Improving connectivity for biodiversity across the City of Melbourne: A framework for evaluating and planning management actions

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About the Clean Air and Urban Landscapes Hub

The Clean Air and Urban Landscapes Hub (CAUL) is a consortium of four universities: the University of Melbourne, RMIT University, the University of Western Australia and the University of Wollongong. The CAUL Hub is funded under the National Environmental Science Program of the Australian Government’s Department of the Environment. The task of the CAUL Hub is to undertake research to support environmental quality in our urban areas, especially in the areas of air quality, urban greening, liveability and biodiversity, and with a focus on applying research to develop practical solutions.

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Executive summary

A key consideration for maintaining biodiversity in urban spaces is the capacity for species to disperse across the landscape. One of the ways this can be evaluated is by measuring how “connected” different patches of habitat are across the urban matrix. There are two main types of habitat connectivity: structural, measuring just the available habitat; and functional, which accounts for the ability of different species to move across the landscape.

The following report contains a methodological framework to measure habitat connectivity for a series of key animal groups across an urban landscape. The report contains a summary of the recent science for measuring habitat connectivity, things to consider when using this approach and worked examples. A suit of GIS files containing final maps will also be included in with this report.

Chapter 1 details the aims of the project, some background information and how the methodology was developed.

Chapter 2 quantifies the current habitat connectivity within the City of Melbourne, centred around the functional connectivity for seven key animal groups.

Chapter 3 demonstrates two hypothetical management scenarios where this framework could be used: a major road development and tree canopy improvement regime.

Chapter 4 introduces limitations of this methodology and the issues to consider when using the framework.

The appendices contain (1) more methodological details and also a step-by-step set of instructions for repeating the connectivity assessment; (2) details of the functional connectivity groups used in the report; (3) a list of data files included with the report and (4) a glossary of terms.
1 Chapter 1

1.1 Scope and aims

*Habitat connectivity, biodiversity and the City of Melbourne*

The City of Melbourne is rich in animal biodiversity, with over 1,800 species of insects, fish, frogs, reptiles, birds and mammal recorded in the last 20 years (City of Melbourne 2017; Mata et al. 2016; Mata et al. 2017). The City of Melbourne is committed to protecting this biodiversity, through a suite of conservation actions and initiatives aimed to improve the condition of the natural environment. One component is improving habitat connectivity, and thus the ability of animals to move throughout the landscape. The Nature in the City strategy (City of Melbourne 2017) includes priorities to “Develop a more ecologically connected urban landscape”, including the following targets:

‘By 2027, the City of Melbourne will be a more ecologically-connected city than in 2017’, with measurable increases in connectivity; and

By 2027, the City of Melbourne would have achieved a ‘net increase in biodiversity, habitats and ecosystem health.

There are three actions under these targets which are directly linked to planning for connectivity:

Action 3 - Undertake plantings to increase understorey habitat on City of Melbourne managed land by 20 per cent;

Action 7 - Improve ecological connectivity across the municipality in a systematic, comprehensive and co-ordinated manner, considering biodiversity corridors and actions identified in the Urban Forest and Open Space Strategies;
Action 8 - Develop a framework within which all projects in the City of Melbourne can consider impacts to ecological connectivity, with a view to enhancement wherever possible.

To that end, the Clean Air and Urban Landscapes Hub (CAUL Hub) has been engaged to develop a framework for the City of Melbourne to provide methodological tools to assist in tracking its progress towards meeting these targets. The purpose of this document is to introduce a framework for evaluating and planning connectivity focused management actions in the City of Melbourne and provide details of how this framework can be applied to future landscape management.

**Aims of the project**

1. To develop a rigorous methodological approach to estimate and map landscape connectivity in the City of Melbourne; and

2. To demonstrate how these landscape connectivity estimates and maps (a) may be used to identify areas that would make the greatest contribution to improving connectivity across the municipality, and (b) provide a tool for City of Melbourne managers and decision-makers to assess the impact of proposed large infrastructure or precinct developments on the municipality’s landscape connectivity.

We are focussing on animal species for this assessment, since in the highly modified and managed urban landscape it is likely that habitat connectivity plays a lesser role in the dispersal of plant species. This document reviews ways to measure structural and functional connectivity in urban environments and proposes a framework for evaluating and planning connectivity focused management actions in the City of Melbourne that considers these different aspects of connectivity.
1.2 Habitat connectivity in urban environments

What is habitat connectivity and why is it important for biodiversity?

The resources that an animal might need – food, shelter and suitable mates – are often patchily distributed across a landscape. The ability to move through a landscape and access these resources is therefore important to individual survival and long-term population viability. Urban landscapes are highly fragmented, often containing patches of remnant vegetation and/or semi-natural habitats surrounded by a matrix of land uses that support human activities (residential, commercial, parks and roads). The ability of these land uses to facilitate or impede species movement is referred to as habitat connectivity (Taylor et al. 1993).

There are two components to habitat connectivity: structural and functional. The “physical arrangement of habitats within a landscape” is referred to as structural connectivity (Watson et al. 2017). This concept includes features such as green corridors, but can also include disconnected features such as vegetation along roadways, or isolated trees, a patch of flowering shrubs, or fallen logs, which may form ‘stepping stones’ (Doerr et al. 2010; Doerr et al. 2014). The ability of a species to move or disperse between habitat patches using structural features is referred to as functional connectivity (Tischendorf & Fahrig 2000; Baguette et al. 2013). Despite the increasing interest and efforts in understanding and assessing functional connectivity within the field of urban ecology (LaPoint et al. 2015), most studies are still limited by traditionally focussing on structural connectivity.

Protection and restoration of features that provide structural connectivity is increasingly common (Watson et al. 2017), however the extent to which these features effectively allow the movement of particular species through the landscape is often unclear, as functional connectivity is context and species specific (Tischendorf & Fahrig 2000; Doerr et al. 2010; Watson et al. 2017). Structural connectivity can be maintained and increased in urban landscapes through the protection of patches of remnant vegetation and/or semi-natural habitats in parks and the design and planning of other green space types, including linear green corridors and street trees. However,

Figure 1.2 (Opposite page) A blue-banded bee *Amegilla chlorocyanea* visiting the flowers of the indigenous austral storksbill *Pelargonium australe*. Photo from Westgate Park, City of Melbourne. Photo by Luis Mata.
to achieve functional connectivity, these features must facilitate both daily animal movements and other dispersal events that lead to stable populations and gene flow (Taylor et al. 1993). This distinction is important, as patches can appear to be structurally connected without being functionally connected. For example, two parks may be connected by a green corridor, yet, if the vegetation in that corridor does not support use by a particular species, then the corridor may fail to facilitate its movement between the parks.

**Approaches to measuring connectivity**

There are a range of approaches to measuring landscape structural connectivity. These include identifying features that are thought to act as a barrier or corridor, measuring habitat patch size, shape and distribution, and calculating indices that represent how connected a landscape is. Many connectivity indices have been derived that describe different aspects of structural connectivity. Calabrese and Fagan (2004) suggest three categories of connectivity indices: (1) structural, measuring physical features of the landscape; (2) potential, using specific habitat data; and (3) actual, based on measurement of actual animal movements. The first of these categories can be used to describe the connectivity index currently outlined in the City Biodiversity Index (CBI) methodology, whereas the second and third categories are more aligned with the concept of functional connectivity, which is further described below. The CBI or ‘Singapore Index’ is an internationally recognised tool for measuring biodiversity in cities (Chan et al. 2014). This tool was endorsed by the Convention on Biological Diversity, and is being considered for use in the City of Melbourne. There are 23 indicators under the CBI, and Indicator #2 (CBI 2) specifically captures issues of connectivity (“Connectivity Measures or Ecological Networks to Counter Fragmentation”).

**Structural connectivity**

The CBI methodology establishes an index to calculate the structural connectivity of a city (Chan et al. 2014). The original index was based on effective mesh size, which is “the probability that two randomly chosen locations in the landscape are connected and not separated by barriers” (Jaeger 2000). Deslauriers et al. (2017) recently improved this methodology for calculating CBI

**Figure 1.3 (Opposite page)** A blue skimmer *Orthetrum caledonicum* flying through Westgate Park (City of Melbourne). Photo by Luis Mata.
Indicator #2 by allowing within patch connectivity to be better quantified and making the index itself easier to interpret. Based on a measure of effective mesh size (Jaeger 2000), the improved CBI 2 considers two patches to be connected if they (1) are ≤ 100m apart and (2) contain no barriers to movement (e.g. roads > 15m wide). The improved methodology accounts for large continuous areas of habitat, so that decreasing fragmentation intuitively leads to an increasing connectivity value. CBI 2 could be adapted by adjusting the threshold value and allocation of barriers according to location or focal species.

