



Hunter & Central Coast  
Regional Environmental  
Management Strategy

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# Landscape Connectivity Assessment: Hunter, Central and Lower North Coast Region of New South Wales





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Regional Environmental  
Management Strategy

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# 1. Introduction



## 1.1. Connectivity modelling background

Changes to the extent and patterns of vegetation from human landuse have resulted in fragmented habitat for native species. Restriction of species movement caused by increased fragmentation or decreased connectivity through the alteration of landcover reduces population viability, increasing extinction risk (Caughley 1994; Fischer & Lindenmayer 2006; Brook et al. 2008). Landscape planning to address changes to the patterns and types of land cover is critical for reducing the impact of fragmentation on connectivity.

A range of approaches to connectivity modelling can be used to characterise connectivity for the assessment of the impacts of fragmentation and to identify critical elements in a connectivity network for conservation and restoration. These approaches include least-cost path analysis, graph theory and Circuit theory, each of which model different aspects of connectivity (Urban & Keitt 2001; Adriaensen et al. 2003; McRae et al. 2008; Foltête et al. 2012). Least-cost path analysis characterise non-habitat/matrix based on dispersal costs which represent the energetic costs, difficulty, or mortality risk of moving across these areas (Adriaensen et al. 2003; Sawyer et al. 2011). Dispersal costs are determined by land cover characteristics, such as the degree of urbanisation or agricultural intensification. Using least-cost path analysis, links between patches of suitable habitat can be identified. The importance of patches and the arrangement of patches within a connectivity network can be quantified using the graph theoretic approach through the calculation of network measures (Minor & Urban 2008; Rayfield et al. 2011).

## 1.2. General approach – mapping woody vegetation

Our approach to modelling connectivity is based on a conceptual model describing fine-scale dispersal behaviour outlined by review conducted by Doerr et al. (2010). This review synthesised all available evidence on the relationship between structural connectivity and landscape-scale dispersal of Australian native fauna species. From the review three key important parameters were identified which can be used in spatially explicit models to characterise dispersal. This conceptual model is the basis for the General Approach to Planning Connectivity from Local-Scales to Regional (GAP CLoSR) connectivity modelling framework (Lechner & Lefroy 2014; Lechner et al. 2015b) (Figure 1):

1. A minimum patch size below which the patch cannot support a population.
2. A gap-crossing distance threshold, between connectivity elements such as scattered trees, which limit the distances of open ground (gaps) which individuals will move across.
3. An interpatch-crossing distance threshold above which fauna can't move between patches.

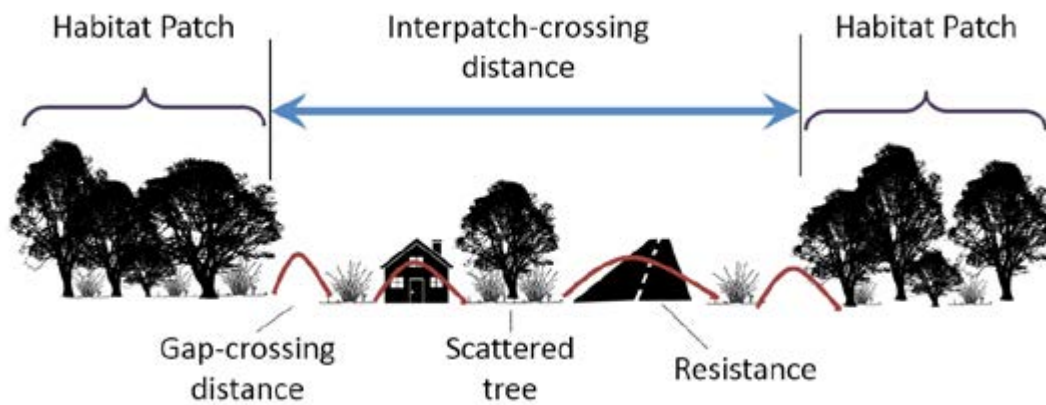


Figure 1. Conceptual model of fine connectivity behaviour where the likelihood of individuals moving between two patches is a property of two thresholds – the Interpatch-crossing distance and gap-crossing distance and the dispersal cost of landcover features (such as roads).

A critical component of the GAP CLoSR framework is the inclusion of fine-scale dispersal behaviour that is often absent from many common connectivity modelling approaches. In order for species to move long distances between patches there is a need for structural connectivity elements such as corridors, or stepping stones to facilitate movement (Fischer & Lindenmayer 2002; Van Der Ree et al. 2004).

### 1.3. Objectives

The objective of this study was to build on the existing Lower Hunter analysis of connectivity (Lechner & Lefroy 2014) using GAP CLoSR, expanding the analysis to the Hunter Central & Lower North Coast. At the regional scale GAP CLoSR uses the Graphab graph theoretic connectivity model (Foltête et al. 2012) to characterise connectivity. The focus of this study was to provide a strategic broad-scale overview of connectivity to guide regional planning. We modelled connectivity using a generalised native woody vegetation versus non-vegetation approach. This approach assumes that our model characterises habitat and connectivity for the majority of the native fauna species that utilise woody native vegetation; and the plant species that depend on these fauna for dispersal. We characterise patch isolation and connectivity characteristics using graph-metrics across the region and conclude by discussing these results in terms of conservation planning.

## 2. Methods



### 2.1. Study area

The Hunter Central & Lower North Coast Region occurs in New South Wales, Australia, approximately 100 km north of Sydney. It covers a total area of approximately 34,851 km<sup>2</sup>, approximately the size of the land mass of Netherlands. The Hunter Central & Lower North Coast has a range of environments including highly urbanised areas, farmlands, mountain ranges and coastal and estuarine environments. This region is expected to see a high level of population growth resulting in increasing pressure on the environment and is also a future growth area for the expansion of coal mining (NSW Department of Planning 2006).



Figure 2. True colour remote sensed imagery with study boundary.

## 2.2. GAP CLoSR

In this report we use the GAP CLoSR framework (Lechner & Lefroy 2014) to map regional scale connectivity to support landuse planning. The framework includes:

- a) a workflow that includes the identification of key ecological connectivity parameters and describes how to pre-process spatial data accordingly (see Figure 3 next page);
- b) GIS tools for pre-processing spatial data based on these parameters; and
- c) a method for running these spatial data within existing connectivity modelling software and how to interpret the outputs for conservation planning.

The regional scale model uses Graphab (Foltête et al. 2012), a graph-network connectivity model with least-cost paths. The model is parameterised in a way which accounts for threshold dynamics in dispersal behaviour. In cases where distances between patches are less than the interpatch-crossing distance threshold and accounting for dispersal costs connectivity will be characterised by a single optimal least cost path patches. Details of the modelling method can be found in Lechner and Lefroy (2014) and Lechner et al. (2015b). GAP CLoSR also includes local-scale analysis using Circuitscape (McRae et al. 2008) to describe a total surface of connectivity. However, this type of analysis is suited to responding to specific planning questions such as assessing the impact of a property development on connectivity within a property and on the surrounding landscape. In this report we do not include Circuitscape outputs, however, we recognise that it is an important part of the GAP CLoSR method.

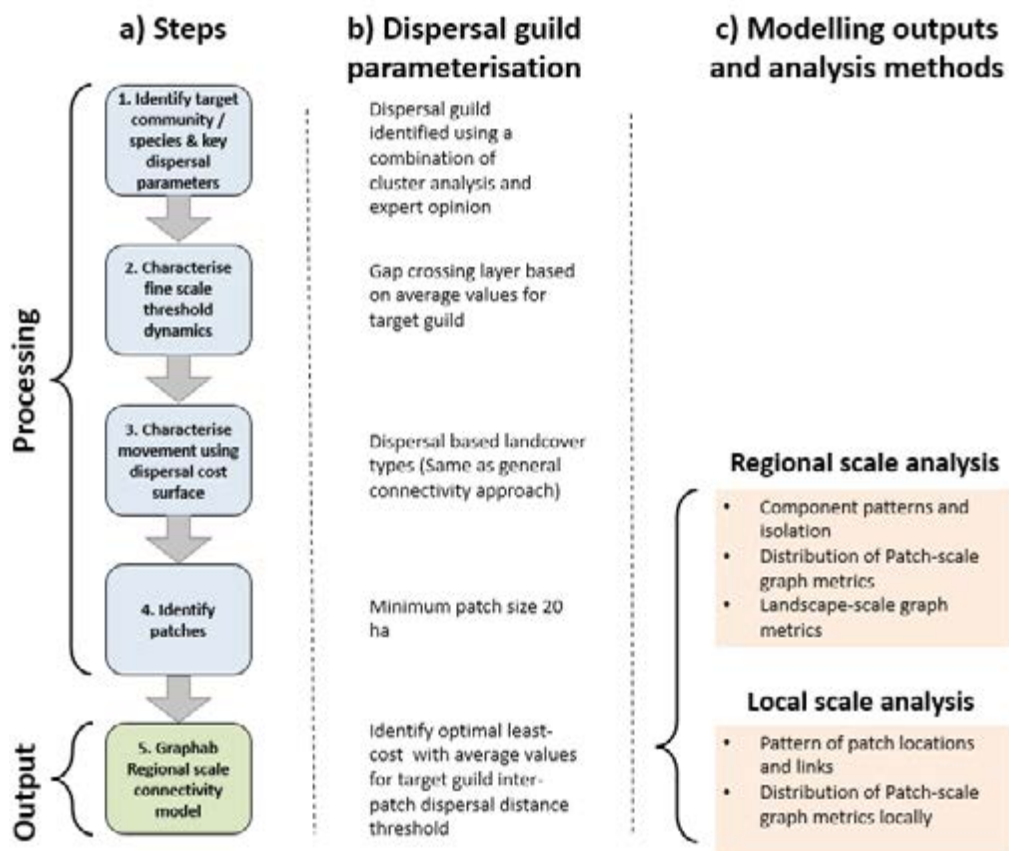


Figure 3. Flow diagram describing the steps used in parameterising the general connectivity model (adapted from Lechner et al.).



