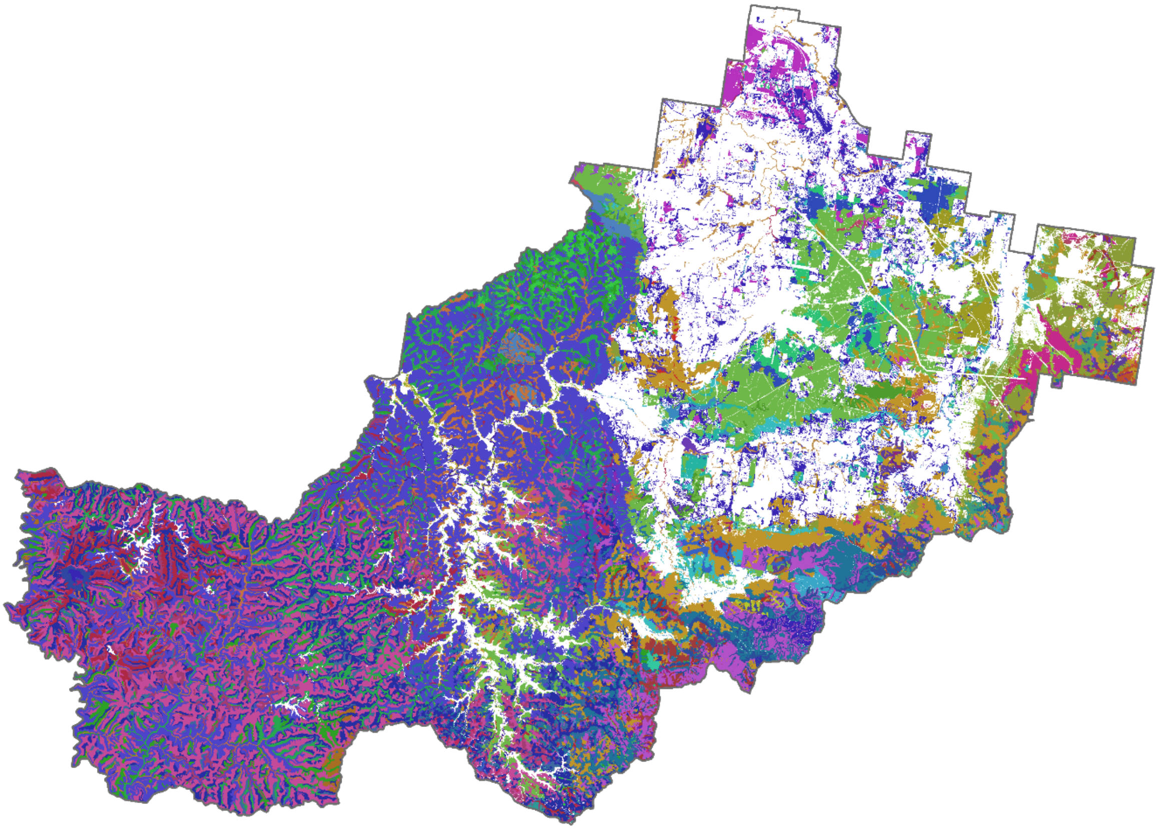


Figure 19 **Final vegetation mapping mosaic for Cessnock Local Government Area**

Note: Eastern NSW plant community type attribution too detailed to list at this scale.

The data will be enhanced with targeted surveys and extra site data to fill gaps and thus provide more confidence in its application. Figure 19 is a visual snapshot of the final vegetation mosaic with the ENSW PCT classification used as the basis for the multicoloured display.

Appendix C. Corridors layer metadata

This layer provides a structural connectivity analysis for the Cessnock Local Government Area (LGA) which covers 196,468 ha. The dataset is scientifically valid and provides fine-scale mapping generated from evidence-based data. The connectivity analysis was conducted at multiple raster scales then combined into a final vector format with accuracy commensurate to a scale range of 1:500 to 1:1,000. This connectivity analysis is one aspect of biodiversity information that maps the current state of biodiversity movement at a scale that can inform local planning decisions.

Background

Habitat fragmentation is a major threat to global biodiversity and awareness of the importance of connectivity or 'wildlife corridors' in statutory planning processes is increasing.

Authorised regulatory agencies, for example councils, require evidence-based biodiversity data to inform review of statutory instruments such as local environment plans (LEPs). Cessnock City Council sought a robust layer from the Department of Climate Change, Energy, the Environment and Water (the department) to review their LEP and the resulting connectivity layer will contribute to thorough consideration of biodiversity across the LGA.

Maintaining structural connectivity or wildlife corridors in a landscape contributes to avoiding or mitigating effects of further habitat fragmentation (Doerr et al. 2010). Connectivity provides a network in the landscape that can facilitate gene dispersal within and between sub-populations so that metapopulations can persist. However, Doerr et al. (2010) differentiates between 2 definitions of connectivity:

- **structural connectivity** is the physical structure of habitat in the landscape
- **effective connectivity** is when structural connectivity has demonstrated or measured gene dispersal, movement and persistence of species.

There are few studies that measure effective connectivity because the process requires intensive resources and long-term monitoring. This is shown in the comprehensive review of connectivity by Doerr et al. (2010) which acknowledges structural connectivity analysis as a prerequisite for robust assessment of effective connectivity. When structural connectivity exists as either a map or a model, field verification to measure effectiveness can be conducted to determine efficacy of connectivity structure.

Production of this layer required highly technical expertise and explanation of the methodology uses technical language. See Appendix G for a glossary of technical terms and acronyms.

Audit of layers

Before any analysis was conducted, an audit of existing layers was required to avoid repetition and establish a scientifically valid methodology. Most importantly, the results of the audit prevented use of any existing outputs that do not satisfy accuracy and application requirements of Cessnock City Council. There are existing corridor analyses that cover the Cessnock LGA, and all vary based on scale, intent and method. Some have been peer-reviewed while others exist in unpublished government reports or databases. Table 5 provides a list of the known connectivity analyses and the attributes of name, currency, intent, scale, coverage and publication status. Links to datasets, where available and as indicated in the table, are provided in the 'More information' section at the end of the report.

The GAP CLoSR study of Lechner and Lefroy (2014) listed in Table 5 is the only connectivity analysis that satisfies local-scale requirements for this study. The intent of the GAP CLoSR study was to provide a decision-support framework for connectivity at local (2.5 m) and regional (100 m) scales for the Lower Hunter (Lechner and Lefroy 2014). The study was the first to introduce the gap-crossing threshold of 106 m and the maximum interpatch dispersal threshold of 1,100 m as defined in the review by Doerr et al. (2010).

For connectivity analyses, Lechner and Lefroy (2014) applied a Graphab connectivity model for regional scale (Foltête et al. 2012) and a Circuitscape connectivity for local scale (McRae et al. 2008).

Resulting outputs from this analysis were in the form of dimensionless (no width) line connections between patches at the local scale, and components (polygons) for regional scale connectivity. Also, the scale of the data used in the study is broader than the data generated within this study for Cessnock City Council. For the Lower Hunter, Lechner and Lefroy (2014) used a vegetation base coverage generated from SPOT satellite imagery at a resolution of 2.5 m and a minimum patch size of 10 ha, compared to this study which used accurate woody polygons with tree crowns ~ 2 m in diameter (0.00012 ha). Overall, the work of Lechner and Lefroy (2014) was the first of its kind at such a scale, but not without some limitations. As mentioned, the scale of the data is relatively broad compared to the Cessnock LGA environmental lands study because patches were defined by node points and the local-scale connections are dimensionless lines.

This study for Cessnock LGA has selected the spatial links analysis tool described in the mapping of habitat linkages study by Drielsma et al. (2007) because it overcomes some of the limitations of GAP CLoSR. The spatial links tool does not require nodes for patches because it can assess each cell (pixel) in a patch as a start/end point. Additionally, spatial links overcomes any limitations of addressing the infinitely variable and complex spatial configuration of any landscape. A more detailed examination of the spatial links methodology compared to other analytical techniques is discussed in the detailed studies of connectivity for planning in Drielsma et al. (2022).

This study adopted the 106 m gap-crossing threshold and overcame the singular 1,100 m maximum dispersal threshold by applying multiple scales that addressed a range of dispersal distances to cater for varying ecological traits of fauna and flora.

The final layer results from the spatial links analysis at fine-scale across the Cessnock LGA were buffered by 1 km to avoid any abrupt termination of connectivity at the edges of the LGA (M. Drielsma et al. 2007).

Table 5 Audit of known connectivity analyses that have covered the Cessnock Local Government Area

Name	Date	Intent	Scale	Coverage	Publication status
Climate change corridors	2007	Climate change adaptation	State	North-east NSW	Three layers (moist, coastal and dry corridors) available on NSW Government SEED database (see link in 'More information' section)
Great Eastern Ranges	2007	Large-scale conservation of biodiversity	National	Eastern Australia	Spatial layer is very broad and resembles the Great Dividing Range along the eastern coastline of Australia (see link in 'More information' section)
Cessnock biodiversity management plan	2011	Regional recovery planning under the EPBC Act (1999)	Regional	Cessnock LGA	Online poster (see link in 'More information' section)
Landscape value mapping	2012	To advise catchment management authorities on state-scale benefits of biodiversity	State	NSW	Drielsma et al. (2012)
GAP CLoSR	2014	To ensure that connectivity planning associated with the Sustainable Regional Development program utilises best practice science and modelling techniques	Local/ Regional	Lower Hunter (Maitland, Port Stephens, Newcastle, Lake Macquarie and Cessnock LGAs)	Lechner and Lefroy (2014)
Lower Hunter strategic assessment corridors	2014	Lower Hunter regional strategic assessment	Regional	Lower Hunter	Unpublished. Data resides on the department's databases
Upper Hunter strategic assessment corridors	2014	Upper Hunter regional strategic assessment	Regional	Upper Hunter (partial coverage of Cessnock LGA)	Unpublished. Data resides on the department's databases

Method

The process for production of the corridors layer considered and integrated:

1. Spatial links analysis – enabled representation of habitat quality, and ease and resistance of plants and animals to disperse throughout the landscape.
2. The study area – which explains landscape types in the Cessnock LGA and how the spatial links analysis enabled avoidance of 'edge effects'.
3. Woody vegetation layer – and an additional low-resolution 1 km buffer outside the border of the LGA to contribute to avoidance of edge effects.
4. Cost dispersal – analysed the energy cost for flora and fauna to move between different landscapes – this enables ranking of corridors and therefore prioritisation of spatial links.
5. Primary habitat – identified habitat that should be easy for flora and fauna to move through, which enables prioritisation of spatial links.
6. Spatial links pre-processing – enabled identification of source and destination points. This was achieved through analysis at 5 different scales at increasing detail representing a range of species' movements.
7. Outputs – identified relative value of spatial links.
8. Spatial links post-processing – produced a categorised layer that captured high connectivity links and removed low connectivity areas.

Steps are described in more detail below.

Spatial links analysis

The spatial links analysis is complex and detailed explanations of the algorithms behind the analysis are provided in Drielsma et al. (2007) and Drielsma et al. (2022). For the purposes of this report, a lay explanation follows to offer the reader a principled understanding of the analysis.

Spatial links is applied through the Links4 software program shown in Figure 20 that illustrates the 3 basic forms of input required:

- a spatial layer representing habitat quality (primary habitat)
- a spatial layer representing dispersal cost (cost dispersal)
- user-defined connectivity parameters that define both ease and resistance of plants and animals to disperse throughout the landscape.

The underlying principle of the Links4 tool is to map the least-cost path between any 2 patches of habitat that support and maintain populations of species.

Complexity arises when we consider the number of different shaped habitat patches and the complexity of the fragmented landscapes in between. Good quality habitat patches are defined in the spatial links tool when the user applies a value threshold to the primary habitat layer as shown by the 'Minimum habitat threshold for source/destination' parameter on the tool in Figure 20.

Every grid cell in the primary habitat layer with a value above that threshold is considered as both a source and destination, and this can result in millions of source–destination combinations.

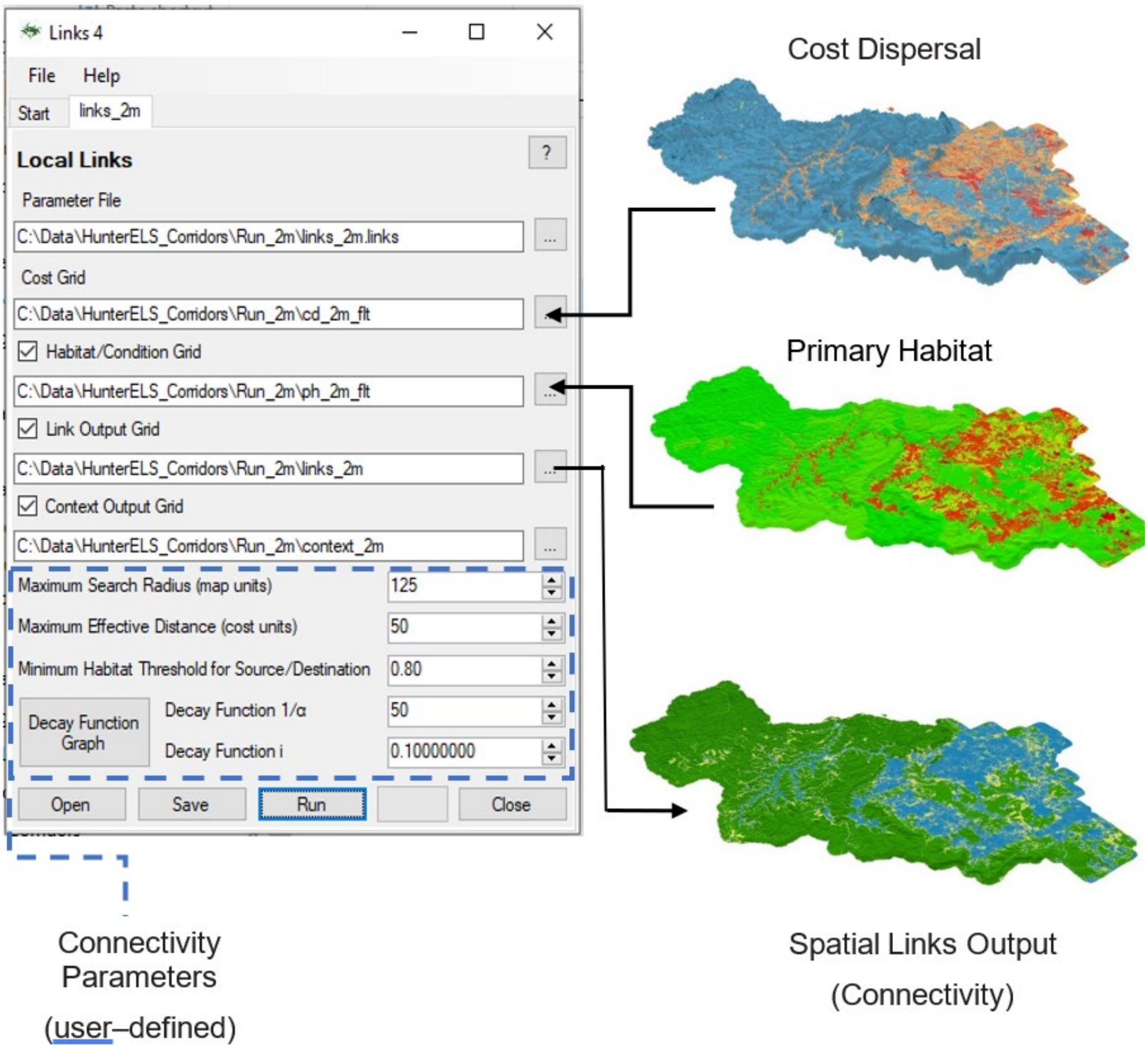


Figure 20 **The spatial links software tool Links4 showing the user-defined parameters and 2 spatial raster layers (cost dispersal and primary habitat) required to produce a connectivity output**

The ecological rigour of the tool is realised when considering that a least-cost path is calculated for every one of the source–destination combinations.

The output layer is a result of the tool cumulatively adding all the least-cost paths so that areas that are frequently used as movement corridors have high values; with the converse being true. Furthermore, for every calculation of a least-cost path, the analysis considers habitat quality, cost/resistance to movement and how fragmentation reduces movement non-linearly. This means that increased fragmentation and poorer habitat exponentially reduces movement.

The section‘Spatial links pre-processing’ below further details the parameters applied for Cessnock LGA and how these result in a multiscaled approach that covers a broad range of species movement.

Study area

The Cessnock LGA study area is bisected into 2 types of landscapes. The western half is dominated by the rugged and continuous sandstone vegetation that is mostly within by NPWS estate or Forestry Corporation of NSW estate. The Hunter Valley in the eastern half contains some of the largest remnants left in the whole of the Hunter Valley. Figure 2 demonstrates this and shows that some of the larger valley remnants are NPWS estate or Crown lands. Figure 21 also shows the 1 km buffer (blue hatched line) of the Cessnock LGA that the spatial links analysis required to avoid edge effects (explained below).

All layers used in the spatial links analysis were completed for the 1 km buffered area and any existing connectivity linkages from adjacent LGAs were reviewed and considered. Only Lake Macquarie and Central Coast LGAs had existing fine-scale connectivity analysis but existing linkages were irrelevant because the effacing boundaries in both cases were contiguous vegetation. This meant that connectivity analysis was superfluous in these areas because they were part of larger patches of good quality primary habitat.

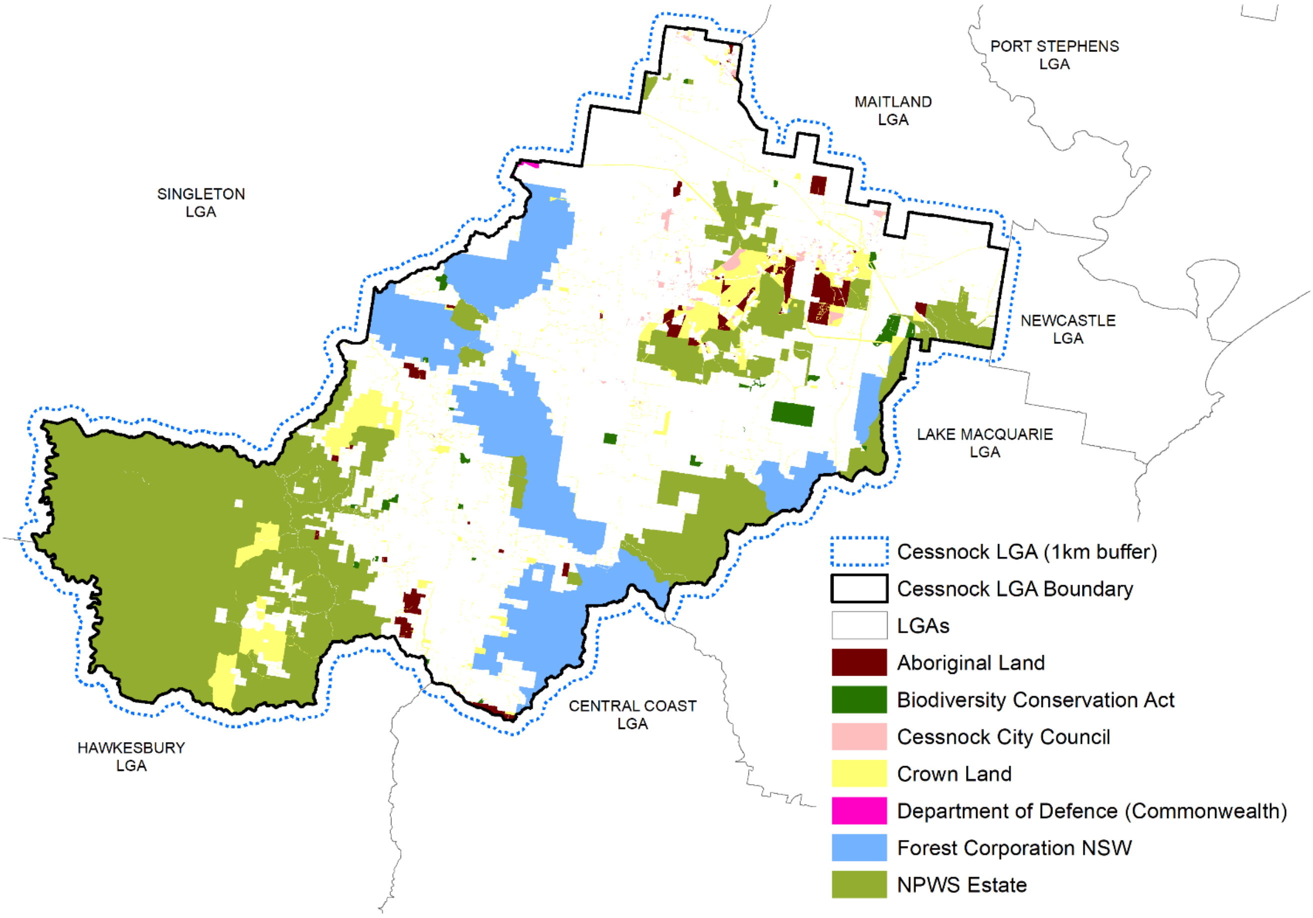


Figure 21 **Cessnock Local Government Area study area with tenure**

The footprint for the spatial links analysis is the LGA buffered by 1 km as shown by the blue hatched line.

As mentioned previously, spatial links analysis requires 2 key input raster layers: cost dispersal and primary habitat. The following provides a detailed description of their derivation with reference to the woody vegetation layer (see Appendix A) that underpins both layers.

Woody vegetation layer

Data generated for the environmental lands study was limited strictly to the Cessnock City Council LGA and, as a result, the fine-scale woody vegetation data did not cover the 1 km buffer area around the LGA. This was overcome by adding the department's foliage percent cover mapping for the 1 km buffer outside of Cessnock LGA (OEH 2011). The foliage percent cover mapping is less accurate than the fine-scale Cessnock woody layer, but this is not a concern because the buffer is only used to negate any subtle edge effects from the corridor analysis.

Cost dispersal

Construction of a cost dispersal surface involved scoring each location (raster grid cell at a specified resolution) with a relative energy cost for flora/fauna dispersal. Relative scoring was scaled to an index between 0 and 100. A value of 0 equates to zero/minimum energy cost (for high-quality vegetation) and 100 equates to high-energy costs or hard barriers (for expansive waterbodies or freeways). Cost dispersal was constructed from spatial layers that best describe or infer dispersal cost and they are:

- woody vegetation
- woody vegetation within degraded landscapes
- landuse
- public tenure
- major roads
- rail
- waterbodies.

One of the main calculations in the spatial links connectivity analysis is to determine the least-cost path between every pair of source and destination points in the landscape (Drielsma et al. 2007).

To determine the least-cost path for a single source–destination pair, the analysis queries the cost dispersal map as it searches radially outward from the source. As the search radius grows, higher cost paths are ignored and the analysis focusses in on least-cost paths until the path with lowest cost to the destination is found.

To achieve the least-cost pathway the analysis cumulatively adds up the cost dispersal scores for each grid cell during the radial searches resulting in paths with high cumulative costs being abandoned until the final lowest cost path remains. It is therefore critical to create a cost dispersal map that avoids any paths crossing large expanses of cleared land (Lechner and Lefroy 2014).

Large or expansive gaps should be avoided because plants and animals will not seek the shortest distance (as the crow flies) between 2 points, they will use pathways that contain habitat or vegetated stepping-stones (Doerr et al. 2010; Drielsma et al. 2022; Lechner and Lefroy 2014). As a result, the cost dispersal map values were rescaled so that most vegetation patches were scaled within the 0 to 25 (low cost) value range and any landscape features that represented gaps or cleared land were rescaled between 80 and 100 (high cost). The value gap from 25 to 80 creates a clear separation and guides the least-cost analysis towards selecting paths between vegetated parts of the landscape. However, not all vegetation patches/trees were treated equally. Small, isolated vegetation patches/trees within very degraded landscapes were downgraded to values within the 40 to 100 range given they are less accessible and less functional as stepping-stones.

A summary of the score ranges for cost dispersal and the priority of layers used is shown in Table 6. Layer priorities shown in the fourth column are highest to lowest for 1 to 3 respectively, meaning layers with higher priorities take spatial precedence over lower priority layers.

Table 6 Summary of all cost dispersal scores with descriptions of inputs and the mapping sources of those inputs

Cost dispersal score	Description	Source layer	Mapping priority
5	Non-disturbed vegetation mapped as a native plant community type	Woody extent and vegetation map	1
15	Disturbed native vegetation	Woody extent and vegetation map	1
20	Eucalypt plantations	Woody extent and vegetation map	1
25	Small native remnants (< 3 ha) and exotic plantations	Woody extent and vegetation map	1
40–100	Exotic and native remnants or paddock trees (< 100 m^2) within degraded landscapes	Woody extent and landuse	2
80–100	Landuse, tenure, waterbodies, roads and rail categories	Landuse, tenure, roads, rail and waterbodies	3

Note: Mapping priorities are highest (1) to lowest (3). Data sources with higher priorities take spatial precedence over lower priorities, that is, polygons with scores of ≤ 25 were prioritised over all other layers; and any polygons mapped as 40–100 (remnants and paddock trees in degraded landscapes) took spatial priority over polygons mapped as 80–100.

All cost dispersal scores of 5–25 (in rows one to 4 in Table 6) were generated from the fine-scale woody extent and vegetation mapping layers (see Appendix A and Appendix

B respectively). Remaining cost dispersal scores in the last 2 rows of the table were generated from multiple layers and these are explained below.

In Table 6, the dispersal cost scores from 40–100 in the fifth row were assigned to woody remnants or paddock trees (< 100 m^2). These remnants/trees were not captured by vegetation mapping because they were too small or isolated to warrant allocation to a plant community type. These remnants/tree polygons were then unioned with the landuse layer so that woody polygons within more degraded landscapes were allocated higher cost dispersal scores (closer to 100) than those in less degraded landscapes (scored closer to 40). That allocation resulted in each remnant/tree being assigned a cost dispersal score between 40 and 100 as shown in Table 7.