Functional connectivity

Functional connectivity depends on the landscape structural connectivity, but also on landscape and site-based characteristics and elements that influence the actual dispersal of individuals (e.g. spatial and temporal availability and distribution of resources and risks), as well as on species ecological traits related to movement (i.e. dispersal, recruitment, life-history and behavioural traits). It requires each part of the landscape to be characterised based on the potential to impede or promote movement for that species. There are three main steps, described below.

First, we must determine how a species moves through the landscape. Whether a landscape or a set of habitat patches are functionally connected can be assessed using genetic or movement tracking techniques (Tischendorf & Fahrig 2000; Calabrese & Fagan 2004). The latter are particularly useful when they can inform and help generalise how a species uses different landscape features and elements, because these data can then be used to map functional connectivity at broader landscape or regional scales. However, collecting information on species movement behaviours or gene flow often requires extensive field research, and consequently, empirical data is often scarce (Pe’er et al. 2011; La Point et al. 2015). In the absence of empirical data, available ecological knowledge can be used to estimate how a species moves through the landscape.

Second, it is important to obtain spatial data that directly measures, or can be used as a proxy for the landscape features that influence movement. These data should be amalgamated or merged within a Geographic Information System (GIS). Location of tree hollows is an example of a layer that directly identifies a particular resource used by species that depend on tree hollows as nesting

Figure 1.4 (Opposite page) The spotted marsh frog *Limnodynastes tasmaniensis*. Photo by Kirsten Parris.
and resting habitat. On the other hand, LiDAR-derived 3D data is an example of a proxy for different habitat layers such as grasses, shrubs and trees (Casalegno et al. 2017) and can also be used as a direct measure of the impacts of buildings on the air-scape connectivity for birds in urban areas (Shepard et al. 2016).

A third step in the assessment of functional connectivity is connectivity modelling. Three main theoretical frameworks have been used for this purpose: the least-cost path analysis, graph theory and circuit theory. The least-cost path analysis has been used across different related methods and is one of the most popular (Sawyer et al. 2011). In general terms, the least-cost path analysis is raster or grid-based, and it attributes a dispersal cost to different land-uses, being the cost associated with dispersal energetic costs, difficulty, exposure to predators and mortality risk of moving across those land-use types. Particular methods include, for example, the GAP CLoSR - General approach to planning connectivity from local-scales to regional connectivity modelling framework (Lechner & Lefroy 2014), and the individual-based model FunCon (Pe’er et al. 2011).

Casalegno et al. (2017) use LiDAR data and compared the results of measuring habitat connectivity using 2D vs 3D habitat models. In the 3D model they separately considered the value of grass, shrubs and trees. They computed several connectivity indexes including: small patch density, largest patch and the ‘connectivity index’ developed by Jaeger (2000). Jaeger (2000) defines ‘effective mesh area’ (EMA), which is the basis for the new CBI Index, as described above. Casalegno et al. (2017) use the original EMA index, rather than the improved CBI 2, as described in Deslauriers et al. (2017). Their assessment does not include biological information on species dispersal, however they refine the generic structural approach such that their method may be considered as a proxy for functional connectivity. To do this they consider connectivity for increasing buffer widths over 1m increments up to 40m. Although this approach is not species specific and does not use species dispersal information, it does allow for an assessment of the dispersal distance at which different attributes of vegetation (herbaceous plants, shrubs, trees) do or do not provide connectivity.

Figure 1.5 (Opposite page) The eastern blue-tongued lizard *Tiliqua scincoides*. Photo by Kazredracer (Flickr, Creative Commons).
1.3 A suitable approach for the City of Melbourne

Outline of our methodological approach

Based on current scientific literature and the specific needs and context of the City of Melbourne, we propose a combination of structural and functional approaches to evaluate connectivity. Our proposed methodology combines the assessment of: (1) structural connectivity for three classes of vegetation, and (2) functional connectivity for seven key animal groups.

Step 1: Structural connectivity for three classes of vegetation

We followed the method outlined by Casalegno et al. (2017), using the updated CBI Indicator #2 methods (IND2CBI_impr, as described in Deslauriers et al. (2017)), and computed connectivity metrics for three key classes of vegetation that are relevant to the City of Melbourne management activities (Figure 1.1):

- Herbaceous plants, defined as vegetation with a LiDAR-derived height below 50cm;
- Midstorey, including planted beds defined by the City of Melbourne, and LiDAR-derived vegetation height between 50cm and 300cm;
- Tree canopy, as mapped by the 2016 canopy cover data layer from the City of Melbourne Open Data Portal.

Step 2: Functional connectivity for seven animal groups

Predicting functional connectivity is data intensive, as it requires detailed information about the target species’ movement abilities, habitat preferences and potential barriers to dispersal. This information is often not known or unavailable. In this study, we could have focussed on two or three species for which suitable data was available. However, this strategy would have limited the ability of the connectivity framework to represent the broader range of animal biodiversity within the municipality, and would be less useful for guiding management. We therefore decided to use a species group approach, by which we considered seven key groups or ‘movement guilds’

Figure 1.6 (Opposite page) The superb fairywren *Malurus cyaneus*. Photo by Patrick K (Flickr, Creative Commons).
of animals that share broad dispersal abilities and habitat requirements. The groups were:

**Insect pollinators** – species that depend on flowering midstorey vegetation as a feeding resource (e.g. blue-banded bee; Figure 1.2).

**Aquatic insects** – species that depend on waterbodies that are better able to move overland (e.g. blue skimmer dragonfly; Figure 1.3).

**Amphibians** – species that depend on waterbodies and are limited in overland dispersal (e.g. spotted march frog; Figure 1.4).

**Reptiles** – species that depend on adequate ground cover refuges, including leaf litter, rocks and coarse woody debris (e.g. eastern blue-tongued lizard; Figure 1.5).

**Woodland birds** – species that depend on dense or complex midstorey vegetation for nesting and resources (e.g. superb fairy wrens; Figure 1.6).

**Tree-hollow using birds** – species that depend on tree hollows and fly above and below the tree canopy during the day (e.g. red-rumped parrot; Figure 1.7).

**Tree-hollow using bats** – species that depend on tree hollows and move within the tree canopy during the night (e.g. Gould’s wattled bat; Figure 1.8).

The definition of these groups was based on discussions during a workshop with City of Melbourne staff and local experts (11th August 2017; see acknowledgements). For each animal group, we identified an approximate dispersal distance, as well as both barriers and connectors within the landscape. Further details on the characteristics of each group and the species within them are provided in Appendix I and III. These groups cover the range of habitat requirements and dispersal abilities of animal biodiversity within the City of Melbourne, including multiple taxa (e.g. insects, amphibians, reptiles, birds and mammals), and multiple levels of habitat structure (e.g. water, ground cover, midstorey and tree canopy). This allows the connectivity...
framework to guide specific management actions, such as increase flowering shrub cover and preserve of hollow bearing trees, while remaining generalisable to multiple species. Importantly, all groups are susceptible to urban landscape change, but are able to persist in urban environments under the right conditions, meaning that they are likely to respond well to management actions that aim to improve connectivity. Further, each group contains species that are charismatic, and more likely to garner public support for conservation actions.

Benefits to this approach for the City of Melbourne

The approach provides a measure of change over time, enabling evaluation of the impacts of different management actions.

The framework can provide ex-anti comparison of different scenarios or management actions.

Output from the analyses aids understanding of the connectivity value of different habitats and for different types of species.

The method represents international best practice for evaluating connectivity.

Figure 1.8 (Opposite page) The Gould’s wattled bat *Chalinolobus gouldii*. Photo courtesy of Ryan Francis.
Chapter 2

2.1 Structural connectivity in the City of Melbourne

Evaluating structural connectivity

Structural connectivity (see section 1.2) relates only to the arrangement of landscape level habitat features, and does not account for how animals might respond to those features. Here we have calculated the structural connectivity for three different habitat heights: herbaceous plants, midstorey and tree canopy. We used the same definitions as those set out by Deslauriers et al. (2017) for the Improved City Biodiversity Index Indicator #2 (CBI 2) to determine the distance between habitat patches and potential barriers. All roads and railways wider than 10m were considered barriers. These features were also buffered by 7.5m to account for edge effects (Deslauriers et al. 2017). Habitat patches were considered connected if they were less than 100m apart. In order to allow for animal movement outside the City of Melbourne municipal border, any impervious surfaces beyond the city boundary were also buffered by 10m and considered as barriers to potential movement.