## 2.3. Focal conservation target and parameterisation

For this report we mapped connectivity using a general connectivity modelling approach where connectivity was characterised between patches of remnant woody vegetation. These patches are likely to be suitable for the majority of faunal native species in the region, and plant species that depend on these fauna for dispersal. Limitations of using these data are described in Lechner and Lefroy (2014).

The connectivity model was parameterised using dispersal values identified in Doerr et al.'s (2010) (Table 1) systematic review of how structural connectivity facilitates dispersal. This review of 80 studies (from 98 sources) derived average values for the gap-crossing distance and interpatch-crossing distance threshold. Of the studies reviewed, 41 provided data on mammals, 32 provided data on birds, 8 provided data on reptiles, and 5 provided data on plants and invertebrates respectively. These values were relevant to our case study region as the majority of the studies reviewed were in similar woodland and forested ecosystems impacted by fragmentation primarily from agriculture.

Table 1. Parameters used to describe dispersal based on Doerr et al. (2010). Values with \* are cited in Doerr et al (2010) but not the result of the systematic review.

	DOERR ET AL. (2010)
Habitat patch size	10–20 ha* (10 ha used)
Interpatch-crossing distance threshold	1.1 km
Gap-crossing distance threshold	106 m

## 2.4. Dispersal-cost surface

The dispersal-cost surface characterises how landcover between habitat patches reduce or prevent movement up to the interpatch-crossing distance threshold. The dispersal-cost surface is a property of a gap-crossing layer and landcover resistance surface.

### 2.4.1. GAP CROSSING LAYER

The gap-crossing distance threshold distance layer was simulated through the creation of a spatial binary gap-crossing layer. This layer identifies distances between structural connectivity elements and patches beyond the gap-crossing distance threshold of 106 m. These areas beyond the threshold are treated as barriers to movement.

To create this layer the input vegetation layer is buffered by half of the gap-crossing distance threshold (Figure 4). If vegetation is located within the gap-crossing distance threshold, the buffers will touch or overlap, meaning there will be no break in the gap-crossing layer pixels between two pixels of vegetation and thus connectivity will be possible. Areas mapped outside the buffer area describe areas in which dispersal cannot take place.

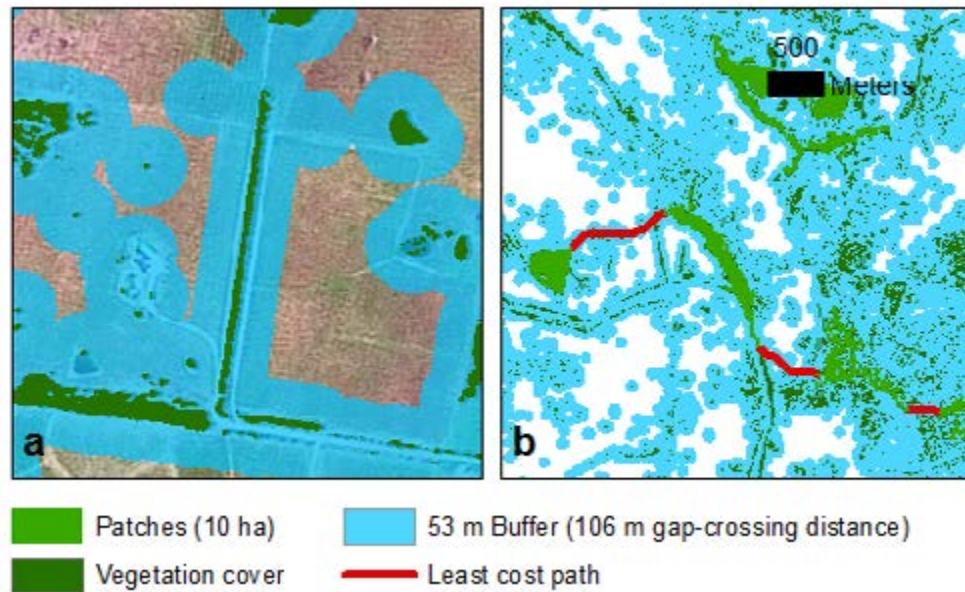


Figure 4. Example of the gap crossing layer (adapted from Lechner et al. in press). Vegetation is buffered by half the gap-crossing distance threshold. a) 53 m buffer around vegetation to simulate 106 m gap-crossing distance. b) gap-crossing layer with example of how least-costs paths are modelled using the layer.

#### 2.4.2. LANDCOVER RESISTANCE SURFACE

Resistance to dispersal between patches is a property of how landcover decreases interpatch-crossing distances as a property of the pixel size. For example, if high resistance land cover doubled movement cost, the interpatch-crossing distance threshold would be reduced from 1.1 km to 550m. In the Hunter we used generic landcover classes to describe resistance (see Lechner & Lefroy 2014 for more details): Hydrology, Transport, Infrastructure and Other. Where Other refers to areas that are predominantly farmland and represent areas where movement up to the 1.1 km threshold is possible (Table 2, Figure 5).

#### 2.4.3. CALCULATING DISPERSAL RESISTANCE SURFACE

In the final step the dispersal cost surface was created by combining the binary gap-crossing layer with the resistance surface based on land cover. These pixels were aggregated to 50 m from the original higher resolution 2.5 m pixels in order to reduce computational demands on the connectivity model.

The dispersal cost pixel values are a function of:

- a) pixel size (if the pixel size is 25 m and there is no resistance the cost should be 25 m)
- b) land cover resistance (200% resistance means a pixel size with of 30 m will have a value of 60 m)
- c) the presence of structural connectivity elements identified with the gap-crossing layer

Below is a summary of the processing ruleset to derive the dispersal cost values for an aggregated pixel:

- a) Structural connectivity elements at the gap-crossing distance takes precedence over all other land cover classes, because dispersal cannot occur in the absence of structural connectivity. Pixels that have structural connectivity at the gap crossing distances were given a value of 1

Table 2. Land cover resistance and dispersal cost in metres for four different land cover classes in areas that have connectivity elements present or absent.

	LAND USE	DEFAULT RESISTANCE CASE	50 m PIXEL VALUE	DESCRIPTION
Structural connectivity elements absent	All	Infinite	$\infty$	Areas without gap crossing features at the gap crossing threshold
Structural connectivity elements present	Other	100%	50	Other land use – predominantly agricultural or grazing areas.
	Hydrology	300%	150	Water bodies such as rivers and lakes
	Transport	200%	100	Roads and train lines
	Infrastructure	200%	100	Urban and industrial areas

and the other pixels were given a value of 0. Thus, pixels with a value of 0 represent areas where dispersal cannot take place. The value of the aggregated pixel was based on the majority of the fine-scale pixel values. This differs from the previous Lower Hunter analysis (Lechner & Lefroy 2014) where if any fine-scale (2.5 m for example) pixels had a value of 0 (no connectivity) the aggregated pixel value was also 0 – a more cautious approach to modelling connectivity.

- b) The dispersal cost for a single aggregated pixel is calculated as an average of all land covers except if there are no barriers identified by the gap-crossing layer (as described in the above steps).

The resulting dispersal resistance surface is a layer that recognises threshold dynamics by ensuring there is no dispersal where gaps are too large between connectivity elements, but still models cumulative costs where dispersal is considered possible but may be impeded by land use.