Table 7 Cost dispersal scores for small woody remnants and paddock trees (0.01–13 ha) within degraded landscapes

Cost dispersal score	Landuse categories surrounding woody remnants/trees
40	Grazing native vegetation, Native/exotic pasture mosaic
45	Abandoned perennial horticulture, Grazing modified pastures, Perennial horticulture
50	Olives, Recreation and culture, Services, Tree fruits
60	Cropping, Grapes, Grazing irrigated modified pastures, Horse studs
65	Airports/aerodromes, Irrigated grapes, Irrigated olives Irrigated perennial horticulture, Irrigated tree fruits, Seasonal vegetables and herbs
70	Poultry farms, Rural residential with agriculture
75	Abandoned intensive animal production, Lake
80	Riparian
90	Channel/aqueduct, Commercial services, Intensive animal production, Public services, Railways, Roads, Rural residential without agriculture, Transport and communication Urban residential
98	Abattoirs, Electricity substations and transmission, Farm buildings/infrastructure, Food processing factory, Landfill, Major industrial complex, Manufacturing and industrial, Mines, Mining, Residential and farm infrastructure, Sawmill, Sewage/sewerage, Tailings, Utilities, Waste treatment and disposal

Note: The degraded landscapes are shown in the landuse categories column. For example, the cost dispersal score 80 is for remnants or paddock trees isolated in riparian areas that are mostly cleared.

Dispersal cost scores from 80–100 in the bottom row of Table 6 were generated from 5 separate map layers: landuse, tenure, roads, rail and waterbodies. Each layer was assigned cost dispersal scores independently from 0–100 then rescaled into the 80–100 range to create the separation from woody vegetation.

All 5 layers were then unioned into one layer and a mean cost dispersal score was allocated where any 2 or more of the 5 maps overlapped spatially. Conversely, where no overlaps were present the cost dispersal score of the only present layer was assigned. Table 8 and Table 9 below show the cost dispersal scores for landuse and tenure. Table 10 combines the cost dispersal scores for roads, rail and waterbodies.

Table 8 Cost dispersal scores for landuse mapping types

Cost dispersal score	Landuse types
81	Nature conservation
82	Other conserved area, Marsh/wetland
83	Reservoir/dam, Reservoir
84	Managed resource protection, Residual native cover, Rehabilitation
86	Production native forests, Other forest plantation, Land under rehabilitation
87	Other minimal use, Water storage - intensive use/farm dams
88	Grazing native vegetation, Softwood plantation forestry, Native/exotic pasture mosaic
89	Grazing modified pastures, Perennial horticulture, Abandoned perennial horticulture
90	Tree fruits, Olives, Land in transition, No defined use, Services, Recreation and culture
92	Cropping, Grapes, Grazing irrigated modified pastures, Horse studs
93	Seasonal horticulture, Seasonal vegetables and herbs, Irrigated perennial horti-culture, Irrigated tree fruits, Irrigated olives, Irrigated grapes, Airports/aerodromes
94	Poultry farms, Rural residential with agriculture
95	Abandoned irrigated perennial horticulture, Abandoned intensive animal production, Lake, Abandoned irrigated perennial horticulture, Abandoned intensive animal production, Lake
96	Dairy sheds and yards, River
98	Intensive animal production, Urban residential, Rural residential without agriculture, Commercial services, Public services, Transport and communication, Roads, Railways, Channel/aqueduct
99	Shadehouses, Manufacturing and industrial, General purpose factory, Food processing factory, Major industrial complex, Abattoirs, Sawmill, Residential and farm infrastructure, Farm buildings/infrastructure, Defence facilities – urban, Utilities, Electricity substations and transmission, Mining, Mines, Tailings, Waste treatment and disposal, Landfill, Sewage/sewerage

Note: Original scoring was performed for these codes within a range of 0–100 but were rescaled to a range 80–100 to separate them as harder barriers than woody vegetation.

Table 9 **Cost dispersal scores for tenure categories**

Cost dispersal score	Tenure categories (details)
80	Cessnock City Council (Ellalong, Housing Comm. Park) Crown Land (Road, Easement, Lease, Reserve, Shared Crown / Council Road) Department of Defence (Commonwealth - Singleton Army Base) NPWS estate (Black Creek Nature Reserve (NR), Cedar Creek NR, Corrabare NR, Finchley Aboriginal Area (AA), Mount Warrawalong NR, Pambalong NR, Watagans National Park (NP), Werakata NP, Yengo NP)
81	Aboriginal Land Biodiversity Conservation Act (Biodiversity Stewardship Agreement, Conservation Agreement, NCT Agreement, Registered Property Agreement, Wildlife Refuge) Cessnock City Council (Black Hill, Cessnock, Ellalong, Kurri Kurri, Paxton, Weston) Crown Land (Cessnock Cemetery, Parcel, Road, Waterway, Easement, Lease, Reserve, Shared Crown / Council Road) NPWS estate (Blue Gum Hills Regional Park (RP), Jilliby State Conservation Area (SCA), Sugarloaf SCA, Werakata SCA, Yengo SCA)
82	Aboriginal Land Cessnock City Council (Bellbird, Black Hill, Cessnock, Cessnock City Council, Heddon Greta, Lease, Varty Park, Weston) Crown Land (Parcel, Road, Waterway, Easement, Lease, Reserve, Reserved for Cemetery, Shared Crown / Council Road) Forestry Corporation NSW (Aberdare State Forest (SF), Awaba SF, Corrabare SF, Heaton SF, Olney SF, Pokolbin SF, Watagan SF)
83	Cessnock City Council (Abermain, Bellbird, Convent Hill Park, Lease, Mount Bright Lookout, Pokolbin, Weston, Wollombi) Crown Land (Cemetery (Ellalong), Parcel, Road, Waterway, Easement, Reserve, Shared Crown / Council Road)
84	Cessnock City Council (Cessnock, Heddon Greta, Hunter River Reserve, Mount View, Nulkaba, Pokolbin, Wollombi) Crown Land (Road, Easement, Reserve, Shared Crown / Council Road)
85	Aboriginal Land Cessnock City Council (Bucketty Bushfire Brigade, Kearsley, Lease) Crown land (Road, Easement, Lease, Reserve, Shared Crown / Council Road)
86	Aboriginal Land Cessnock City Council (Alkira Avenue Park, Cessnock City Council, Kearsley, Lease, Weston) Crown Land (Road, Easement, Lease, Reserve, Shared Crown / Council Road)
87	Cessnock City Council (Cessnock, Greta, Heddon Greta, Nulkaba, Paxton, Rothbury, Thomas Fell Park, Weston)

Cost dispersal score	Tenure categories (details)
88	Aboriginal Land Cessnock City Council (Lovedale, Paxton Park, Weston) Crown Land (Bailey Park, Easement, Millfield Cemetery, Reserve, Shared Crown / Council Road, Trade & Investment)
89	Cessnock City Council (Bellbird, Bridges Hill/ Convent Hill Park, Chinaman's Hollow, KURRI KURRI, Tomalpin Street Reserve, Weston) Crown land (Crown, Crown Road, Easement, Reserve, Shared Crown / Council Road)
90	Aboriginal Land Cessnock City Council (Bimbadeen Lookout, Heddon Greta, Lease, North Rothbury, Paxton Park, Rothbury, Slack's Park, Weston) Crown Land (Road, Easement, Reserve, Shared Crown / Council Road)
91	Cessnock City Council (Chinaman's Hollow Cricket Oval, Ellalong, Kearsley, Laguna, Lease, Lovedale, Rothbury, Stanford Merthyr Park: Varty Park Off Leash Area, Wollombi Community Hall) Crown Land (Cemetery (Kurri Kurri), Road, Waterway, Easement, Lease, Reserve, Shared Crown / Council Road)
92	Aboriginal Land Cessnock City Council (Cessnock, East End Oval, Greta Median Strip Park, Kurri Kurri, Maybury Peace Park, neath, Paxton Park) Crown Land (Cemetery (Greta), Road, Dedication, Easement, Lease, Reserve, Shared Crown / Council Road)
93	Cessnock City Council (Bellbird, Cessnock, Greta Central Park, Jeffries Park, Laguna Community Hall, Lease, Pokolbin, Quarry Street Park, Stanford Merthyr, Swamp Creek Park, Weston Bears Park, Wollombi Tennis & Croquet Courts) Crown Land (Road, Dedication, Easement, Lease, Reserve, Shared Crown / Council Road)
94	Cessnock City Council (Brooks Street Reserve, Cessnock, Cessnock Sportsground / Baddeley Park, East Branxton, Ellalong Park, Greta, Greta Median Strip Park, Heddon Greta, Jeffery Park, Kurri Kurri, Lease, Maybury Peace Park - Playground, Neath Pony Ground, Pelaw Main, Stanford Merthyr Playground, Varty Park Cricket Oval, Wickham Street Reserve) Crown Land (Dedication, Easement, Lease, Reserve, Shared Crown / Council Road)
95	Cessnock City Council (Aberdare, Abermain Plaza Hall, Ayrfield Miners Memorial Park, BELLBIRD, Bellbird Miner's Memorial Park, Booth Park, Branxton, Branxton Oval, Branxton Pool, Brunner Park, Buckland Avenue Playground, Cessnock, Cliftleigh, Conway's Corner, Crawfordville / Millfield - Sportsground, East Branxton, Ernie Dunlop Park, Former Greta Council Chambers, George Winter Park, Greta, Greta Arts & Sports Community Hall, Hedleigh Park, Jacob's Park, Kitchener, Kurri Kurri, Kurri Kurri Senior Citizens Hall, Kurri Kurri Skate Park,

Cost dispersal score	Tenure categories (details)
	Lease, Lee-Ann Crescent Park, Lloyd Park, Log Of Knowledge Park, Macquarie Avenue Playground, Margaret Johns Park, Meredith Park, Mount Vincent, Pokolbin Park, Stanford Merthyr, Vernon Street Netball Complex, Victoria Park, Weston Memorial Park, Whitburn Park - Playground, Wollombi) Crown Land (Cemetery (Greta), Crown - Property NSW, Easement, Reserve, Shared Crown / Council Road)
96	Aboriginal Land Cessnock City Council (Aberdare, Abermain, Abernethy Playground, Apex Park Cessnock, Bellbird, Bellbird Community Hall, Bellbird Workers Club, Birralee Junior Park, Birralee Park - Playground, Birralee Senior Park, Bluey Frame Park, Booth Park - Playground, Bowen St Park, Branxton, Branxton Community Hall, Brigade Shed, Brooks Street Reserve, Carmichael Park, Cemetery (Cessnock), Cessnock, Cessnock Civic Indoor Sports Centre, Cessnock Pensioners Association - Performing Arts Centre, Cessnock Pool / Shakespeare Park, Cliftleigh, Dalwood Rd Park, Doyle Street Park, Drain Oval, East Branxton, Edgeworth David Park, Ellalong, Ernie Dunlop Park - Multi-Purpose Court, Ernie Dunlop Park - Playground, Former Greta Courthouse, Greta, Greta Median Strip Park, Harle Street Playground, Heddon Greta, Hedleigh Park, HJ Sternbeck Park, Howe Park, Hunter Prelude Early, Johns Park, Kearsley, Kitchener, Kurri Kurri, Kurri Kurri Aquatic and Fitness Centre, Kurri Kurri Central Oval, Kurri Kurri Central Tennis Courts, Kurri Kurri Community Centre, Kurri Kurri Sportsground, Lease, Lindsay Street Park, Manning Park, Margaret Street Playground, Marthaville, Mavis Street Park, McFarlane Street Playground, Miller Park, Millfield, Molly Worthington Netball Courts, Mount View Park, Mulbring Park, Norman Brown Park, North Cessnock - Community Hall, North Cessnock - Playground, North Rothbury, Nulkaba, Nulkaba Park, O'Brien Street Playground, O'Toole Street Playground, Pelaw Main, Pelaw Main Centenary Park, Pokolbin, Private Ownership, Quorrobolong, Rotary Park, Rothbury Riot Miner's Memorial, Shiraz Grove Park, Simm Park, Stephen Street, Stephenson Park, TAFE Park, Tulloch Street Park, Turner Park - Cycos & Athletics Facility, Turner Park - Tennis Courts, Soccer Ground & Amenities, Varty Park Soccer Field, Veterans Memorial Park, Weston Civic Centre, Winten (No 23) Pty Ltd) Crown Land (Aberdare Cemetery, Cemetery (Cessnock), Easement, Kearsley Community Hall, Lease, Reserve, Shared Crown / Council Road)
97	Crown Land (Cemetery (Branxton), Cemetery (Ellalong), Cemetery (Greta), Road, Crown Waterway, Dedication, Easement, Firefighters Park-Passive Park Reserve, Lease, Reserve, Shared Crown / Council Road)
98	Aboriginal Land Crown Land (Branxton Park, Cemetery (Branxton), Cemetery (Cessnock), Cemetery (Greta), Cessnock City Council, Road, Waterway, Dedication, Easement, Greta Cemetery, Lease, Reserve, Shared Crown / Council Road)

Table 10 **Cost dispersal scores for major roads, railway lines and waterbodies**

Cost dispersal scores	Landcover type
99	Roads
99	Rail
82	Waterbodies

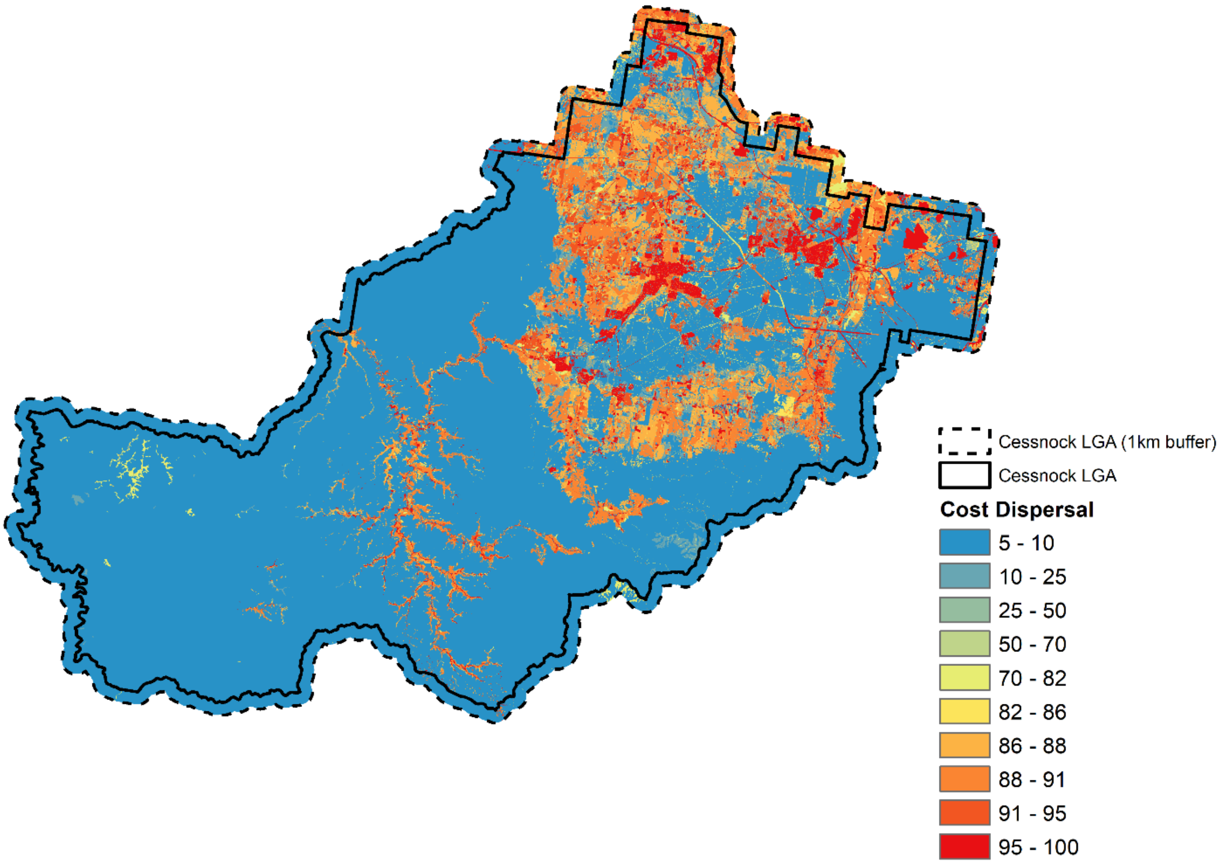


Figure 22 **Final cost dispersal layer for Cessnock Local Government Area**

LGA boundary as black line with 1 km buffer as hatched black line representing the full analysis extent. Cost dispersal scores range from the lowest 5 (blue) up to the highest cost of 99 (red).

Figure 22 provides the final cost dispersal layer showing the lowest dispersal cost scores as large, vegetated areas whereas higher cost scores are associated with no or little vegetation.

Primary habitat

Derivation of a primary habitat layer required a 'habitat quality' score that is not dissimilar to the inverse of the cost dispersal layer. That is, high-quality habitat should be easy to move through whereas areas of poor-quality habitat would be the equivalent of high-cost dispersal. Primary habitat scoring is a relative index between 0 and 100, where 0 represents very poor habitat or complete disturbance, and 100 represents intact or high-quality habitat. Primary habitat metadata was constructed from the following spatial layers that best describe or infer habitat quality:

- public tenure
- vegetation
- woody extent (patches < 100 m^2)
- landuse
- waterbodies.

Primary habitat scores were allocated to each of these layers. Allocations for each layer were applied by reviewing attributes for each layer and translating that to a relative score of habitat quality.

Any measure of habitat 'condition' is valuable input for derivation of this layer. Unfortunately, condition mapping is resource intensive and availability throughout NSW is very limited and, if it exists, is only suitable at broad regional scales. As a result, condition mapping was not used and was instead inferred from the layers listed above.

The primary habitat scores assigned to the public tenure layer took spatial priority over all other layers. Scoring of public tenure was an inverse of unscaled scores for cost dispersal, that is, primary habitat = 100 − cost dispersal. Cost dispersal scores for public tenure were thoroughly reviewed (see Table 9) and inversion of those scores was efficient.

Freehold areas not covered by public tenure required 2 scenarios: remaining layers spatially overlap, or they don't. A mean of the primary habitats scores was assigned to spatial overlaps. Because public tenure took spatial precedence, spatial overlaps could be any unique combination of the 4 remaining layers: vegetation mapping, woody vegetation extent, landuse and waterbodies. This resulted in 2, 3 or 4 overlaps at each grid cell in the landscape outside of public tenure,

Where there were no spatial overlaps the solution was to assign the primary habitat score belonging to the single layer value that was present. Table 11 shows the description, extent and priority of the 5 layers used in generating the primary habitat layer.

Table 12 lists the attributes and primary habitat scores assigned to the public tenure layer.

Table 11 Mapping priority of spatial layers used to derive primary habitat

Mapped data	Description	Spatial extent contributed	Mapping priority
Public tenure	Public tenure mapping of LGA. By default, all that is not mapped in this layer is assumed freehold	Full extent of layer	1
Vegetation map (refined by woody extant patches > 100 m^2)	Fine-scale vegetation map refined by accurate woody extant layer that was filtered patches > 100 m^2	All areas outside of public tenure	2
Woody extant (patches < 100 m^2)	Subset of the woody extant mapping used to refine the vegetation map. Covers the whole LGA	All areas outside of public tenure	2
Landuse	Landuse mapping covering whole of LGA	All areas outside of public tenure	2
Waterbodies	Waterbody layer covering whole LGA. Does not include streams	All areas outside of public tenure	2

Table 12 Primary habitat scores derived from the public tenure layer

Primary habitat scores	Tenure categories (details)
100	Cessnock City Council (Ellalong) Crown Land (Shared Crown / Council Road; Crown; Easement; Reserve)
99	Cessnock City Council (Cessnock City Council; Housing Comm. Park; Cessnock) NPWS Estate (Black Creek NR; Corrabare NR; Finchley AA; Cedar Creek NR; Mount Warrawalong NR; Pambalong NR) Crown Land (Shared Crown / Council Road; Undefined; Crown; Crown Road; Reserve; Lease) Commonwealth Department of Defence (Singleton Army Base)
98	Cessnock City Council (Cessnock) NPWS Estate (Yengo NP; Watagans NP; Werakata NP) Crown Land (Shared Crown / Council Road; Undefined; Easement; Crown; Crown Road; Reserve)
96–97	Cessnock City Council (Weston; Kurri Kurri; Ellalong; Cessnock) Crown Land (Shared Crown / Council Road; Undefined; Crown Road; Crown; Crown Waterway; Reserve; Easement; Crown Parcel; Reserve; Lease)

Primary habitat scores	Tenure categories (details)
95	Aboriginal land (Aboriginal-owned land) Cessnock City Council (Paxton; Weston; Cessnock City Council; Cessnock) Biodiversity Conservation Act (Registered Property Agreement; Wildlife Refuge; Conservation Agreement; NCT Agreement; Biodiversity Stewardship Agreement) Crown Land (Shared Crown / Council Road; Reserve; Crown; Easement; Crown Road) NPWS Estate (Yango SCA; Werakata SCA; Sugarloaf SCA; Jilliby SCA; Blue Gum Hills RP)
94	Cessnock City Council (Black Hill; Cessnock) Crown Land (Shared Crown / Council Road; Undefined; Crown Parcel; Crown; Crown Road; Cessnock Cemetery; Reserve)
93	Crown Land (Shared Crown / Council Road; Reserve; Crown; Easement; Crown Road)
91–92	Cessnock City Council (Weston; Cessnock City Council; Cessnock; Varty Park; HEDDON GRETA) Crown Land (Shared Crown / Council Road; Undefined; Easement; Crown Road; Crown; Crown Waterway; Reserve; Lease; Crown Parcel)
90	Aboriginal land (Aboriginal-owned land) Forestry Corporation NSW (Olney SF; Aberdare SF; Heaton SF; Pokolbin SF; Watagan SF; Corrabare SF; Awaba SF) Cessnock City Council (Cessnock City Council) Crown Land (Shared Crown / Council Road; Undefined; Easement; Crown Parcel; Reserved for Cemetery; Crown Road; Crown; Crown Waterway; Reserve; Lease)
89	Crown Land (Shared Crown / Council Road; Reserve; Easement; Crown Road)
79–88	Cessnock City Council (Mount View; Hunter River Reserve; Cessnock City Council; Cessnock; Pokolbin; Nulkaba; Heddon Greta; Wollombi; Cessnock; Bellbird; Mount Bright Lookout; Abermain; Weston; Lease; Pokolbin; Convent Hill Park; Black Hill) Crown Land (Crown Parcel; Shared Crown / Council Road; Crown; Easement; Reserve; Crown Road; Cemetery (Ellalong); Crown Waterway)
78	Crown Land (Shared Crown / Council Road; Easement; Reserve)
76–77	Cessnock City Council (Cessnock City Council; Lease) Crown Land (Shared Crown / Council Road; Easement; Reserve)
75	Aboriginal land (Aboriginal-owned land) Cessnock City Council (Cessnock City Council; KEARSLEY) Crown Land (Shared Crown / Council Road; Reserve)
71–74	Cessnock City Council (Cessnock City Council; Kearsley; Weston; Alkira Avenue Park; Lease; Bucketty Bushfire Brigade)

Primary habitat scores	Tenure categories (details)
	Crown Land (Shared Crown / Council Road; Undefined; Crown; Crown Road; Reserve; Lease)
70	Aboriginal land (Aboriginal-owned land) Cessnock City Council (Cessnock City Council) Crown Land (Shared Crown / Council Road; Crown; Easement; Lease)
63–69	Cessnock City Council (Cessnock City Council; Weston; Nulkaba; Greta; Rothbury; Thomas Fell Park; Cessnock; Heddon Greta; Paxton) Crown Land (Shared Crown / Council Road; Reserve; Crown; Easement; Crown Road; Undefined; Millfield Cemetery)
62	Crown Land (Bailey Park; Shared Crown / Council Road; Easement; Reserve)
61	Cessnock City Council (Weston) Crown Land (Shared Crown / Council Road; Trade & Investment; Reserve)
60	Aboriginal land (Aboriginal-owned land) Cessnock City Council (Paxton Park; Lovedale) Crown Land (Millfield Cemetery; Shared Crown / Council Road; Easement; Reserve)
57–59	Crown Land (Shared Crown / Council Road; Crown; Easement; Reserve; Undefined)
55 56	Cessnock City Council (Bellbird; Bridges Hill/ Convent Hill Park; Chinaman's Hollow) Crown Land (Shared Crown / Council Road; Reserve; Easement; Crown Road)
54	Crown Land (Shared Crown / Council Road; Crown; Undefined; Easement; Reserve)
51–53	Cessnock City Council (Cessnock City Council; Bimbadeen Lookout; Heddon Greta; Paxton Park; Rothbury; Weston; Unknown; KURRI KURRI; Tomalpin Street Reserve) Crown Land (Shared Crown / Council Road; Undefined; Easement; Reserve)
50	Aboriginal land (Aboriginal-owned land) Cessnock City Council (Weston; Cessnock City Council; Slack's Park) Crown Land (Easement; Reserve)
47–49	Cessnock City Council (Varty Park Off Leash Area; Chinaman's Hollow Cricket Oval; Rothbury; North Rothbury; Lease) Crown Land (Shared Crown / Council Road; Undefined; Crown Road; Crown; Crown Waterway; Reserve; Undefined; Easement)
46	Crown Land (Shared Crown / Council Road; Undefined; Easement; Crown; Lease; Reserve)
43–45	Cessnock City Council (Cessnock City Council; Stanford Merthyr Park; Lease; Wollombi Community Hall; Lovedale: Laguna; Ellalong; Kearsley; Unknown)