Detailed methodology for the calculation of both structural and functional connectivity can be found in the appendices, including details of the raw GIS data used to construct ‘habitat’ and ‘barrier’ land use definitions (Appendix I and II). The connectivity indices throughout the report were calculated using the formula proposed by Deslauriers et al. (2017) that disregards the overall area of the landscape under consideration, thus allowing for the direct comparison of different landscape areas. The connectivity index, which corresponds exactly with the improved CBI 2, is presented alongside the effective mesh size. Both the connectivity index and the effective mesh size increase as the habitat fragments within the
In order to illustrate the connectivity of different habitat types, throughout this chapter we show images of the entire City of Melbourne municipality (Figures 2.1 and 2.5), as well as a closer section showing the area covering the southern end of Royal Park (Figures 2.3 and 2.6). Habitat patches are coloured according to the connected area they have been identified as residing within (the actual colour is randomly assigned).

**Herbaceous plants**

Habitat included in this structural connectivity calculation included all vegetation classified by LiDAR as greater than 0 cm in height, but not taller than 50 cm. This habitat was very sparsely distributed across the City of Melbourne, mostly confined to small patches within parks (Figure 2.1A). As such the connectivity index (CBI 2 = 8,184 m2; EffMesh = 0.056) is low compared to other types of habitat (Table 2.1).

**Midstorey**

Midstorey habitat included areas identified as shrub beds by the City of Melbourne and any vegetation between 50 cm and 300 cm in height (classified by LiDAR). In general, midstorey is distributed across a wider area of the City of Melbourne (CBI 2 = 102,129 m2; EffMesh = 0.132; Figure 2.1B).

**Tree canopy**

Two sets of data were used to calculate this connectivity index: LiDAR classified vegetation identified as taller than 300 cm and the open source tree canopy data set from the City of Melbourne (Tree Canopy 2014). The City of Melbourne is currently very well connected in terms of the structural connectivity of the tree canopy (CBI 2 = 413,366 m2; EffMesh = 0.138; Figure 2.1C), especially when compared to the other structural connectivity indices (Table 2.1). This is particularly apparent in the Royal Botanic Gardens and Fawkner Park (Figure 2.3), where the habitat patches are classified as being part of the same connected area. In contrast, patches of tree canopy habitat in the central business district (CBD) are almost entirely disconnected from each other (visualised by the different colours in Figure 2.4).
Table 2.1 Structural and functional connectivity indices as calculated following the framework methodology.

<table>
<thead>
<tr>
<th>Connectivity type</th>
<th>Number of connected areas</th>
<th>Total area (m²)</th>
<th>Connectivity Index</th>
<th>Effective Mesh Size</th>
<th>Total number of habitat patches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural connectivity</td>
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<td></td>
<td></td>
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<tr>
<td>Tree canopy</td>
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<td>2995812</td>
<td>413366</td>
<td>0.13798</td>
<td>44159</td>
</tr>
<tr>
<td>Midstorey</td>
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<td>102129</td>
<td>0.13200</td>
<td>13395</td>
</tr>
<tr>
<td>Herbaceous plants</td>
<td>176</td>
<td>146617</td>
<td>8184</td>
<td>0.05582</td>
<td>4547</td>
</tr>
<tr>
<td>Functional connectivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insect pollinators</td>
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<td>5391747</td>
<td>1056015</td>
<td>0.19586</td>
<td>108658</td>
</tr>
<tr>
<td>Aquatic insects</td>
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<td>5339727</td>
<td>4148404</td>
<td>0.77689</td>
<td>24085</td>
</tr>
<tr>
<td>Amphibians</td>
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<td>806932</td>
<td>85804</td>
<td>0.10633</td>
<td>10430</td>
</tr>
<tr>
<td>Reptiles</td>
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<td>537214</td>
<td>0.14508</td>
<td>5476</td>
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<tr>
<td>Woodland birds</td>
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<td>4813553</td>
<td>4082976</td>
<td>0.84822</td>
<td>121580</td>
</tr>
<tr>
<td>Tree-hollow using birds</td>
<td>202</td>
<td>6313243</td>
<td>2985352</td>
<td>0.47287</td>
<td>76167</td>
</tr>
<tr>
<td>Tree-hollow using bats</td>
<td>159</td>
<td>3314490</td>
<td>1735761</td>
<td>0.52369</td>
<td>45319</td>
</tr>
</tbody>
</table>
2.2 Functional connectivity in the City of Melbourne

Evaluating functional connectivity

We calculated functional connectivity for seven key animal groups, with varying habitat requirements and dispersal abilities. More details regarding these different groups can be found in Appendices I and III. Functional connectivity for each group was calculated using the same formula as the improved CBI 2, but habitat combinations and barrier definitions varied for each group. Habitat layers were buffered to account for the dispersal distance of each animal group; for example, if a species disperses 1000 m, the habitat for this species was buffered by 500 m. The barriers for each group were then removed from the buffered habitat, creating a fragmentation geometry. The existing habitat patches were then classified according to which connected area they resided within.

Indigenous perspectives on species selection

The team engaged to conduct this study includes a broad disciplinary base but does not necessarily cover the full range of expertise in the different taxa that inhabit the City of Melbourne. Consequently, we have used a network of species experts to refine our assessment of functional connectivity according to the most important species in the City of Melbourne. During the study’s early stages the research team and the City of Melbourne Urban Sustainability Branch staff agreed to pause the work for three months to enable the participation of members of local Indigenous community to advise on species/taxa selection and the study as a whole. A three month delay was however not adequate to enable the involvement of Indigenous experts. Future work on this line of research and practice should strive to find the right pathways to guarantee the involvement of the Indigenous community from the beginning.

Insect pollinators

Functional connectivity for the insect pollinators group included tree canopy, midstorey and shrub beds, and any herbaceous plants or turf less than 25 m from a shrub/tree patch, assuming this group can disperse at least 350 m. Barriers included roads wider than 10 m. There are 108,658 patches of habitat that is potentially suitable for insect pollinators, grouped into 218 connected areas (Table 2.1).
Figure 2.1 Habitat patches of herbaceous plants (A), midstorey (B) and tree canopy (C) across the City of Melbourne, coloured by the connected area they are classified as being part of.
The connectivity index for the insect pollinator group is seemingly very high (CBI 2 = 1,056,015 m²; EffMesh = 0.19586), with substantial areas of habitat across the city that are well connected for this group (Figure 2.5A). For example, Royal Park is one large connected patch for this group, as is the residential area within the west of Melbourne; these connected areas however are separated from each other due to the barrier that roads present. It appears that very small patches of habitat are important for providing connectivity across residential areas for this group (Figure 2.7); for example, the western edge of Royal Park could provide a movement corridor, linking the patches within the park (Figure 2.6A).

Aquatic insects

Aquatic insects with flying adults such as dragonflies and damselflies require both waterbodies and substantial stands of vegetation, but are capable of flying at least 1,500 m. As such, midstorey and tree canopy within 500 m of any waterbodies were considered viable habitat in this model. Waterbodies and vegetation were buffered by 750 m, with roads wider than 10 m forming the barriers for this group.

As illustrated by Figure 2.5B, the main waterways within the City of Melbourne serve as connections for large areas of the suitable aquatic insect habitat. More isolated patches occur in parks with water features, such as Carlton Gardens and Fitzroy Gardens. The 67 connected areas of potential aquatic insect habitat are made up of 24,085 actual habitat patches (CBI 2 = 4,148,404 m², EffMesh = 0.77689) leading to this group having the second highest connectivity index after woodland birds (Table 2.1).

Amphibians

Many environmental variables affect the ability of amphibians to move about urban landscapes, including the availability of sun/shade and the degree of human disturbance. Here, we were only able to consider habitat suitability (ponds, creeks and herbaceous plants or midstorey cover less than 10 m from water) and the barrier effect of roads (wider than 5 m) and buildings. We buffered by 500 m the habitat of this group to allow for the 1,000 m dispersal distance for this group.

Habitat potentially suitable for amphibians occupied the smallest total area of the City of Melbourne when compared to the other animal
Figure 2.2 Habitat patches of grass (A), midstorey (B) and canopy (C) in Royal Park, coloured by the connected area they are classified as being part of.
Figure 2.3 Canopy habitat patches in the Royal Botanic Gardens Melbourne and Fawkner Park, coloured by connected area (showing mostly one colour, meaning fully connected habitat patches).
Figure 2.4 Canopy habitat patches in the City of Melbourne central business district, coloured by connected area (showing many different coloured patches of habitat, indicating this area is very fragmented).
Figure 2.5 Habitat patches for (A) insect pollinators, (B) aquatic insects, (C) amphibians, (D) reptiles, (E) woodland birds, (F) tree-hollow using birds, and (G) tree-hollow using bats across the city of Melbourne, coloured by the connected area they are classified as being part of.
Figure 2.6 Habitat patches for (A) insect pollinators, (B) aquatic insects, (C) amphibians, (D) reptiles, (E) woodland birds, (F) tree-hollow using birds, and (G) tree-hollow using bats in Royal Park, coloured by the connected area they are classified as being part of.
groups (Table 2.1). It was also the least connected (CBI $2 = 85,804 \text{ m}^2$; EffMesh = 0.10633). The Moonee Ponds Creek has the potential to act as a key corridor, but is both lacking substantial riparian habitat and is fragmented by major road crossings (Figure 2.5C).