## 2.5. Regional connectivity model using Graphab

The graph theoretic approach with the Graphab software (Foltête et al. 2012) was used to represent the landscape as a network of habitat patches greater than 10 ha connected by least-cost paths (Minor & Urban 2007; Dale & Fortin 2010; Etherington & Penelope Holland 2013). Patches that are connected to each other but isolated from other patches are known as components. Whether a patch is connected to another patch is a function of:

- Distances between patches
- Interpatch-crossing distance threshold
- The resistance of the landcover
- Presence of structural connectivity at the gap-crossing distance threshold

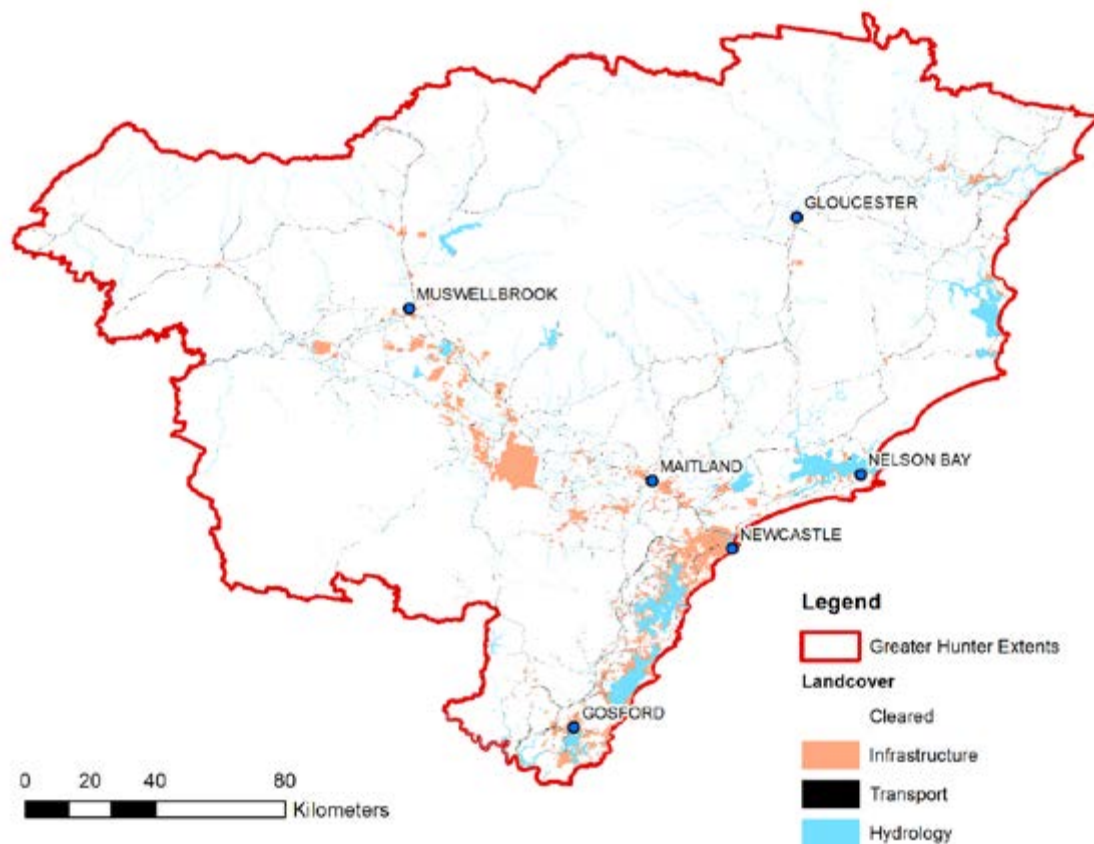


Figure 5. Land cover map of resistance categories.

The two inputs into the Graphab software were the habitat layer (patches >10 ha) and the dispersal cost surface with pixel size of 50 m. We found that 50 m was the finest pixel size that could be processed by the Graphab connectivity software in the Midlands.

A range of methods can be used to interpret the outputs of the connectivity model (Figure 6). These methods include visual assessments based on the patterns of connections and components and quantitative methods using graph metrics (Urban et al. 2009; Rayfield et al. 2011) (see Lechner & Lefroy 2014 for more detail). Patch-scale graph metrics are calculated for each patch to describe the role of a patch in the provision of connectivity for a whole network. We also calculated simple landscape-scale graph metrics describing the characteristics of components such as mean component size. Both landscape- and patch-scale graph metrics are described in Table 3.

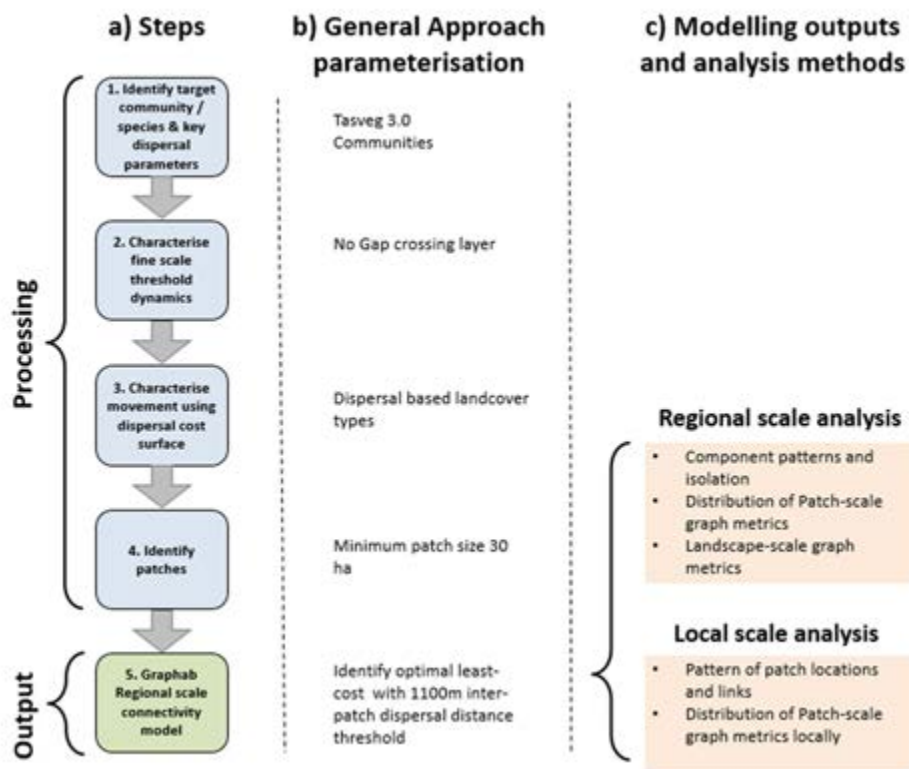


Figure 6. Regional and local-scale analysis using the graph theoretic approach available with the Graphab software.

Table 3. Landscape (network) and patch-scale graph metrics used in the study with their ecological significance and definition and source. Delta graph metrics are calculated as using a removal method which calculates the relative importance of each patch as the rate of variation in the global metric resulting from their removal. These delta -metrics describe values for a patch with reference to the landscape scale (adapted from Rayfield et al. 2011; Foltête et al. 2012; Lechner & Lefroy 2014).

GRAPH METRIC	ECOLOGICAL SIGNIFICANCE AND DEFINITION	REFERENCE
<b>LANDSCAPE-SCALE GRAPH METRICS</b>		
Mean size of components (km <sup>2</sup> )	Simple measure that describes the average component area. Useful for describing the level of isolation between groups of landscape patches.	(Urban & Keitt 2001)
Size of largest component (km <sup>2</sup> )	A simple measure that describes the area of the largest component. Useful for describing the level of isolation between groups of landscape patches.	(Urban & Keitt 2001)
Number of components	Simple measure that describes the number of isolated areas in the landscape. High number of components to total number of patches indicate that the landscape is highly fragmented. Useful for describing the level of isolation between groups of landscape patches.	(Urban & Keitt 2001)
<b>PATCH-SCALE GRAPH METRICS</b>		
Betweenness centrality (BC)	Number (or proportion) of pairwise geodesic pathways in a network that use the patch. A useful indicator of which patches are stepping stones for dispersal.	(Bodin & Norberg 2007; Minor & Urban 2008)

GRAPH METRIC	ECOLOGICAL SIGNIFICANCE AND DEFINITION	REFERENCE
Node flux (Flux)	Sum of the fluxes for all incoming links adjacent to a pathc. Where the dispersal flux of a link is calculated as the area of patches adjacent to the link multiplied by the probability of dispersal between patches. Describes the rate of movement between a patch and its neighbours.	(Urban & Keitt 2001; Minor & Urban 2007)
Clustering coefficient (ClusCoe)	Measures the level of redundancy within a network. High values indicate that alternative paths exist and pathways through the focal patch is not unique. Average proportion of a focal patches neighbouring patches that are also neighbouring patches with each other.	(Ricotta et al. 2000; Minor & Urban 2008)
Closeness centrality (ClosCen)	Mean geodesic distance of a patch to all reachable patches. Describes whether a patch occupies a central position in the habitat network due to their proximity to other habitat patches.	(Urban et al. 2009)
Connectivity correlation (ConCorr)	Indicates the degree of compartmentalisation or presence of sub-networks. Important for reducing the spread of cascading disturbances such as fires or invasive species. Average degree of focal patch relative to the average degree of its neighbours.	(Minor & Urban 2008)
Node degree (NodeDeg)	Characterises connectedness of a focal patch and its potential accessibility. For example, a node degree of zero indicates that the patch is a dead end in a pathway. A simple metric describing the number of links associated with a focal patch.	(Ricotta et al. 2000)
Eccentricity (Eccen)	Largest geodesic distance between the patch and all other patches. Describes maximum isolation.	(Bunn et al. 2000; Urban & Keitt 2001)
Delta Integral index of connectivity (IIC)	The dIIC refers to the probability that two dispersers randomly located in the landscape within a patch can access each other. Higher value indicate greater connectivity.	(Pascual-Hortal & Saura 2006)
Delta Graph diameter (GraphDia)	Diameter of largest component. Describes the compactness of a habitat network.	(Saura & Pascual-Hortal 2007; Minor & Urban 2008)
Delta Harary index (Harary)	The number of patches that contribute to linking patches across the landscape. High value indicate a highly connected landscape.	(Ricotta et al. 2000)

## 3. Results

### 3.1. Visual assessment of connectivity across the Hunter Central & Lower North Coast

Woody vegetation in the Hunter Central & Lower North Coast is predominantly found within two large components in the east and the west of the region (Figure 7). These components are made up of large contiguous patches. The component to the east includes 1527 patches and had a total area of 8599 km<sup>2</sup>, comprising approximately ~53% of the total area of vegetation in the Hunter Central & Lower North Coast. The component to the west includes 545 patches and had a total area of 6977 km<sup>2</sup>, comprising approximately ~43% of the total area of vegetation in the region. The remaining components comprise ~4% of the total area and found within small components in the central region in the low lying valley floor from Muswellbrook to Maitland and finally Newcastle. This area is highly fragmented made up of small components comprising a small number of patches. If we expand our view to outside of the study area (Figure 8), the fragmented central region of Hunter represents a barrier in the Great Eastern Ranges corridor initiative that runs north to south along the Great Divide.

