Australian Government
Bureau of Meteorology

What can landscape vegetation connectivity tell us about ecosystem operation?

Evidence domain map: preliminary findings from an exemplar evidence base for framing an environmental ecosystem account

evidentiary

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Contents

Glossary

Term	Meaning
Ecosystem asset	An ecosystem asset is an ecosystem that may provide benefits to humanity. They are spatial areas containing a combination of biotic and abiotic components and other characteristics that function together. A subset of environmental assets with an emphasis on the living systems. They are environmental assets seen from a systems perspective according to the SEEA-EEA (Bureau of Meteorology, 2013).
Ecosystem capacity	The capacity to supply ecosystem goods and services to humans, whether or not humans are currently consuming the goods and services. Estimating ecosystem capacity depends on knowing the objectives for the ecosystem including sustainability objectives. For example, the capacity of an ecosystem (measured by extent and condition or quantity and quality) is different depending on whether it is being managed for sustainable forestry, sustainable conservation, or sustainable agriculture (Bureau of Meteorology, 2013).
Ecosystem characteristics	'Ecosystem characteristics relate to the ongoing operation of the ecosystem and its location. Key characteristics of the operation of an ecosystem are (i) its structure (e.g., the food web within the ecosystem), (ii) its composition, including living (e.g., flora, and micro-organisms) and non-living (e.g., mineral soil, air, sunshine and water) components, (iii) its processes (e.g., photosynthesis, decomposition) and (iv) its functions (e.g., recycling of nutrients in an ecosystem, primary productivity). Key characteristics of its location are (i) its extent, (ii) its configuration (i.e., the way in which the various components are arranged and organised within the ecosystem), (iii) the landscape forms (e.g., mountain regions, coastal areas) within which the ecosystem is located and (iv) the climate and associated seasonal patterns. Ecosystems also relate strongly to biodiversity at a number of levels. For this reason ecosystem characteristics include within and between species diversity and the diversity of ecosystem types.' (European Commission et al. 2013).
Ecosystem operation	Key characteristics of the operation of an ecosystem are its structure, composition, processes and functions (European Commission et al., 2013 and see 'ecosystem characteristics' above for more detail).
Evidence base	A carefully structured electronic database of evidence relating to specific questions or assumptions of management relevance. For environmental accounting purposes the evidence base represents the body of evidence which is relevant to the account topic and of sufficient quality, used to underpin the account conceptual models and provide the account with credibility and legitimacy. (R. Richards, pers. comm., 2014).
Evidence domain map	A broad search to ascertain what evidence exists and what gaps there may be about a topic in order to inform and direct future research or evidence collation in the area.
Landscape connectivity	The degree to which the landscape facilitates or impedes movement among patches (Hansson 1991).
Landscape vegetation connectivity (LVC)	The measure of the physical connectedness of the vegetation across a landscape that potentially influences the movement of genes, propagules, individuals and populations. It includes the landscape scale connectedness maintained within large patches of vegetation as well as that related to vegetation corridors and stepping stones. It is sometimes referred to as 'structural vegetation connectivity' (typically measured using remote sensing methods) to distinguish it from 'ecological connectivity' (usually measured through on-ground observations and analysis). (R. Mount, pers. comm., 2014).

1 Introduction

The National Plan for Environmental Information (NPEI) was established in 2010. The NPEI was seen by the Australian Government as a tool for improving the quality and coverage of environmental information in Australia. Good environmental information is essential to improve our understanding, management and prediction of environmental change, human impacts and our management responses. This understanding is core to a healthy environment, society and economy.

While humanity has developed sophisticated accounting systems to measure economic activity (such as the National System of Accounts), environmental activity has not been measured in a comparably sophisticated fashion. Furthermore, there has traditionally been an 'information silo' approach where environmental and economic information has been stored separately, despite the fact that the economy and the environment are heavily intertwined. The lack of consistent, comparable and integrated statistical standards for economic and environmental information has meant that it has been difficult to compare the impacts that economic activity has on the environment and vice versa (European Commission et al., 2013).

The *System of Environmental-Economic Accounting Experimental Ecosystem Accounting* (SEEA–EEA) aims to address both of these deficiencies with regard to environmental information. It has been designed as a way 'to obtain a better measurement of the crucial role of the environment as a source of natural capital and as a sink of by-products generated during the production of man-made capital and other human activities (United Nations Statistics Division, 2014).' As well as providing a statistical framework to track changes in ecosystem assets, allowing them to be measured, it also enables these changes to be linked with economic accounting systems (European Commission et al., 2013).

Between 2011 and 2014, the Bureau of Meteorology had the role of developing approaches to environmental accounting. As part of that role the Bureau worked on exemplar SEEA–EEA accounts to demonstrate how SEEA–EEA could be used within Australia. Further, the Bureau established the basic processes and frameworks for environmental accounting, including a series of guidelines and workbooks to assist those framing and publishing environmental accounts.

The Bureau's environmental accounting role ceased in mid-2014 and this study has been released to ensure the key documents remain publically available.

The subject for a demonstrator SEEA–EEA account was landscape vegetation connectivity (LVC). While the LVC account was not being framed for any specific policy application or, at this stage, for actual production, it was aligned with, and relevant to, multiple activities by a wide range of environmental management agencies (e.g. Fitzsimons et al., 2013). The particular exemplar evidence base presented here contributes to the Bureau's guidelines on evidence-based conceptual modelling for environmental accounting purposes.

LVC was selected for the exemplar account subject for two reasons. Firstly, vegetation connectivity is a core characteristic of an ecosystem, integral to the conservation of biodiversity, regulating climate and providing other ecosystem services such as timber, water catchment protection and erosion control (Fitzsimons et al., 2013). Secondly, and crucial for the purpose of creating an environmental account, landscape vegetation connectivity can be measured and reported in account tables.

In order to provide credibility and legitimacy, an evidence base of best available scientific knowledge relating to the account subject was developed in accordance with the requirements outlined in Module 4 of the *Environmental account framing workbook* (Bureau of Meteorology, 2013). This exemplar evidence base underpins the conceptual models of the exemplar account and was developed using a systematic approach to the search, collation, assessment and extraction of evidence.