**Reptiles**

Species in this group require ground cover, and are capable of dispersing up to 1,000 m. Habitat layers used for this group included all understorey cover: midstorey vegetation (from LiDAR), shrub beds (as defined by the City of Melbourne) and all areas of turf or herbaceous plants. These layers were combined and buffered by 500m, and all roads (wider than 5m) and buildings were treated as barriers.

The majority of reptile habitat patches can be found in parks across the City of Melbourne. The 5,476 habitat patches form 263 connected areas (Table 2.1) with CBI $2 = 537,214 \text{ m}^2$ and EffMesh = 0.14508 (Figure 2.5D). Because of the roads and tramlines running through Royal Park, this area is fragmented into more than five different connected areas, despite the entire park being suitable habitat for reptiles (Figure 2.6D).

**Woodland birds**

Woodland bird habitat was classified as the combination of midstorey vegetation (shrub, midstorey LiDAR and garden bed layers), tree canopy and any turf or herbaceous plants layer within 10 m of the tree canopy or midstorey vegetation. Barriers to woodland bird movement were roads wider than 15 m and buildings taller than 10 m. The combined habitat layers were buffered by 750 m, with the dispersal distance for this group set to 1500 m.

There were 121,580 habitat patches suitable for woodland birds within the City of Melbourne, which currently form 199 connected areas (Table 2.1). The municipality is well connected for this group (CBI $2 = 4,082,976 \text{ m}^2$; EffMesh = 0.84822; Figure 2.5E). Pockets of isolated habitat do exist south of the Yarra River around Westgate Park and the Docklands area (Figure 2.5E).

**Tree-hollow using birds**

Many bird species use tree hollows for breeding and roosting in. Therefore the herbaceous plants and tree canopy habitat layers for this group needed
Figure 2.7 Pollinator habitat patches across Kensington coloured by connected area.
to be within 500 m and 1000 m, respectively, of recorded tree hollows. Roads wider than 15 m and tall buildings were considered barriers to movement, and the dispersal distance was limited to 500 m (habitat layers were buffered by 250 m).

The 76,167 habitat patches suitable for tree-hollow using birds in the City of Melbourne were grouped in 202 connected areas (CBI 2 = 2,985,352 m²; EffMesh = 0.47287; Table 2.1). The patches north of the Yarra form one largely connected area (Figure 2.5F), with habitat in the southern parts of the city being more fragmented. Suitable habitat for this group in Royal Park is separated by the Upfield train line (Figure 2.6F).

Tree-hollow using bats

Not only do tree-hollow using bats differ in their activity patterns to other tree hollow users, but they have different dispersal capabilities. Our reference species, the Gould’s wattled bat *Chalinolobus gouldii* (Figure 1.8), for example, moves across large distances in rural areas; however, this is tempered in urban environments, leading to our model using only a dispersal distance of 1000 m. Tree canopy within 250 m of tree hollows was buffered by 500 m, and then fragmented by roads wider than 15 m and buildings taller than 10 m. Because of their dispersal capabilities, tree-hollow using bats could potentially access a large area of the city (CBI 2 = 1,735,761 m²; EffMesh = 0.52369; Table 2.1; Figure 2.5G). Given the apparent impact of roads and open spaces on this group, an important limitation of this model was the lack of information regarding artificial light at night, the presence/absence of which might influence the effect of a road barrier. For example, the Upfield train line in Royal Park (Figure 2.6G) may not actually be barrier to this group if it is mostly unlit at night.
3 Chapter 3

3.1 Example scenarios for using the connectivity framework

The value of this framework is its use as a planning tool. This could be for deciding on the best place to position new garden beds, measuring the impact of a future development, or comparing the City of Melbourne to other municipalities, both locally and globally. In this section we will use two different scenarios to demonstrate how our connectivity framework can be used to for future planning. The scenarios presented here represent two different applications of the framework; one positive (adding habitat) and one negative (removing habitat) and the corresponding connectivity calculations. In order to allow comparison of the ‘before and after’ connectivity indices we used the same functional connectivity groups, and their corresponding habitat requirements, as analysed in Chapter 2. These scenarios were chosen, after consultation with different departments within the City of Melbourne council, as being the most representative of current planning considerations. Other options included: improving riparian habitat along rivers and creeks; identifying small gaps that could be easily connected; improving a habitat patch to make it a corridor for more species; and mitigating the barrier effect of roads for different animal groups.

3.2 Scenario 1: Addition of a major road development – worked example

Scenario outline

What are the implications of a major infrastructure development for animal biodiversity connectivity in the City of Melbourne? Any development can have a range of impacts on connectivity, both negative (e.g. lost habitat or increased barriers to movement) and positive (e.g. if revegetation takes place). Here, we used the estimated footprint of a
substantial road network being added to North and West Melbourne suburbs as an additional barrier to all functional connectivity groups (Figures 3.1 and 3.2). Adding this development to the city also reduces the total area of habitat for all groups.

Methodology

The following methodology is applied to habitat layers constructed in Chapter 2, where the habitat for each species group is made up of a combination of different layers and rules, using logical statements such as AND/OR. Table 3.1 contains a fully worked example for calculating functional connectivity for woodland birds, with the additional steps for this specific scenario highlighted for clarity. A generalised methodology is provided in Table AI.1 (Appendix I).

Effect on insect pollinator functional connectivity

Potentially viable habitat for insect pollinators was reduced by over 5,000 m² when the road development is added. This reduces the functional connectivity index (CBI² = 985,777 m²; EffMesh = 0.18301; Table 3.2; Figure 3.3B). The major intersections fragment the habitat around the Moonee Ponds Creek, and around Dynon Road and Footscray Road (Figure 3.4B).

Effect on aquatic insect functional connectivity

Aquatic insect functional connectivity decreased slightly following a large reduction in habitat availability (CBI² = 4,079,870 m²; EffMesh = 0.76681; Table 3.2; Figure 3.3C). The majority of this habitat loss occurred along Footscray Road and also under the major intersection in Figure 3.4C, where the Moonee Ponds Creek passes under the proposed structure.

Effect on amphibian functional connectivity

For the amphibian group the connectivity index slightly increased under this development scenario (CBI² = 86,098 m²; EffMesh = 0.10749; Table 3.2; Figure 3.3D), despite potential habitat area reducing by nearly 6,000 m².

Effect on reptile functional connectivity

The functional connectivity of the reptile group decreased slightly (CBI² = 535,325 m²; EffMesh = 0.14465; Table 3.3; Figure 3.3E) following a small
Figure 3.1 Overview of the City of Melbourne municipality with existing habitat patches (green) and proposed new road development (red).
reduction in habitat area. Figure 3.4E illustrates the highly fragmented landscape for this group around the proposed development.

**Effect on woodland bird functional connectivity**

Suitable woodland bird habitat in the City of Melbourne is very well connected, and the effect of this proposed road development is minimal for this group (CBI 2 = 4,086,487 m²; EffMesh = 0.85074; Table 3.2; Figure 3.3F). The connectivity index increases slightly due to the reduction in the number of habitat patches overall.

**Effect on tree-hollow using bird functional connectivity**

The road development has a major effect on the calculated functional connectivity for the hollow-tree using bird group (CBI 2 = 1,046,953 m²; EffMesh = 0.19364; Table 3.2; Figure 3.3G), with the loss of over 13,000 habitat patches. Although there are habitat patches remaining underneath the major intersection (Figure 3.4G), it is likely that these will remain very isolated, and therefore not meaningfully contributing to the connected habitat as a whole.

**Effect on tree-hollow using bat functional connectivity**

The major road development decreased potential tree-hollow using bat habitat by 2,000 m² (Table 3.2). However, the connectivity index increased slightly (CBI 2 = 1,735,476 m²; EffMesh = 0.52393). This is because the remaining habitat had slightly fewer habitat patches, but more areas that were connected. This means that the road development removed some especially fragmented areas of habitat (Figure 3.3H).