Primary habitat scores	Tenure categories (details)
	Crown Land (Shared Crown / Council Road; Cemetery (Kurri Kurri); Easement; Crown Waterway; Reserve; Lease; Undefined; Crown Road)
42	Crown Land (Shared Crown / Council Road; Undefined; Easement)
41	Cessnock City Council (Greta Median Strip Park; Kurri Kurri; Cessnock) Crown Land (Shared Crown / Council Road; Easement; Crown Road)
40	Aboriginal land (Aboriginal-owned land) Cessnock City Council (Paxton Park; Cessnock) Crown Land (Shared Crown / Council Road; Easement; Lease)
21–39	Cessnock City Council (Lindsay Street Park; Bellbird Community Hall; Shiraz Grove Park; Branxton Community Hall; McFarlane Street Playground; O'Brien Street Playground; Lease; Cessnock City Council; Millfield; Carmichael Park; Cessnock; Greta; Kurri Kurri Aquatic and Fitness Centre; Tulloch Street Park; Manning Park; Unknown; Johns Park; Simm Park; Stephen Street; Harle Street Playground; Cessnock Pool / Shakespeare Park; Hedleigh Park; Mount View Park; Cessnock Civic Indoor Sports Centre; North Cessnock; Doyle Street Park; Birralee Senior Park; Miller Park; Kurri Kurri; Hunter Prelude Early; Nulkaba Park; Turner Park; Cliftleigh; Birralee Park; O'Toole Street Playground; North Rothbury; Mulbring Park; TAFE Park; Rotary Park; Kurri Kurri Central Oval; Birralee Junior Park; Kurri Kurri Sportsground; EAST Branxton; Abermain; Howe Park; Molly Worthington Netball Courts; Varty Park Soccer Field; Branxton; Whitburn Park; Victoria Park; Former Greta Council Chambers; Ayrfield Miners Memorial Park; Stanford Merthyr; Jacob's Park; Lloyd Park; Brunner Park; Abermain Plaza Hall; Vernon Street Netball Complex; Wollombi; Branxton Pool; Meredith Park; Pokolbin Park; Kitchener; Lee; Buckland Avenue Playground; Macquarie Avenue Playground; Mount Vincent; Booth Park; Aberdare; Branxton Oval; Greta Arts & Sports Community Hall; Conway's Corner; Kurri Kurri Senior Citizens Hall; Log Of Knowledge Park; Margaret Johns Park; Bellbird Miner's Memorial Park; George Winter Park; Kurri Kurri Skate Park; Crawfordville / Millfield; Ernie Dunlop Park; Bellbird; Weston Memorial Park; Ellalong Park; Brooks Street Reserve; Maybury Peace Park; Pelaw Main; Greta Median Strip Park; Varty Park Cricket Oval; Wickham Street Reserve; Stanford Merthyr Playground; Neath Pony Ground; Jeffery Park; Heddon Greta; Cessnock Sportsground / Baddeley Park; Pokolbin; Wollombi Tennis & Croquet Courts; Greta Central Park; Jeffries Park; Swamp Creek Park; Weston Bears Park; Quarry Street Park; Laguna Community Hall; Neath; East End Oval) Crown Land (Cemetery [Cessnock]; Shared Crown / Council Road; Easement; Lease; Reserve; Kearsley Community Hall; Undefined; Cemetery (Greta; Crown; Dedication; Crown Road)

Primary habitat scores	Tenure categories (details)
20	Aboriginal land (Aboriginal-owned land) Cessnock City Council (Cliftleigh; Veterans Memorial Park; Mavis Street Park; Bluey Frame Park; Unknown; Brooks Street Reserve; Pelaw Main Centenary Park; Brigade Shed; Turner Park ; Aberdare; Margaret Street Playground; East Branxton; Heddon Greta; HJ Sternbeck Park; Cessnock City Council; Quorrobolong; Ellalong; Cessnock; Pokolbin; Bowen St Park; Cessnock Pensioners Association ; Edgeworth David Park; Bellbird; Weston Civic Centre; Manning Park; Private Ownership; Abernethy Playground; Marthaville; Lease; Rothbury Riot Miner's Memorial; Nulkaba; Hedleigh Park; Norman Brown Park; Ernie Dunlop Park ; Kearsley; Kurri Kurri Community Centre; Kitchener; North Cessnock ; Stephenson Park; Booth Park ; Drain Oval; Kurri Kurri Central Tennis Courts; Winten (No 23) Pty L; Pelaw Main; Bellbird Workers Club; Greta; Greta Median Strip Park; Abermain; Cemetery (Cessnock); Apex Park Cessnock; Kurri Kurri; Dalwood Rd Park; Former Greta Courthouse) Crown Land (Shared Crown / Council Road; Aberdare Cemetery; Easement; Reserve)
11–19	Crown Land (Shared Crown / Council Road; Undefined; Greta Cemetery; Easement; Crown; Cemetery (Greta); Branxton Park; Dedication; Reserve; Lease; Crown Road; Reserve; Crown Waterway; Cemetery (Branxton); Firefighters Park)
10	Aboriginal land (Aboriginal-owned land) Crown Land (Shared Crown / Council Road; Cessnock City Council; Greta Cemetery; Easement; Crown; Crown Waterway; Cemetery (Branxton); Undefined; Cemetery (Greta); Crown Road; Dedication; Cemetery (Cessnock); Reserve; Lease)

Vegetation mapping was refined by woody extent mapping filtered to woody vegetation patches > 100 m^2 and is an important layer generating the primary habitat layer. Spatial accuracy of vegetation mapping provided the ideal classification for habitat quality in the absence of a good condition layer.

Table 13 lists the vegetation mapping categories and scores allocated whereby a score of 95 is for native vegetation and scores ≤ 85 are either tiny remnants, disturbed or exotic.

Table 13 Primary habitat scores derived from the vegetation and woody extent layers

Primary habitat scores	Description	Source Layer
95	Non-disturbed vegetation mapped as a native plant community type	Woody extent and vegetation map
85	Disturbed native vegetation	Woody extent and vegetation map
80	Eucalypt plantations	Woody extent and vegetation map
75	Small native remnants (< 3 ha) and exotic plantations	Woody extent and vegetation map

Woody vegetation patches < 100 m^2 were introduced into the analysis as they are small-scale stepping-stones across degraded landscapes. The scoring for this layer is the inverse of the unscaled scores for the cost dispersal layer shown in Table 14 (Landuse categories surrounding woody remnants/trees).

Table 14 shows primary habitat scores allocated to the remnant trees and the surrounding landuse that determines the scores. These are trees within degraded lands which have low primary habitat scores, whereas trees with non-degraded lands have higher habitat scores. Table 15 lists primary habitat scores allocated for landuse categories.

Table 14 Primary habitat scores for trees < 100 m^2 within degraded landuse categories

Primary habitat score	Landuse categories surrounding woody remnants/trees < 100 m^2
95	National Park
90	Marsh/wetland
85	Reservoir/dam
80	Residual native cover, Rehabilitation
70	Land under rehabilitation
65	Water storage - intensive use/farm dams, Other minimal use
60	Native/exotic pasture mosaic, Grazing native vegetation
55	Grazing modified pastures, Abandoned perennial horticulture, Perennial horticulture
50	Services, Olives, Tree fruits, No defined use, Recreation and culture
40	Horse studs, Cropping, Grazing irrigated modified pastures, Grapes
35	Irrigated tree fruits, Irrigated grapes, Irrigated perennial horticulture, Airports/aerodromes, Seasonal vegetables and herbs, Irrigated olives
30	Poultry farms, Rural residential with agriculture
25	Abandoned intensive animal production, Lake
20	River
10	Intensive animal production, Public services, Urban residential, Railways, Rural residential without agriculture, Transport and communication, Roads, Channel/aqueduct, Commercial services
2	Landfill, Mining, Major industrial complex, Tailings, Sewage/sewerage, Mines, Farm buildings/infrastructure, Utilities, Food processing factory, Manufacturing and industrial, Waste treatment and disposal, Abattoirs, Residential and farm infrastructure, Sawmill, Electricity substations and transmission

Table 15 Primary habitat scores derived from the landuse layer

Primary habitat score	Landuse types
98	National park, Nature conservation, Strict nature reserves
90	Marsh/wetland, Other conserved area
80	Managed resource protection, Rehabilitation
75	Other forest plantation
70	Land under rehabilitation, Production native forests, Residual native cover
65	Other minimal use
60	Grazing native vegetation, Softwood plantation forestry
50	Land in transition, No defined use, Olives, Perennial horticulture, Services, Tree fruits
30	Horse studs, Recreation and culture, Waste treatment and disposal
25	Abandoned perennial horticulture
20	Lake, Native/exotic pasture mosaic, Reservoir, Reservoir/dam, River, Rural residential with agriculture, Water storage - intensive use/farm dams
15	Grapes, Urban residential
10	Airports/aerodromes, Channel/aqueduct, Commercial services, Cropping, Grazing irrigated modified pastures, Grazing modified pastures, Irrigated grapes, Irrigated olives, Irrigated perennial horticulture, Irrigated tree fruits, Poultry farms, Public services, Seasonal horticulture, Seasonal vegetables and herbs, Sewage/sewerage, Transport and communication
5	Abandoned intensive animal production, Abandoned irrigated perennial horticulture, Dairy sheds and yards, Intensive animal production, Railways, Roads, Rural residential without agriculture, Utilities
2	Abattoirs, Defence facilities - urban, Electricity substations and transmission, Farm buildings/infrastructure, Food processing factory, General purpose factory, Landfill, Major industrial complex, Manufacturing and industrial, Mines, Mining, Residential and farm infrastructure, Sawmill, Shadehouses, Tailings

The waterbodies layer had a single primary habitat score of 10 for each of its entities. Waterbodies may be barriers for many species, but they do provide drinking water and are habitat for fish, wetland birds, insects, frogs, water rats, etc.

Lastly, all layers were then combined and analysed to produce the final primary habitat layer as shown in Figure 23.

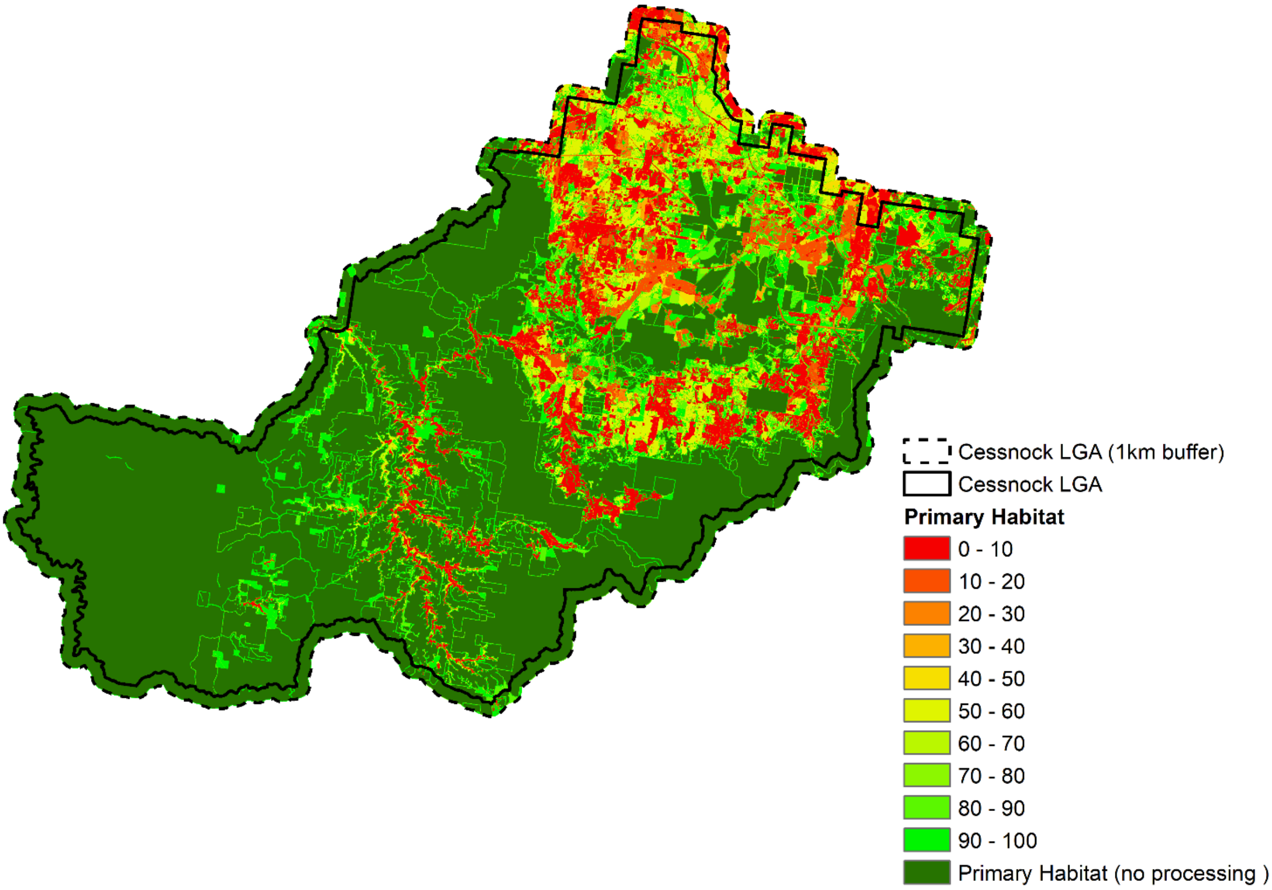


Figure 23 **Final primary habitat layer for Cessnock Local Government Area**

High scores in green represent good quality habitat and low scores towards red represent low quality habitat. The dark green 'Primary Habitat (no processing)' areas are large contiguous areas of good habitat and corridors within these areas are superfluous. Also, they were removed from the spatial links analysis for processing efficiency.

Spatial links pre-processing

Analysis was performed at 5 different scales to represent a range of species movements by adopting the method outlined in the Greater Sydney connectivity analysis (Thapa et al. 2021). The method involves running 5 scales of spatial links analyses whereby each analysis is performed on layers with increasing cell sizes and increasing dispersal distance parameters.

In this process, cell sizes were increased by a power law of 2 and aggregated using a mean statistic. Aggregation of smaller cells to larger cells is not straightforward as the location on the new aggregated larger cell can shift slightly (offset) and thus vary the mean value of the underlying smaller cells. The study negated this effect by running extra spatial links analyses at each scale to cater for multiple locations of an aggregated larger cell (Thapa et al. 2021). Figure 24 explains this using a representation of 16 offset locations of an 8 × 8 m cell aggregated from smaller 2 × 2 m cells.

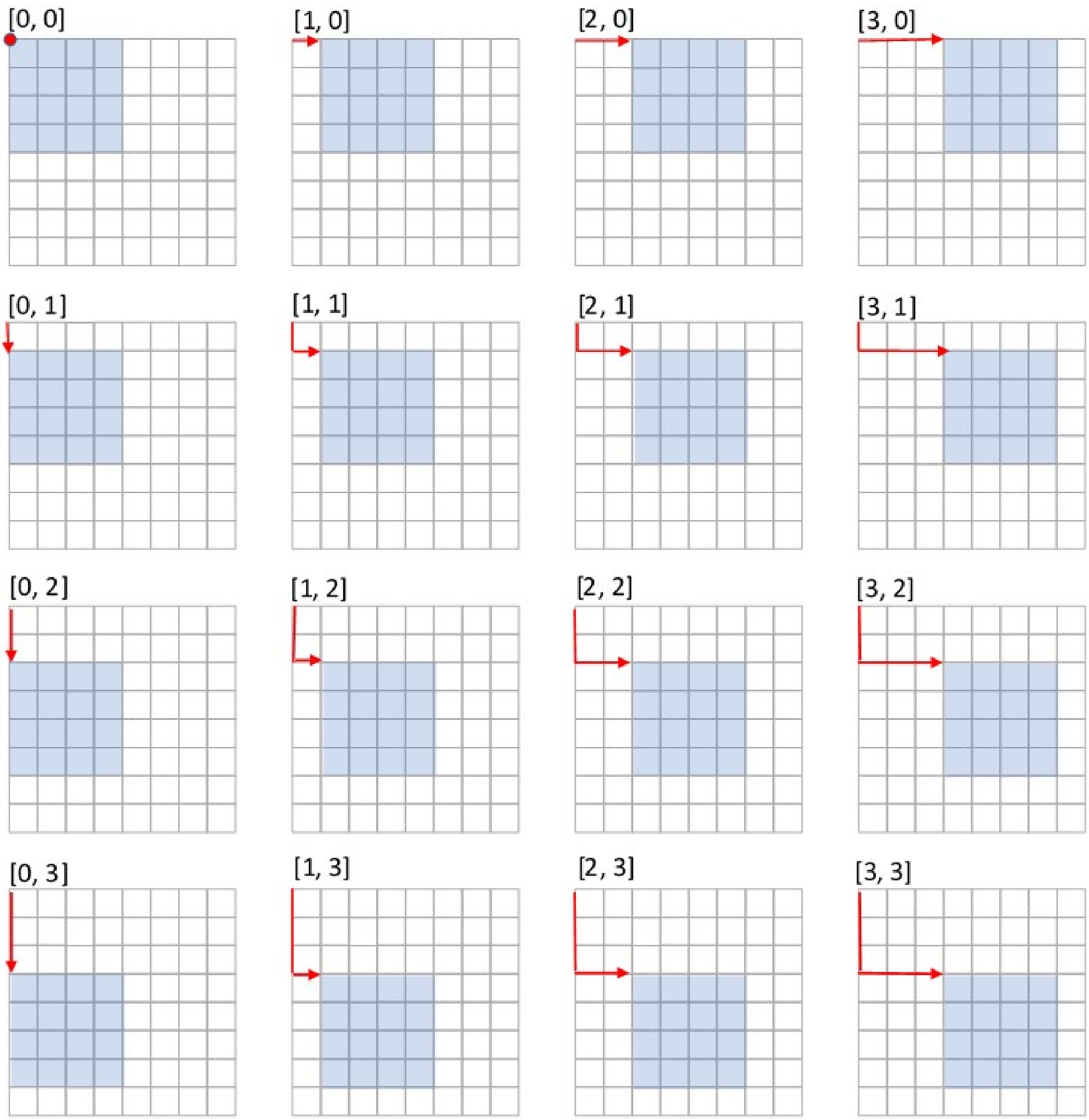


Figure 24 **Example of 16 spatial offsets used when aggregating a 2 × 2 m cell to an 8 × 8 m cell**

Note: The smaller cell sizes outlined in grey (2 × 2 m) are aggregated to a larger (8 × 8 m) cell size in blue whereby each offset is progressively shifted by one grey cell across (x direction) or down (y direction). The shift is illustrated using red arrows and the top left corner of the larger cell were the tuple [x, y] shown represents the shifted location of that corner. The new cell value of each aggregated blue cell is calculated from the mean value of the 16 cells underneath. The results in 16 new study areas with slightly different values because not all aggregated means are the same.

All offsets, cell sizes and dispersal parameters for the Cessnock multiscale approach are listed in Table 16.

Table 16 **Multiscaled approach parameters for Cessnock spatial links analysis**

Cell size (m)	Cell size (ha)	No. of pixel offsets	Pixel offset distance (m)	Minimum effective cell distance (EDmin)	Maximum effective cell distance (EDmin)	Maximum search radius (m)	Maximum path cost (dmax)
2 × 2	0.0004	1	0	2	50	125	3150
4 × 4	0.0016	4	2	4	100	250	6250
8 × 8	0.0064	16	2	8	200	500	12,500
16 × 16	0.0256	16	4	16	400	1,000	25,200
32 × 32	16	16	8	32	800	2,000	50,400

Note: Five scales were analysed based on increasing cell size that represents greater dispersal ranges. The total number of spatial links analyses ran was 53 as per the total of the 'No. of pixel offsets' column. Table adapted from Thapa et al. (2021).

Table 16 highlights the 5 scales used (rows) and the sum of the 'No. of pixel offsets' represents the number of spatial links analyses ran, that is, 53. The minimum and maximum effective cell distances (EDmin and EDmax) are the dispersal ranges of species when factoring the cost of dispersal and habitat quality. The maximum search radius (m) is a hard threshold that restricts the spatial links algorithm from searching for a destination beyond that distance. This is the maximum distance that can be travelled.

The extensive review of connectivity analysis by Doerr et al. (2010) calculated that an average movement beyond 1,100 m was not achievable regardless of habitat quality, that is, that animals rarely travelled further than 1,100 m. This study extended beyond this to 2,000 m to cater for larger home range species such as raptors and adopt the Greater Sydney approach of Thapa et al. (2021). Maximum path cost (dmax) in the last column is the factored cost of travelling the distance of the maximum search radius.

The spatial links analysis uses the final primary habitat layer scoring to determine locations of all source and destination points across a study area. The end user selects a primary habitat threshold above which areas are regarded as source–destination pairs. For this study, a threshold of 80 was applied, meaning that any primary habitat cell with a score above 80 was regarded as a source–destination. This resulted in many millions of source–destination paths, particularly at the 2 × 2 m cell size. Processing efficiencies were implemented to reduce processing time without compromising spatial links rigorous analysis.

Processing efficiency was achieved by 'hollowing out' the large areas of primary habitat with contiguous vegetation. All primary habitat values ≥ 90 and with areas > 50,000 m^2 (5 ha) were selected as large contiguous areas of vegetation. An internal buffer of 30 m was applied to these large patches so only the 30 m wide perimeters of the large patches remained and were used as source–destination areas. Internal areas of contiguous habitat patches were removed because they do not require connectivity analysis and markedly slow down analysis processing time. This is illustrated in Figure 25.

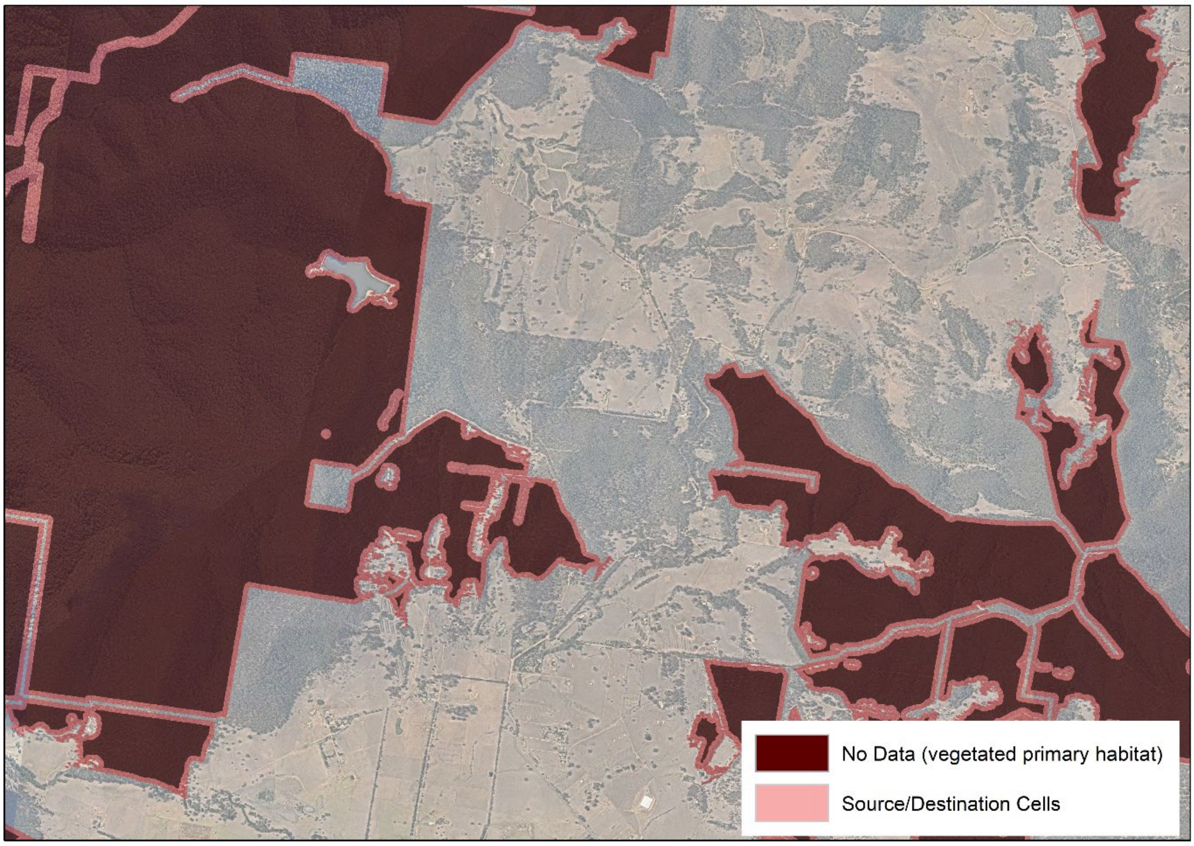


Figure 2525 Example of large and vegetated primary habitat areas that were 'hollowed out' to improve processing efficiency

Note: The habitat areas were extracted from the primary habitat layer with 2 simple criteria: values ≥ 90 and areas > 50,000 m^2. A 30 m perimeter of each primary habitat (shown in pink) was retained as the source–destination cells for spatial links analysis. The dark areas ('No Data' shown in dark red) were completely removed from the analysis as connectivity across those areas is not required and does not affect the analysis across the remaining landscape.

Outputs

To reiterate, the 53 spatial links outputs were necessary to cover 5 scales of dispersal and negate spatial shifts resulting from aggregation. All outputs have relative value scales where high values equate to high connectivity and low values equate to low connectivity. Resolving these outputs into one final layer involved adding them together at the resolution of the smallest scale (2 × 2 m cell size) so that areas of connectivity across scales and offsets are reinforced. For each scale that required offsets, the offsets were added together first before finally adding the 5 scales together. Figure 26 illustrates the process by showing a subset of Cessnock LGA at the southern end of Ellalong.