The associated technical guide (the main document) was developed to assist with creating evidence based conceptual models for environmental accounting purposes. This guide should be referred to for further details on the method used for the development of the exemplar evidence base.

The development of the exemplar evidence base provided many valuable lessons around the process and need for good science to underpin environmental accounting. The development of future accounts will benefit from these lessons.

1.1 Purpose of the exemplar evidence base

An exemplar evidence base for an environmental account on landscape vegetation connectivity was developed based on the question 'How does landscape vegetation connectivity influence the characteristics (operation, location and biodiversity) of an ecosystem asset, and its capacity to deliver ecosystem services?' (Please see the Glossary for more details on the definitions of the terms used here, many of which are consistent with the SEEA–EEA.

In response to this question the following requirements were set:

1. develop and produce an exemplar evidence base for the Bureau of Meteorology,
2. summarise the character of the items in the evidence base in a report, and
3. deliver the evidence base using the Zotero software.

These requirements were met and this report is the summary of the character of the items in the evidence base developed as per the first requirements and delivered as per the third requirement.

Given the broad nature of the question related to the account subject, an initial broad search or 'evidence domain mapping' was completed that will support the development of the main account subject conceptual model. Completing sub-searches on more specific aspects of how landscape vegetation connectivity influences an ecosystem asset was then discussed with a view to supporting the development of specific ancillary conceptual models. Due to time and budget constraints this more detailed work was left to a later stage.

The resulting evidence base can be best described as an 'evidence domain map' as a more general search phrase was used in order to gain a sense of the evidence that was available on this broader topic. Figure 1 was informed by the evidence domain map, and consists of a cause and effect network diagram of changes to ecosystem operation in respect to habitat and biodiversity from measured gross changes in landscape vegetation connectivity. Based on this evidence mapping, more detailed evidence can be assembled with improved confidence.

Now that the evidence base for the evidence domain map has been completed for the landscape vegetation connectivity account, the next steps in the process are to:

- develop evidence bases for important relationships in the cause and effect network diagram (Figure 1) to support the production of prioritised ancillary conceptual models;
- provide the evidence and models to a science synthesis workshop, where experts will synthesise the evidence to develop new knowledge;

- use the synthesis and findings of the workshop to refine the models; and
- use the finished models and evidence synthesis findings in order to underpin the landscape vegetation connectivity environmental account.

1.2 Method overview

Given the importance of the evidence base in providing credibility and legitimacy to the account, it is vital that the evidence base is developed and maintained in a manner that is comprehensively representative, transparent, robust and that follows a systematic process. The conceptual framework is provided by the *Guide to environmental accounting in Australia* and the associated *Environmental account framing workbook* (Bureau of Meteorology, 2013). More specifically, the *Methods for evidence-based conceptual modelling in environmental accounting: a technical note* (Bureau of Meteorology, 2014) provides a step by step process for developing an evidence base in this manner under 'The process of developing an evidence base.'

A concise version of this process was used to develop the evidence base. It consisted of three distinct phases outlined below.

Phase 1: Planning

- Define and prioritise questions, through establishing a set of candidate questions surrounding the account and prioritising the most appropriate questions for evidence search and collation.
- Create a draft evidence base structure from the priority questions.
- Develop a search strategy for each priority question. See Appendix 2 for an outline of the search strategy used, which includes the relevant search terms, search strings, search sources and relevance criteria including inclusion and exclusion criteria.

Phase 2: Search

- Execute the search using the scientific literature databases Science Direct, Web of Science and CSIRO Publishing. Other databases searched included TROVE and Google Scholar.
- Filter the search returns for relevance based on title and later on abstract using the inclusion and exclusion criteria outlined in Appendix 2. On reading the abstract, non-relevant items will be removed from the evidence base.
- Obtain full text from free sources where possible and also purchase or access full text through the Bureau.

Phase 3: Evidence familiarisation and reporting

- Develop the data extraction spreadsheet, which is designed to capture all relevant information from the studies that will be used for the final synthesis. Ensure that the Bureau's project team agrees upon with the spreadsheet's field headings.
- Deliver a report that summarises the general findings from the evidence base (this report).

In addition to these three phases, the following tasks were completed:

- The data extraction spreadsheet was populated with the relevant information from each evidence item.
- The main account subject conceptual model developed for the guidelines was validated using the evidence from the data extraction spreadsheet.

1.3 Limitations

The evidence base developed was atypical in that it was an exemplar evidence base designed to demonstrate what an environmental account evidence base may look like, and how to go about developing one for environmental accounting purposes. Consequently, there was no specific driver for the account and no identifiable end user. The question around which the search strategy was developed was broad and was not anchored in any specific ecosystem or in any specific relationship outlined in the cause and effect diagram. The timeframe was tight, being two months from project commencement to completion.

This resulted in a number of outcomes. Firstly, the search conducted was not as representative or comprehensive as would normally be undertaken for an evidence base with a more defined topic area. Only one general search string was used within five databases. Given the generality of the account subject, the evidence uncovered was similarly broad, and the resulting evidence base is better characterised as an 'evidence domain map' of the topic 'landscape vegetation connectivity.' An evidence domain map uses a broad search to ascertain what evidence exists and what gaps there may be on a topic in order to inform and direct future research or evidence collation in the area.

Additionally, there were some changes to what information was to be sought from the evidence during the project. In the early search phase, studies discussing spatial metrics were deemed relevant and preferable, and the search was restricted to case studies between 2004 and 2014. At the data extraction stage, the core question of the evidence became 'what does landscape vegetation connectivity allow us to know about ecosystem operation?' which is more appropriately answered by theory than by case studies related to spatial metrics. It was able to respond in part to the new core question as many of the case studies in the evidence base discussed the question in the introduction section, making reference to theoretical and broader review papers. However, many of the theoretical papers and reviews were published prior to 2004 and so are not captured in our search due to the date exclusion criteria.

When developing evidence bases for future environmental accounts, it is recommended to involve experts in the account topic from the beginning of the search process, including peer reviewing the search strategy. In this case, doing so would likely have alerted us to the understanding that we needed to include the term 'functional connectivity' in our search string, and some of the issues including that of the case study and date restrictions might have been avoided.