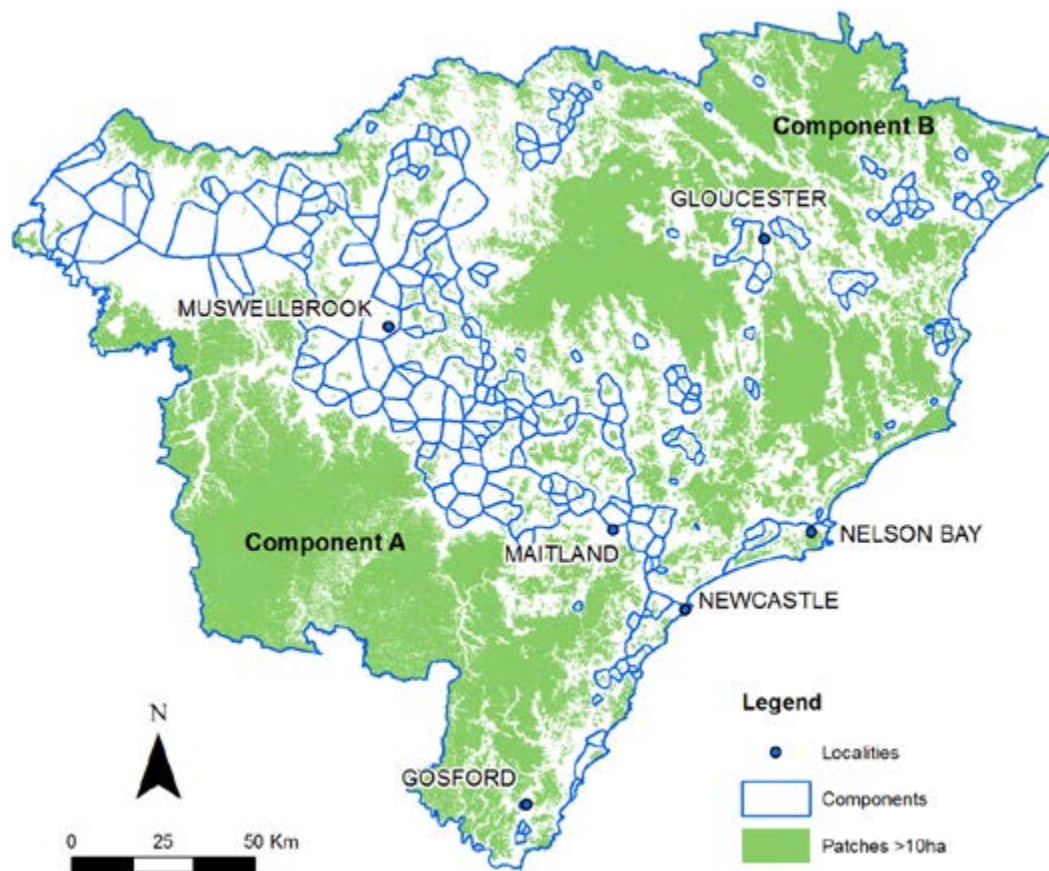
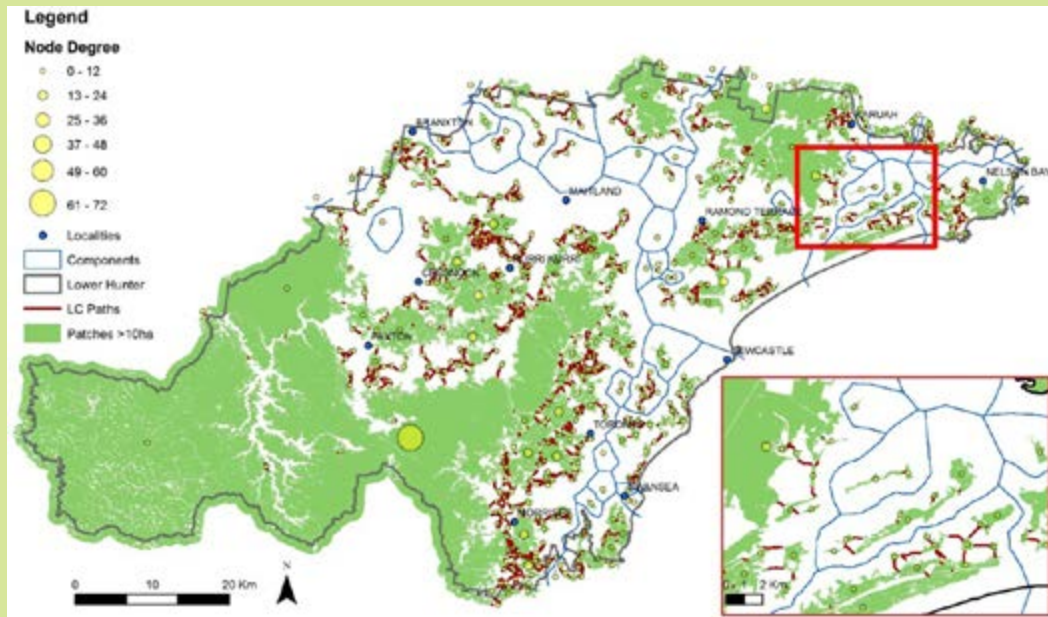


Figure 7. Assessment of regional connectivity where barriers to connectivity are visualised through the identification of component boundaries. Components represent patches that are linked to each other but isolated from other patches in different components.

### 3.1.1. INTERPRETING BLUE COMPONENT LINES



The blue lines are used to identify which patch are part of the same component. The location of the lines are for visualisation purposes only. The lines are found at the midpoint between patches from different components.

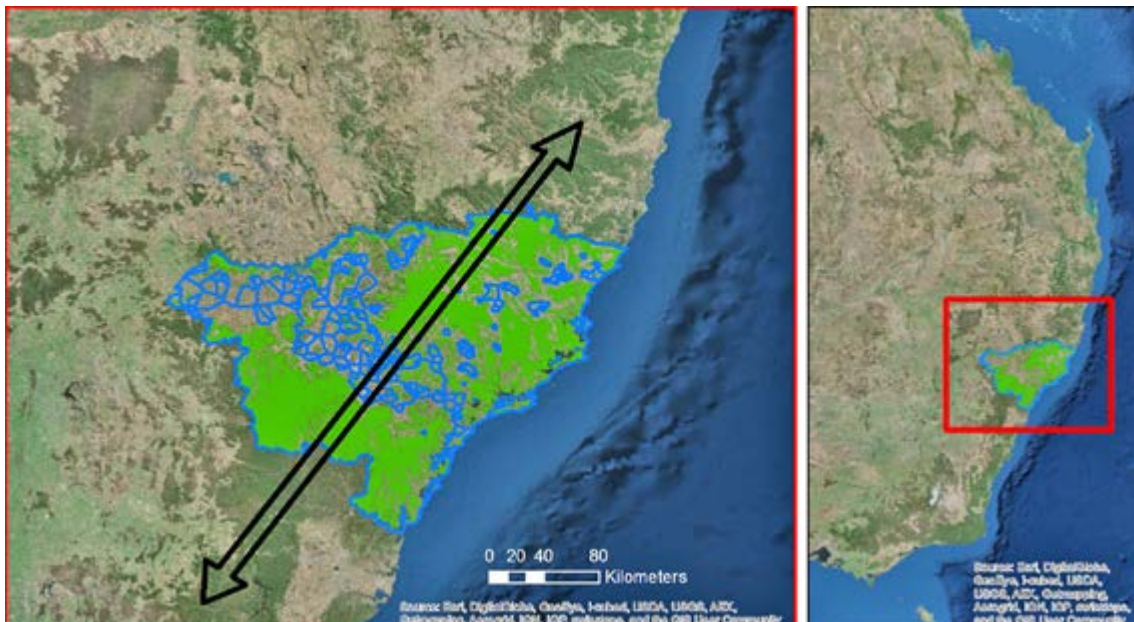


Figure 8. State-wide context for connectivity. The Hunter Central & Lower North Coast region is a key barrier for connectivity within the Great Eastern Ranges national wildlife corridor scheme the runs north to south along the Great Divide.



The graph of the cumulative distribution of patch area shows that the 4 largest patches include 50% of the total area, and the top 24 patches comprise 80% of the total area (Figure 9). Within the Hunter Central and Lower North Coast region the model identified 250 components and 2876 patches.