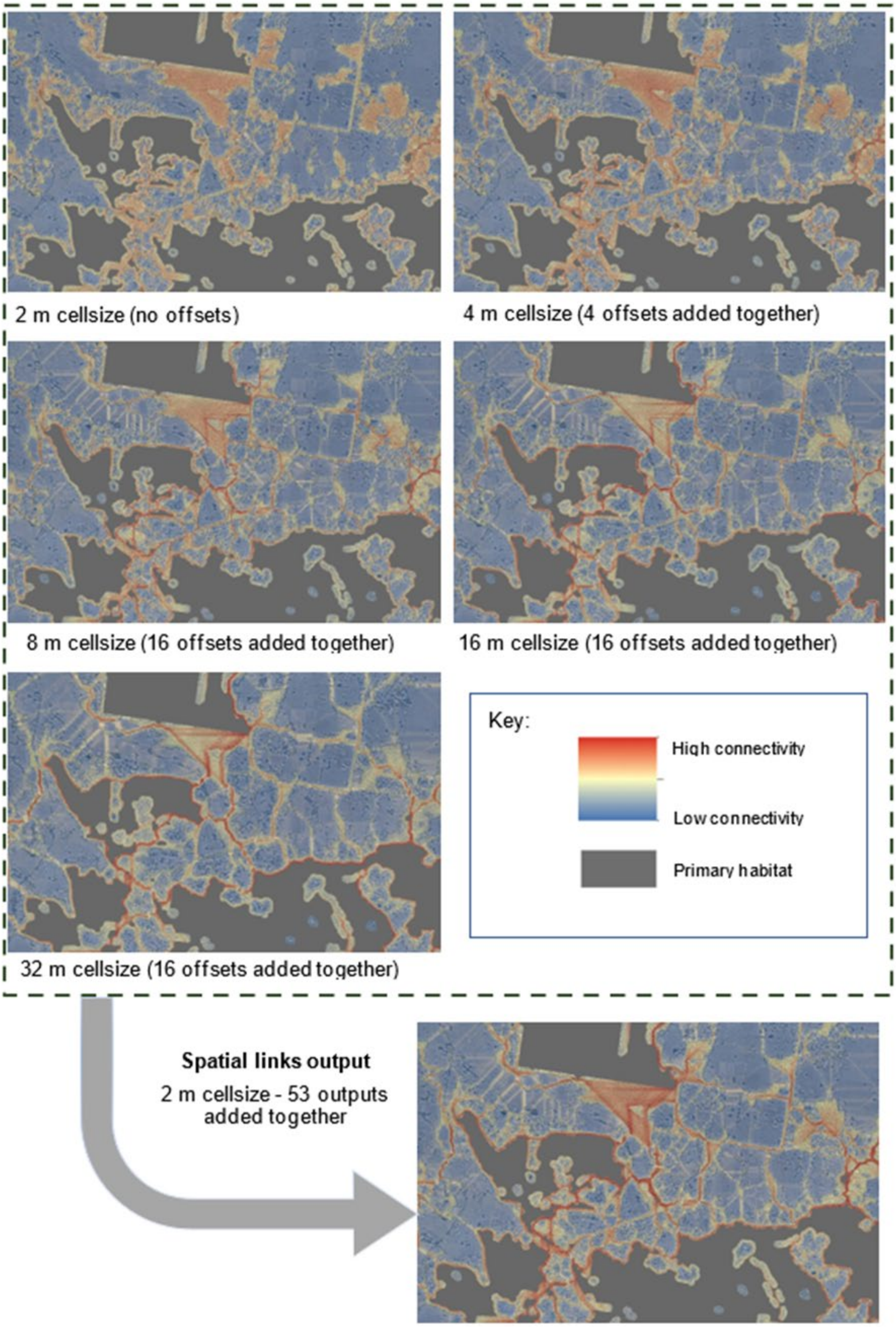


Figure 26 A zoomed in area south of Ellalong showing the progressive adding together of all 53 spatial links outputs. Low connectivity shown as blue, high connectivity shown in red and primary habitat shown in grey.

Effects of the increased scale and dispersal ranges on connectivity shown in Figure 26 is demonstrated by greater connectivity across highly fragmented areas at 32 × 32 m cell size compared to little or no connectivity in the same areas at the 2 × 2 m cell size. Furthermore, all outputs are continuous raster surfaces meaning that all output scales, regardless of their connectivity differences, maintain very low values across cleared lands, urban areas and highly fragmented environments.

To provide a layer useful for Cessnock City Council planning purposes, the final spatial links output needed to be refined so that low connectivity areas were removed. Additionally, categories of connectivity were required so that end users can understand and apply the layer at the local planning scale. This refinement is called post-processing and the steps involved are explained in the following section.

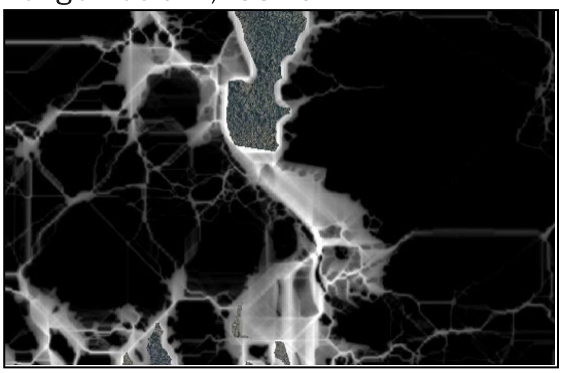
Spatial links post-processing

The primary aim of post-processing was to produce a categorised vector layer that captures high connectivity links and removes low connectivity areas. Applying a threshold value to links output and thus removing low connectivity values was not the preferred method since this approach is flawed. This is because of variance in values of high connectivity across different parts of the landscape.

For example, a very strong connectivity link between 2 close patches of primary habitat will remain largely unaffected by a threshold removal because its connectivity values are at the upper end of the range. Compare that to an area in a sparser landscape where a definite connectivity link is present, but its value range is at the lower end or even breaches the threshold. In this case the threshold reduction may reduce the link to be very narrow or even sever the link at its weakest point.

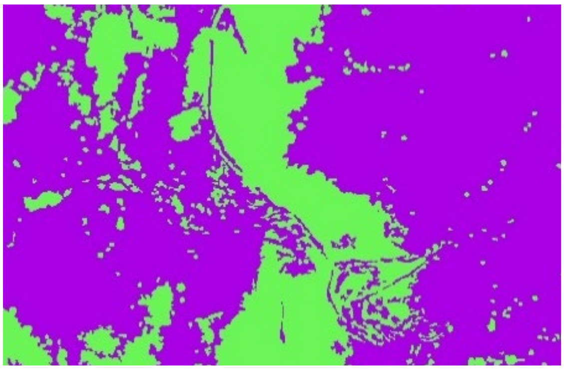
In summary, a simple threshold approach does not address the relative variation in connectivity across a study area and a more thorough approach was required. As a result, a new approach was derived for this study and is outlined stepwise below. The approach is supported by thumbnail images of a small area to help visualise the steps and support the ESRI-based GIS terminology adopted in these details.

1. All 53 outputs were added together to produce a single layer with every pixel value that is the sum of 53 layers. Output value range was 0–2,438.79.



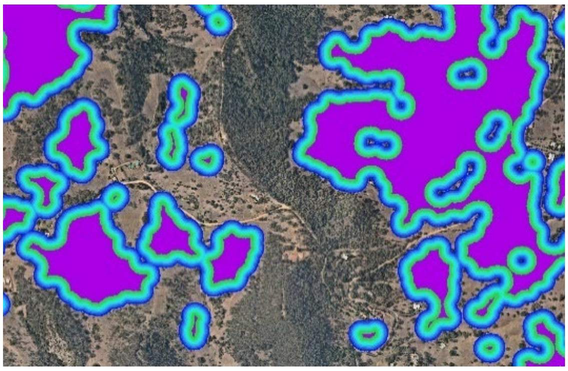
2. Output converted to integer with value range 0–2,439.

3. Removed areas that are cleared and have distances greater than 106 m as per the review of Doerr et al. (2010) that was also implemented by Lechner and Lefroy (2014):
   a. Converted fine-scale woody layer to binary raster, that is cleared land has raster value of 0 (purple) and woody has raster value 1 (green)

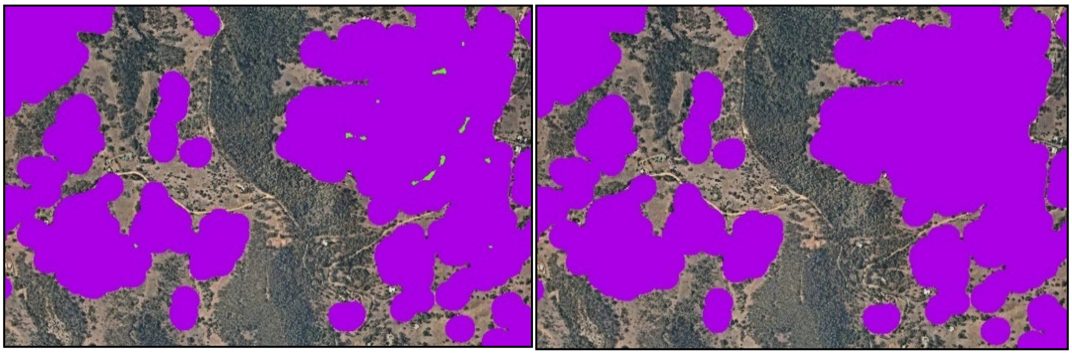


   b. On the raster woody layer, performed ArcMap's Focalstats tool with a mean statistical value parameter derived from within a circular neighbourhood of radius 53 m. All output pixels with mean value equal to 0 were in cleared areas with nearest vegetation pixel at least 53 m away in any direction. Extracted only those pixels with value = 0 to make new raster layer of core cleared areas (purple in thumbnail below)

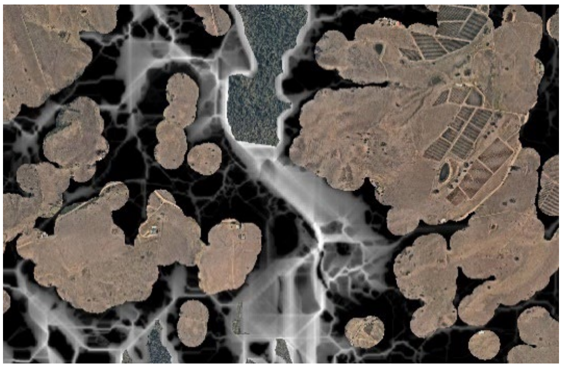
   c. Buffered the core cleared areas by 53 m (blue in thumbnail below) using the Eucdistance tool to create a cleared gap layer



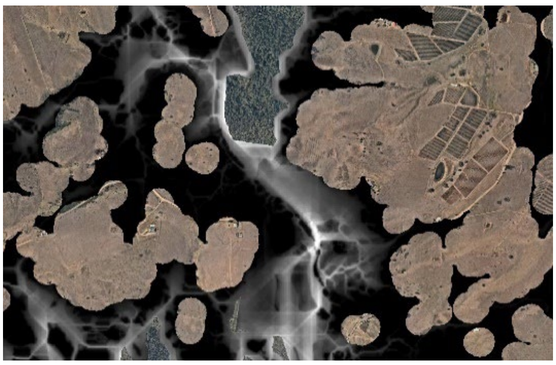
Buffering resulted in small islands of vegetation (small green areas within purple patch in left thumbnail below) within the cleared gap raster. These vegetation islands were small and had very low connectivity value, so they were filled in, meaning that vegetated islands with area < 30 m^2 were added to the cleared gap raster. This was achieved by applying ArcMap's RegionGroup tool to a raster of the islands. The RegionGroup resulted in pixel counts or area statistics by which to apply the 30 m^2 threshold. The cleared gaps layer was then finalised by reclassifying the vegetation islands to cleared (right thumbnail below)



d. The next step was to erase cleared gaps from the spatial links output

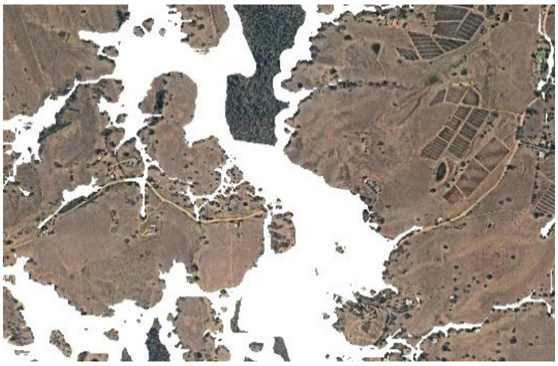


Strong corridor values in the links output did not align in the middle of riparian/vegetation strips so when low connectivity values are culled via a threshold, the edges of the strip contract and a spatial offset appears on one edge of the strip because of the central misalignment. This was partially negated by performing a Focalstats analysis generating a maximum statistic within a 40 m radius to add higher values to the strip edge areas. The result was then multiplied by the original links output and the threshold shift was reduced. Note that a spatial shift remains in the layer but is negligible.



4. A threshold value of 114,000 from spatial links output was selected using visual assessment of the layer displayed with 32 classes defined by Natural Break's (Jenks in ArcMap). Any links values < 114,000 were removed and this resulted in retention of narrow and isolated corridors but removed cleared gap areas not covered by the

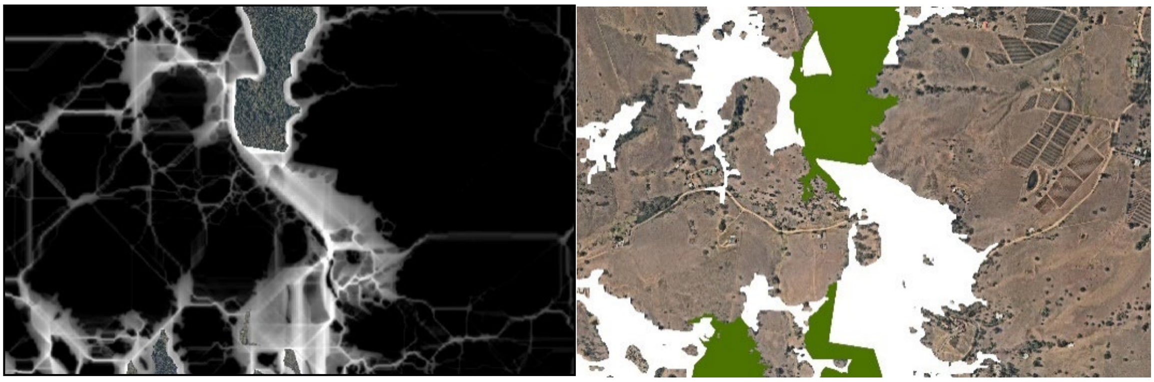
analysis in Step 3 above. Links layer values were then reclassified to 1 (white in thumbnail below).



5. The non-processing area was reinserted with a value of 2 (green in thumbnail below).

6. Refinement of the raster was then performed to remove narrow isolated corridors and smooth edges. ArcMap's Expand and Shrink tools were combined in Python code to execute a Shrink-then-Expand sequence on connectivity cells (only white cells with value of 1) using a distance of 2 cells (4 m). This was iterated 8 times to erode slivers and isolated remnants resulting from the threshold reduction in Step 4 above.

7. The raster was then converted to a polygon layer where remnants < 6,000 m^2 were eliminated. A last manual review and refinement of the layer was then performed. The thumbnails below show the pre-processing spatial inks output on the left and the post-processed output on the right with refined connectivity links (white) and non-processed areas (green).



In summary, post-processing steps were designed to retain definite areas of connectivity and remove marginal areas of connectivity across the study area. This approach addressed variance on connectivity across the landscape by applying a gap clearing threshold followed by iterative steps that avoided the flaws inherent in a single threshold approach. The layer that resulted from this post-processing was further classified to aid planners and end users in using and interpreting the data. These classifications are detailed in the next section.

Final layer

The post-processed layer had 2 attributes or classes:

1. the non-processed areas
2. the refined connectivity links in between.

Display and attribution of a connectivity layer is important if it is to be used for any landuse or environmental planning application. As such, the last step was to convert the layer into categorical form with the attributes shown in Table 17. The final categorical layer is essentially in 2 parts:

1. primary habitat areas that are large, vegetated areas of good quality habitat
2. the connectivity/corridor analysis between those large habitat areas.

The connectivity/corridor areas were further subdivided spatially to assist with planning decisions.

Table 17 Attributes of the final Cessnock connectivity analysis

Attribute name	Description	Source
Primary habitat	Large areas of contiguous vegetation. Derived from primary habitat score ≥ 90 with area > 50 ha. NB spatial links analysis not applied in these areas	Primary habitat layer
Corridor (vegetated)	Vegetated part of corridor	Spatial links analysis
Corridor (cleared)	Non-vegetated part of corridor	Spatial links analysis
Corridor (waterbody)	Waterbody within a corridor	Spatial links analysis
Corridor (roads)	Road within a corridor	Spatial links analysis

The primary habitat areas within the layer were the non-processed areas because they were habitat layer values ≥ 90 and with areas > 50,000 m^2 (5 ha). The concept and function of primary habitat was adopted from a 'minimal viable habitat' definition in the Southern Mallee study by Drielsma et al. (2016) whereby minimal viable habitat is the minimum area required to support a fauna population indefinitely. In that study Drielsma et al. (2016) estimated minimal viable habitat parameters for arid/semi-arid fauna groups in the Southern Mallee area of NSW as shown in Table 18.

Table 18 Minimal viable habitat areas estimated for fauna groups in the arid/semi-arid Southern Mallee region of New South Wales

Name	Minimum viable habitat area (ha)	Maximum average home range movement (m)	Maximum average dispersal distance (m)
Swamp birds	750	217	284,737
Flood breeding waterbirds	500	347	284,737
Riparian seed-eating birds	4,000	130	3,338
Floodplain debris species	50,000	217	4,343
Breeding possums (*Trichosurus vulpecular* and *Pseudocheirus peregrines*)	4,000	273	3,338
Litter reptiles	7	43	108
Litter reptiles heavier soils	6	87	108
More mobile reptiles	1,000	108	217
White-browed treecreeper (*Climacteris affinis*)	7,500	869	3,338
Free-flying bats	5,000	4,343	4,343
Shrubby woodland bats	1,000	668	4,343
Shrubby mallee birds	2,000	217	3,338
Shrubby woodland birds	5,000	651	3,338
Grassy woodland birds	5,000	434	3,338
Chenopod birds	2,500	347	3,338
Sandy soil reptiles	500	22	108
Ningaui (*Ningaui yvonneae*)	12,500	217	1,086
Spinifex reptiles	500	22	108
Malleefowl (*Leipoa ocellata*)	2,000	334	5,007

Note: These areas represent a single, hypothetical, circular block of ideal habitat considered necessary to support a population indefinitely. Average home range and dispersal distances are also estimated. Table reproduced from Drielsma et al. (2016).

Table 18 reflects the multiscaled traits of fauna and the implications of selecting a single threshold for all fauna groups. The minimum viable habitat of 50,000 ha (maximum in Table 18) for the floodplain debris species would not cover all other groups because a 'maximum' approach would ignore remnants that support populations of fauna that have small home and dispersal ranges, such as litter reptiles. Conversely, adopting minimum viable habitat of 6 ha for litter reptiles is not viable for wider ranging species. For the purposes of this non-arid landscape study, good quality habitat that had an area > 5 ha threshold was adopted to cater for large remnants that support smaller range species. Remnants below that threshold will be mostly captured as connectivity links.

Table 19 further breaks down the categories of corridors and clearly shows that the spatial links connectivity network strongly adheres to vegetated linkages. Furthermore, the non-vegetated corridors never exceed the gap-crossing threshold of 106 m, that is, the distance between any patch of vegetation within a corridor is < 106 m.

Table 19 Area statistics for the final connectivity/corridor layer

Attribute	Area (ha)	% of total corridors
Corridor (vegetated)	18,711.00	79.78
Corridor (cleared)	4,264.62	18.18
Corridor (road)	390.51	1.67
Corridor (waterbody)	87.54	0.37
Total	23,453.66	100.00

Note: These statistics apply to the area outside of primary habitat.

The final layer with its 5 categories and a zoomed inset is shown in Figure 27.

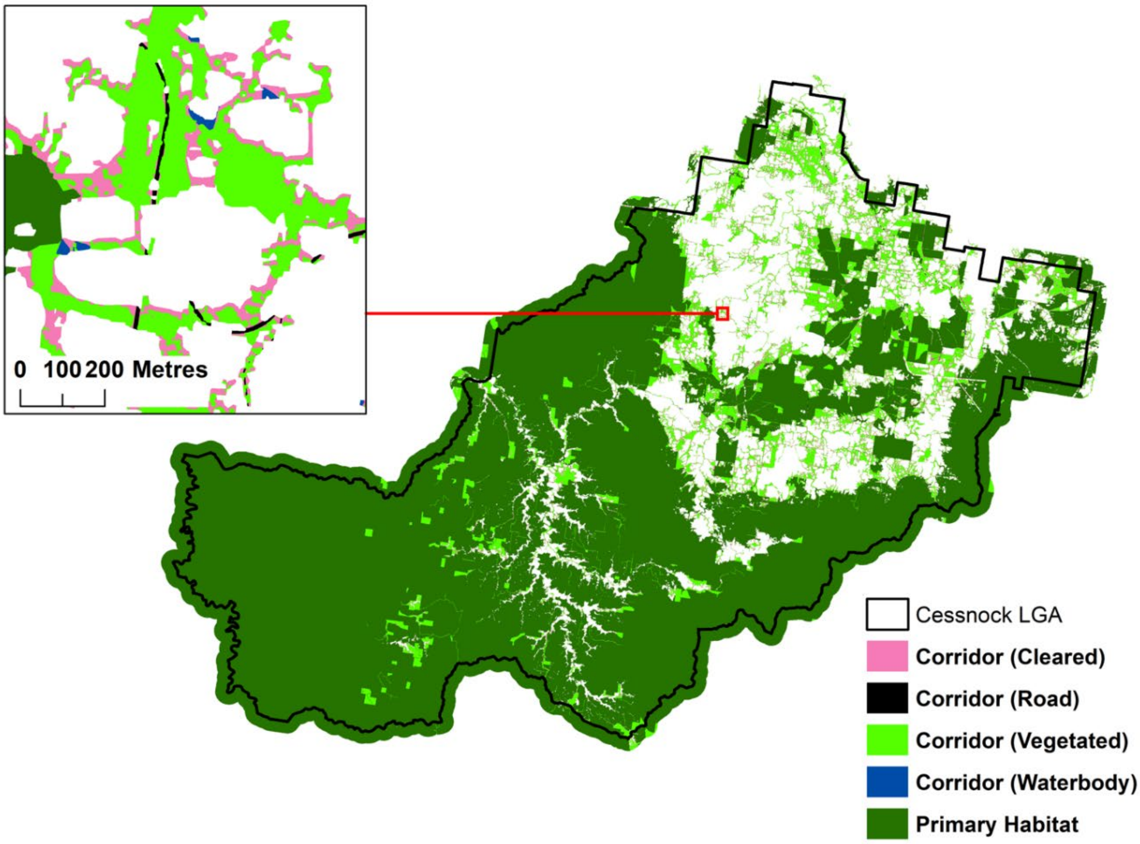


Figure 27 **The final structural connectivity/corridors layer for Cessnock Local Government Area**

Inset highlights the corridor categories, that is, vegetation in lime green, non-vegetated in pink, waterbodies in blue and roads in black.

Review

To summarise, an analysis of area statistics helps reinforce the local-scale accuracy of the layer. The LGA with a 1 km buffer was the study area and that equates to an area of 224,084 ha. Of that area, the primary habitat category covers 153,173 ha (68% of the buffered LGA) and the corridors cover 23,453.66 ha (10% of buffered LGA).

A review of the methodology and final layer was provided by experts from the Science, Economic and Insight Division within the department.

This layer was prepared in 2022 and is therefore representative of data available at the time. As new information becomes available, the layer will be reviewed, updated and redistributed. Refer to contributor acknowledgements in Appendix H.

Appendix D. Environment layer metadata

This single layer captures critical environmental features and biodiversity persistence for Cessnock Local Government Area (LGA) which covers 196,468 ha. The layer is in raster format with a 2 × 2 m cell size and is the result of consolidating layers that capture all aspects of biodiversity. Those consolidated layers contributed species composition information, structure/condition of habitat, and ecological function attributes at the same scale and with a common scoring. The common scale and scoring system allowed for direct comparison, making it possible to combine them into one single environment layer using a peer-reviewed scientific methodology.

Background

In 2015, the Hunter Development Corporation (HDC) requested the Department of Climate Change, Energy, the Environment and Water (the department, then the Office of Environment and Heritage) to derive an environmental layer for their integrated infrastructure planning tool (IIPT).

The IIPT is a regional scale geographic information system (GIS) strategic planning tool that considers and accounts for all important aspects of urban development planning. These include infrastructure assets, housing market values, sewage, water and the environment.

The tool guides urban development to the most suitable and cost-effective locations in addition to informing development proposals by reporting their associated planning costs.

The role of the department was to derive an environmental layer for input into the IIPT using the Lower Hunter region as a pilot. Prior to the Lower Hunter pilot, HDC had run an IIPT analysis across the whole of the Hunter using a biodiversity sensitivity analysis layer derived by Eco Logical Australia (2012) as the environment input.

For input into the IIPT, a single environmental layer is required and should be constructed from all relevant individual spatial layers to capture 'whole of biodiversity'. Developing this layer requires a basis in ecological theory. The methodology of this study is based on the biodiversity indicator works of Noss (1990) and Andreasen et al. (2001) that pursue indicators for monitoring biodiversity and ecological integrity. The methodology used those works and ecological theory to rescale and transform environmental spatial layers so they could be directly comparable and then combined into one single layer.

The environmental layer should ideally include statutory constraints and address ecological integrity that is comprised of species composition, habitat structure and ecological function (Noss 1990). As such, the environmental layer can inform the IIPT of statutory environmental constraints in addition to any adverse environmental outcomes from enacted developments.

By 2016, three analyses of the IIPT tool had been performed by HDC in conjunction with other stakeholders as follows:

1. HDC ran the IIPT for the whole of the Hunter using Eco Logical Australia (2012) sensitivity analysis data as the environmental layer input.
2. HDC ran a finer scale IIPT analysis for the Lower Hunter region using a draft environmental layer derived from the Commonwealth's Lower Hunter strategic assessment and departmental databases. The Lower Hunter strategic assessment focused on urban development, infrastructure corridors and the protection of Commonwealth matters of national environmental significance. HDC engaged the department for environmental layer derivation.
3. HDC then ran an IIPT analysis for Lake Macquarie City Council area using fine-scale data sourced from council's environmental databases. Departmental data was superseded in any case where council data was of better quality or more comprehensive. HDC engaged both council and the department for that process, and council provided invaluable recommendations and review of the analysis.