2 Summary of findings

2.1 Key messages

There are things that LVC can tell us about ecosystem operation, including:

- exposure or vulnerability to threats of some species
- habitat opportunities for some species
- opportunities for dispersal and gene flow
- opportunities for movement in response to threats (including climate change)
- species diversity or composition.

There are things that LVC cannot always tell us about ecosystem operation, including:

- functional connectivity (measures of actual ecological connections and interactions)
- habitat quality
- the long term impacts of past and current fragmentation on an ecosystem.

3 Findings

It should be noted that the findings are not based on a fully comprehensive synthesis of evidence. The intent is to provide a sound scoping study ensuring a comprehensive search of available electronic literature to inform the findings. An intensive search of individual organisations and contacting of targeted authors for unpublished literature would require additional resources. The search did however provide a sample of evidence using a systematic and transparent approach. Over 300 evidence items (from several thousand search returns) have been assessed for relevance and are stored in the Bureau of Meteorology evidence library. A final 107 were deemed relevant and used as the basis for this report (see the evidence base reference list). The search result statistics can be seen in Appendix 1.

Landscape and vegetation condition attributes

It is important to acknowledge that landscape vegetation connectivity is not a one-to-one surrogate for the condition of an ecosystem and how well it is operating. For example, Oliver et al., 2007 analysed the knowledge and opinions of 31 Australian ecologists on the ecosystem attributes considered most important as biodiversity surrogates, and those that were considered most feasible to assess. Experts considered that, on average, landscape context attributes should contribute approximately one-third (0.36) to an assessment of within-vegetation-type species-level biodiversity status, while vegetation condition attributes should contribute the remaining two-thirds (0.64). A minimum set of 11 compositional, structural and functional vegetation condition attributes were identified which include richness of native trees, cover of native trees, shrubs and perennial grasses, cover of exotic shrubs, perennial grasses, legumes and forbs, cover of organic litter, recruitment of native tree/shrub saplings, native tree health, tree hollows and evidence of grazing. The results presented below seek to map the evidence domain for what landscape vegetation connectivity can and cannot tell us about the operation of ecosystems within the context of establishing measurements suitable for use in an environmental account.

3.1 What can landscape vegetation connectivity tell us about ecosystem operation?

The cause and effect diagram in Figure 1 illustrates the reviewed evidence – that landscape vegetation connectivity (and changes to it) results in a wide range of changes to ecosystem operation (structure, composition, function and process) in reference to habitat and biodiversity. The evidence is grouped by the type of ecosystem operation change that has been studied. The model has a set of numbered cause and effect relationships. The evidence is organised in the library according to these numbered relationships and in the table in section 3.2 of this report following Figure 1.

The evidence shows that a key advantage of landscape metrics is that they are relatively simple and quick to calculate. This is important for environmental accounting, given that rapid environmental change requires the use of indicators that are easy and efficient to obtain (Uuemaa, et al., 2013). Approximately 16 studies in the evidence base focused on measuring the spatial pattern of the landscape and vegetation at different scales. A large variety of methods exist to measure landscape connectivity. Some of the more common spatial metrics include the use of aerial photographs, satellite images, Landsat and state wide vegetation maps. Some studies critiqued commonly used existing metrics and developed their own, including the Integral Index of Connectivity (Pascual-Hortal and Saura, 2006), Ecological Connectivity Index (Pino and Marull, 2012) and a combination of graph theory with models of land cover permeability and least cost analysis (Rubio et al., 2012). However, landscape vegetation connectivity is not only relatively easy to measure, significantly, it can tell us a number of important things about ecosystem operation in terms of habitat and biodiversity. This includes whether some species may be exposed or vulnerable to threats, experience increased or reduced habitat opportunities, have the ability to disperse and allow gene flow and have opportunities to move in response to threats such as climate change. Knowledge about landscape vegetation connectivity can also tell us something about overall species or community diversity or composition.

Exposure or vulnerability to threats of some species

Landscape vegetation connectivity can indicate whether particular species may be exposed to threats from predators or invasive species. In a Canadian study examining whether non-native invasive species were more abundant in grasslands adjacent to roads or railways than in dense forest, support was found for the notion that transportation corridors might encourage invasive species (Hansen and Clevenger, 2005). In an urban context, a study of green corridors in North Carolina found that the nests of certain birds were more exposed to mammalian nest predators as the width of the corridor decreased and where the matrix contained fewer buildings (Sinclair et al., 2005).

Habitat opportunities for species (increased or reduced)

Changes in landscape vegetation connectivity can result in increased habitat opportunities for some species and reduced habitat opportunities for others (Amici et al., 2010, Baranyi et al., 2011, Biro et al., 2013, Boykin et al., 2013, Carthew et al., 2013, Cord et al., 2014, Goetz et al., 2009, Kadoya and Washitani, 2011, Lloyd and Marsden 2008, Shanahan and Possingham, 2009). A study of bird species richness in *Polylepis* woodland patches and agricultural matrix habitats in the Peruvian Andes illustrates this. Around half the bird community, including fourteen threatened or restricted range species, were dependant on *Polylepis* habitat and most had very narrow niches, thus their habitat opportunities were reduced by fragmentation. Conversely, the interface between the *Polylepis* patches and the surrounding matrix was dominated by invasive ecological generalists, whose habitat opportunities increased with *Polylepis* woodland fragmentation (Lloyd and Marsden, 2008).

Opportunities for dispersal and gene flow

Landscape vegetation fragmentation can lead to small and isolated pockets of species, which through inbreeding and subsequent loss of genetic diversity can become more vulnerable to environmental change and be at a higher risk of extinction. Ensuring the connectivity of landscapes to allow species dispersal and gene flow is therefore critical to effective and long term conservation management (Baguette 2013, Braunisch et al., 2010, Chetkiewicz and Boyce 2009, Coulon et al., 2004, Harvey et al., 2005, Spear et al., 2010, Amos et al., 2012, Beier and Gregory 2012, Coates et al., 2007, Cousins 2006, Ferreira et al., 2013, McRae and Beier 2007, Mellick et al., 2011, Sork and Smouse 2006, Townsend and Levey 2005, Wang et al., 2008). Primary conservation interventions to increase landscape connectivity and thus dispersal and gene flow opportunities are corridors and stepping stones. Some studies that examined this include that of Townsend et al., 2005, where results suggested that corridors do facilitate pollen transfer in fragmented landscapes, and Tucker and Simmons, 2009, where the establishment of Donaghy's Habitat Linkage in Queensland's Atherton Tablelands linking two large habitat areas has noticeably increased the dispersal and colonisation of a subset of native species.