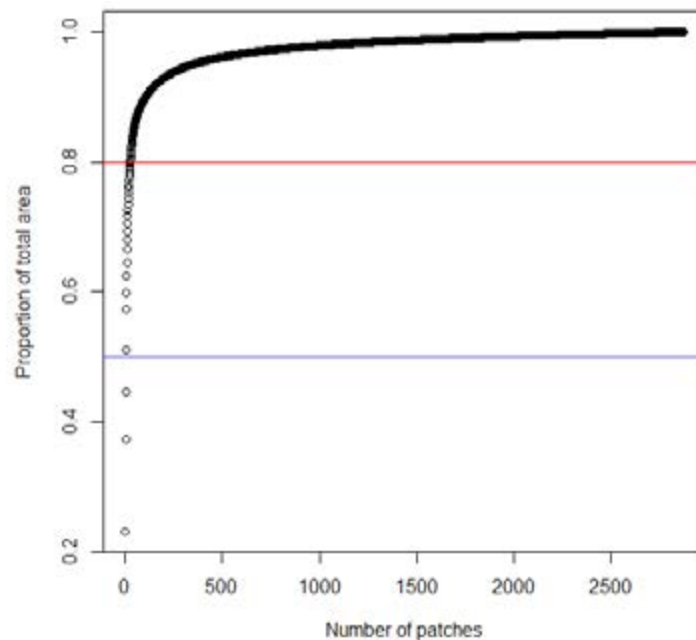


Figure 9. Plot of the proportion of total number of patches plotted against the cumulative patch area.

### 3.2. Patch-scale graph metric analysis

We produced a number of maps of the describing the distribution of graph metrics values for each patch (Figure 10 – Figure 14). For each patch-metric importance for dispersal is characterised with larger symbols representing the higher values of the patch for dispersal. These patch values are useful for interpreting spatial priorities. For visualisation purposes the patch values were categorised with graduated symbols. In some cases the categories were based on quantiles-normalising values. Quantisation was conducted as some patch-metrics had clumped distributions with lots of high or low values but nothing in between. Where the patch-metric values were distributed evenly the categories were based on equal intervals. If possible accessing the original spatial data and reclassifying according to a specific planning problem is better solution than only using the regional scale maps.

The first graph metric mapped (Figure 10), the delta Integral Index of Connectivity (dIIC), is a good overall measure and represents the reachability of habitat across the landscape as a property of the connection between patches and the area of habitat provided by each patch. Formally it can be defined as the probability that two points randomly placed within a landscape fall into habitat areas that can be reached (Pascual-Hortal & Saura 2006). dIIC is suited to the GAP CLoSR parameterisation as it is based on a binary dispersal model where patches are either connected or not due to the interpatch dispersal distance threshold. Values for this metric increase with greater connectivity from 0 to 1. The larger patches in the Hunter Central & Lower North Coast dominate the dIIC values as they connect many patches in the landscape and also hold the largest area.

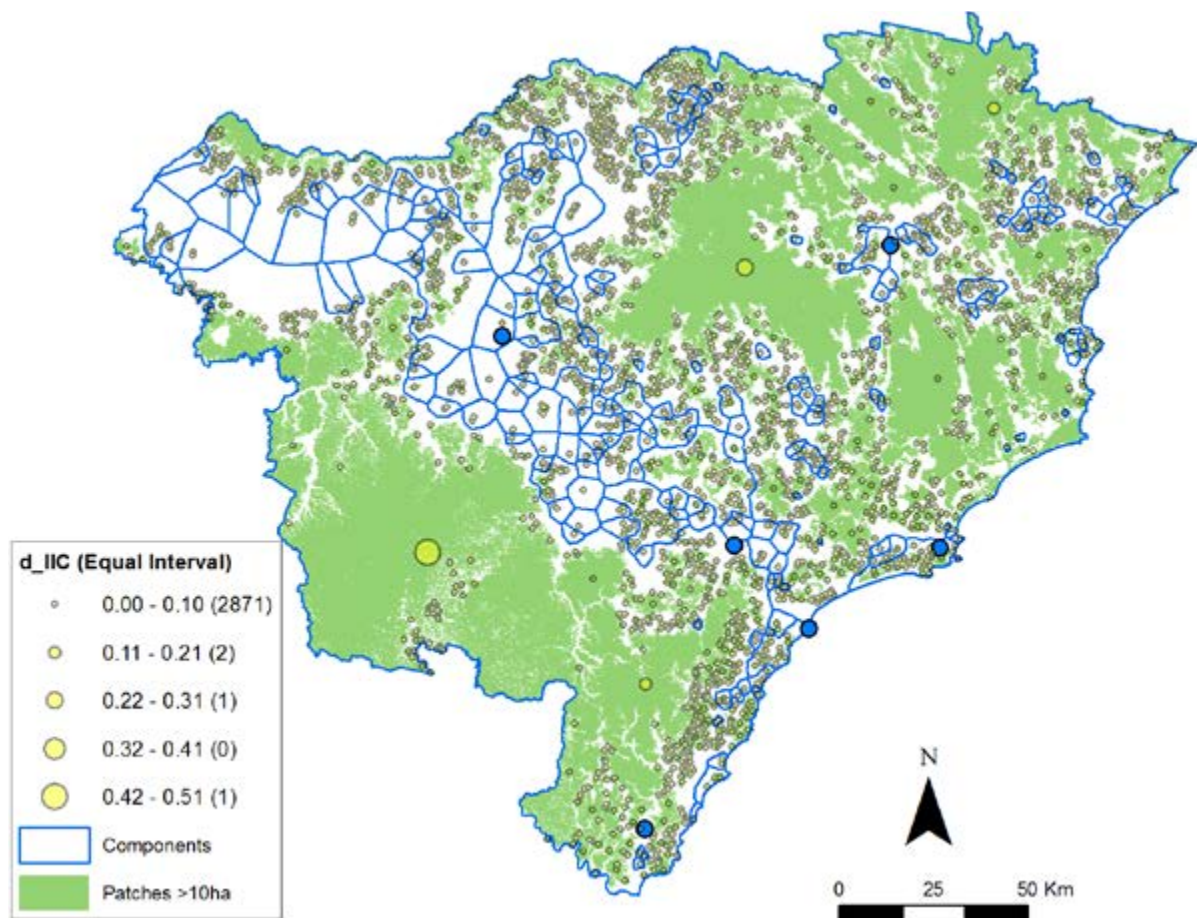


Figure 10. Regional-scale connectivity analyses based on least-cost paths for patches greater than 10 ha using Graphab. Circular graduated symbols located at the centre of patches describe the dIIC, a measure of the probability that two dispersers randomly located in the landscape within a patch can access each other.

We calculated 12 patch-scale graph-metrics (including dIIC) to describe the range of responses of the graph metrics to functional connectivity in the region. While each graph-metric is calculated based on unique equations describing the topological relationship between patches and their properties the responses of these metrics to landscape pattern were correlated (similar). A simple method for providing a broad assessment of all of the graph-metric responses is through a principle components analysis (PCA) (Figure 11). The PCA analysis found three groups of correlated graph metrics. The first group includes only the clustering coefficient, the second group includes closeness centrality, flux and eccentricity and the final group included all the rest of the graph-metrics including area.

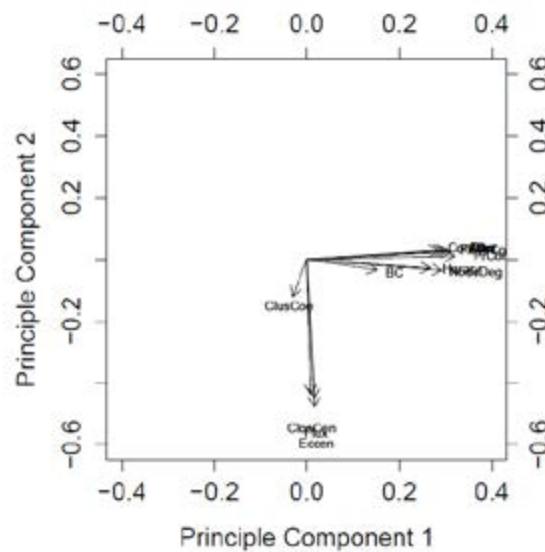


Figure 11. Ordination plot from a principal components analysis (PCA) of the 12 graph metrics and area in the plane of Principle Component 1 and Principle Component 2. Where principle components 1 and 2 describe 80% of the total variation.

We produced a number of maps describing the distribution of graph metrics values for group 1 and 2 graph metrics: clustering coefficient, closeness centrality, flux and eccentricity (Figure 12 – Figure 15). Group 3 graph-metrics had similar patterns to area and the dIIC (Figure 12). The clustering coefficient tended to rank small patches highly, which connect many patches. These high ranking patches were commonly found in highly fragmented areas. The clustering co-efficient identifies patch redundancy only on the connections to neighbouring patches (not the whole network). Thus, its characteristics are quite unique as most graph-metrics are calculated as a property of the whole network. The group 2 graph-metrics (Figure 13 – Figure 15) showed a range of responses, but, in most cases patches within the eastern component appeared to on average have higher values. The eastern component has more connections and more patches and thus graph-metric values for these patches were higher.