The purpose of an environment layer is to provide a single accurate layer that contributes to assessment of environmental considerations for landuse planning and decision-making. The environment layer developed for this study was initially designed to be embedded into the IIPT tool but is extremely valuable as a standalone layer that is envisaged to assist Cessnock City Council with their landuse planning.

The method used in the Cessnock environmental lands study is a result of the previous 3 IIPT analyses requiring one single spatial layer to capture 'whole of biodiversity'. The method here has been applied to all fine-scale environmental data for the Cessnock LGA and incorporates recommendations to the methodology provided by Lake Macquarie City Council in 2016.

Production of this layer required highly technical expertise and explanation of the methodology uses technical language. See Appendix G for a glossary of technical terms and acronyms.

Method

The methodology is not prescriptive because it does not define what spatial layers are required. Layer selection is dependent on factors such as user preferences, data availability, study area size, scale and geographic location. In that sense, the methodology is a 'framework' to combine layers for any given situation. However, with regards to the Cessnock LGA, layers representing both statutory environmental constraints and general ecosystem health/function were available. Therefore, the aim of capturing environmental hotspots/constraints and the 'whole of biodiversity' in one final environment layer was possible.

The IIPT required the environmental layer to be in an index, commensurate with infrastructure and non-environmental data used within the IIPT. Biodiversity, or environment, has no quantifiable or measurable units, so representation by a relative index is warranted for the purposes of landuse decision-making. Both ends of a relative index scale are readily defined. For example, areas of high ecological condition, such as national parks and nature reserves will have ceiling values of 100. At the other end of the scale, built environments where there is virtually no remaining ecological function have a landscape values of 0. The methodology described below was developed to distribute intermediate data values within this range.

The methodology is summarised in steps below:

1. environmental data audit
2. selection of environmental layers and rescaling values
3. assign biodiversity component contributions for each layer and calculate final weightings
4. apply final weightings to spatial inputs and derive output in GIS
5. review output value range and calibrate.

Each step is explained in further detail below and a graphical representation of the steps is provided below in Figure 28.

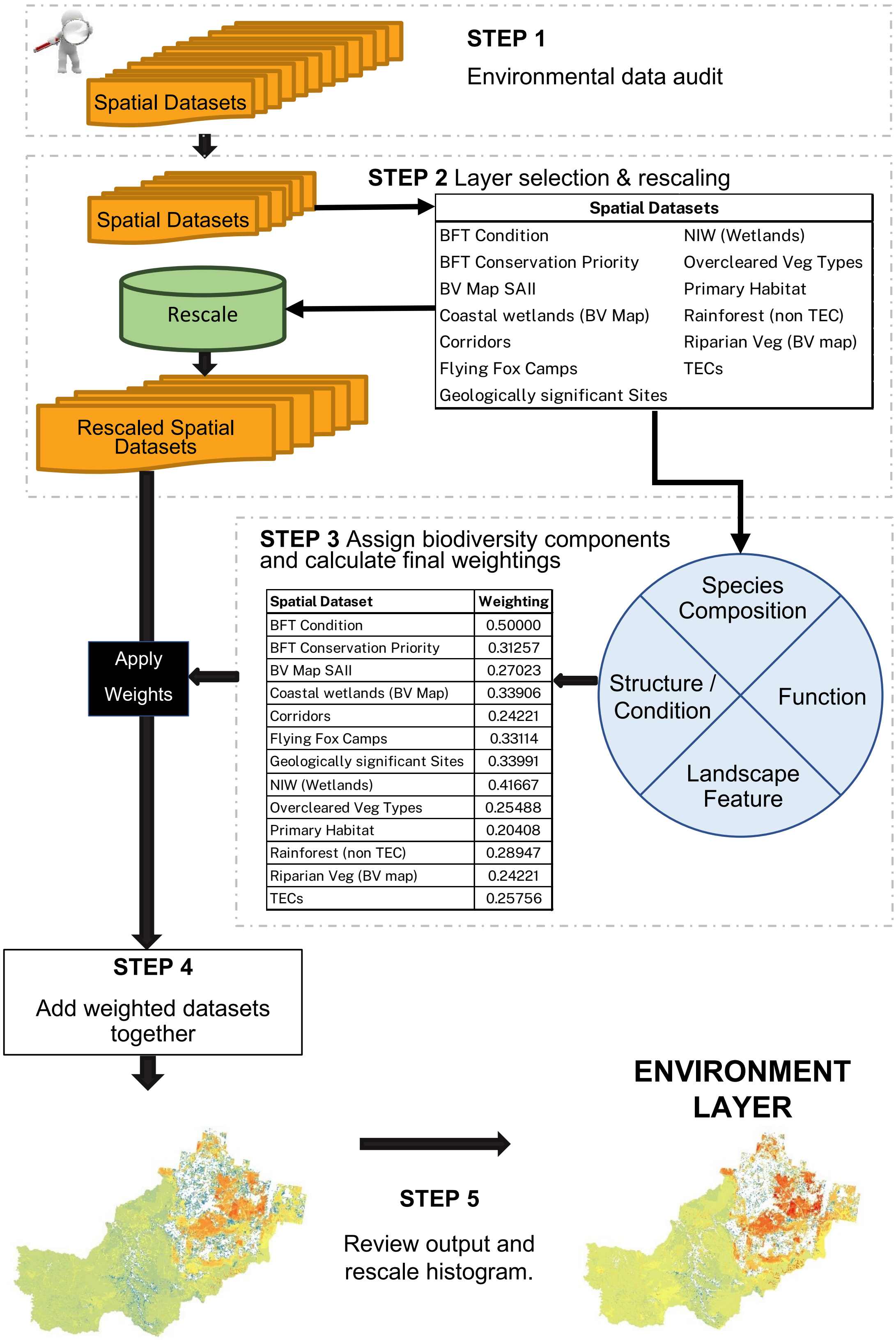


Figure 28 **Methodology to derive a single environment layer**

Relevant spatial layers are selected then rescaled to a common measurement. Layers are then de-composed and scored against components described by Noss (1990)

Data audit and rescaling

The purpose of a data audit was to review all available biodiversity layers and select those that captured all aspects of biodiversity at a local scale and that are fit-for-purpose.

Data audit

The spatial layers selected for Cessnock LGA were tenure blind so the full extent of the LGA was considered. This meant that formally reserved tenures such as NSW National Parks and Wildlife (NPWS) estate were included.

Layers collected in this analysis were guided by the IIPT studies. However, since those studies took place, NSW Government legislation has changed (now *Biodiversity Conservation Act 2016*), rendering some of the original high environmental value layers redundant. In addition, the previous study of Lake Macquarie City Council recommended that corridors be omitted from the environment layer because they were predominantly regional scale and would have covered too much of the landscape.

With the current Cessnock LGA fine-scale corridor layer (see Appendix C) this issue has been overcome because the corridors adhere strongly to woody vegetation and permit application in the environment layer. Layers selected for inclusion in the Cessnock environment layer are listed in Table 20, together with the source of the layer, a brief description and a reference/citation.

Table 20 Layers included in the environment layer

Layer	Source	Description	Citation
BFT condition (Biodiversity Forecasting Toolkit [BFT])	Lower Hunter strategic assessment	A regional scale modelled layer that represents vegetation condition for input into the BFT analysis (below)	Drielsma et al. (2014)
BFT conservation priority	Lower Hunter strategic assessment	Modelled conservation priorities that maps where biodiversity will persist over time if protected. The modelling considers vegetation condition, habitat fragmentation, landuse, threats to biodiversity and persistence over time	Drielsma et al. (2014)
BV coastal wetlands	Biodiversity values (BV) map	Coastal wetlands	Biodiversity values map and threshold tools online portal (see link in 'More information' section)
BV riparian vegetation	Biodiversity values map	Riparian vegetation	

Layer	Source	Description	Citation
BV serious and irreversible impacts (SAII)	Biodiversity values map	Threatened entities that are susceptible to serious and irreversible impacts	
Corridors	This study	Fine-scale corridors produced as part of this study	This report
Flying-fox camps	DCCEEW	Four flying-fox camps: Cessnock (near Millfield), Cessnock East, Weston and Black Hill	Australian Government online national flying-fox monitoring viewer (see link in 'More information' section)
Geologically significant sites	NSW State Heritage Register	Only one geologically significant site: Bow Wow Gorge near Quorrobolong	State Heritage Inventory (see link in 'More information' section)
Nationally important wetlands (NIW)	DCCEEW	One Commonwealth-listed wetlands of importance: Ellalong lagoon	Australian Government Directory of important wetlands (see link in 'More information' section)
Over-cleared vegetation types	This study and eastern NSW plant community types database	Fine-scale vegetation map with % cleared figures from the NSW vegetation information database	This report
Primary habitat	This study	Primary habitats from connectivity corridors	This report
Rainforest (non-TEC)	This study	Rainforest communities not threatened but captured by the Cessnock fine-scale vegetation mapping derived for this study	This report
Threatened ecological communities	This study	NSW threatened ecological communities (TEC) extracted from the Cessnock fine-scale vegetation mapping derived for this study	This report

Note: DCCEEW = Department of Climate Change, Energy, the Environment and Water, NSW; TEC = threatened ecological community

All layers in Table 20 capture and quantify different aspects of the environment, including both legislative requirements and the persistence of biodiversity. It is beyond the scope of this study to reiterate details of each layer, but further information regarding their derivation and intent can sourced via the citations in Table 20.

Layers are either raster or vector formats that contain either continuous or thematic values as their quantification. To overcome this variance, a common scale was developed by rescaling all layers into a common value range. The value range selected was 0–1 whereby a layer may be scored as 0 and 1 only (binary) or, have their values rescaled to any fraction/s within the 0–1 scale.

The data format difference (raster v vector) was addressed by conversion of all layers to a 2 × 2 m cell size raster. Raster format is best suited for spatial modelling and thus implemented for this methodology.

Data rescaling

The aim was to have all layers rescaled into a binary format meaning that if the layer feature/s was present it received a value of 1 and a value of 0 for where it is absent. For example, the threatened ecological community (TEC) layer is thematic and all TECs within the layer are equally important. In this case the layer could be rescaled to have maximum value 1 for anywhere a TEC is present and 0 where TECs are absent.

The binary rescaling option was chosen for 10 out of the 13 layers. For 2 of the 3 other layers (i.e. BFT condition and BFT conservation priority) a linear transformation in GIS was used to rescale the layer between 0 and 1 as shown in Equation 1.

1. $$S_{rescaled} = \frac{1}{(S_{max} - S_{min})} * (S - S_{min})$$

where:

S = source layer value

S_{min} = the minimum value of the source layer

S_{max} = the maximum value of the source layer

$S_{rescaled}$ = rescaled number.

The third layer was over-cleared vegetation types and the source layer used was the fine-scale vegetation mapping from this study (see Appendix B). Over-cleared statistics were applied to each vegetation community where applicable whereby statistics were extracted from the NSW Government plant community classification database (Connolly et al. 2021). Using the over-cleared statistics, each vegetation community was then classified into the percentage cleared tiers implemented by the *Biodiversity assessment method* (DPIE 2020). Those tiers were then rescaled into the 0–1 value range and are shown in Table 21 along with details of each layer's original format and rescaled results.

Table 21 The spatial layers' original format and rescaling outputs

Layer	Thematic / Continuous	Binary / Rescaled
BFT condition	Continuous	Original values 5–94 linearly rescaled to 0–1
BFT conservation priority	Continuous	Original values 0–910 linearly rescaled to 0–1
BV coastal wetlands	Thematic	Binary: 0–1
BV riparian vegetation	Thematic	Binary: 0–1
BV SAII	Thematic	Binary: 0–1
Corridors	Thematic	Binary: 0–1
Flying-fox camps	Thematic	Binary: 0–1
Geologically significant sites	Thematic	Binary: 0–1
NIW (wetlands)	Thematic	Binary: 0–1
Over-cleared vegetation types	Thematic	Rescaled based on *Biodiversity assessment method* offset tiers (DPIE 2020): • 0: Not over-cleared vegetation type • 0.2: < 50% cleared • 0.5: ≥ 50 and < 70% cleared • 0.8: ≥ 70 and < 90% cleared • 1: ≥ 90% cleared
Primary habitat	Thematic	Binary: 0–1
Rainforest (non-TEC)	Thematic	Binary: 0–1
TECs	Thematic	Binary: 0–1

Note: BFT = Biodiversity Forecasting Toolkit; BV = biodiversity value (map); SAII = serious and irreversible impacts; NIW = national important wetlands; TEC = threatened ecological community.

Component contributions and weightings

The next step after rescaling each layer was to 'de-compose' each layer into components of biodiversity so they could be comparatively assessed. Noss (1990) states that a simple, comprehensive and operational definition of biodiversity is unlikely to be defined. In the absence of such a definition, Noss (1990) suggests a conceptual framework that identifies 3 major components of biodiversity to monitor and measure biodiversity. The 3 Noss (1990) components are widely regarded as primary attributes of ecosystems and are described in the top 3 rows of Table 22. A fourth component, 'landscape feature' has been added as it refers to non-biological aspects or features that contribute to a well-functioning landscape, rather than the persistence of biodiversity per se.

Table 22 The Noss (1990) biodiversity components and landscape feature component descriptions

Biodiversity component	Description
Species composition (Noss 1990)	Identity and variety of elements in a collection i.e. species lists, species diversity, genetic diversity
Structure / Condition (Noss 1990)	Physical organisation or pattern of a system i.e. habitat complexity, condition and pattern
Function (Noss 1990)	Ecological and evolutionary processes i.e. genetic and ecosystem processes
Landscape feature	Non-biological contributors to biodiversity i.e. cave roosts, flying-fox camps, terrain, substrate

De-composing an environmental layer into its contribution to these 4 biodiversity components assists in quantifying and focussing on the layer's intent and what it represents in terms of biodiversity.

The following describes the method of using expert review to score the 4 component contributions listed in Table 22. This is followed by a normalisation procedure of those contributions so that an unbiased weighting for each layer is produced.

Component contributions

For each environmental dataset, the 4 components shown in Table 22 are allocated a relative contribution within a scale of 0–100 (where 0 = low and 100 = high) so that all contributions total 100. The contributions are aimed to reflect the relative amount the layer contributes to each component and are assigned by expert review.

Table 23 lists the expertly assigned contributions to the 4 components for each dataset.

Table 23 The 4 biodiversity components and the relative contribution of each dataset

Layer	Species composition	Structure / Condition	Function	Landscape feature	Layer total
BFT condition	0	90	10	0	100
BFT conservation priority	50	30	20	0	100
BV coastal wetlands	40	0	40	20	100
BV riparian vegetation	20	10	30	40	100
BV SAII	80	10	10	0	100
Corridors	0	20	70	10	100
Flying-fox camps	0	0	50	50	100

Layer	Species composition	Structure / Condition	Function	Landscape feature	Layer total
Geologically significant sites	0	0	0	100	100
NIW (wetlands)	40	0	50	10	100
Over-cleared vegetation types	100	0	0	0	100
Primary habitat	0	10	90	0	100
Rainforest (non-TEC)	80	10	10	0	100
TECs	80	10	0	10	100
Component total	**490**	**190**	**380**	**240**	**na**

Notes:

Each layer's contribution totals 100 so that they are weighted equally. The column totals reflect each component's overall contribution by the layers.

BFT = Biodiversity Forecasting Toolkit; BV = biodiversity value (map); SAII = serious and irreversible impacts; NIW = national important wetlands; TEC = threatened ecological community; na = not applicable.

The relevant contributions in Table 23 capture the whole methodology because the de-composition into that independent framework permits each layer to be directly comparable. The next step was to convert these contributions to a single weighting for each layer. Importantly, calculation of that single weighting needs to include compensation for the bias resulting from the total component contributions as reflected in the last row of Table 23. To explain, the layers predominantly capture the species composition component with a total of 490, whereas the structure/condition component is least represented with a total of 190. No one component is more important than another in capturing ecological integrity, so this bias requires compensation.

Weighting

The weighting methodology outcome is a single weighted value for each layer. The methodology does this by including the contribution of every layer to each biodiversity component shown as rows in Table 24. Each layer's total contribution is equal at 100 and this is by design. Conversely, the component totals shown in the last row are unequal and that bias was expected. The next 2 steps compensate for the component bias via normalisation then use the normalised values to create a single weighting. The component bias is overcome by converting each component contribution in Table 23 to a fraction of the component total as shown below in Table 24. For example, the BFT condition score of 90 for structure/condition converts to fraction of 0.474 because 90 ÷ 190 = 0.474 (where 190 is the component total as shown in Table 23).

Table 24 Conversion of expert-assigned component contributions (Table 23) to a fraction of component totals

Layer	Species composition	Fraction	Structure/ Condition	Fraction	Function	Fraction	Landscape feature	Fraction	Layer total
BFT condition	0	0	90	0.474	10	0.026	0	0	100
BFT conservation priority	50	0.102	30	0.158	20	0.053	0	0	100
BV coastal wetlands	40	0.082	0	0	40	0.105	20	0.083	100
BV riparian vegetation	20	0.041	10	0.053	30	0.079	40	0.167	100
BV SAII	80	0.163	10	0.053	10	0.026	0	0	100
Corridors	0	0	20	0.105	70	0.184	10	0.042	100
Flying-fox camps	0	0	0	0	50	0.132	50	0.208	100
Geologically significant sites	0	0	0	0	0	0	100	0.417	100
NIW (wetlands)	40	0.082	0	0	50	0.132	10	0.042	100
Over-cleared vegetation types	100	0.204	0	0	0	0	0	0	100
Primary habitat	0	0	10	0.053	90	0.237	0	0	100
Rainforest (non-TEC)	80	0.163	10	0.053	10	0.026	0	0	100
TECs	80	0.163	10	0.053	0	0	10	0.042	100
Component total	**490**	**1**	**190**	**1**	**380**	**1**	**240**	**1**	

Note: BFT = Biodiversity Forecasting Toolkit; BV = biodiversity value (map); SAII = serious and irreversible impacts; NIW = national important wetlands; TEC = threatened ecological community.

Applied weightings and calibration

From the fractions in Table 24, conversion results in all component totals equal one. The next step was to total each row of fractions to produce a final weighting for each layer as shown in Table 25. For example, the final corridors weighting of 0.33114 is the sum of 0.105, 0.184 and 0.042.

Table 25 Final weightings for each layer result from the summing of fractions across each row

Layer	Species composition fraction	Structure / Condition fraction	Function fraction	Landscape feature fraction	Final weightings
BFT condition	0	0.474	0.026	0	0.50000
BFT conservation priority	0.102	0.158	0.053	0	0.31257
BV coastal wetlands	0.082	0	0.105	0.083	0.27023
BV riparian vegetation	0.041	0.053	0.079	0.167	0.33906
BV SAII	0.163	0.053	0.026	0	0.24221
Corridors	0	0.105	0.184	0.042	0.33114
Flying-fox camps	0	0	0.132	0.208	0.33991
Geologically significant sites	0	0	0	0.417	0.41667
NIW (wetlands)	0.082	0	0.132	0.042	0.25488
Over-cleared vegetation types	0.204	0	0	0	0.20408
Primary habitat	0	0.053	0.237	0	0.28947
Rainforest (non TEC)	0.163	0.053	0.026	0	0.24221
TECs	0.163	0.053	0	0.042	0.25756
Component total	**1**	**1**	**1**	**1**	**4**

Note: BFT = Biodiversity Forecasting Toolkit; BV = biodiversity value (map); SAII = serious and irreversible impacts; NIW = national important wetlands; TEC = threatened ecological community.

Applying final weights to the layers was achieved by multiplying each layer by its final weight. For binary layers, the value of 1 was replaced by the final weights, these are, the corridors layer with 2 values [0, 1] became [0, 0.33114]. For the non-binary layers, the principle is the same but multiple values are changed. For example, the over-cleared vegetation types layer has values of 0, 0.2, 0.5, 0.8 and 1, but after multiplying each by the final weight of 0.20408 it produced new values of 0, 0.04081, 0.10204, 0.13626, 0.20408.

Once all weights were applied a single raw layer was derived by adding all weighted layers together. These last 2 steps of applying weights then adding the weighted layers together is described by Equation 2.

$$2. \qquad EL_{raw} = \sum_{i=1}^{n} w_i d_i$$

where:

EL_{raw} = the raw version of the environment layer

n = the number of contributing layers

w = is the final weighting of the ith layer

d = ith rescaled layer.

The first raw version of the environment layer produced values ranging from 0 to 1.85827. To produce a final product that is user-friendly, some enhancements were required. These enhancements were to linearly rescale the raw output's value range into 0–100 as integer and then adjust for any histogram skew in the data. The 2 enhancements of rescaling and conversion to integer were implemented simply by applying Equation 3.

$$3. \qquad EL_{rescaled} = Int\left[\left(\frac{1}{Max[EL_{raw}]} * EL_{raw} * 100\right) + 0.5\right]$$

where:

EL_{res} = the rescaled version of EL_{raw} in integer format

Int[ ] = function that converts values to integer by truncation of decimal values. Note: Before the function is applied, a fraction of 0.5 is added to the floating-point term in brackets to ensure the nearest whole number is assigned.

The final step was mostly aesthetic because it adjusted for histogram skewing. Adjusting the histogram evenly spread data values across the 0–100 range so the histogram is not skewed either left towards 0 or right towards 100. In this case, the rescaled layer had a small left skew so that values from 0 to 90 were linearly rescaled to 0–100 with values > 90 left unchanged. The pre- and post-skew histograms are shown in Figure 29.

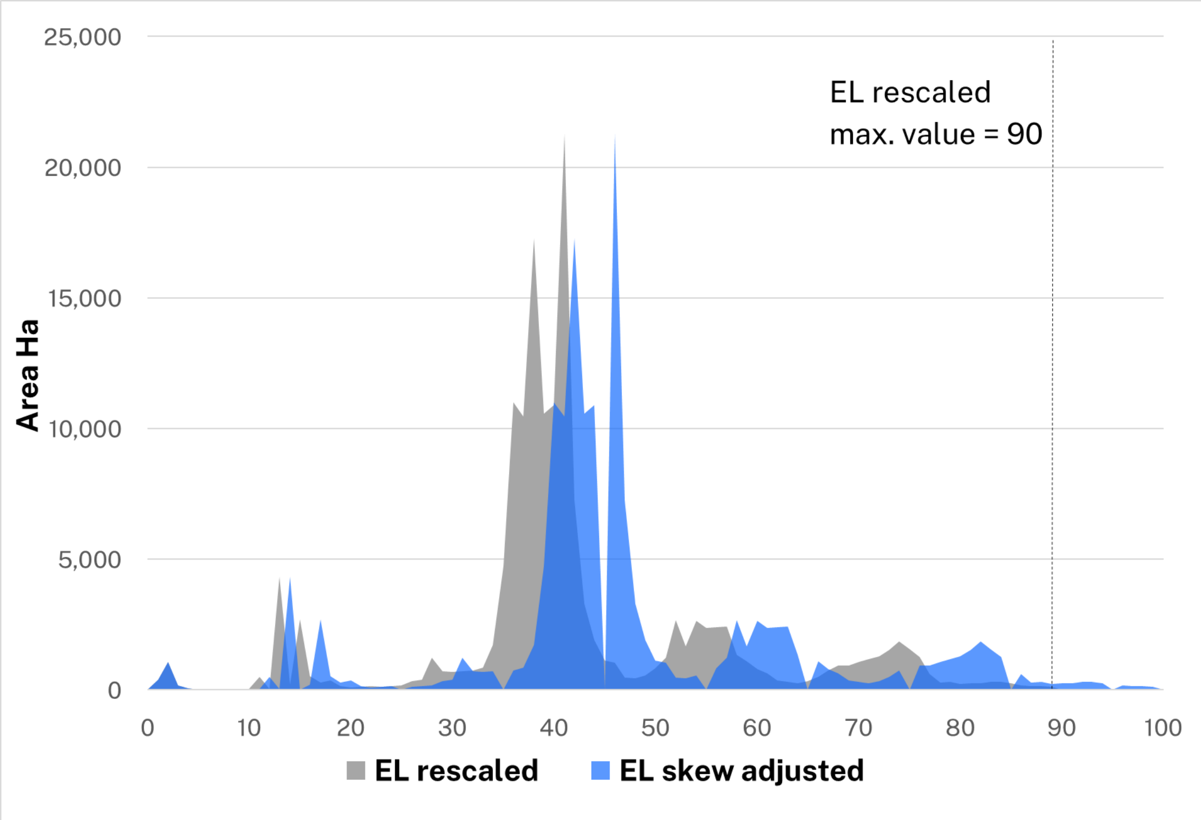


Figure 29 **Histogram for rescaled environment layer ($EL_{rescaled}$) in grey and the skew-adjusted histogram in green ($EL_{skew\ adjusted}$). All values of $EL_{rescaled}$ 0–90 (grey) were linearly rescaled to 0–100 (blue)**

Review

A thorough review of biodiversity component weightings was conducted as part of the 3 IIPT tool analyses projects (HDC, the department and Lake Macquarie City Council) mentioned earlier in the 'Background' section. A further review of the component weightings for this study was undertaken by expert ecologists in the department, although changes were minimal due to the thorough reviews in the past.

This layer was prepared in 2022 and is therefore representative of data available at the time. As new information become available, the layer will be reviewed, updated and redistributed. Refer to contributor acknowledgements in Appendix H.

Final layer

The skew-adjusted environment layer is the final raster layer with a 2 × 2m cell size and an integer value range of 0–100 as shown in both Figure 30 and Figure 31. Figure 30 displays the environment layer across the whole LGA, and Figure 31 includes NPWS estate and Forestry Corporation of NSW estate to highlight the spatial distribution of environmental values outside of these tenures.