Opportunities to move in response to threats (including climate change)

Where landscape vegetation is fragmented, organisms may be prevented from escaping areas that are dangerous or no longer habitable due to new environmental conditions. Appropriate landscape vegetation connectivity therefore ensures that any necessary movement is possible (Beier et al., 2008, Ewers and Didham, 2006, Hoebinger et al., 2012, Koen et al., 2010, Lai, et al., 2011, Magrach et al., 2012, McRae et al., 2012, Theobald et al., 2011, Watts and Handley 2010, Williams and Snyder 2005, Winfree et al.,2005, Vallecillo et al., 2009). Designing and maintaining corridors and linkages is the most commonly recommended strategy for biodiversity conservation in the 21st Century in light of climate change. In their study of corridors in Arizona, USA, Brost and Beir, 2011 note that a network of linkages connecting multiple habitat areas will more effectively assist species to respond to climate change than individual linkages promoting short-term movements between separated habitat areas. They claim that a network of linkages is better suited to enable a long-term shift in species range by facilitating repeated species movements (Brost and Beier, 2011).

Species diversity or composition

How a species is impacted by changes to landscape vegetation connectivity in terms of exposure to threats, increased or reduced habitat opportunities, opportunities for dispersal and gene flow and opportunities to move in response to threats will ultimately affect the diversity and composition of that species (Crooks et al., 2011, Lindborg and Eriksson, 2004, Panzacchi et al., 2010, Sirami, et al., 2010, Vallecillo et al., 2009, Mita et al., 2007, Amos et al., 2012, Beier and Gregory 2012, Coates et al., 2007, Cousins 2006, Ferreira et al., 2013, McRae and Beier 2007, Mellick et al., 2011, Sork and Smouse 2006, Townsend and Levey 2005, Tucker and Simmons 2009, Wang et al., 2008). In their study of landscape connectivity at the community level for semi-natural herbaceous patches in an urban area near Paris, France, Muratet et al., 2013 demonstrated that landscape connectivity is related to the species composition of communities, finding a strong influence from landscape connectivity on the species composition of the plant community that was studied, indicating that strongly-linked patches exhibit

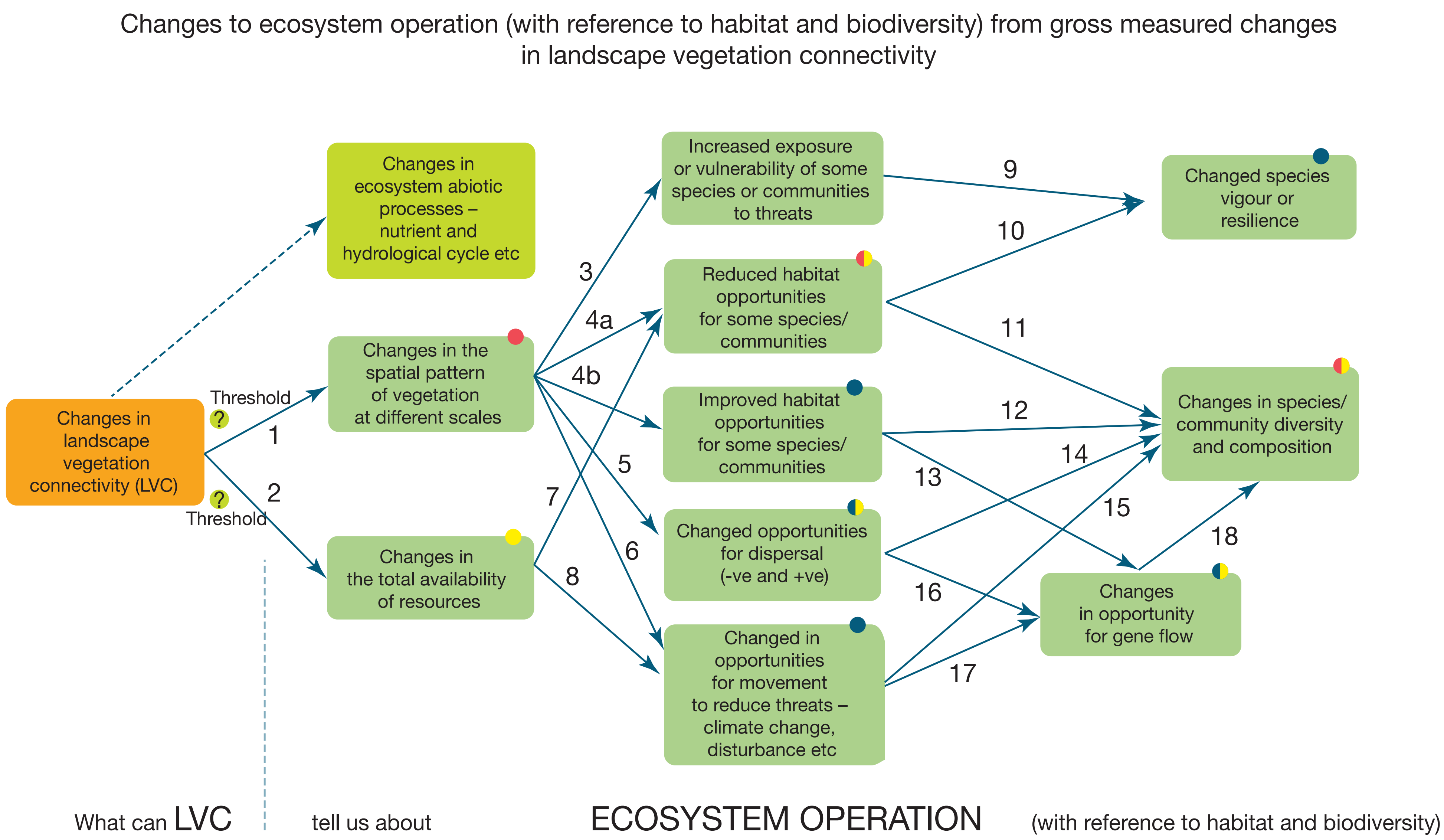

Figure 1. Cause and effect network diagram

This diagram relates changes to ecosystem operation (structure, composition, process and function), with reference to habitat and biodiversity, to measured gross changes in landscape vegetation connectivity (LVC). Changes to ecosystem operation characteristics are shown by the coloured dots. Red = structure, Yellow = composition, Red/Yellow = structure and composition, Blue = function, Blue/Yellow= function and composition.