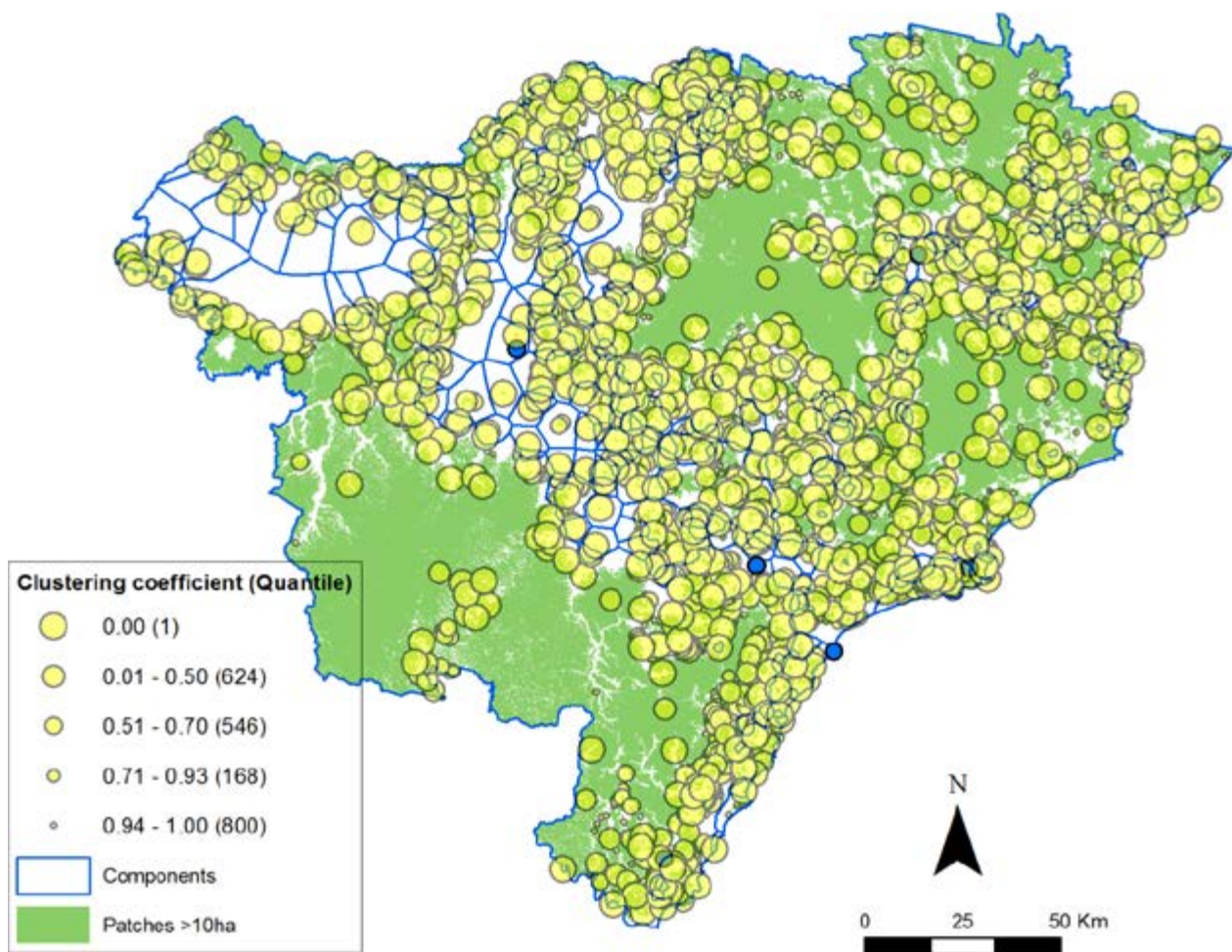


Figure 12. Regional-scale connectivity analyses based on least-cost paths for patches greater than 10 ha using Graphab. Circular graduated symbols located at the centre of patches describe the Clustering Co-efficient, which is a measure of patch redundancy in a connectivity network.

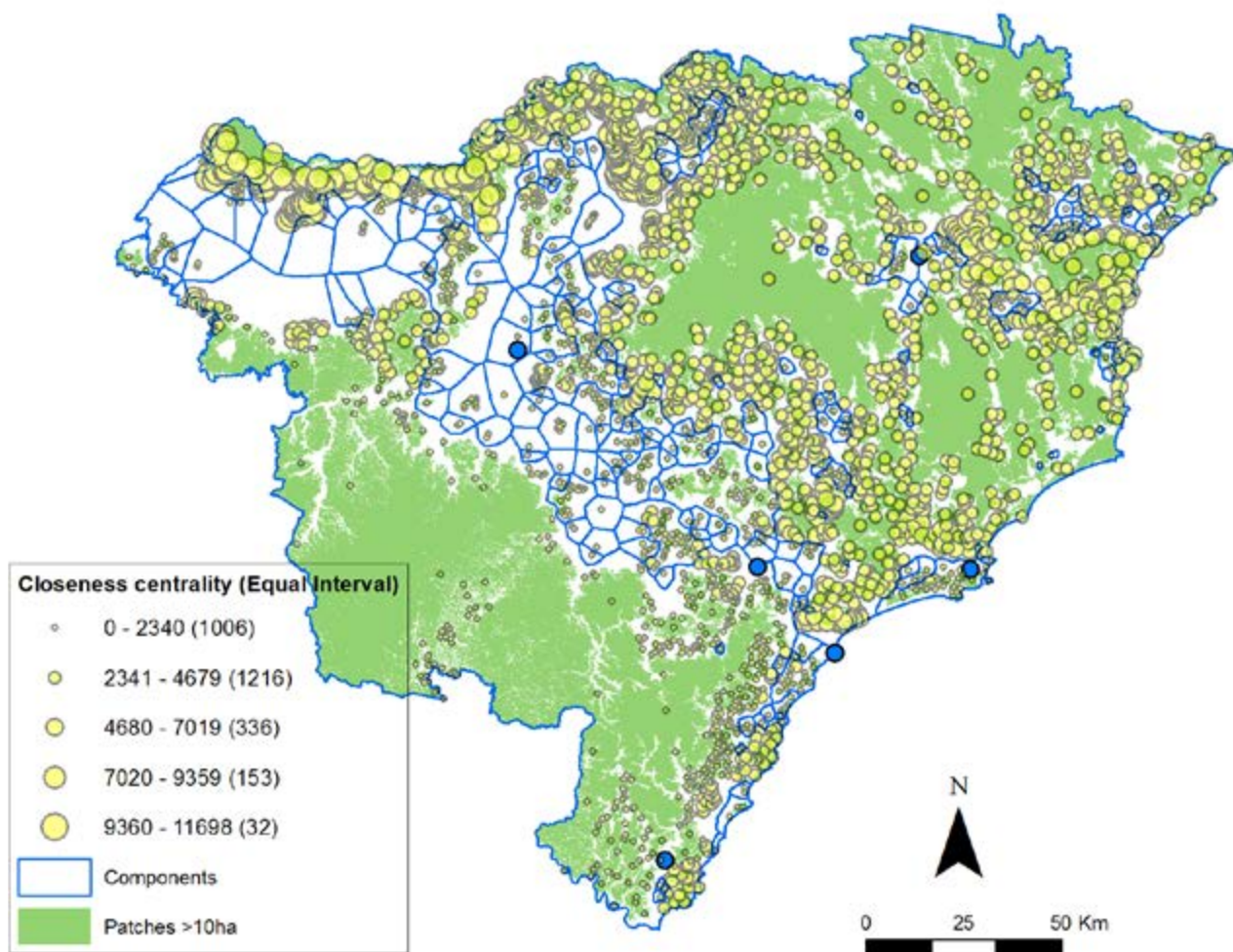


Figure 13. Regional-scale connectivity analyses based on least-cost paths for patches greater than 10 ha using Graphab. Circular graduated symbols located at the centre of patches describe the Closeness centrality, which describes whether a patch occupies a central position in the habitat network.