### 3.3 Scenario 2: Adding biodiversity corridors to the City of Melbourne

**Scenario outline**

What could structural and functional connectivity look like in 20 years’ time? As part of the Urban Forest Strategy, the City of Melbourne has identified some key locations that can be considered as potential biodiversity corridors. Targeted garden bed and tree planting over the next 10 years should result in full tree canopy cover across those streets identified as being part of a biodiversity corridor. To model this, we added
Figure 3.2 Closer view of the main impact area of the new road development (red).
Table 3.1 Step-by-step methodology for quantifying the potential effect of a major road development on woodland bird functional connectivity.

<table>
<thead>
<tr>
<th>Step/sub-step</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Prepare habitat layers</td>
<td>Combine canopy layers, midstorey layers. Geoprocessing &gt; Union ¹  &lt;br&gt; Buffer the combined layers by 10 m. Geoprocessing &gt; Buffer &gt; Distance value is 10 m ²  &lt;br&gt; Find the parts of the turf layer that are 10 m from cover &lt;br&gt; Input “turf” and buffered cover layer. Geoprocessing &gt; Intersect &lt;br&gt; Unify &amp; dissolve 10 m turf layer and combined cover layers habitat layers. Geoprocessing &gt; Union ³  &lt;br&gt; Account for woodland bird dispersal distance &lt;br&gt; Woodland bird dispersal distance is 1,500 m ⁴  &lt;br&gt; Geoprocessing &gt; Buffer &gt; Distance value is half the dispersal distance (750 m).</td>
</tr>
<tr>
<td>2. Prepare barrier layers</td>
<td>Filter existing barrier layers &lt;br&gt; Create new road development layer &lt;br&gt; Create all woodland bird barriers &lt;br&gt; Buffer the barrier layer &lt;br&gt; Filter the existing road layer according to width (&gt;10 m) and the building layer according to height (&gt;10 m) ⁵  &lt;br&gt; Either add an existing shape file with the proposed development or create a new file from scratch  &lt;br&gt; Combine all the barrier layers. Geoprocessing &gt; Union  &lt;br&gt; Buffer the combined barrier layer by 7.5 m ⁶  &lt;br&gt; Geoprocessing &gt; Buffer &gt; Distance value is 7.5 m ⁷</td>
</tr>
<tr>
<td>3. Create fragmentation geometry</td>
<td>Erase barriers from the habitat layer &lt;br&gt; Combine all woodland bird barriers &lt;br&gt; Buffer the barrier layer  &lt;br&gt; Input layer = All woodland bird habitat buffered ⁸  &lt;br&gt; Clip layer = All woodland bird barriers  &lt;br&gt; Geoprocessing &gt; Clip ⁹</td>
</tr>
<tr>
<td>4. Identify connected areas</td>
<td>Find remaining connected areas &lt;br&gt; Identify connected areas  &lt;br&gt; Input layer = the buffered habitat with barriers removed (step 3) ¹⁰  &lt;br&gt; Geoprocessing &gt; Arc Toolbox &gt; Data Management Tools &gt; Features &gt; Multipart to singlepart  &lt;br&gt; Right click on the layer created in this step, open attribute table and toggle editing on ¹¹  &lt;br&gt; Open “field calculator” and “create new field” using “row_number” function  &lt;br&gt; Make sure you save the edits to this layer ¹²</td>
</tr>
<tr>
<td>5. Identify connected habitat patches</td>
<td>Intersect original habitat layer with identified connected areas &lt;br&gt; Intersect the original woodland bird habitat (step 1) with the results of step 4 (identified, connected areas) ¹³  &lt;br&gt; Geoprocessing &gt; Intersect ¹⁴</td>
</tr>
<tr>
<td>6. Calculate area and export</td>
<td>Calculate area of each patch &lt;br&gt; Export attribute table to “.csv”  &lt;br&gt; Right click on the layer created in Step 5. Open attribute table and toggle editing on ¹⁵  &lt;br&gt; Open “field calculator” and “create new field” using “area” function.  &lt;br&gt; Remember to save the layer edits, calling the new column “habitat area” or similar  &lt;br&gt; Right click on layer name in layers panel and select “save as”. Make sure to select csv file type ¹⁶</td>
</tr>
</tbody>
</table>
Table 3.1 (Cont.)

<table>
<thead>
<tr>
<th>Step/sub-step</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculation of connectivity indices in Excel</td>
<td>Spreadsheet should include a column with patch ID and habitat area. Delete all other columns.</td>
</tr>
<tr>
<td>Square the area of each habitat patch</td>
<td>Create a new column, &quot;Square patch area&quot; Apply =POWER(cell number, 2) to the whole column.</td>
</tr>
<tr>
<td>Calculation of connectivity index (CBI 2)</td>
<td>Total sum of squares (SUM &quot;Square patch area&quot; column). Total sum of original habitat area (SUM &quot;habitat area&quot; column). Connectivity = Sum of squares/Sum original area.</td>
</tr>
<tr>
<td>Calculation of effective mesh size (EffMesh)</td>
<td>Effective mesh size = connectivity/Sum of original habitat area.</td>
</tr>
</tbody>
</table>

1. Combine the cover habitats for this animal group.
2. Finding the area 10m around the canopy and midstorey cover.
3. Makes "All woodland bird habitat".
4. Makes "All woodland bird habitat buffered".
5. Only wide roads and tall buildings are barrier for this group.
6. Barriers such as roads may have an edge effect on the habitat around them.
7. Makes "All woodland bird barriers".
8. The barriers prevent movement, even in patches that are connected, so erase the connected habitat.
9. This will leave the buffered habitat, minus all the current and future potential barriers.
10. This step checks which of the buffered areas are still connected and which are now on their own.
11. This step gives each buffered area that remained connected a unique number in a new field. Call the new field something sensible like “patchID” or “patch_number”.
12. Makes "Buffered woodland bird habitat, connected area identified".
13. This step links each actual habitat patch with its related connected area so that connected patches of habitat are grouped together.
14. Makes "Woodland bird habitat, connected area identified".
15. This step calculates the actual area of each connected habitat patch. A patch is a collection of smaller pieces of habitat that classed as connected due to their proximity/lack barriers.
16. The final calculation is done in Excel.
blocks of canopy habitat to all the identified streets, simulating full canopy coverage for that street (Figure 3.5). We also added small areas to represent garden bed planting which is proposed along with other streetscape improvements (e.g. added benches) and could provide important habitat for some animal groups (e.g. insect pollinators and reptiles). Habitat connectivity across the City of Melbourne increased for all the investigated animal groups (Table 3.3), which could be due to an increase in total habitat area and also a reduction in the number of different habitat fragments; more habitat patches were considered to be connected to each other.  

**Effect on overall tree canopy connectivity**

Increasing the total tree canopy area in the City of Melbourne by 750,000 m² increased the connectivity by over 49,000 m² (CBI 2 = 462,745 m²; EffMesh = 0.12349; Table 3.3). The best corridors seem to be those in Kensington and along the Footscray Road and Docklands areas (Figure 3.7A).  

**Effect on insect pollinator functional connectivity**

The connectivity of suitable habitat for insect pollinators was improved by adding these proposed biodiversity corridors (CBI 2 = 1,6432,98m²; EffMesh = 0.23260; Table 3.3), especially for habitat patches in East Melbourne (Figure 3.7B).  

**Effect on reptile functional connectivity**

Despite the smaller increase in potential reptile habitat (113,000 m² compared to over one million m² in other groups), the functional connectivity for the reptile group increased under this scenario (CBI 2,794,230 m²; EffMesh = 0.20813; Table 3.3). This improvement is most noticeable around Kensington and Parkville (Figure 3.7C), while Royal Park is still fragmented for this group.  

**Effect on woodland bird functional connectivity**

Habitat for woodland birds was already well connected across the City of Melbourne, however adding the proposed biodiversity corridors did improve on this (CBI 2,512,5676 m²; EffMesh = 0.80407; Table 3.3). Notably, the Port Melbourne area still remains separated from the rest of the
Table 3.2 Structural (tree canopy habitat) and functional connectivity indices as calculated following the framework methodology, showing before and after the addition of a major road development to the Footscray road and docklands area.