3.2 Evidence for model relationships

Relationship numbers	References	Potential Measures
1	Ferraz, et al., 2005, Hamberg, 2009, Lira, et al., 2014a, Lunt, et al., 2010. Malavasi, et al., 2013, Pascual-Hortal, and Saura, 2006, Pascual-Hortal, and Saura, 2007, Pascual-Hortal, and Saura, 2008 Pino, and Marull 2012, Piquer-Rodríguez, et al., 2012, Rayfield, et al., 2010, Rocchini, et al., 2006, Rocha, et al., 2007, Rubio, et al., 2012, Sesnie, et al., 2008, Yadav, et al., 2012.	• Landsat TM/ETM+ images. • Aerial photographs and SPOT satellite images and Fragstats software. • State-wide vegetation maps and Landsat analyses of woody vegetation cover • Integral Index of Connectivity (based on graph structures and a habitat availability index, integrating forest attributes like habitat quality and network connectivity in a single measure) • Ecological Connectivity Index • Spatially explicit least-cost habitat graphs (to examine how matrix quality and spatial configuration influence assessments of habitat connectivity) • Satellite images and Landsat 7 • Graph theory with models of land cover permeability and least-cost analysis • Landsat Enhanced Thematic Mapper (ETM+) bands and vegetation indices
1, 3	No evidence items found address these relationships.	
1,3,9	Hansen and Clevenger 2005, Sinclair et al., 2005.	
1, 4, 4A, 4B, 5	Donald and Evans, 2006.	
1,4A	Amici et al., 2010, Baranyi et al., 2011.	• Habitat suitability model using focal species and maps based on fuzzy classification method,
1,4A,4B	Biro et al., 2013, Boykin et al., 2013, Carthew et al., 2013, Cord et al., 2014, Goetz et al., 2009, Kadoya and Washitani, 2011, Lloyd and Marsden 2008, Shanahan and Possingham, 2009.	• Pitfall and Elliott trapping, • Satoyama Index (measures habitat diversity)
1, 4A, 4B, 11, 12	Crooks et al., 2011, Lindborg and Eriksson, 2004, Panzacchi et al., 2010, Sirami, et al., 2010.	• Globcover v. 2.1 (for mapping land cover)
1,4A,10	No evidence items found address these relationships.	
1,4A,11	Bonthoux et al., 2013, Higdon et al., 2006, Marcantonio et al., 2013, Maron et al., 2012, Martinuzzi 2009, Matisziw and Murray 2009.	• Ordinary Least Square (OLS) and quantile regression (for the relationship between the plots and road distances) • Landsat Thematic Mapper imagery (to calculate vegetation cover)

Relationship numbers	References	Potential Measures
1,4B,12	Brudvig et al., 2009, Mason et al., 2007, Means and Medley, 2010.	
1,4B,13	No evidence items found address these relationships.	
1,4B,13,18	No evidence items found address these relationships.	
1,5	Baguette and Van Dyck, 2007, Bierwagen, 2007, Chacon Leon, and Harvey, 2006, Crist et al., 2005, Cushman and Landguth, 2012, Doerr et al, 2010, Fischer and Lindenmayer, 2007, Galpern and Manseau 2013, Gilbert-Norton et al., 2009, Gillies and St. Clair, 2010, Henry et al., 2007, Hilty and Merenlender 2004, Pinto and Keitt, 2009, Rouget et al., 2006, Rubio and Saura, 2012, Šálek et al., 2009, Saura and Rubio 2010, Saura et al. 2011b, Spencer et al., 2010.	• GIS data and Landsat TM satellite imagery • resistant kernel approach for predicting habitat connectivity, • functional grains • Conditional Minimum Transit Cost (CMTC) tool • Multiple Shortest Paths (MSPs) tool. • least-cost path analysis and a target-driven algorithm • IIC and PC connectivity metrics (based on graph structures and on the concept of habitat availability to quantify functional connectivity) • Guidos and Conefor Sensinode software packages
1, 5, 6	Ewers and Didham, 2006, Hoebinger et al., 2012, Koen et al., 2010, Lai, et al., 2011, Magrach et al., 2012, McRae et al., 2012, Theobald et al., 2011, Watts and Handley 2010, Williams and Snyder 2005, Winfree et al.,2005.	• We computed least cost corridors with ArcGIS tool, the program ArcView to produce a vector map showing land cover, FRAGSTATS 3.3 to compute the landscape metrics, and GUIDOS 1.3 for the MSPA • Circuit theory to estimate landscape resistance to organism movement and gene flow • Steiner Multigraph Problem to model the problem of minimum-cost wildlife corridor design • GIS neighborhood analyses and effective distance analyses (to detect barriers that, if removed, would significantly improve connectivity) • Probability of Functional Connectivity Index • Shortest Path Optimization methodology
1,5,6,14,15	Vallecillo et al., 2009.	
1,5,14	Mita et al., 2007, Muratet et al., 2013, Pavlova et al., 2012, Savage et al., 2011.	• Index of Plant Community Integrity (IPCI) (measured wetland condition) • Normalised difference vegetation index

Relationship numbers	References	Potential Measures
1,5,16	Baguette 2013, Braunisch et al., 2010, Chetkiewicz and Boyce 2009, Coulon et al., 2004, Harvey et al., 2005, Spear et al., 2010.	• Mantel tests and multiple regressions on distance matrices detected and quantified the effect of different landscape features on relatedness among individuals.
1,5,16,18	Amos et al., 2012, Beier and Gregory 2012, Coates et al., 2007, Cousins 2006, Ferreira et al., 2013, McRae and Beier 2007, Mellick et al., 2011, Sork and Smouse 2006, Townsend and Levey 2005, Tucker and Simmons 2009, Wang et al., 2008	• Make explicit predictions of expected genetic outcomes for a range of species based on available data • Isolation by resistance model using electrical circuit theory (for gene flow) • Habitat suitability modelling integrated into Least Cost Path analysis
1,6	Beier et al., 2008, Brost and Beier 2011,	• Corridors designed using least-cost modelling, based on raster data.
1,6,17	No evidence items found address these relationships.	
1,6,17,18	No evidence items found address these relationships.	
2,7	Coetzer et al., 2013,	
2,7,10	No evidence items found address these relationships.	
2,7,11	Jorge et al., 2013, McAlpine et al., 2002	
2,8	Hodgson et al., 2011,	
2,8,15	No evidence items found address these relationships.	
2,8,17	No evidence items found address these relationships.	
2,8,17,18	No evidence items found address these relationships.	