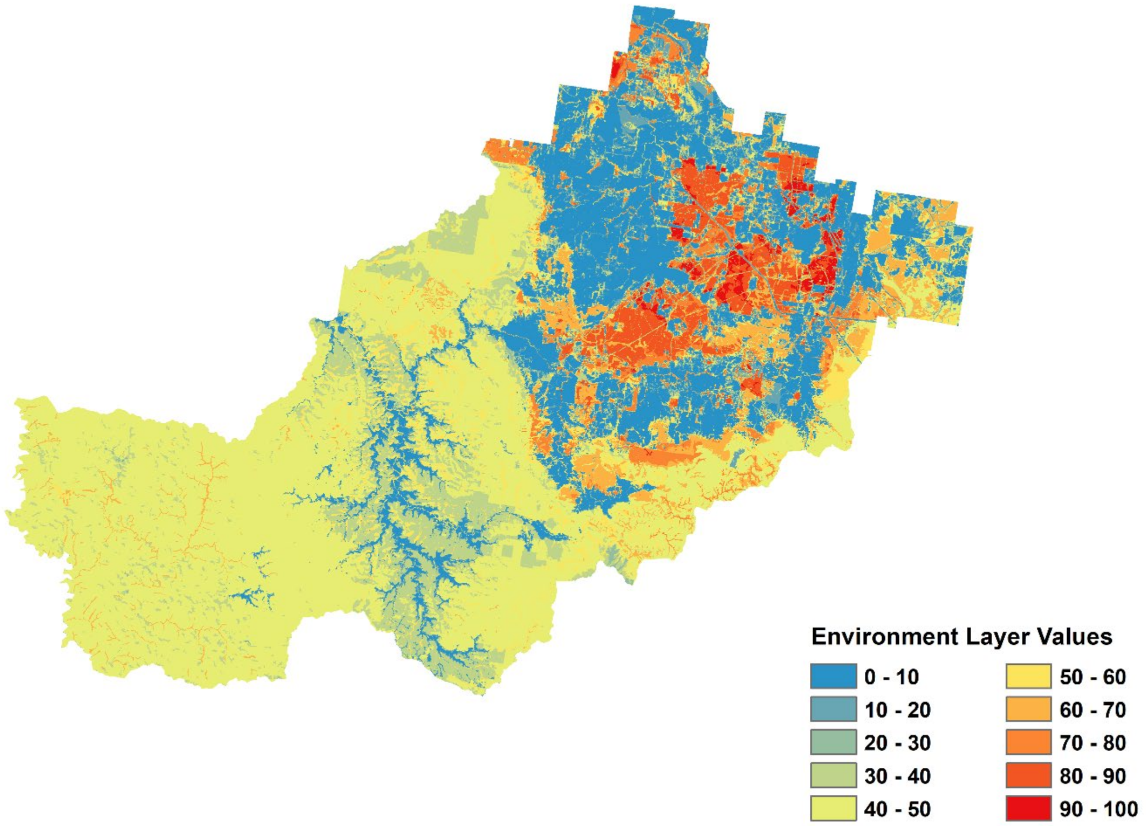


Figure 30 Final environment layer for Cessnock Local Government Area with values 0–100 and 2 × 2 m cell size. The value range from blue to red shows low to high environmental value respectively.

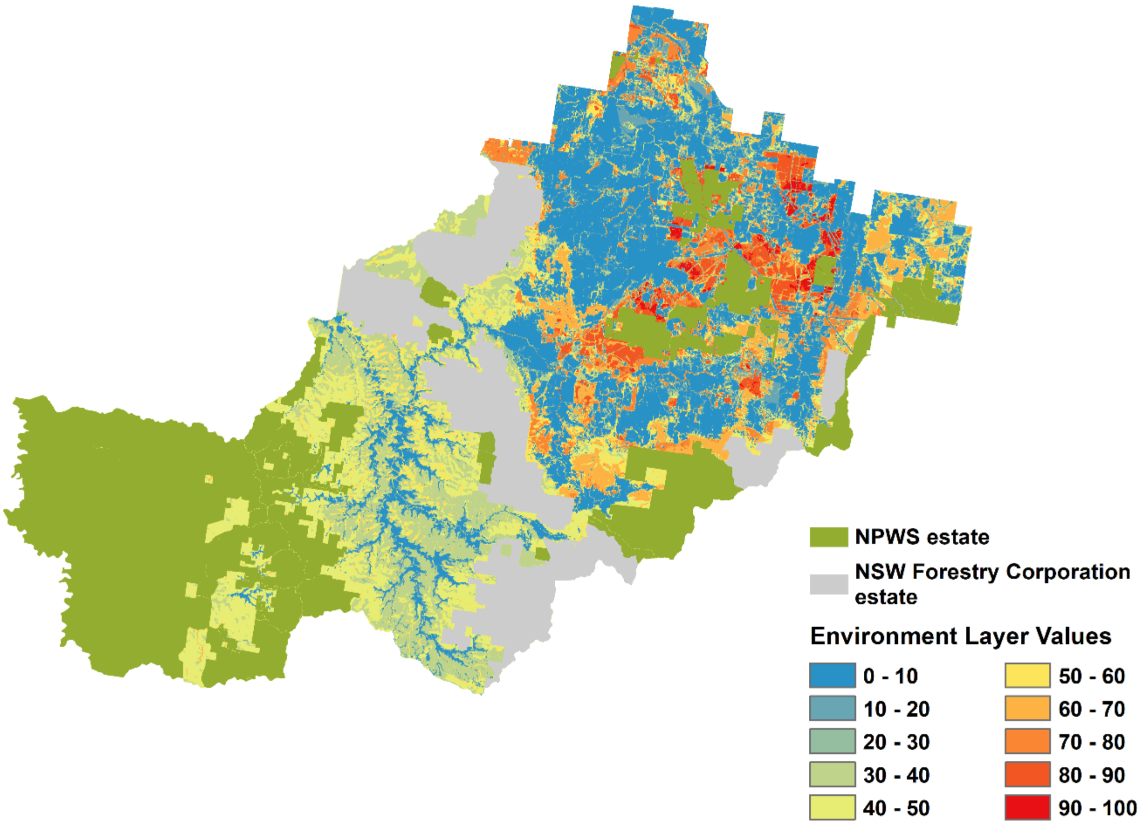


Figure 31 **Final environment layer for Cessnock Local Government Area overlain with NPWS estate and Forestry Corporation of NSW estate, with values 0–100 and 2 × 2 m cell size. The value range from blue to red shows low to high environmental value respectively.**

Appendix E. Streambank layer metadata

This layer maps all streambanks of larger streams in the Cessnock Local Government Area (which cover 196,468 ha) using the Strahler system to identify stream type. All tenures were mapped excluding National Parks and Wildlife Service (NPWS) estate because they are formally reserved and protected under local environment plans. Data is in vector format and was produced to a scale range of 1:500 to 1:3,000.

Background

The object of this part of the Cessnock environmental lands study was to identify streambank edges accurately so that native vegetation within 40 m of a streambank edge could be mapped. Cessnock City Council will require this data for their LEP zoning framework specifically where the watercourse plus 40 m from the top of bank for third order streams or larger, comprises riparian and estuarine vegetation on waterfront land, consistent with the NSW *Water Management Act 2000* or equivalent future legislation.

To account for this legislative requirement, a buffer of 40 m was applied to mapped streambanks to ensure that any development or other activities consider the recommended riparian corridor widths as specified under the Act to establish and preserve the integrity of riparian corridors.

The first step in mapping streambanks is to map stream order, which is undertaken using the Strahler system. The Strahler system (Strahler 1952, 1957) is based on the confluence of streams of the same order, as shown in Figure 32.

A first order stream has no other streams flowing into it. When 2 streams with the same order join, the resulting stream has the next highest order than the joining streams. For example, when 2 second order streams join, the resulting stream is third order (DPI 2018).

When 2 streams with different orders join, the resulting stream has the same order as the highest order of the 2 joining streams. For example, when a first and second order stream join, the downstream stream is second order.

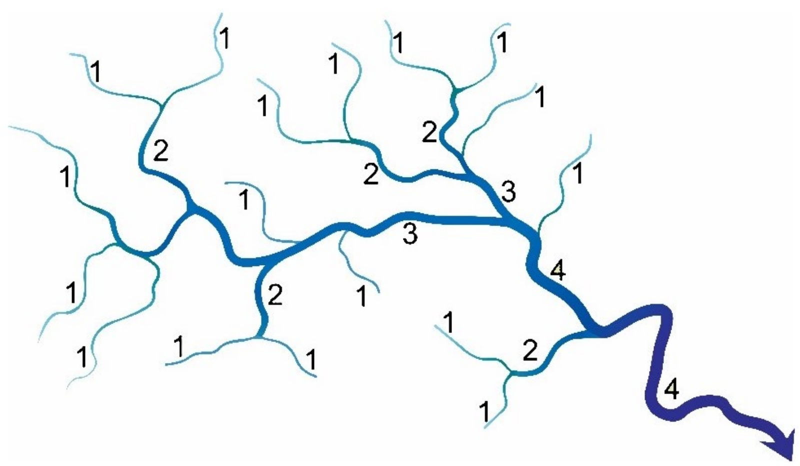


Figure 32 The Strahler system of stream order

Production of this layer required highly technical expertise and explanation of the methodology uses technical language. See Appendix G for a glossary of technical terms and acronyms.

Audit of existing layers

An audit was conducted of the available stream spatial layers covering the study area. These were limited to the streams shown on the 1:25,000 topographic maps and mapped stream order. In both layers, streams are represented as single lines representing the stream bed and do not depict the locations of streambanks.

Method

The process for delineating streambanks for the Cessnock LGA was:

1. map stream order
2. add light (or laser) detection and ranging (LiDAR) and Nearmap imagery as a basemap to refine the original stream order mapping
3. use hillshading to show the top edge of the streambank and topographic features of streambanks
4. apply a buffer of 40 m to streambanks to enable Cessnock City Council to take statutory considerations into account.

All analyses were undertaken in the geographic information system ArcMap (ESRI 2015) version 10.4. Layers used in this study and the sources of this data are shown in Table 26. All layers created during the analysis were saved in the Department of Climate Change, Energy, the Environment and Water (the department) corporate file geodatabase called 'Streambanks'.

Stream order mapping was clipped to the study area. All streams higher than second order were buffered by 100 m to create the area of interest for mapping streambanks. High-resolution LiDAR was converted to a hillshade to facilitate the delineation of streambanks. Streambanks were mapped at a scale of 1:3,000 as lines using a pen graphic tablet and the layer saved to a file geodatabase. Streambanks were then buffered by 40 m (as required by the Water Management Act). This layer was reviewed to remove gaps where the gap was entirely within a mapped streambank area.

Table 26 Data sources used to map streambanks in the Cessnock Local Government Area study area

Layer	Spatial Data Source/s
Stream order	NSW Department of Climate Change, Energy, the Environment and Water
LiDAR (light detection and ranging)	Cessnock City Council
NearMap imagery of Cessnock LGA	Cessnock City Council

The 3 data sources are described below.

Stream order

The initial step was to select all third order and above streams from the stream order layer. This was called StreamOrderCessnockLarge. This layer was clipped to the study area and called StreamOrderStudyAreaLarge. The streams in this layer were buffered by 100 m to generate the area of interest for the mapping of streambanks. This was called StreamOrderStudyAreaLarge100m.

Stream order in the Cessnock Local Government Area (LGA) outside of the NPWS estate is shown in Figure 33. The total area of Cessnock LGA is 196,468 ha and the area of Cessnock LGA outside of NPWS estate in 139,404 ha. This area is called the 'study area' in this appendix.

The length of stream orders within the Cessnock LGA is provided in Table 27. There are 1,184 kilometres of third order and above streams in the study area. Table 27 also provides the proportion of each stream order in the area of interest and notes which stream orders in the table were used in the method. Stream orders 1 and 2 were not used as these are not covered by the requirements to obtain Council approval before proceeding for activities within 40 m of prescribed streams which only relate to third order and higher.

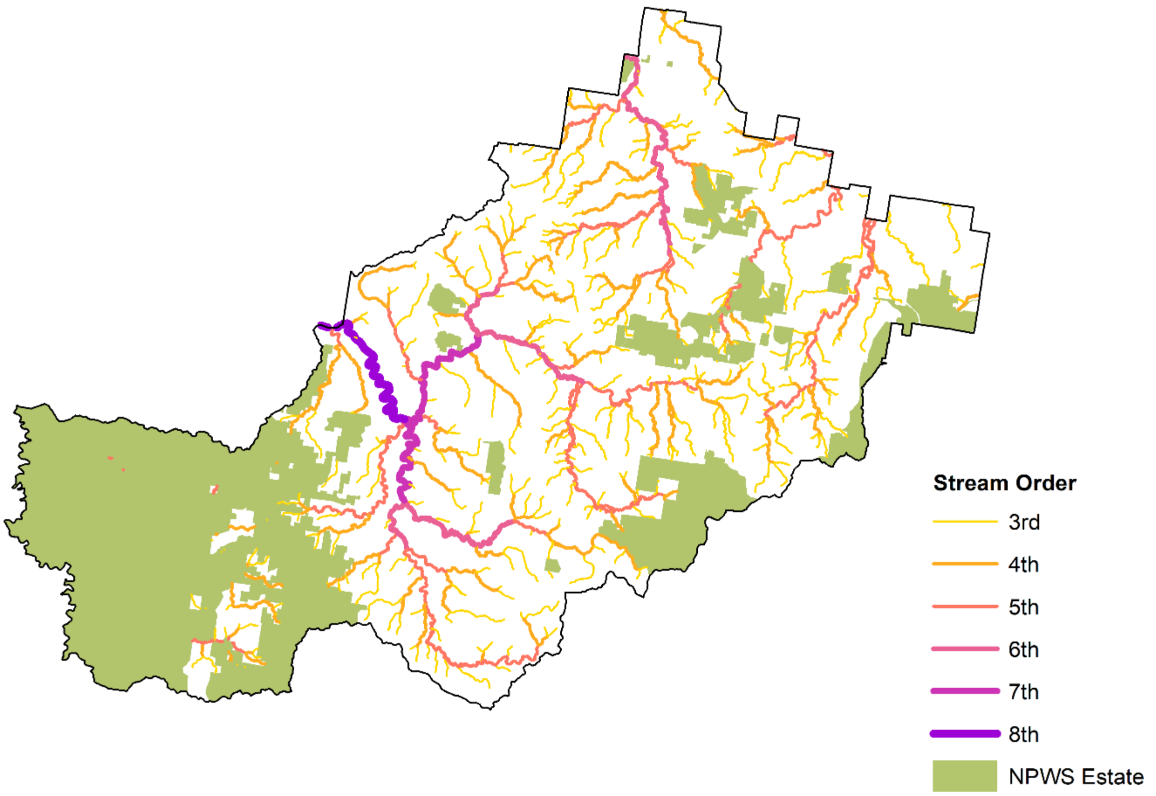


Figure 33 **Stream order (third order and greater) in the Cessnock Local Government Area outside of NPWS estate**

Table 27 Stream order lengths within the Cessnock Local Government Area

Stream order	Length (km)	Percentage in AoI	Usage
1	535	45.2%	Not used
2	326	27.5%	Not used
3	535	12.3%	Used
4	326	7.5%	Used
5	217	5.0%	Used
6	64	1.5%	Used
7	26	0.6%	Used
8	13	0.3%	Used
9	<1	0.004%	Used
Total	**1,184**		

Note: AoI = area of interest.

LiDAR

LiDAR is commonly used to make high-resolution maps, with applications in geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, remote sensing, atmospheric physics, airborne laser swath mapping, laser altimetry and contour mapping. The LiDAR imagery provided by council had a resolution of 1 m and was compiled from several sources to create a mosaic that covered the study area. LiDAR is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses, combined with other data recorded by the airborne system, generate precise, 3-dimensional information about the shape of the Earth and its surface characteristics (NOAA 2022).

The components of the mosaic, the date of their capture and area captured is provided in Table 28. The extent of LiDAR components image capture and the date of capture is shown in Figure 34.

Table 28 LiDAR components, date of image capture and extent of capture

Layer	Date of imagery	Area captured (ha)
Gosford West	17 May 2017	92,400
Maitland 0212	12 July 2012	123,600
Maitland 1012	12 July 2012	4,800
Maitland 2012 MKP	1 January 2012	4,800
Morisset 0914	1 September 2015	172,800
Singleton 1011	24 February 2012	148,400
Wollombi 0112	11 February 2013	33,600

Nearmap imagery of Cessnock LGA

A high-accuracy delineation of most of the study area using Nearmap imagery with 6 cm pixel resolution was available. This imagery was used as a background for the streambank mapping to provide the most recent high-resolution aerial imagery of the study area. It was not used in the processing of streambank mapping. A very small area in the western section of the study area was not covered by the Nearmap imagery. In this area, 50 cm pixel resolution ADS40 imagery was used to provide background context.

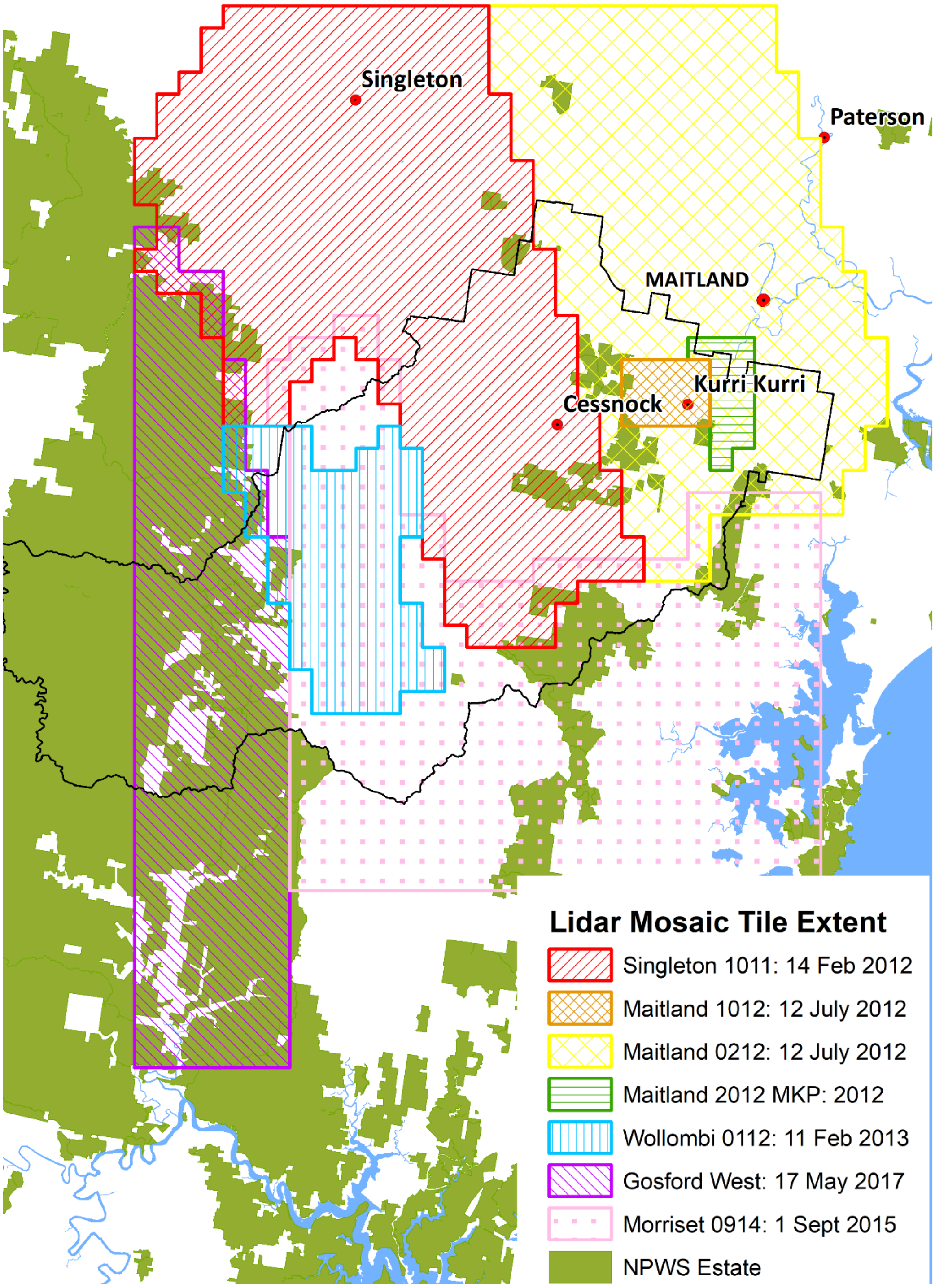


Figure 34 LiDAR date of image capture and extent of capture

Hillshading

Creating visual models from LiDAR data is crucial for characterising relief features (Davis 2012). Hillshading was used to accurately delineate the top edge of streambanks. Hillshade is a technique used to create a realistic view of terrain by creating a 3-dimensional surface from a 2-dimensional display of it. Hillshades make it easier to visualise changes in elevation over a landscape.

The buffered streams layer StreamOrderStudyAreaLarge100m was used as the extent of the area of interest for generating a fine-scale (i.e. 1 m resolution) hillshade that depicted topographic features such as streambanks. The extent was limited to reduce the size of the hillshade layer used in analysis.

The fine-scale LiDAR layer provided by Cessnock City Council was geoprocessed to create the hillshade and this was saved as HillshadeGrid. The hillshading was generated using an azimuth angle of 315° and altitude angle of 45°. This layer was converted to a TIFF layer as this provides better definition between values, creating a sharper image in the map display, and was saved as HillshadeTIFF. The HillshadeTIFF was displayed using a graduated colour ramp that showed low shadow values as black and high sunlit values as white. An example near Rothbury of the HillshadeTIFF is shown in Figure 35.

Figure 35 An example near Rothbury of the hillshade used in streambank mapping

Streambank mapping

The hillshade layer was displayed over a background of a high-resolution satellite image from Nearmap that was supplied by Cessnock City Council. The map display scale was set to 1:3,000 to facilitate accurate delineation of streambanks while also providing an efficient scale to map all streambanks within a reasonable time frame (6–8 weeks). To store the mapped streambanks, a new polyline feature class was created and called streambanks.

Starting in the north-west of the study area, the streambanks feature class was edited by adding new lines along streambanks. These were labelled as 'Streambanks'. The addition and editing of lines to the feature class was undertaken using a Wacom pen tablet. The Streaming function (continuous insertion of vertices at a specified distance) was used to ensure accurate delineation along the streambank with the vertices inserted at every 5 m. The Snapping function was also used to ensure that streambank line endpoints aligned accurately by snapping to nearby endpoints occurring when within 5 × 5 m pixels.

The delineation of streambanks commenced along the largest stream order in the area (initially this was Anvil Creek at Branxton) and working progressively upstream. Streambank line segments were generally delineated to the display extent limits apparent on the screen, being about 700 m vertically (north–south) and 1,400 m horizontally (east–west).

Initially, streambanks were mapped at lengths greater than these distances by pausing the mapping, scrolling the display along the stream, and then continuing mapping. This was found to be time consuming and the mapping of streambanks at lengths of under 700 m vertically and 1,400 m horizontally was undertaken instead.

Where a lower order tributary was encountered, the streambanks along it were mapped to the location where 2 second order streams join to become a third order stream. Where a stream flowed out of or into the study area, each streambank was finished at the study area limit. Streambank mapping was generally undertaken from north to south and west to east depending on the direction the stream flowed. Once streambank mapping of a drainage system was completed, the next adjacent drainage system was mapped.

To facilitate the accurate delineation of streambanks, the area being mapped was viewed at a scale of 1:30,000 to provide context and viewed using the 1:25,000 topographic maps and the Nearmap imagery interchangeably as background. Working at the scale of 1:3,000, the hillshading was visually scanned to determine the general width of the stream channel and identify where streambanks were clearly defined and where they were not readily apparent. Where streambanks were not clearly defined, referral to the Nearmap image and mapped stream order provided insights into their probable location. Figure 36 shows are area with poorly defined streambanks on the left and then with mapped streambanks on the right. Streambanks were mapped at a consistent stream channel width across the area of poorly defined streambanks.

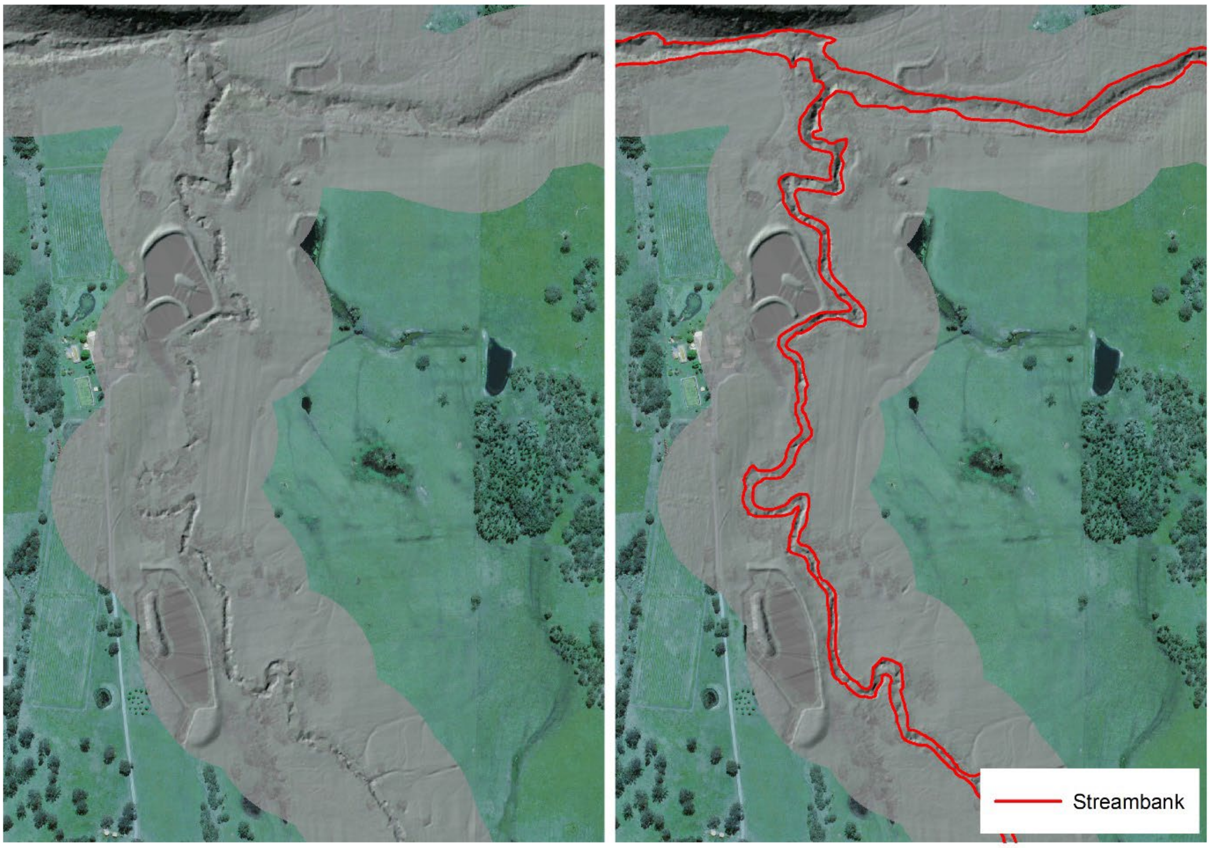


Figure 36 **An area of poorly defined streambanks (left) and the final mapped streambanks (right)**

In other areas, the actual streambanks diverged quite significantly (> 100 m) from the mapped stream order and were not visible on the hillshading derived from the stream order feature class (i.e. they were outside the mapped area of interest). In these situations, a temporary hillshading was derived to cover the map display area, showing where the actual streambanks were located. Figure 37 shows an area near Sawyers Gully where the actual streambanks diverged about 300 m from the stream order mapping.