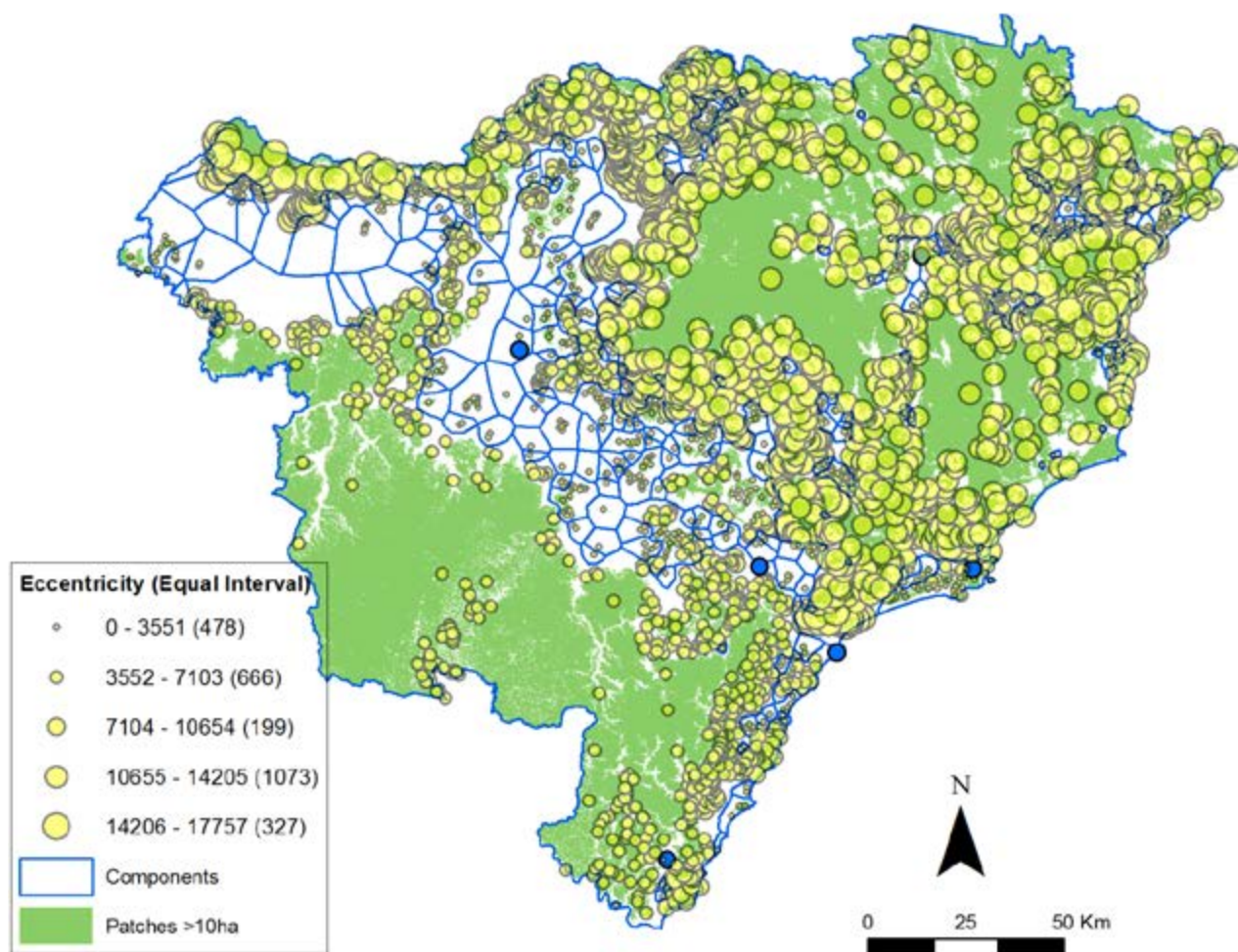


Figure 14. Regional-scale connectivity analyses based on least-cost paths for patches greater than 10 ha using Graphab. Circular graduated symbols located at the centre of patches describe the Eccentricity, which is a measure patch isolation.

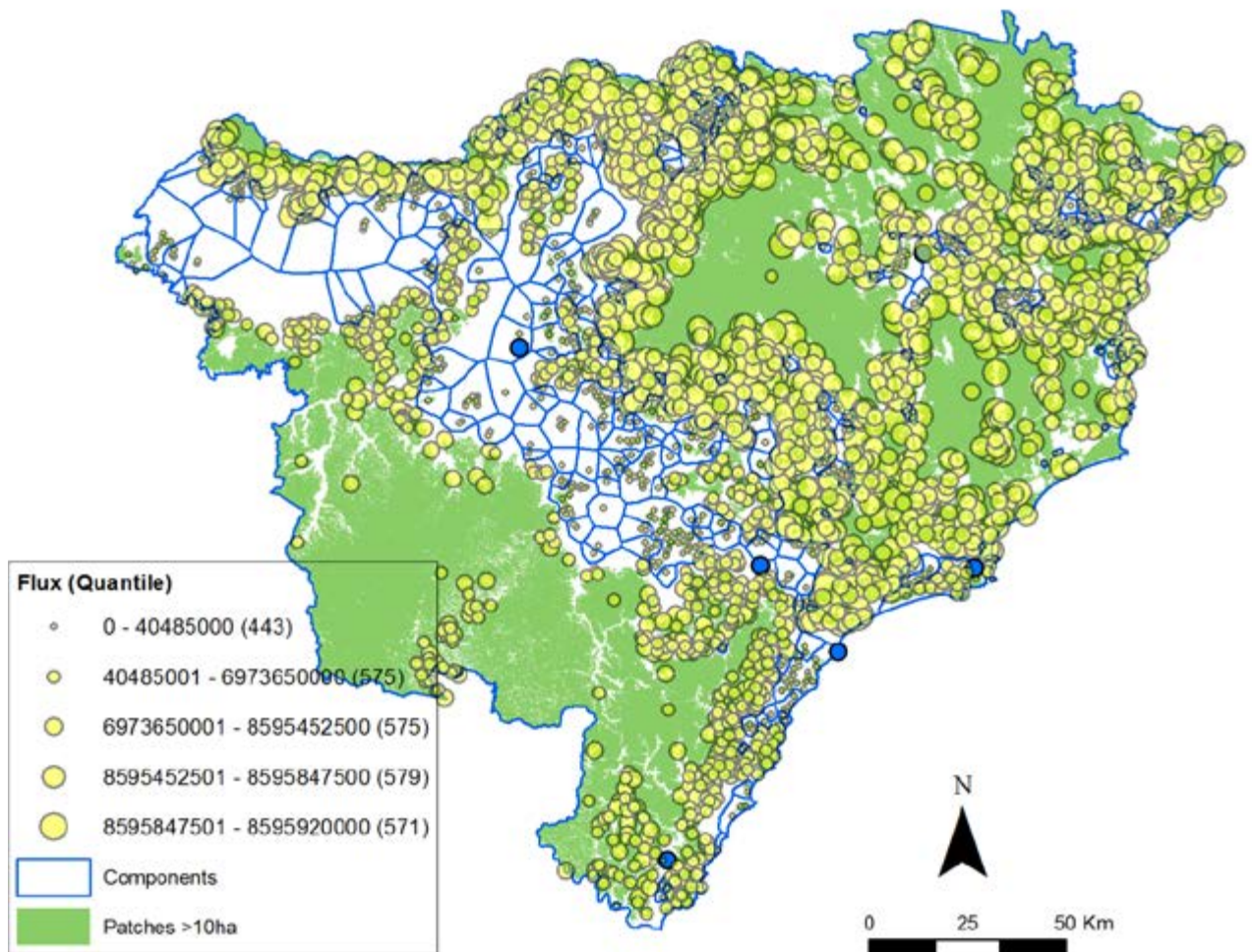


Figure 15. Regional-scale connectivity analyses based on least-cost paths for patches greater than 10 ha using Graphab. Circular graduated symbols located at the centre of patches describe the Flux, which is a measure of area weighted rate of movement.

### 3.2.1. SENSITIVITY ANALYSIS

A simple sensitivity analysis of the results was conducted looking at the impact of interpatch dispersal distance on landscape level graph-metrics dIIC and Flux. The sensitivity analysis shows that changing interpatch dispersal distance will affect the connectivity outputs measured (Figure 16). However, the relationship between interpatch dispersal distance and graph-metric values showed a relatively consistent linear positive trend without any major thresholds in interpatch dispersal distance observed. Further sensitivity analysis can be found in Lechner et al. (2015) and Lechner and Lefroy (2014).

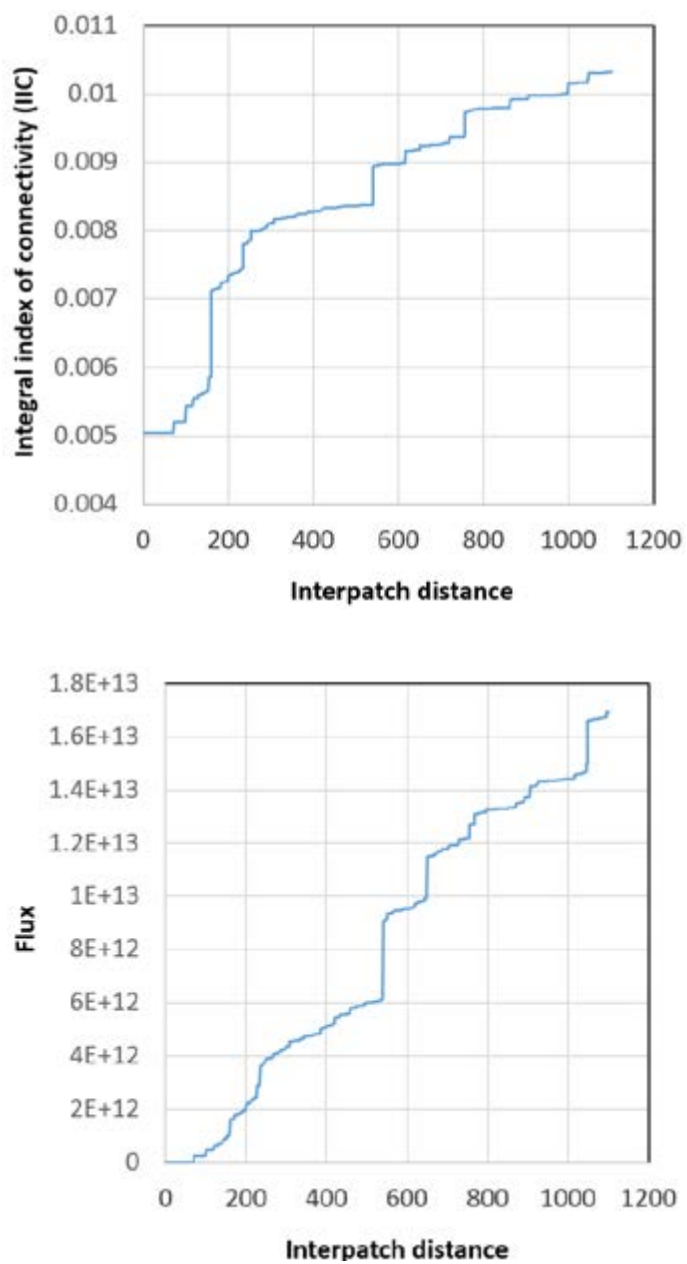


Figure 16. Sensitivity analysis for (left) dIIC and (right) flux versus the interpatch-crossing distance. For this analysis the gap-crossing distance was ignored.