3.3 Thresholds

Six relevant evidence items discussed thresholds or general rules regarding vegetation connectivity and ecosystem operation. These studies have not undergone critical appraisal and we would advise that this process be completed before any of these thresholds are relied upon in practice. The thresholds and some background information from the studies are discussed below.

Distance thresholds for gap and inter-patch crossing

One study which undertook a systematic review of 80 studies regarding functional connectivity in terrestrial native Australian species calculated that many species were unable to cross open areas (the matrix) that exceeded 106 metres. Furthermore, many species were unable to disperse between patches of habitat separated by more than 1100 metres, even where there was structural connectivity between the patches. The study highlighted that these thresholds were based on limited data, but could be used as a useful starting point (Doerr, V. et al., 2010).

Critical fragmentation point

Ferraz et al, 2005 assessed the landscape changes between 1984 and 2002 in a Brazilian watershed undergoing rapid deforestation. They found that a critical point where fragmentation increased rapidly occurred when mature forest declined to roughly 35% of the study area. They recommend that natural resource managers maintain the proportion of mature forest above this threshold.

Corridors increases movement between habitat patches by approximately 50%

In their literature review on corridors, Gilbert-Norton et al., 2009 found that corridors increase movement between habitat patches by approximately 50% compared to patches that are not connected with corridors. It was also found that corridors were more important for the movement of invertebrates, non-avian vertebrates and plants than they were for birds.

Urban forest fragments should be at least 3 ha in size

In a study conducted in two distinct urban areas in Finland, Hamberg 2009 found that in order to reduce the impact of the edge effect on urban forest vegetation composition, urban forest fragments left within urban development should be at least 3 ha in size and tree volume at the edge should be at least 225-250 m^3 ha^{-1}.

Species-area relationship change point at 40% vegetation cover

Maron et al., 2012 examined the relationship between landscape-level species richness of woodland-dependent birds and native vegetation extent in eastern Australia and found that the species–area relationship exhibited a rapid change-point at approximately 40% vegetation cover. They noted that this was more accurately explained by two disjunct slopes rather than a continuous threshold model or a classic species–area curve. They warned that the 40% threshold may not be applicable to all landscape types.

Reduction of remnant vegetation to 30% will result in vertebrate fauna loss over time

In their literature review on the impact of clearing and related fragmentation effects on terrestrial biota, McAlpine et al., 2002 note that the evidence suggests that the reduction of remnant vegetation to 30% will result in the loss of 25–35% of vertebrate fauna, with the full impact not realised for at least another 50–100 years.

3.4 What landscape vegetation connectivity cannot tell us about ecosystem operation

While landscape vegetation connectivity can tell us much about ecosystem operation, there are some things it cannot tell us. Three such areas were discussed in the evidence, namely functional connectivity, habitat quality and the long term impacts of past and current fragmentation.

Functional connectivity

Mapping the spatial configuration of the landscape and vegetation tells us about structural connectivity, from which much can be inferred about biodiversity and ecosystem operation. However, the structural connectivity of a landscape will not always provide enough information to understand the functional connectivity of the species within that landscape. The extent to which landscapes are connected depends on how animals perceive, use and move through the various habitat patches and how these patches are configured. Thus, animal dispersal behaviour must be considered when measuring patch and landscape connectivity. Since different species will perceive the connectivity of the same landscape in different ways and at different spatial scales, measuring the dispersal behaviour and ability of key species is important in order to understand the functional connectivity of that landscape (Kadoya, 2009, Pascual-Hortal and Saura, 2007, Fischer, J., Lindenmayer, D.B., 2007, Rayfield, et al., 2010, Winfree et al., 2005)

In their study of the Atlantic forest in Brazil, Jorge et al., 2013 found that 88% of the remaining forest did not contain four of its previously common largest mammals. Due to these mammals' unique ecological roles most of the remaining Atlantic Forest is likely to be suffering from trophic cascade effects, such as changes in patterns of seed dispersal and mesopredator release that may reverberate onto many other organisms and ecosystem processes.

The four mammals did not occur in some of the largest and most protected forest patches, highlighting the importance of looking beyond land cover and structural connectivity alone to the functional connectivity and quality of those patches in order to truly understand ecosystem health.

When attempting to measure functional connectivity, it is important to select appropriate 'umbrella species' (a wide-ranging species whose requirements include those of many other species) that can reflect the dispersal behaviour of other species in that ecosystem. Cushman and Landguth 2012 evaluated the effectiveness of using three carnivores as umbrella species for functional connectivity in the Rocky Mountains, USA. The three carnivores had limited dispersal ability, thus they were a weak indicator of the behaviour of species with higher dispersal abilities.

Habitat Quality

While land cover maps are often used to derive species distribution models, they may not adequately represent the relevant vegetation characteristics for many species' habitats. Although it is well understood that the presence of particular species can be highly dependent on certain forest structure condition, such as tree canopy cover, land cover and vegetation maps often do not characterise forest structure in enough detail. Therefore if land cover or vegetation maps used to support habitat models do not adequately represent the relevant species-environment relationships, the final distribution maps may not match actual species distribution (Martinuzzi et al., 2009). Lira et al., 2014a discuss this in the context of the Brazilian Atlantic Forest, noting that while structural connectivity is important, so too is the age of the remaining forest, given that many species need more pristine forest patches, as opposed to secondary or regrowth forests, to survive.