<table>
<thead>
<tr>
<th>Connectivity type</th>
<th>Number of connected areas</th>
<th>Total area (m²)</th>
<th>Connectivity Index</th>
<th>Effective Mesh Size</th>
<th>Total number of habitat patches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>Structural connectivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree canopy</td>
<td>254</td>
<td>263</td>
<td>2995812</td>
<td>2996130</td>
<td>413366</td>
</tr>
<tr>
<td>Functional connectivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insect pollinators</td>
<td>218</td>
<td>233</td>
<td>5391747</td>
<td>5386452</td>
<td>1056015</td>
</tr>
<tr>
<td>Aquatic insects</td>
<td>67</td>
<td>80</td>
<td>5339727</td>
<td>5320598</td>
<td>4148404</td>
</tr>
<tr>
<td>Amphibians</td>
<td>160</td>
<td>166</td>
<td>806932</td>
<td>801000</td>
<td>85804</td>
</tr>
<tr>
<td>Reptiles</td>
<td>263</td>
<td>271</td>
<td>3702962</td>
<td>3700756</td>
<td>537214</td>
</tr>
<tr>
<td>Woodland birds</td>
<td>199</td>
<td>212</td>
<td>4813553</td>
<td>4803433</td>
<td>4082976</td>
</tr>
<tr>
<td>Tree-hollow using birds</td>
<td>202</td>
<td>232</td>
<td>6313243</td>
<td>5406583</td>
<td>2985352</td>
</tr>
<tr>
<td>Tree-hollow using bats</td>
<td>159</td>
<td>164</td>
<td>3314490</td>
<td>3312432</td>
<td>1735761</td>
</tr>
</tbody>
</table>
Figure 3.3 Overview of the City of Melbourne showing the effect of a proposed road network on habitat patches of tree canopy (A) and on habitat patches for insect pollinators (B), aquatic insects (C), amphibians (D), reptiles (E), woodland birds (F), tree-hollow using birds (G) and tree-hollow using bats (H), classified by connected area. The road development is shown in red.
Figure 3.4 View of proposed major road development and the surrounding habitat patches of tree canopy (A) and for insect pollinators (B), aquatic insects (C), amphibians (D), reptiles (E), woodland birds (F), tree-hollow using birds (G) and tree-hollow using bats (H), classified by connected area. The road development is shown in red.
Figure 3.5 Overview of the City of Melbourne showing proposed tree canopy cover for nine precincts after the Urban Forest planting strategy. The biodiversity corridors (yellow) should have full tree canopy cover by 2023. Existing vegetation is shown in green.
Figure 3.6 Close up of the East Melbourne precinct biodiversity corridor showing the projected canopy cover (yellow) and additional garden beds (orange), overlaid on current vegetation (green).
Figure 3.7 Overview of the City of Melbourne showing the effect of the proposed biodiversity corridors on habitat patches of tree canopy (A) and on habitat patches for insect pollinators (B), aquatic insects (C), amphibians (D), reptiles (E), woodland birds (F), tree-hollow using birds (G) and tree-hollow using bats (H), classified by connected area.
Table 3.3 Structural (tree canopy habitat) and functional connectivity indices as calculated following the framework methodology, showing before and after the addition biodiversity corridors across nine City of Melbourne precincts.

<table>
<thead>
<tr>
<th>Connectivity type</th>
<th>Number of connected areas</th>
<th>Total area (m²)</th>
<th>Connectivity Index</th>
<th>Effective Mesh Size</th>
<th>Total number of habitat patches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>Structural connectivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree canopy</td>
<td>254</td>
<td>190</td>
<td>2995812</td>
<td>3747111</td>
<td>413366</td>
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<tr>
<td>Functional connectivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insect pollinators</td>
<td>218</td>
<td>156</td>
<td>5391747</td>
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<tr>
<td>Reptiles</td>
<td>263</td>
<td>192</td>
<td>3702962</td>
<td>3816040</td>
<td>537214</td>
</tr>
<tr>
<td>Woodland birds</td>
<td>199</td>
<td>184</td>
<td>4813553</td>
<td>6374639</td>
<td>4082976</td>
</tr>
<tr>
<td>Tree-hollow using birds</td>
<td>202</td>
<td>186</td>
<td>6313243</td>
<td>7862001</td>
<td>2985352</td>
</tr>
<tr>
<td>Tree-hollow using bats</td>
<td>159</td>
<td>146</td>
<td>3314490</td>
<td>4933477</td>
<td>1735761</td>
</tr>
</tbody>
</table>
Effect on tree-hollow using parrot functional connectivity

The connectivity index of habitat for tree-hollow using birds increased with addition of the proposed corridors (CBI 2 = 4,514,901 m²; EffMesh = 0.57427; Table 3.3), with only the Yarra River forming a significant barrier for this group (Figure 3.7E).

Effect on tree-hollow using bat functional connectivity

Tree-hollow using bat functional connectivity increased to CBI 2 = 3,978,200 m², with the probability of two bats in the landscape being in the same connected area rising from EffMesh = 0.52369 to EffMesh = 0.80637 (Table 3.3). After adding the biodiversity corridors, most of the City of Melbourne is considered to be part of the same connected area (Figure 3.7F).
Chapter 4

4.1 Caveats and limitations of our assessment

Although we have gone some way to investigate and quantify the existing structural and functional connectivity in the City of Melbourne, there are some important limitations to the indices presented here that we wish to acknowledge. These can be considered in two main groups: (1) the limitations of the connectivity index as a stand-alone measure, and (2) the assumptions made about the data used to calculate the connectivity index. Further exploration of the GIS layers included with this report will help to illustrate some of these problems, however we outline some of the important ones below.

The connectivity metric

It is important to recognise that the structural or functional connectivity index is not meaningful on its own – the meaning comes through comparisons. For example, it can be used to compare across municipalities, evaluate the likely impact of two competing development plans, or assess changes over time. How the connectivity index is interpreted relies also on viewing the spatial information used to generate the index; for example, the CBI 2 method calculates connectivity independently of the actual area of the habitat, so a landscape could be very connected (high index) but be made up of many small habitat patches.

Importantly, the index does not mean presence or absence of a species/group. The framework measures the connectivity of potentially suitable habitat for an animal, but cannot predict if the animal is actually present in any of those connected areas. Similarly, the method cannot inform which areas are particularly good or bad quality habitat, without further refining the spatial data characteristics at the start of the calculation.
Data resolution and accuracy

There are several key assumptions made when using this framework. These relate to either the spatial data or the information used to determine the functional connectivity parameters for a particular animal group. During this preliminary investigation we assumed that all GIS layers provided to us were accurate representations of land use categories currently existing in the City of Melbourne. We also assumed that where land use was described as ‘shrub bed’ each shrub bed contained viable habitat. A similar assumption was made regarding the ‘turf’ land use layer, however some areas classed as turf will be (for example, very closely mown sports pitches) not viable habitat for some species. Finally, the City of Melbourne does not exist as an isolated landscape; it is surrounded by other local government areas. This connectivity assessment only includes data from within the City of Melbourne, and does not consider the implications of land use classes in the broader metropolitan area. We are also missing information about land use classes within private gardens, where vegetation availability may lead to additional habitat areas not included in this study.

Some features of interest to The City of Melbourne such as green roofs and walls are very small, and hence unlikely to have contributed anything to the connectivity metrics calculated here. For example, the method used here does not impose a minimum patch size needed for particular taxa, however it is likely that patches only a few square metres in area could not be used as habitat for many taxa. Further, as features such a green roofs are on buildings they likely became ‘non-habitat’ in our analyses due to their height, proximity to roads, or both. Hence, further refinement of the nature of barriers and habitat would be needed in future studies to more fully assess the role of green roofs in contributing to connectivity in this area.

Functional connectivity parameters

In addition to the specialist knowledge shared among the co-authors of this report, we also consulted with several other biodiversity experts from the Melbourne area. This, along with the primary literature, helped us to decide on appropriate habitat and dispersal parameters for each of our seven functional groups (see Appendices I and III for more information). However, most of the information on species
dispersal has been gathered outside urban habitats, either in suburban or agricultural landscapes. Currently, there is relatively little information on how animal species may use urban environments. It is therefore possible that the dispersal abilities of each functional group have been over or underestimated in this assessment. This information is important to collect in the future and should be considered as a priority for future research in the City of Melbourne.

**Missed environmental considerations**

For the connectivity calculations demonstrated in the previous chapters we used basic habitat definitions (vegetation of different heights, the presence of water or tree hollows) and barriers (roads, buildings). However, there are other environmental considerations that should be included, particularly when calculating functional connectivity for an animal group. In terms of habitat, some animals may require more specific habitat types, such as proximity to refugia (for amphibians and reptiles), flowering plants (for insect pollinators) or indigenous/native vegetation. While we varied the classification of barriers according to road width, it may be that traffic volume plays a greater role in determining whether a given animal species/group will cross a road. For nocturnal species, the presence of artificial light at night may also create barriers to movement. It may also be that areas we have assumed were good habitat for a species are in fact unsuitable due to high levels of human activity (such as within a park). There will also be temporal variation (daily, weekly and yearly) in both habitat areas and perceived barriers, which will alter the connectivity of the landscape. By collecting other environmental data across the municipality, the accuracy of the functional connectivity calculations could be improved.