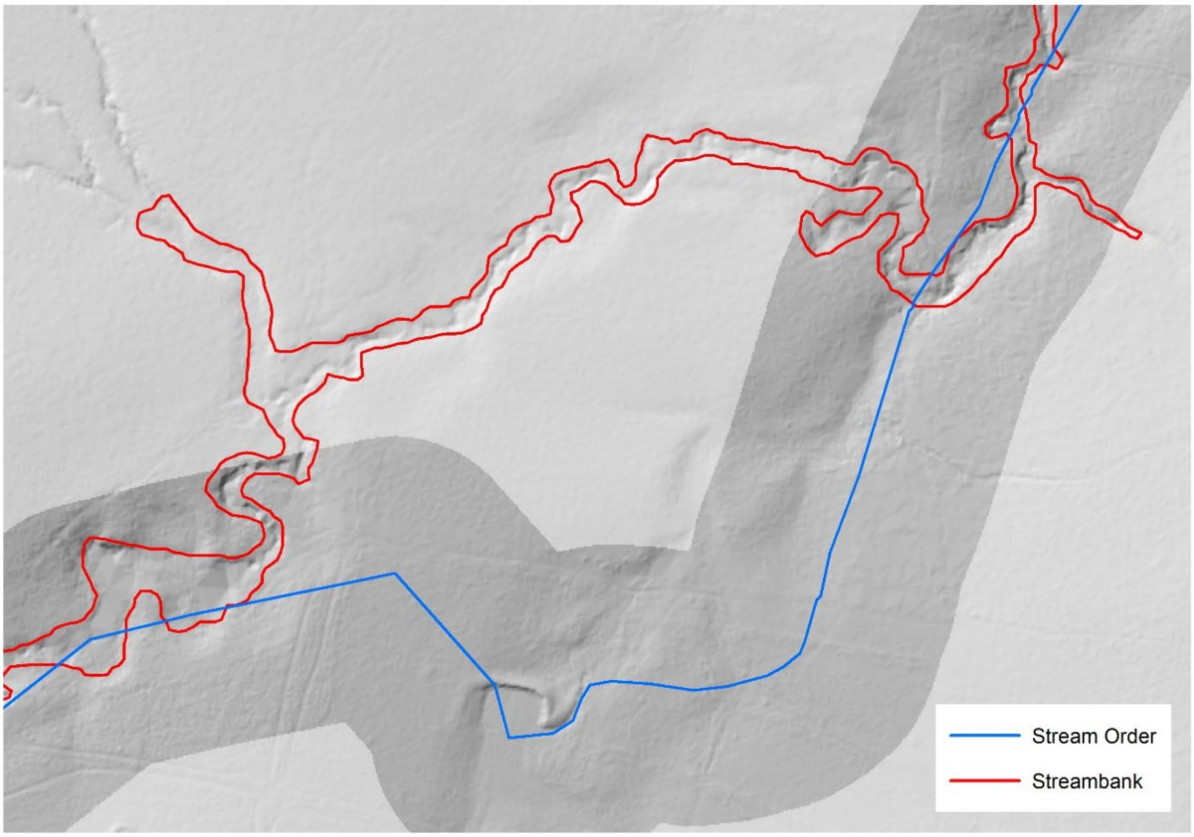


Figure 37 An area showing where actual streambanks (in red) diverged from mapped stream order (in blue)

In the western part of the study area there is a large area of elevated sandstone that has been eroded by streams with narrow valleys that have deeply incised streams. In this area, many of the streams do not have readily identifiable streambanks and were therefore mapped as single lines to depict the streambed. These streams were assigned the label 'Streambed' to differentiate them from streambanks. Figure 38 shows an area where incised streams occur in the sandstone near Mount Finch in the south-west of the study area.

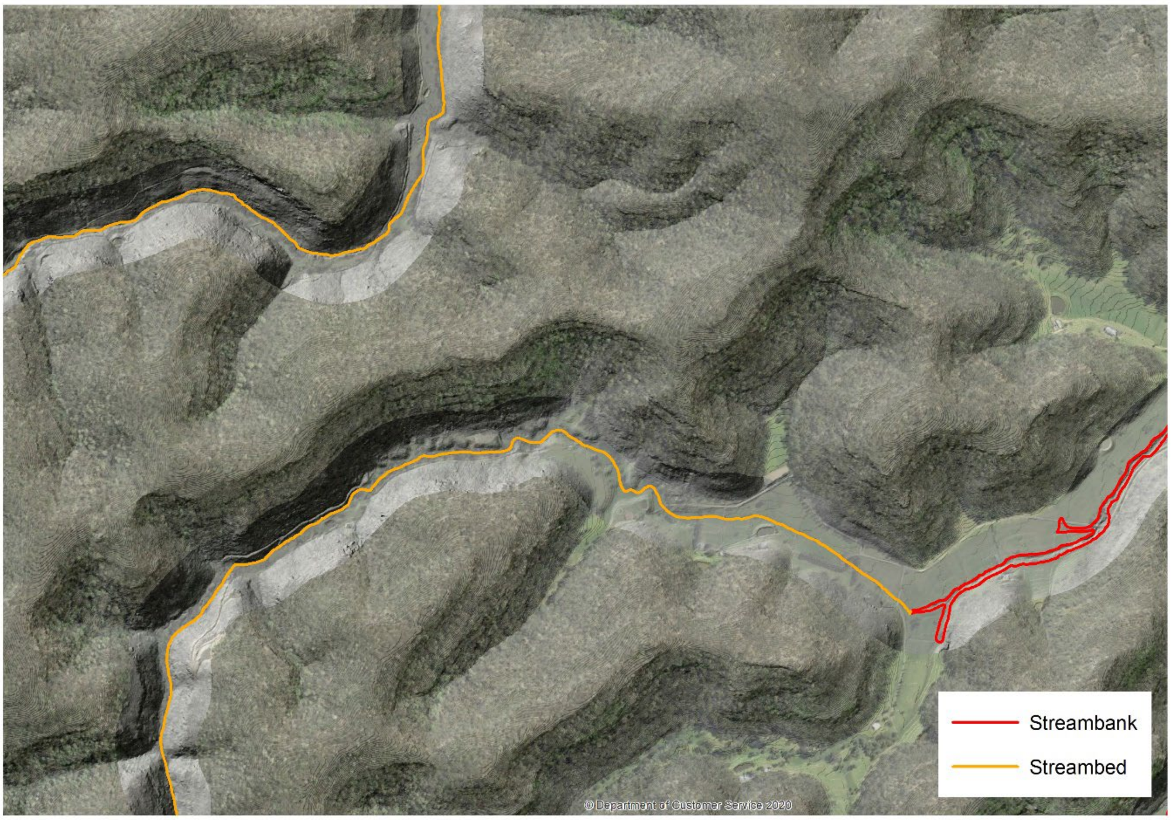


Figure 38 An area showing where incised streams occur in the western sandstone areas

Throughout the study area there are numerous dams for agricultural, horticultural and industrial purposes on mapped streams of third order and higher. Due to the alteration of the topography and the presence of standing water, it is not possible to delineate the location of streambanks that have been inundated. Where dams were identified, the edge of the dammed waterbody was mapped and labelled as 'Dams'. Figure 39 shows an example of a mapped colliery dam near Mulbring.

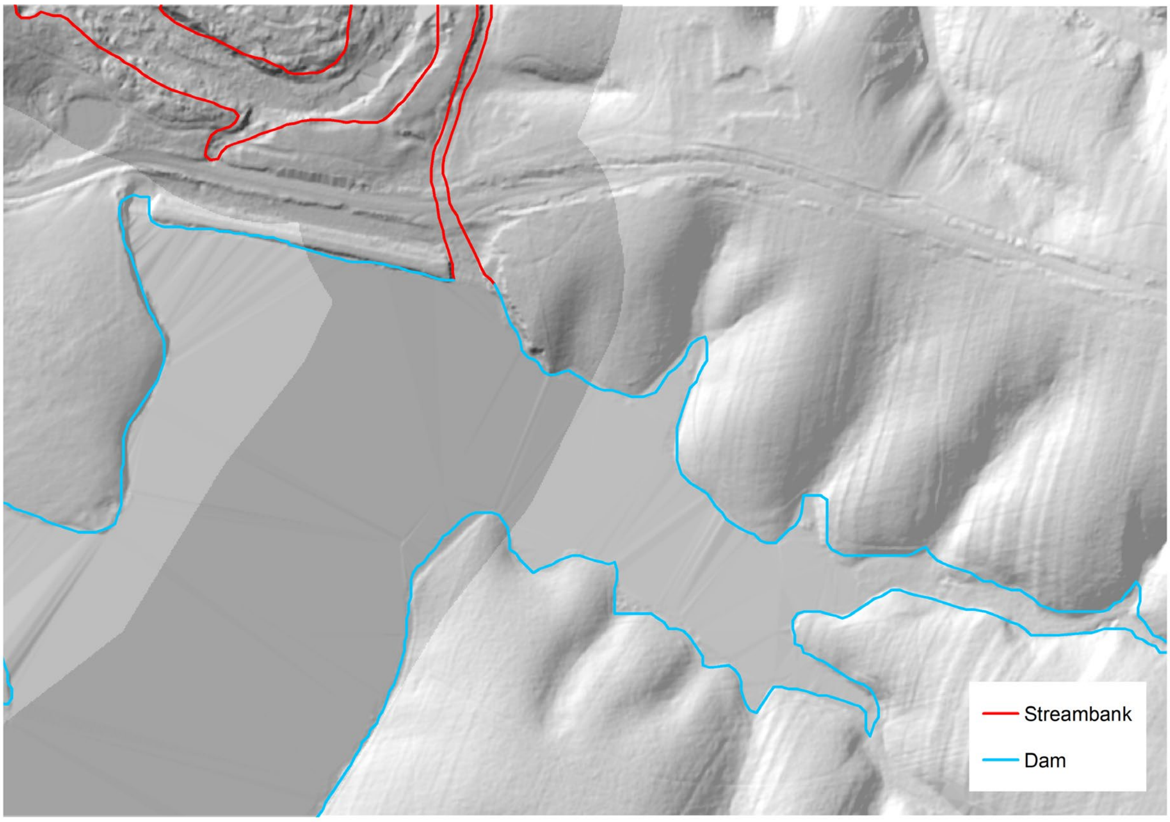


Figure 39 An example of a mapped dam near Mulbring

There are several large areas of disturbance that have significantly altered the natural topography of the landscape, changing the course of streams and creating pondage to store surface water. These are typically associated with urban areas where drains are constructed, and with coal mines and quarries. Where no discernible streambank or streambed could be identified, none were mapped. Figure 40 shows an area at Southland colliery near Pelton where disturbance has eliminated streambanks and streambeds from the landscape.

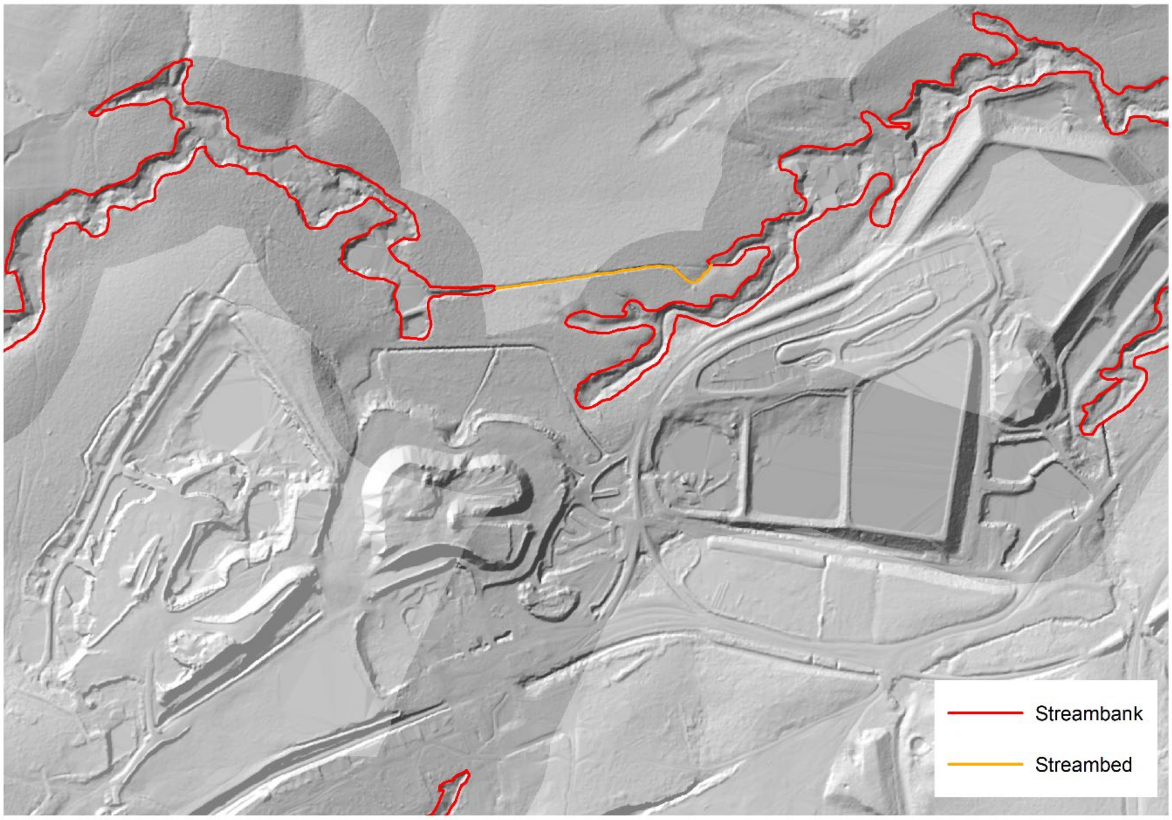


Figure 40 **An area of highly disturbed land at Southland colliery near Pelton (shown in hillshade)**

Buffering

The streambanks layer was buffered by 40 m on both sides and clipped to the study area then saved as the layer Streambanks40mOriginal. Streambanks were then buffered by 40 m (as required by the Water Management Act) and any areas where streambanks had internal gaps greater than 80 m were removed and the buffer revised to cover the gap.

The buffering did not use the Label field from streambanks to differentiate buffer type as this would create overlapping polygons where different streambank types abutted each other. This layer was copied and named Streambanks40mRevised and was edited to 'explode' the single polygon to multiple polygons. This created 91 discrete drainages. This layer was reviewed to remove gaps where the gap was entirely within a mapped streambank area. That is, the distance between corresponding streambanks was greater than 80 m. Figure 41 shows an area on Congewai Creek near Millfield where the distance between streambanks was greater than 80 m and where these internal gaps were removed and attributed as streambanks.

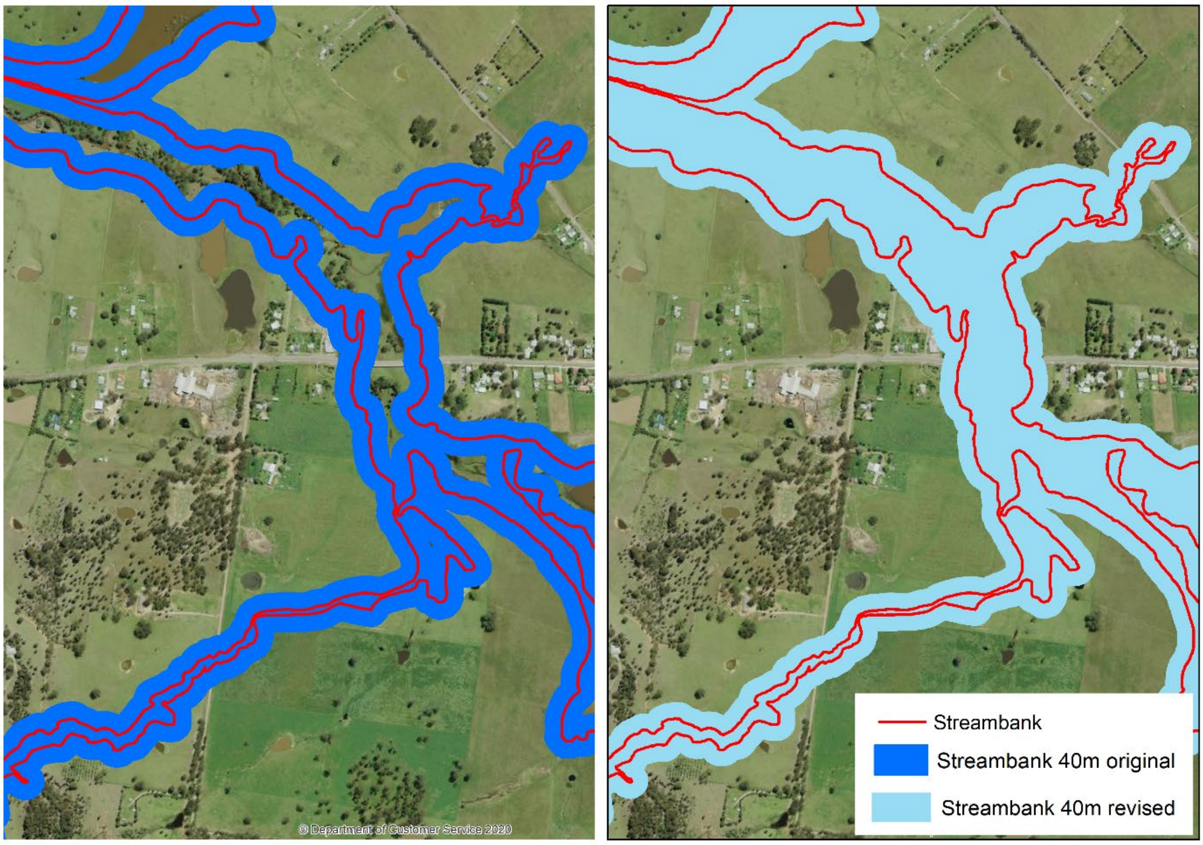


Figure 41 **Area at Millfield where internal gaps (left) between streambanks were removed and the 40 m buffer revised (right)**

The Streambanks40mRevised layer was edited to add a Label field and an AreaHa field to calculate the final total area. The layer was then dissolved on the Label and AreaHa field and saved as a polygon feature class layer called Streambanks40mFinal and the total area was then calculated as 13,080 ha. This area represents a riparian zone that extends 40 m beyond the streambanks of all third order and larger streams in the study area.

Attributes

Attribution for the streambanks layer contains only 6 relevant fields as shown below in Table 29. The fields created_user, created_date, last_edited_user and last_edited_date were generated using the Enable Editor Tracking (Data Management) tool in ArcMap.

Table 29 Attribution for streambank layer

Attribute name	Contents	Example
Label	Description of line element	Streambank
created_user	Automatically generated	STEEDA
created_date	Automatically generated	20/04/2022 5:20:23
last_edited_user	Automatically generated	STEEDA
last_edited_date	Automatically generated	6/5/2022 1:07:25 PM
LengthM	Length in metres	1,105

The Label field was populated with ‘Streambank’, ‘Streambed’ or ‘Dam’. Attribution for the Streambanks40mFinal layer is also simple and easy to interpret with only 2 relevant fields as shown in Table 30.

Table 30 The attributes of the Streambanks40mFinal layer

Attribute name	Contents	Example
Label	Description of polygon element	Streambank buffer 40m
AreaHa	Calculated area in hectares	13,080.866

Results

The number and length of mapped streambank segments by type is shown in Table 31. A total of 2,389 km of streambanks were mapped across the study area. Dams accounted for nearly 3% of the length of streambanks mapped, with streams accounting for around 82% and streambeds for the remaining 15%. A graph of the frequency of mapped streambank lengths by type is provided in Figure 42.

Table 31 Number of mapped streambank segments by type

Labels	No. segments	Length (m)	Length (km)
Dam	238	64,737	64.7
Streambank	2,122	1,954,480	1,984.5
Streambed	626	369,759	369.8
Total	**2,986**	**2,388,976**	**2,389.0**

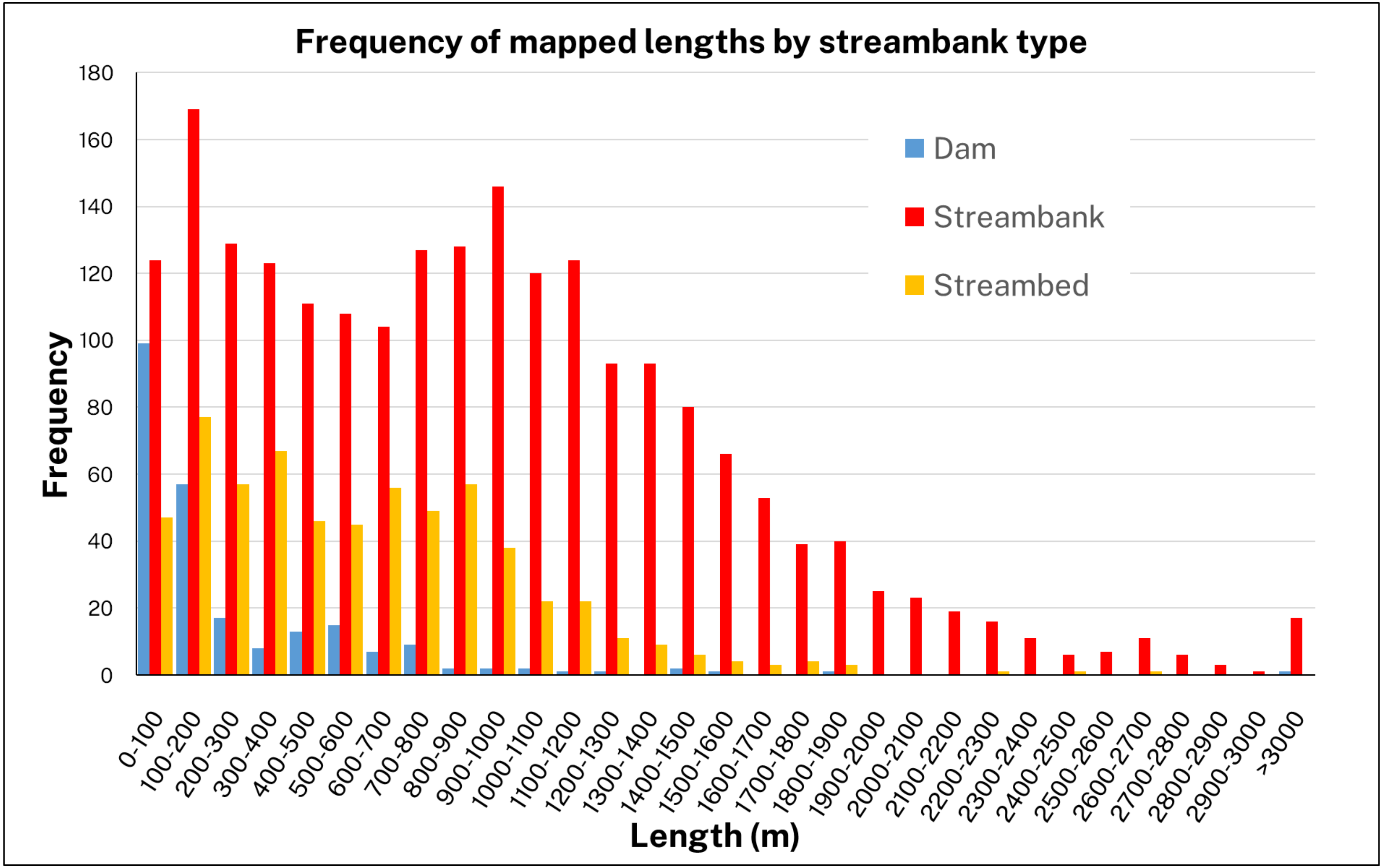


Figure 42 **Frequency of mapped streambank lengths by type**

The shortest streambank length was 9 m and consisted of a short section of streambed between 2 dams on a third order stream in the Congewai area. Figure 43 shows the type of streambanks mapped across the study area. The layer Streambanks40mFinal covered an area of 13,080 ha (or 131 km^2). Figure 44 shows the final revised buffer applied to streambank mapping

Final layers

The 2 final layers are the streambanks line feature layer and the Streambanks40mFinal polygon feature layer. The Streambanks40mFinal layer represents the riparian zone where council approval will be required for controlled activities as required by the Water Management Act.