Hodgson et al., 2011 argue that habitat quality is crucial for species survival in a changing climate.

While structural connectivity enables movement in response to threats such as climate change, it is large and high-quality habitats that provide source populations and locations for colonisation. Therefore the availability of large and high quality habitat is what will mainly determine the ability of species to shift in response to climate change, because populations must be established successively in each new region (Hodgson et al., 2011).

Long term impacts of past and current fragmentation

The impacts of landscape fragmentation such as changes in genetic, morphological or behavioural traits of species can take time to appear. Hence it may not be accurate to analyse how species diversity relates to current landscapes, as the long term impacts of past fragmentation on that landscape may not yet have materialised (Ewers and Didham, 2006). Lindborg and Eriksson, 2004 analysed semi-natural grassland patches in Sweden, and found time lags of 50–100 years in the response of plant species diversity to changing configuration of habitats in the landscape.

4 Conclusion

Landscape vegetation connectivity is widely used around the world as an indicator of ecosystem health. This is so because it is relatively quick and straightforward to measure, and because it can inform us about numerous aspects of ecosystem operation in relation to habitat and biodiversity. Some of these key aspects include whether some species may be exposed or vulnerable to threats, experience increased or reduced habitat opportunities, have the ability to disperse and allow gene flow and have opportunities to move in response to threats such as climate change. Knowledge about landscape vegetation connectivity can also tell us something about overall species or community diversity or composition. However there are some things that landscape vegetation connectivity cannot, or does not always tell us about ecosystem operation, including the functional connectivity of the landscape, habitat quality and the long term impacts of past and current fragmentation.

5 Evidence Base References

Amici, V., Geri, F., Battisti, C., 2010. An integrated method to create habitat suitability models for fragmented landscapes. *Journal for Nature Conservation* 18, 215–223.

Amos, J.N., Bennett, A.F., Mac Nally, R., Newell, G., Pavlova, A., Radford, J.Q., Thomson, J.R., White, M., Sunnucks, P., 2012. Predicting Landscape-Genetic Consequences of Habitat Loss, Fragmentation and Mobility for Multiple Species of Woodland Birds. *PLoS ONE* 7, 2.

Baguette, M., Blanchet, S., Legrand, D., Stevens, V.M., Turlure, C., 2013. Individual dispersal, landscape connectivity and ecological networks. *Biological Reviews* 88, 310–326.

Baguette, M., Van Dyck, H., 2007. Landscape connectivity and animal behavior: functional grain as a key determinant for dispersal. *Landscape Ecology* 22, 1117–1129.

Baranyi, G., Saura, S., Podani, J., Jordán, F., 2011. Contribution of habitat patches to network connectivity: Redundancy and uniqueness of topological indices. *Ecological Indicators* 11, 1301–1310.

Beier, P., Gregory, A.J., 2012. Desperately Seeking Stable 50-Year-Old Landscapes with Patches and Long, Wide Corridors. *PLoS Biol* 10.

Beier, P., Majka, D.R., Spencer, W.D., 2008. Forks in the Road: Choices in Procedures for Designing Wildland Linkages. *Conservation Biology* 22, 836–851.

Bierwagen, B.G., 2007. Connectivity in urbanizing landscapes: The importance of habitat configuration, urban area size, and dispersal. *Urban Ecosystems* 10, 29–42.

Biro, M., Szitar, K., Horvath, F., Bagi, I., Molnar, Z., 2013. Detection of long-term landscape changes and trajectories in a Pannonian sand region: comparing land-cover and habitat-based approaches at two spatial scales. *Community Ecology* 14, 219–230.

Bonthoux, S., Barnagaud, J.-Y., Goulard, M., Balent, G., 2013. Contrasting spatial and temporal responses of bird communities to landscape changes. *Oecologia* 172, 563–574.

Boykin, K.G., Kepner, W.G., Bradford, D.F., Guy, R.K., Kopp, D.A., Leimer, A.K., Samson, E.A., East, N.F., Neale, A.C., Gergely, K.J., 2013. A national approach for mapping and quantifying habitat-based biodiversity metrics across multiple spatial scales. *Ecological Indicators, Biodiversity Monitoring* 33, 139–147.

Braunisch, V., Segelbacher, G., Hirzel, A.H., 2010. Modelling functional landscape connectivity from genetic population structure: a new spatially explicit approach. *Molecular Ecol*ogy 19, 3664–3678.

Brost, B.M., Beier, P., 2011. Use of land facets to design linkages for climate change. *Ecological Applications* 22, 87–103.

Brudvig, L.A., Damschen, E.I., Tewksbury, J.J., Haddad, N.M., Levey, D.J., 2009. Landscape connectivity promotes plant biodiversity spill over into non-target habitats. *PNAS* 106, 9328–9332.

Carthew, S.M., Garrett, L.A., Ruykys, L., 2013. Roadside vegetation can provide valuable habitat for small, terrestrial fauna in South Australia. *Biodiversity and Conservation* 22, 737–754.

Chacon Leon, M., Harvey, C.A., 2006. Live fences and landscape connectivity in a neotropical agricultural landscape. *Agroforestry Systems* 68, 15–26.

Chetkiewicz, C.-L.B., Boyce, M.S., 2009. Use of resource selection functions to identify conservation corridors. *Journal of Applied Ecology* 46, 1036–1047.

Coates, David J., Sampson, Jane F., Yates, Colin J., 2007. Plant mating systems and assessing population persistence in fragmented landscapes. *Australian Journal of Botany* 55, 239–249.

Coetzer, Kaera L., Erasmus, Barend F. N., Witkowski, Edward T. F., Reyers, Belinda, 2013. The Race for Space: Tracking Land-Cover Transformation in a Socio-ecological Landscape, *South Africa. Environmental Management* 52, 595–612.

Cord, A.F., Klein, D., Mora, F., Dech, S., 2014. Comparing the suitability of classified land cover data and remote sensing variables for modeling distribution patterns of plants. *Ecological Modelling* 272, 129–140.

Coulon, A., Cosson, J.F., Angibault, J.M., Cargnelutti, B., Galan, M., Morellet, N., Petit, E., Aulagnier, S., Hewison, A.J.M., 2004. Landscape connectivity influences gene flow in a roe deer population inhabiting a fragmented landscape: an individual–based approach. *Molecular Ecology* 13, 2841–2850.