**Specificity: Species-specific habitat affinity and dispersal capabilities**

We took a species group approach for modelling functional connectivity in order to study a variety of different habitat requirements, potential barriers and dispersal capabilities. However, this means that the subtleties of different species within each group will be lost in the assumptions made about how those organisms behave. For example, European honeybees *Apis mellifera* will behave differently to Australian native bees such as blue-banded bees (Genus *Amegilla*; Figure
1.2), requiring different plant species; however, at the moment both species are considered broadly as ‘insect pollinators’.

Another important subtlety is that viable residency habitat is different to what may be considered a movement corridor (where species spend less time, using it just for dispersal). Because the threshold for road barrier width was set to a certain level (10 m) our assessment suggests that members of the insect pollinator group could disperse through residential areas (in particular through western Melbourne; Figure 2.7), despite there being limited habitat available (in the model they are able to cross the non-habitat gaps due to their dispersal capabilities). If road barrier width was set lower, this would not be the case.

An important next step for The City of Melbourne could be to test the accuracy of the mapped connected areas and validate their use by specific animal species/groups. This should be done by collecting data on species occurrences in mapped connected areas, validating the dispersal distances used here, and collecting further information on the barrier effects of roads and other urban stressors. This information can be then used to update the metrics calculated here and refine the input parameters.

4.2 Conclusion and considerations for future application

Conclusions

Understanding connectivity for multiple species at a landscape scale is a common goal in biodiversity management. However, with a myriad of methods available, and little scientific consensus, selecting the ‘right’ metrics and approaches is notoriously difficult. Each method has different pros and cons, data requirements and assumptions. Ultimately, the best approach for a given location is one that can effectively guide management actions. That is, one that takes into account the management context, the actions that are feasible, the scale at which these actions are implemented, and broadly represents the species/taxa of interest.

We believe the approach outlined in this work is appropriate for the City of Melbourne because it combines structural and functional aspects, is tailored to habitats managed by the municipality, and is broad enough to capture a wide range
of species. It has been developed based on an understanding of the recent scientific literature and connectivity metrics, extensive consultation with the City of Melbourne to ensure that it addresses key goals, and the amount of data available. We believe it is the right blend of approaches to support the City of Melbourne efforts to increase animal biodiversity connectivity in the future. We welcome further discussion and feedback from the City of Melbourne to refine the approach, and ensure that the end product is fit for purpose.

How to use the connectivity framework

The primary aim of this project is to provide a working framework by which connectivity can be calculated for the municipality, in an easy and repeatable way. This report contains both a detailed methodology (Appendix I) and worked examples in order to facilitate repeated calculations for a variety of different management planning applications, both positive and negative. Below we outline the advantages of using this framework to investigate existing and potential connectivity within the City of Melbourne, and also how it can be used as a management tool. We hope that this framework, along with further data collection and development can be used to evolve an ecological connectivity plan for the City of Melbourne.

Use of the index - structural vs functional

We would advocate the evaluation of functional connectivity where possible, over structural connectivity, as it is more specific and, hence, useful to The City of Melbourne. However, for international comparisons, using common definitions of habitat, barrier and distance thresholds as in the CBI (a structural connectivity assessment) would be an appropriate approach.

Use the framework to assess proposals/guide actions

Things to consider when using this framework:

Identify goals – In particular what species or habitat type is the focus? This dictates which data will be used.

Compare different options for functional connectivity parameters, such as barrier definitions (e.g. how wide or how busy are road barriers?).
Validate the chosen habitat by ground truthing (i.e. what habitat is currently being used by that species in the city of Melbourne).

Add in species distribution data for a more accurate baseline evaluation of current connectivity.

Explore sensitivity by varying the species dispersal capabilities incrementally.

Identifying opportunities

Visually exploring the connected areas in GIS software will allow the identification of potential places for future management actions. Put simply, habitat (coloured by connected area ID) switching from one connected area to another will occur across a large gap or significant barrier. These areas can be identified from the maps, where the colours change. The framework can evaluate adding small pieces of habitat (such as corridors, green laneways, green roofs or pop-up parks) in these strategic areas.

Remember that increasing connectivity for one group can have unseen additional effects. This could be increased connectivity for less desirable species, potentially encouraging the movement of invasive animals across the urban landscape.


Appendix I: Detailed methodology

The following methodology is adapted from the City Biodiversity Index Indicator #2 calculation as improved by Deslauriers et al. (2017). Initially, structural connectivity measures were calculated using the same parameters as Deslauriers et al. (2017). Functional connectivity was then determined for the seven key animal groups by varying the habitat requirements or assumed dispersal capabilities for each group (similar to methods used by Casalegno et al. (2017)).

**Structural connectivity**

Following methodology outlined by Deslauriers et al. (2017). A rough summary of this as follows:

1. Buffer around areas of ‘natural habitat’ (e.g. 50 m);
2. Remove any ‘barriers’ from this layer (e.g. roads > 10 m wide);
3. With remaining buffered habitat, use GIS software to identify connected areas and the original habitat within them; and
4. Calculate area of connected habitat patches, and then apply the improved City Biodiversity Index indicator #2 (CBI 2) equation to estimate the connectivity index and effective mesh size (i.e. the probability that two points dropped at random into the landscape will be connected).

The improved CBI 2 equation is reproduced from Deslauriers et al. (2017).

\[
\text{CBI 2} = \frac{1}{A_{\text{total}}} (A_{G1}^2 + A_{G2}^2 + A_{G3}^2 + \ldots + A_{Gn}^2)
\]

Where \( n \) is the number of connected areas; \( A_{G1}^2, A_{G2}^2, A_{G3}^2 \ldots \) indicate the size of each connected area; and \( A_{\text{total}} \) is the total area of
Table A1.1 General step-by-step methodology for calculating connectivity index from Deslauriers et al. (2017) and Jaeger et al. (2008). NB after each step a new layer is made, which is then used in subsequent steps.

<table>
<thead>
<tr>
<th>Step/sub-step</th>
<th>Method</th>
</tr>
</thead>
</table>
| 1. Prepare habitat layers | Unify habitat layers (you may also like to dissolve after each union to limit file size) 1  
Geoprocessing tools > Union > Input the two layers you wish to combine 2 |
| Buffer habitat layers | Buffer & dissolve habitat layers  
Geoprocessing > Buffer > Distance value is half the dispersal distance for your species. |
| 2. Prepare barrier layers | Unify barrier layers (you may also like to dissolve after each union to limit file size) 3  
Geoprocessing tools > Union > Input the two layers you wish to combine |
| Buffer barrier layers | Buffer & dissolve barrier layers 4  
Geoprocessing > Buffer > Distance value is 7.5m |
| 3. Create fragmentation geometry | Erase barriers from the habitat layer  
Input layer = final buffered habitat layer 5  
Clip layer = final buffered barrier layer  
Geoprocessing > Clip |
| 4. Identify connected areas | Find remaining connected patches  
Input layer = buffered habitat AFTER barrier removal 6  
Geoprocessing > Arc Toolbox > Data Management Tools > Features > Multipart to singlepart |
| Identify connected areas | Right click on the layer created in this step, open attribute table and toggle editing on 7  
Open “field calculator” and “create new field” using “row_number” function. |
| 5. Identify connected habitat patches | Intersect original habitat layer with identified connected areas  
Inputs = layer created in step 4 & original habitat layer (made up of combined habitat types) 8  
Geoprocessing > Intersect |
| 6. Calculate area and export | Calculate area of each patch  
Right click on the layer created in Step 5. Open attribute table and toggle editing on 9  
Open “field calculator” and “create new field” using "area” function. |
| Export attribute table to “.csv” | Right click on layer name in layers panel and select “save as”. Make sure to select csv file type 10 |
Table AI.1 (Cont.)

<table>
<thead>
<tr>
<th>Step/sub-step</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Connectivity calculation</td>
<td>Spreadsheet should include a column with patch ID and area.</td>
</tr>
<tr>
<td>Calculation of (area)$^2$</td>
<td>Calculate square of patch area for each habitat patch (i.e. for the whole column of data).</td>
</tr>
<tr>
<td>Calculation of connectivity index (CBI 2)</td>
<td>Connectivity index = SUM of squared connected patches/SUM of original habitat area</td>
</tr>
<tr>
<td>Calculation of effective mesh size (EffMesh)</td>
<td>Effective mesh size = Connectivity index/SUM of original habitat area</td>
</tr>
</tbody>
</table>

1 If using more than one habitat layer, combine them to form one layer. E.G. grass AND trees. Do this step as many times as needed to combine 3+ layers.
2 Habitat classed as “connected” if it is less than the dispersal distance apart. Patches closer than this will merge.
3 Combine the different types of barrier together to make single layer. E.G. roads AND buildings
4 Barriers such as roads may have an effect on the habitat around them. Buffer accordingly
5 The barriers prevent movement, even in patches that are connected, so erase the connected habitat
6 Checks which of the buffered habitat areas are still connected and which are now on their own.
7 Gives each area that remained connected a unique number in a new field. Call the new field something sensible like “patchID” or “patch_number”
8 Links each original habitat patch with its related connected area so that connected patches of habitat are grouped together
9 This step calculates the actual area of each connected habitat patch. A patch is a collection of smaller pieces of habitat that classed as connected due to their proximity/lack barriers
10 The final calculation is done in Excel
all habitat patches in the landscape. The unit of measurement used in this study is m$^2$. For more information about the connectivity calculation and effective mesh size consult Jaeger (2000) and Jaeger et al. (2008).