## 4. Discussion



### 4.1. Overview

The analysis found that the remaining woody vegetation in the Hunter Central & Lower North Coast is mostly contiguous, found in large patches and/or functionally connected with 96% of the woody vegetation found within two large components in the east and west. At the regional-scale and greater the lack of connectivity between these two components is the largest issue. When looking only at the local scale only the contiguous large patches stood out as being important for connectivity. Due to the distribution of patch sizes, with a large proportion of vegetation (~80% of the woody vegetation patches found within the 24 largest patches) these patches tended to have high patch-scale graph-metric values as would be expected. While smaller patches had lower patch-scale graph metric values as they were not as critical for connecting large areas of vegetation. Identifying small individual patches that are critical for connectivity is more logical on a case by case basis in response to a regional plan for development (for example, Lechner et al. 2015a).

The greatest issues associated with connectivity of woody vegetation identified was the disconnect between the east and west, and the importance of the Hunter Central & Lower North Coast region for connecting vegetation in the neighbouring regions. The ecological impact of this disconnect is outside the scope of this study, however, the importance of the north–south connection is highlighted in the Greater Eastern Ranges wildlife corridor plan.

Fragmentation and isolation is likely to also be problematic for species and communities that depend only on the small fragmented patches found within the central region of the Hunter Central & Lower North Coast region. Further local-scale analysis or single species/community analysis is required to identify these specific impacts.

Future work in the region needs to look at the impact of spatial uncertainty on the connectivity modelling outcomes from classification error in the remote sensing data, choice of spatial unit and ecological parameters (Lechner et al. 2009; Arponen et al. 2012; Lechner et al. 2012; Rudnick et al. 2012). Furthermore, it is important that the results of the connectivity modelling are understood in context within individual species habitat requirements that are represented by the modelling. Connectivity is only one of many ecological processes that ensures the persistence of species.

### 4.2. Conclusions

The assessment of connectivity of woody vegetation in the Hunter Central & Lower North Coast show that the region is divided into two large components by a fragmented central area. Future restoration should focus on connecting these two regions and aim to reduce impacts within these areas. Modelling of development and restoration scenarios with respect to regional development plans would aid in the assessment of assessing conservation and restoration priorities.

## 5. References



- Adriaensen F, Chardon JP, De Blust G, et al (2003) *The application of 'least-cost' modelling as a functional landscape model*. *Landsc Urban Plan* 64:233–247.
- Arponen A, Lehtomäki J, Leppänen J, et al (2012) *Effects of Connectivity and Spatial Resolution of Analyses on Conservation Prioritization across Large Extents*. *Conserv Biol* 26:294–304.
- Bodin Ö & Norberg J (2007) *A network approach for analyzing spatially structured populations in fragmented landscape*. *Landsc Ecol* 22:31–44.
- Brook BW, Sodhi NS, & Bradshaw CJA (2008) *Synergies among extinction drivers under global change*. *Trends Ecol Evol* 23:453–460.
- Bunn AG, Urban DL, & Keitt TH (2000) *Landscape connectivity: A conservation application of graph theory*. *J Environ Manage* 59:265–278.
- Caughley G (1994) *Directions in conservation biology*. *J Anim Ecol* 63:215–244.
- Dale MRT & Fortin M-J (2010) *From Graphs to Spatial Graphs*. *Annu Rev Ecol Evol Syst* 41:21–38. doi:10.1146/annurev-ecolsys-102209-144718
- Doerr VAJ, Doerr ED, & Davies MJ (2010) *Does structural connectivity facilitate dispersal of native species in Australia's fragmented terrestrial landscapes?*
- Etherington TR & Penelope Holland E (2013) *Least-cost path length versus accumulated-cost as connectivity measures*. *Landsc Ecol* 28:1223–1229.
- Fischer J & Lindenmayer DB (2002) *The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales*. 1. Species composition and site occupancy patterns. *Biodivers Conserv* 11:807–832.
- Fischer J & Lindenmayer DB (2006) *Habitat Fragmentation and Landscape Change: An Ecological and Conservation Synthesis*. Island Press, Washington
- Foltête JC, Clauzel C, & Vuidel G (2012) *A software tool dedicated to the modelling of landscape networks*. *Environ Model Softw* 38:316–327.
- Lechner AM, Brown G, & Raymond CM (2015a) *Modeling the impact of future development and public conservation orientation on landscape connectivity for conservation planning*. *Landsc Ecol* 30:699–713. doi: 10.1007/s10980-015-0153-0
- Lechner AM, Doerr V, Harris RMB, et al (2015b) *A framework for incorporating fine-scale dispersal behaviour into biodiversity conservation planning*. *Landsc Urban Plan*. doi: 10.1016/j.landurbplan.2015.04.008
- Lechner AM, Langford WT, Bekessy SA, & Jones SD (2012) *Are landscape ecologists addressing uncertainty in their remote sensing data?* *Landsc Ecol* 27:1249–1261. doi: 10.1007/s10980-012-9791-7
- Lechner AM & Lefroy EC (2014) *General Approach to Planning Connectivity from Local Scales to Regional (GAP CLoSR): combining multi-criteria analysis and connectivity science to enhance conservation outcomes at regional scale*. Centre for Environment, University of Tasmania. [www.nerplandscapes.edu.au/publication/GAP\\_CLoSR](http://www.nerplandscapes.edu.au/publication/GAP_CLoSR)
- Lechner AM, Stein A, Jones SD, & Ferwerda JG (2009) *Remote sensing of small and linear features: Quantifying the effects of patch size and length, grid position and detectability on land cover mapping*. *Remote Sens Environ* 113:2194–2204.

- McRae BH, Dickson BG, Keitt TH, & Shah VB (2008) *Using circuit theory to model connectivity in ecology, evolution, and conservation*. Ecology 89:2712–2724.
- Minor ES & Urban DL (2008) *A graph-theory framework for evaluating landscape connectivity and conservation planning*. Conserv Biol 22:297–307.
- Minor ES & Urban DL (2007) *Graph theory as a proxy for spatially explicit population models in conservation planning*. Ecol Appl 17:1771–1782. doi: 10.1890/06-1073.1
- NSW Department of Planning (2006) *The Lower Hunter Regional Strategy 2006*. Government of New South Wales, Sydney
- Pascual-Hortal L & Saura S (2006) *Comparison and development of new graph-based landscape connectivity indices: Towards the prioritization of habitat patches and corridors for conservation*. Landsc Ecol 21:959–967. doi: 10.1007/s10980-006-0013-z
- Rayfield B, Fortin MJ, & Fall A (2011) *Connectivity for conservation: A framework to classify network measures*. Ecology 92:847–858. doi: 10.1890/09-2190.1
- Ricotta C, Stanisci A, Avena G, & Blasi C (2000) *Quantifying the network connectivity of landscape mosaics: a graph-theoretical approach*. Community Ecol 1:89–94.
- Rudnick DA, Ryan SJ, Beier P, et al (2012) *The role of landscape connectivity in planning and implementing conservation and restoration priorities*. 1–23.
- Saura S & Pascual-Hortal L (2007) *A new habitat availability index to integrate connectivity in landscape conservation planning: Comparison with existing indices and application to a case study*. Landsc Urban Plan 83:91–103. doi: 10.1016/j.landurbplan.2007.03.005
- Sawyer SC, Epps CW, & Brashares JS (2011) *Placing linkages among fragmented habitats: Do least-cost models reflect how animals use landscapes?* J Appl Ecol 48:668–678.
- Urban D & Keitt T (2001) *Landscape connectivity: A graph-theoretic perspective*. Ecology 82:1205–1218. doi: 10.1890/0012-9658(2001)082[1205:LCAGTP]2.0.CO;2
- Urban DL, Minor ES, Treml EA, & Schick RS (2009) *Graph models of habitat mosaics*. Ecol Lett 12:260–273.
- Van Der Ree R, Bennett AF, & Gilmore DC (2004) *Gap-crossing by gliding marsupials: Thresholds for use of isolated woodland patches in an agricultural landscape*. Biol Conserv 115:241–249.

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