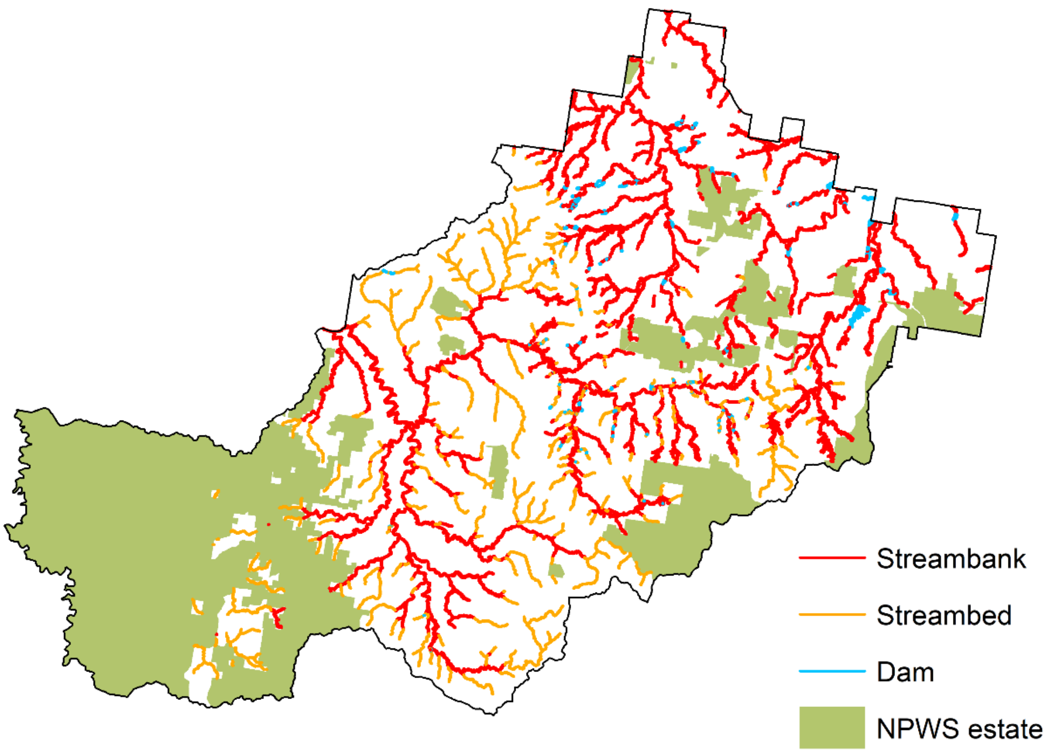


Figure 43 The final mapped streambank types in Cessnock Local Government Area

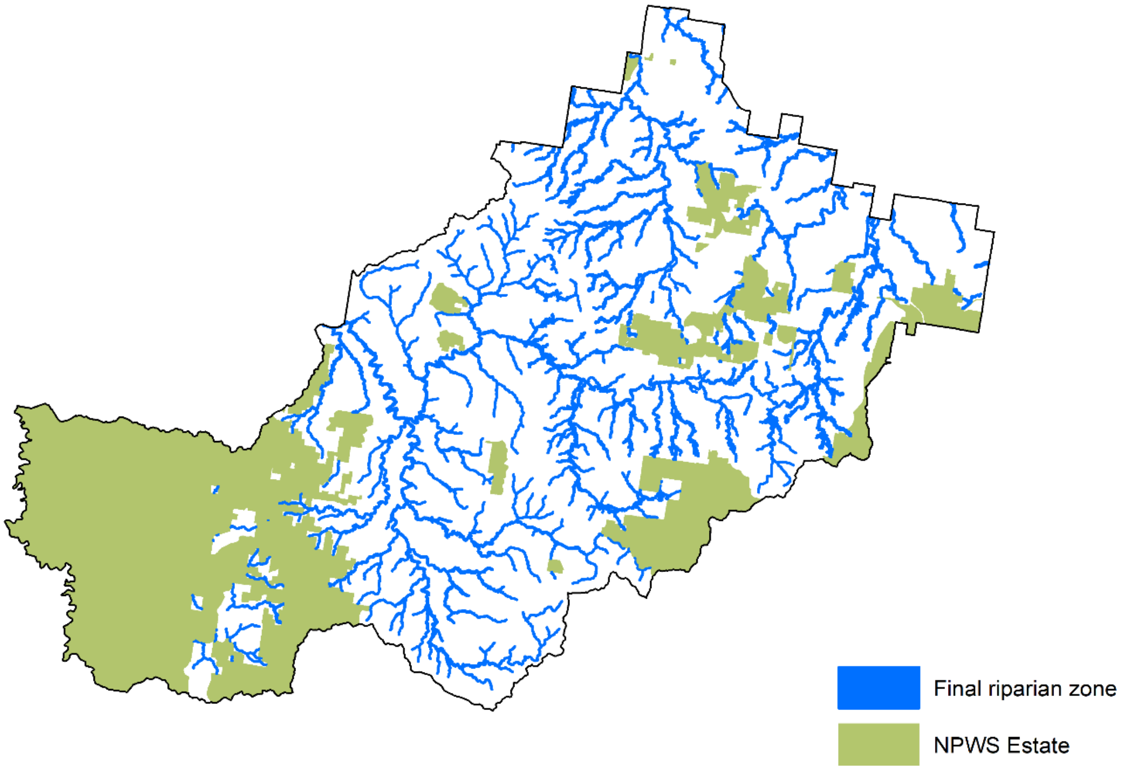


Figure 44 **The final 40 m riparian zone buffers in Cessnock Local Government Area study area**

Review

The streambanks layer was visually reviewed several times across the study area at a scale of 1:10,000 to identify any missed sections of streambanks and errors such as gaps between adjoining segments. Incomplete linework and incorrect streambank location identification or designation of streambank type was also reviewed and corrected.

The layer was also reviewed by a highly experienced GIS technician familiar with the objectives and purpose of the streambanks mapping project. Refer to contributor acknowledgements in Appendix H.

This layer was prepared in 2022 and is therefore representative of data available at the time. As new information becomes available, the layer will be reviewed, updated and redistributed.

Appendix F. Tenure layer metadata

This layer maps all tenures across the Cessnock Local Government Area (LGA) which covers 196,468 ha. The layer includes National Parks and Wildlife Service (NPWS) estate, Biodiversity Conservation Trust properties, Forestry Corporation of NSW estate, Crown lands, Commonwealth of Australia estate, Cessnock City Council tenure and Aboriginal-owned lands. By default, all other tenure outside of these categories is assumed to be freehold. The data is in vector format and is combined from layers sourced from respective landowners and land managers.

Background

A complete tenure layer is an essential requirement for any landuse planning. Commonwealth, state and local planning and environment legislation is often specific to tenure or ownership. As such, the Cessnock City Council's review of the local environment plan (LEP) environmental zoning requires the most current snapshot of tenure ownership possible. The purpose of this study was to collate all available tenure data sources into one single spatial layer to assist Cessnock City Council's LEP zoning review.

Production of this layer required highly technical expertise and explanation of the methodology uses technical language. See Appendix G for a glossary of technical terms and acronyms.

Method

Construction of the tenure layer involved sourcing and collating all relevant tenure data from the appropriate authorities. The sources of data are shown below in Table 32.

Table 32 Data sources for tenure categories

Tenure	Spatial data source/s
NPWS estate	DCCEEW
Forestry Corporation of NSW estate	Forestry Corporation of NSW
Department of Defence (Commonwealth) land	Department of Defence (Commonwealth)
Biodiversity Conservation Trust properties	BCT
Aboriginal land	DCCEEW, DPI
Crown land	CCC, DPI, DCCEEW
Cessnock City Council	CCC

Note: DCCEEW = Department of Climate Change, Energy, the Environment and Water; DPI = Department of Primary Industry; BCT = Biodiversity Conservation Trust; CCC - Cessnock City Council.

There is high confidence in the data where an agency or government department regularly administers is its own tenure boundaries. As a result, those boundaries are current and there is no spatial overlap with other layers. These high confidence layers are NPWS estate (from the Department of Climate Change, Energy, the Environment and Water [the department]), Biodiversity Conservation Trust lands (from the Trust), Department of Defence lands (from Australian Government) and Forestry Corporation of NSW estate.

All other layers contained spatial overlaps, conflicting attribution and currency issues. To resolve these conflicts a systematic approach was taken as outlined below:

1. Combine the high confidence layers (top 4 rows in Table 32) into one layer, called step1. This layer takes precedence over all others.
2. For Aboriginal land, Crown land and Cessnock City Council land layers, any overlaps with step1 were excised.
3. Multiple Crown land layers (council and the department) were combined into one Crown lands layer. Several iterations were performed when combining these layers and conflicts were reviewed at each iteration using the Department of Primary Industry's IndustryView tool to check lot ownership. Combined Crown land layer is called step2.
4. Combine step2 and Cessnock City Council land layer. Each conflict was reviewed using IndustryView portal. This layer was called step3 crownCCC**.**
5. Combine Aboriginal land with crownCCC and resolve conflicts using DPI IndustryView tool to check lot ownership. This layer was step4.
6. Merge layers step1 and step4 to finalise the non-freehold tenure component of the LGA. At this stage, all freehold tenure is null or blank. This layer was step5.
7. Combine and cookie cut step5 with LGA boundary layer so that all freehold tenure is not blank and can be attributed Freehold. Layer called step6.
8. Step6 reviewed and renamed Cessnock_LGA_Tenure to produce the final tenure layer.

An important step in each iteration above was to eliminate slivers that resulted from small spatial inaccuracy between 2 layers. Each sliver was reviewed to determine if it was a legitimate small polygon or an accuracy artefact. This was achieved by examining the sliver's area (metres squared) and its shape determined by a perimeter-to-area ratio as per Equation 1 below.

$$r = \frac{perimter\ (m)}{area\ (m^2)} \quad (1)$$

where *r* is the perimeter-to-area ratio.

This was an intensive part of the process as some small polygons were legitimate, such as war memorials. The perimeter-to-area ratio helped eliminate these because they are normally rectangular in shape and have low *r* values (i.e. $r < 1$). Long thin slivers that result from spatial inaccuracy have high *r* values (e.g. $r > 2$).

In summary, all efforts were made to resolve spatial conflicts and slivers at each iteration. However, the data still requires a more thorough review, particularly for the Crown land, Aboriginal land and Cessnock City Council tenures. All other tenures can be regarded as accurate and current.

Attributes

Attribution for the tenure layer is interpreted with only 4 relevant fields as shown below in Table 33.

Table 33 Attribution for final tenure layer

Attribute	Contents	Example
Tenure	Land owner	Cessnock City Council
Label	Name/Title of land	Abermain Plaza Hall
Description	Information regarding management, cadastre, etc.	Community Hall
Data_Source	Source of spatial data	Cessnock City Council
final_diss	Field used in layer construction and is a concatenation of the above 4 attributes separated by a '~'. This field can be removed if necessary	Cessnock City Council~Abermain Plaza Hall~Community Hall~Cessnock City Council

In some cases, there is no information in the source data for the Label and Description fields. In these cases, the entries of 'Unknown' or 'Undefined' are used.

Results

The areal breakdown of these tenure categories is shown in Table 34.

Table 34 Areal and percentage breakdown of tenures across Cessnock Local Government Aea (LGA)

Tenure	Area (ha)	% of LGA
Freehold	100,441	51.12
NPWS estate	57,063	29.04
Forestry Corporation of NSW estate	24,500	12.47
Crown land	9,701	4.94
Aboriginal land	2,562	1.30
Biodiversity Conservation Trust properties	1,427	0.73
Cessnock City Council lands	702	0.36
Department of Defence (Commonwealth) lands	72	0.04
Total	**196,468**	**100.00**

A further breakdown of the tenure categories into woody vegetation (see Appendix A) and cleared land is shown in Table 35.

Table 35 Percentage breakdown of woody versus cleared vegetation by tenure category

Tenure	% woody	% cleared
NPWS estate	> 99%	< 1%
Forestry Corporation of NSW estate	99.89	0.11
Department of Defence lands (Commonwealth)	98.40	1.60
Aboriginal land	93.96	6.04
Biodiversity Conservation Trust properties	82.71	17.29
Crown land	82.43	17.57
Freehold	58.11	41.89
Cessnock City Council	36.35	63.65

Note: Woody vegetation was not mapped for NPWS estate because it is formally protected and is not considered in local environment plan (LEP) rezoning. NPWS estate is confidently estimated at > 99% vegetated.

Table 34 and 35 results show that freehold tenure dominates the LGA (51.12%) and contains the most cleared land (41.89%). Conversely, NPWS estate and Forestry Corporation of NSW estate contain the highest percentage of woody vegetation (both > 99%) and together make up 41.51% of the LGA.

Commonwealth Defence lands, Aboriginal land, Biodiversity Conservation Trust properties and Crown land also have high percentages of woody vegetation but are only a small portion of the LGA, that is 8.57% combined.

Cessnock City Council owns a very small portion of the LGA (0.36% or 702 ha) and this consists predominantly of community facilities, urban parks and gardens.

Final layer

The final tenure layer contains 7 categories of tenure, with all other lands classified as freehold by default. Labels and descriptive details for each polygon or tenure type are stored in the attributes of the layer where they exist. The resultant layer is shown in Figure 45.

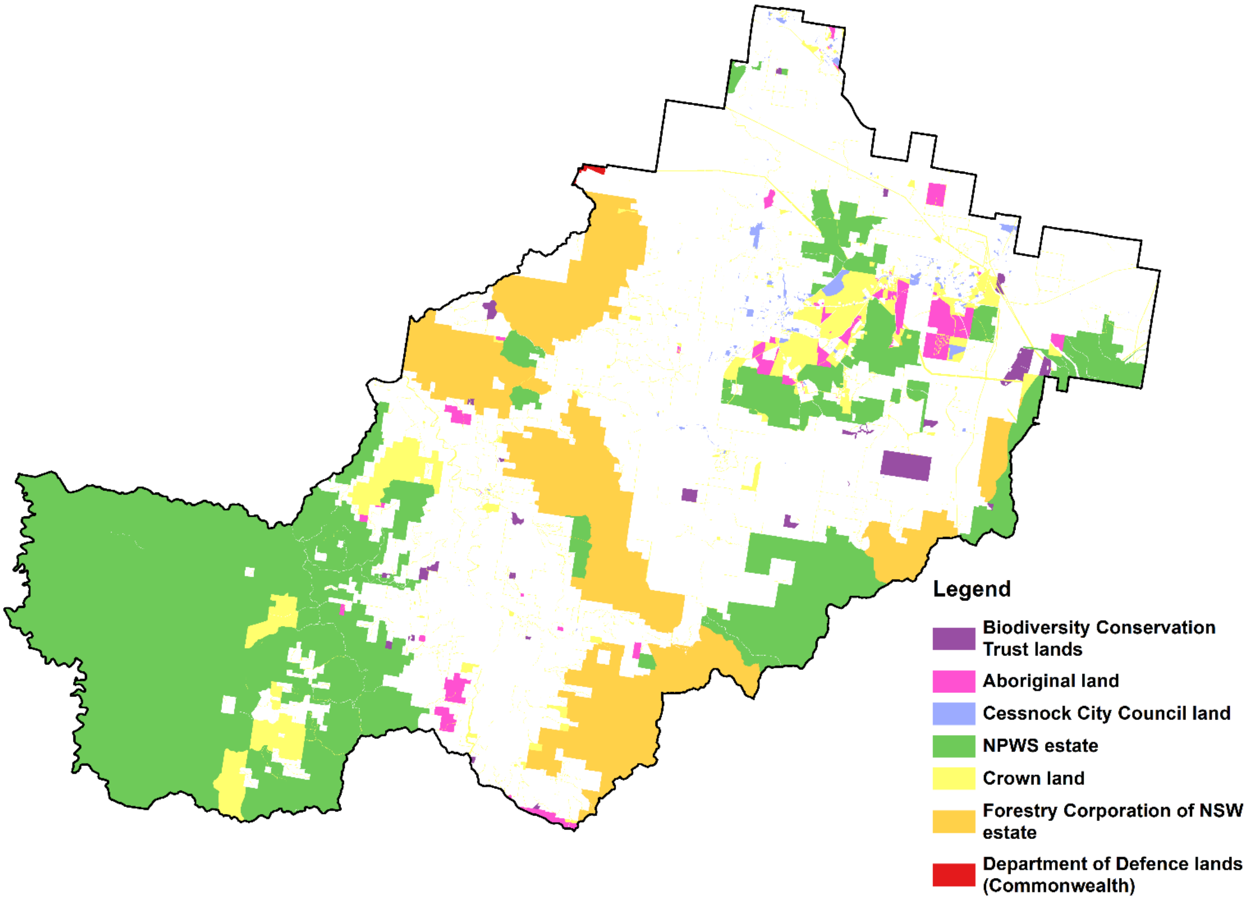


Figure 45 All non-freehold tenure within the Cessnock Local Government Area

Review

As discussed earlier, there are high confidence layers that include NPWS estate, Biodiversity Conservation Trust properties, Department of Defence lands (Commonwealth) and Forestry Corporation of NSW. Other tenure data sources such as Crown lands and lands owned/administered by Cessnock City Council have lower confidence ratings and as such required review where overlaps existed. Cessnock City Council provided a review of their tenure in a first draft of the layer and their recommended changes were implemented in the final layer. However, this does not preclude any errors or artefacts that exist in the Department of Primary Industry's Crown land layer. The maintenance and quality control for the Crown land layer rests with the Department of Primary Industry and was beyond the scope of this study.

This layer was prepared in 2022 and is therefore representative of data available at the time. As new information becomes available, the layer will be reviewed, updated and redistributed. Refer to contributor acknowledgements in Appendix H.

Appendix G. Glossary of technical terms and acronyms

Outputs of this study are robust due to systematic design, multidisciplinary approach and collaboration with partners. Production of each layer required expert ecological skills and fieldwork, expertise in spatial analysis and industry-specific knowledge. Appendices use highly technical language to describe methodologies. These technical terms and acronyms are explained below.

Table 36 Glossary of terms and acronyms used in this report

Technical term or acronym	Definition
ADS40	High-resolution multispectral camera that is mounted on fixed-wing aircraft to capture NSW Government's aerial image acquisition program
AoI	Area of interest is a focus area on a map
ArcGIS	Geographical Information Systems software by ESRI
ArcScan	An extra functional module of ArcGIS designed to capture legacy hardcopy maps into digital spatial format
ASL	Above sea level
BFT	Biodiversity Forecasting Toolkit software developed to assist and inform planning decisions for biodiversity
Buffering	Spatial function in ArcGIS to expand or shrink the boundaries of polygons
Circuitscape	Open-source software to predict patterns of movement, gene flow and genetic differentiation among plant and animal populations in heterogeneous landscapes
Compressed ECW	Enhanced compression wavelet (ECW) is a form of image compression used for satellite and aerial imagery
DEM	Digital elevation model
DCCEEW	NSW Department of Climate Change, Energy, the Environment and Water
Eucdistance tool	ArcGIS raster tool used to calculate Euclidean distances from source objects
Edge effects	Unwanted effects resulting from spatial analyses that encounter boundary or data edges
ERDAS Imagine	Image analysis software
ESRI	US company from Redlands California that makes ArcGIS software

Technical term or acronym	Definition
FFP	Full floristic plots. These are systematic 20 × 20 m plots on the ground that record all species present within
Focalstats tool	ArcGIS raster tool that calculates a range of statistics for a user-defined area around an object
Geoscape	A comprehensive representation of our environment
GIS	Geographic information system
Graphab	Open-source software devoted to the modelling of ecological networks from the framework of graph theory
HDC	Hunter Development Corporation
IBRA	Interim Biogeographical Regions of Australia
IIPT	Integrated Infrastructure Planning Tool
Interpatch dispersal threshold and gap-crossing threshold	Physical distance limits associated with flora/fauna movement through patchy habitat and cleared land respectively
Jp2	Image compression format
LEP	Local environment plan
LiDAR	Light detection and ranging or laser imaging detection and ranging
Links4 (spatial links)	Spatial tool used for modelling connectivity networks
LZW	Lempel–Ziv–Welch (LZW) is an image compression format
Metadata	Data that describes other data
Nearmap	Nearmap Limited is an Australian aerial imagery technology and location data company that provides frequently updated, high-resolution imagery
Node points	Junctions or bends in a liner network
NumPy	Scientific analysis module available to Python programming software
PCT	Plant community types (PCT) are a way of describing the unique groups or suites of plant species that occur together
Python	Open-source programming language/software
Raster	Spatial data format that consists of grid cells or pixels such as any image
RegionGroup tool	ArcGIS raster tool that groups together spatially connected clumps of objects
RDP	Rapid data points
RGB	Red, green and blue, used to describe the 3 visible colour bands of images

Technical term or acronym	Definition
R-G-B-NIR	Red, green, blue and near infrared, used to describe the 3 visible colour bands and single near infrared band of images
SAII	Serious and irreversible impacts (*Biodiversity Conservation Act 2016*)
SPOT imagery	SPOT is a French satellite that records aerial imagery
Shrink-then-Expand tool/sequence	ArcGIS tool that shrinks then expands image objects iteratively to smooth object edges
TEC	Threatened ecological community (*Biodiversity Conservation Act 2016*)
TIF or TIFF	Image compression format
Vector	GIS data format that constructs objects as points, lines and polygons

Appendix H. Acknowledgements

The Hunter Central Coast Branch of Biodiversity and Conservation Division values the contribution of partners to this study. Primary partner Cessnock City Council has received the 6 datasets and is using outputs to inform planning decisions.

The Department of Climate Change, Energy, the Environment and Water (the department) provides support to local government to enable evidence-based planning decisions. Biodiversity and Conservation Division collaborated with Cessnock City Council to deliver evidence-based map layers that facilitate council's review of their local environment plan. All partners provided in-kind subject-matter experts and coordination, and acknowledge the contribution of staff and partners in Table 37 and Table 38.

Table 37 Contributors, position titles and agencies that contributed resources

Contributor	Position	Agency
Lucas Grenadier	Senior Team Leader, Hunter Central Coast, Biodiversity and Conservation Division	Department of Climate Change, Energy, the Environment and Water (DCCEEW)
Dr Mark Cameron	Conservation Assessment Data Officer, Hunter Central Coast, Biodiversity and Conservation Division	DCCEEW
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Elizabeth Magarey	Senior Scientist, Science Economics and Insights Division	DCCEEW
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Emma McDermott		Formerly Cessnock City Council now DCCEEW
Mark Manning		Cessnock City Council
Graham Wood		Formerly Cessnock City Council now Hunter Water Corporation
Keren Brown		Cessnock City Council
Daniela Gambotto		Cessnock City Council
Iain Rush		Cessnock City Council
Alison Chisolm		Cessnock City Council
Karinda Stone		Cessnock City Council
Robbie Economos		Lake Macquarie City Council
Lisa Redmond		Lake Macquarie City Council
Rochelle Lawson		Central Coast Council
Stephen Bell		Ecological Consultant
Mark Fisher		Ecological Consultant
Heidi Crook	Assistant Director Environment and Sustainability	NSW Department of Defence

Table 38 Contributors and elements of the study they contributed to

Contributor	Agency	Project initiation	Coordination	LEP enviro. zone review	NPWS on-park mapping supply	App 1 WNW metadata	App 2 Vegetation metadata	App 3 Corridors metadata	App 4 Environment metadata	App 5 Streambanks metadata	App 6 Tenure metadata	Final report
Lucas Grenadier	DCCEEW	✓	✓	✓	–	–	–	–	–	–	✓	✓
Dr Mark Cameron	DCCEEW	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓
Liz Crane	DCCEEW	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓
Joe Thompson	DCCEEW	–	✓	–	–	–	–	–	–	–	–	✓
Aaron Mulcahy	DCCEEW	–	–	–	–	✓	✓	–	–	✓	–	–
Andrew Steed	DCCEEW	✓	–	–	–	–	–	–	–	✓	–	–
Daniel Connolly	DCCEEW	–	–	–	–	–	✓	–	–	–	–	–
Elizabeth Magarey	DCCEEW	–	–	–	–	–	✓	–	–	–	–	–
Ashley Deveridge	DCCEEW	–	–	–	✓	–	–	–	–	–	–	–
Jamie Love	DCCEEW	–	–	–	–	–	–	✓	–	–	–	–
Michael Drielsma	DCCEEW	–	–	–	–	–	–	✓	✓	–	–	–
Paul Taylor	Cessnock City Council	–	–	–	–	✓	✓	–	–	✓	✓	–
Emma McDermott	Formerly Cessnock CC now DCCEEW	✓	✓	✓	–	–	–	–	–	–	–	–
Mark Manning	Cessnock City Council	–	✓	✓	–	–	–	–	–	–	–	–

Contributor	Agency	Project initiation	Coordination	LEP enviro. zone review	NPWS on-park mapping supply	App 1 WNW metadata	App 2 Vegetation metadata	App 3 Corridors metadata	App 4 Environment metadata	App 5 Streambanks metadata	App 6 Tenure metadata	Final report
Graham Wood	Formerly Cessnock CC now Hunter Water	–	–	✓	–	–	–	–	–	✓	✓	–
Keren Brown	Cessnock City Council	–	–	✓	–	–	–	–	–	–	–	–
Daniela Gambotto	Cessnock City Council	–	✓	✓	–	–	–	–	–	–	–	–
Iain Rush	Cessnock City Council	–	–	–	–	–	–	–	–	–	–	–
Alison Chisolm	Cessnock City Council	✓	✓	✓	–	–	–	–	–	–	–	–
Karinda Stone	Cessnock City Council	✓	–	–	–	–	–	–	–	–	–	–
Robbie Economos	Lake Macquarie City Council	✓	–	–	–	–	–	–	–	–	–	–
Lisa Redmond	Lake Macquarie City Council	✓	–	–	–	–	–	–	–	–	–	–
Rochelle Lawson	Central Coast Council	✓	–	–	–	–	–	–	–	–	–	–
Stephen Bell	Eastcoast Flora Survey	–	–	–	–	–	✓	–	–	–	–	–
Mark Fisher	3D Ecology Mapping	–	–	–	–	✓	✓	–	–	–	–	–
Heidi Crook	NSW Department of Defence	–	–	–	–	–	–	–	–	–	✓	–

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