Three separate structural connectivity indices were calculated for different vegetation types: herbaceous plants, midstorey and tree canopy. The separate habitat areas were defined by combining land use polygons (e.g. shrub bed, turfed areas or tree locations) and vegetation height classes derived from LiDAR data.

Herbaceous plant layers: LiDAR herbaceous plant layers (vegetation height class 0-50 cm)

Midstorey layers: LiDAR mid-storey layers (height 50-300 cm) and shrub bed land use layer from City of Melbourne.

Tree canopy layers: LiDAR canopy layers and open source canopy layer combined.

**Functional connectivity**

The determination of functional connectivity was very similar to the methodology followed for structural connectivity, except ‘habitat’ and ‘barriers’ are defined more explicitly according to each animal group. In addition, the dispersal distance differs for each group, ranging from 350 m to 1500 m. These values were taken from the primary literature for the example or related species.

Following the combination of Casalegno et al. (2017) and Deslauriers et al. (2017) methods (as summarised above), a rough rubric for creating connectivity maps and calculating their corresponding indices is to:

1. Decide what habitat the ‘animal’ needs;
2. Buffer this habitat according to dispersal capabilities;
3. Remove habitat that coincides with barriers; and
Table A1.2 The seven animal groups used to define different calculations of functional connectivity within the City of Melbourne.

<table>
<thead>
<tr>
<th>Group</th>
<th>Ideal habitat requirements</th>
<th>Barriers</th>
<th>Median dispersal distance (m)*</th>
<th>Example taxa</th>
<th>References</th>
<th>Land use Layers included in model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insect pollinator</td>
<td>Mid-storey, Shrub bed, Trees, Turf &lt; 25m from shrub/trees</td>
<td>Roads &gt; 10m width</td>
<td>350</td>
<td>Blue-banded bee <em>Amegilla chlorocyanea</em></td>
<td>Stevens et al 2012; Haddad 1999</td>
<td>LiDAR mid-storey, Shrub beds, Canopy, Turf or LiDAR Grass &lt;25m from cover.</td>
</tr>
<tr>
<td>Aquatic insect</td>
<td>Ponds, Vegetation &lt; 500m from water</td>
<td>Roads &gt; 10m width</td>
<td>1500</td>
<td>Blue skimmer <em>Orthetrum caledonicum</em></td>
<td>Theischinger &amp; Hawking 2006;</td>
<td>All water features and rivers. LiDAR midstorey, Shrub beds, LiDAR grass or Canopy within 500m of water.</td>
</tr>
<tr>
<td>Amphibian</td>
<td>Ponds, Understorey vegetation &lt; 10m from water</td>
<td>Roads &gt; 5m width, All buildings</td>
<td>1000</td>
<td>Spotted marsh frog <em>Limnodynastes tasmaniensis</em></td>
<td>Heard et al 2012; Hale et al 2013</td>
<td>Water features, Moonee Ponds Creek and turf/grass/shrubs within 10m of water.</td>
</tr>
<tr>
<td>Reptile</td>
<td>Mid-storey cover, Shrub bed, Grass</td>
<td>Roads &gt; 5m width, All buildings</td>
<td>1000</td>
<td>Eastern blue-tongued lizard <em>Tiliqua scincoides</em></td>
<td>Koenig et al, 2001; Souter et al, 2007</td>
<td>LiDAR mid-storey, Shrub beds, LiDAR grass, Turf.</td>
</tr>
<tr>
<td>Woodland bird</td>
<td>Mid-storey cover, Trees, Turf &lt;10m from cover</td>
<td>Roads &gt; 15m width, Buildings &gt;10m</td>
<td>1500</td>
<td>Superb fairywren <em>Malurus cyaneus</em></td>
<td>White et al 2005; Watson et al 2001</td>
<td>LiDAR mid-storey, Shrub beds, Canopy, Turf or LiDAR Grass &lt;10m from cover.</td>
</tr>
<tr>
<td>Tree-hollow using</td>
<td>Tree hollows, Trees &lt; 1000m from hollows, Turf &lt; 500m from hollows</td>
<td>Roads &gt; 15m width, Buildings &gt;10m</td>
<td>500</td>
<td>Red-rumped parrot <em>Psephotus haematonotus</em></td>
<td>Lowry &amp; Lill 2007; Lees &amp; Peres 2009</td>
<td>Tree hollows and canopy within 1000m of hollows. Turf less than 500m from hollows.</td>
</tr>
<tr>
<td>Tree-hollow using bat</td>
<td>Tree hollows, Canopy &lt; 250m from hollows</td>
<td>Roads &gt; 15m width, Buildings &gt;10m</td>
<td>1000</td>
<td>Gould’s wattled bat <em>Chalinolobus gouldii</em></td>
<td>Lumsden et al 2001; Wilson 2013</td>
<td>Tree hollows and canopy within 250m of hollows.</td>
</tr>
</tbody>
</table>

*Gap crossing ability, smallest mean home range/minimum mean dispersal distance
4. Divided the remaining habitat into patches according to whether these are connected or not.

The seven animal groups used in this report were determined during the ‘Species Selection Workshop’, 11th August 2017. The details of the habitat requirements and movement parameters for each functional connectivity group were further refined using the primary literature. Please refer to Appendix III for more information on parameter selection. Table Al.2 summarises the essential habitat, barriers and average dispersal distance for each functional connectivity group. Where OR is used, the assumption is that the animal will freely move between these habitats, but outside this enters the regular matrix of ‘non-natural area’ and begins crossing a ‘gap’ which relates back to the dispersal capabilities. Full details of each specific habitat layer and treatment are provided in Appendix II.
Appendix II: List of GIS layers

*Base map data layers*
- All water features
- All building footprints
- All property footprints

*Barrier layers*
- All buildings
- Buildings > 10 m height
- Roads > 5 m width
- Roads > 10 m width
- Roads > 15 m width
- Impervious edge of the City of Melbourne, buffered by 7.5 m
- Roads > 5 m width buffered by 7.5 m
- Roads > 10 m width buffered by 7.5 m
- Roads > 15 m width buffered by 7.5 m

*Tree canopy habitat*
- Tree canopy 2016
- Canopy buffered by 2 m (small buffer to remove layer errors, used as original habitat patches)
- Canopy buffered by 50 m
- 50 m buffered canopy with 10 m road and edge removed
- 50 m buffered canopy with barriers removed, connected areas identified
- Original canopy habitat, patches identified by connected area
- Excel file containing patch area information, plus connectivity calculation for canopy

Buildings > 10 m height buffered by 7.5 m
- All buildings buffered by 7.5 m
**Midstorey habitat**

‘Shrub bed’ layer

Midstorey layer

LiDAR midstorey (50-100 cm height)

Combined shrub bed, midstorey and LiDAR midstorey (buffered by 2 m to remove errors used as original habitat)

All midstorey habitat, buffered by 50 m

50 m buffered midstorey, with 10m road and edge removed

50 m buffered midstorey, with barriers removed, connected areas identified

Original midstorey habitat, patches identified by connected area

Excel file containing patch area information, plus connectivity calculation for midstorey habitat
Appendix III: Functional connectivity parameters

References for functional information (i.e. dispersal distances and habitat selection):

**Insect pollinators:** Stevens et al. (2012) and Haddad (1999).

**Aquatic insects:** Theischinger & Hawking (2006).

**Amphibians:** Heard et al. (2012) and Hale et al. (2013).

**Reptiles:** Koenig et al. (2001) and Souter et al. (2007).

**Woodland birds:** White et al. (2005) and Watson et al. (2001).

**Tree-hollow using bird:** Lowry & Lill (2007) and Lees & Peres (2009).

**Tree-hollow using bat:** Lumsden et al. (2001) and Wilson (2013).
Appendix IV: Glossary of terms

Connected Area
Dispersal distance
Functional connectivity
Habitat Patch
Structural connectivity
Wildlife connectivity