Cousins, S.A.O., 2006. Plant species richness in midfield islets and road verges – The effect of landscape fragmentation. *Biological Conservation* 127, 500–509.

Crist, M.R., Wilmer, B., Aplet, G.H., 2005. Assessing the value of roadless areas in a conservation reserve strategy: biodiversity and landscape connectivity in the northern Rockies. *Journal of Applied Ecology* 42, 181–191.

Crooks, K.R., Burdett, C.L., Theobald, D.M., Rondinini, C., Boitani, L., 2011. Global patterns of fragmentation and connectivity of mammalian carnivore habitat. *Philosophical Transactions of the Royal Society B* 366, 2642–2651.

Cushman, S.A., Landguth, E.L., 2012. Multi-taxa population connectivity in the Northern Rocky Mountains. *Ecological Modelling* 231, 101–112.

Doerr, V., Doerr, E., Davies, M.J., 2010. *Does Structural Connectivity Facilitate Dispersal of Native Species in Australia's Fragmented Terrestrial Landscapes?* (CEE Systematic Review). CSIRO Sustainable Ecosystems, Canberra, A.C.T.

Donald, P.F., Evans, A.D., 2006. Habitat connectivity and matrix restoration: the wider implications of agri-environment schemes. *Journal of Applied Ecology* 43, 209–218.

Ewers, R.M., Didham, R.K., 2006. Confounding factors in the detection of species responses to habitat fragmentation. *Biological Reviews* 81, 117–142.

Ferraz, S.F.D., Vettorazzi, C.A., Theobald, D.M., Ballester, M.V.R., 2005. Landscape dynamics of Amazonian deforestation between 1984 and 2002 in central Rondonia, Brazil: assessment and future scenarios. *Forest Ecology and Management* 204, 67–83.

Ferreira, P.A., Boscolo, D., Viana, B.F., 2013. What do we know about the effects of landscape changes on plant–pollinator interaction networks? *Ecological Indicators, Linking landscape structure and biodiversity* 31, 35–40.

Fischer, J., Lindenmayer, D.B., 2007. Landscape modification and habitat fragmentation: a synthesis. *Global Ecology and Biogeography* 16, 265–280.

Galpern, P., Manseau, M., 2013. Modelling the influence of landscape connectivity on animal distribution: a functional grain approach. *Ecography* 36, 1004–1016.

Gilbert-Norton, L., Wilson, R., Stevens, J.R., Beard, K.H., 2010. A Meta-Analytic Review of Corridor Effectiveness. *Conservation Biology* 24, 660–668.

Gillies, C.S., St. Clair, C.C., 2010. Functional responses in habitat selection by tropical birds moving through fragmented forest. *Journal of Applied Ecology* 47, 182–190.

Goetz, S.J., Jantz, P., Jantz, C.A., 2009. Connectivity of core habitat in the Northeastern United States: Parks and protected areas in a landscape context. *Remote Sensing of Environment, Monitoring Protected Areas* 113, 1421–1429.

Gonzalez, A., Rayfield, B., Lindo, Z., 2011. The disentangled bank: How loss of habitat fragments and disassembles ecological networks. *American Journal of Botany* 98, 503–516.

Hamberg, L., 2009. *The effects of habitat edges and trampling intensity on vegetation in urban forests.* University of Helsinki, Helsinki.

Hansen, M.J., Clevenger, A.P., 2005. The influence of disturbance and habitat on the presence of non-native plant species along transport corridors. *Biological Conservation* 125, 249–259.

Harvey, C.A., Villanueva, C., Villacis, J., Chacon, M., Munoz, D., Lopez, M., Ibrahim, M., Gomez, R., Taylor, R., Martinez, J., Navas, A., Saenz, J., Sanchez, D., Medina, A., Vilchez, S., Hernandez, B., Perez, A., Ruiz, E., Lopez, F., Lang, I., Sinclair, F.L., 2005. Contribution of live fences to the ecological integrity of agricultural landscapes. *Agriculture Ecosystems and Environment* 111, 200–230.

Henry, M., Pons, J.-M., Cosson, J.-F., 2007. Foraging behaviour of a frugivorous bat helps bridge landscape connectivity and ecological processes in a fragmented rainforest. *Journal of Animal Ecology* 76, 801–813.

Higdon, J.W., MacLean, D.A., Hagan, J.M., Reed, J.M., 2006. Risk of extirpation for vertebrate species on an industrial forest in New Brunswick, Canada: 1945, 2002, and 2027. *Canadian Journal of Forest Research* 36, 467–481.

Hilty, J.A., Merenlender, A.M., 2004. Use of Riparian Corridors and Vineyards by Mammalian Predators in Northern California. *Conservation Biology* 18, 126–135.

Hodgson, J.A., Moilanen, A., Wintle, B.A., Thomas, C.D., 2011. Habitat area, quality and connectivity: striking the balance for efficient conservation. *Journal of Applied Ecology* 48, 148–152.

Hoebinger, T., Schindler, S., Seaman, B.S., Wrbka, T., Weissenhofer, A., 2012. Impact of oil palm plantations on the structure of the agroforestry mosaic of La Gamba, southern Costa Rica: potential implications for biodiversity. *Agroforestry Systems* 85, 367–381.

Jorge, M.L.S.P., Galetti, M., Ribeiro, M.C., Ferraz, K.M.P.M.B., 2013. Mammal defaunation as surrogate of trophic cascades in a biodiversity hotspot. *Biological Conservation, Special Issue: Defaunation's impact in terrestrial tropical ecosystems* 163, 49–57.

Kadoya, T., 2009. Assessing functional connectivity using empirical data. *Population Ecology* 51, 5–15.

Kadoya, T., Washitani, I., 2011. The Satoyama Index: A biodiversity indicator for agricultural landscapes. *Agriculture, Ecosystems and Environment* 140, 20–26.

Koen, E.L., Garroway, C.J., Wilson, P.J., Bowman, J., 2010. The Effect of Map Boundary on Estimates of Landscape Resistance to Animal Movement. *PLoS ONE* 5.

Lai, Katherine J., Gomes, Carla P., Schwartz, Michael K., McKelvey, Kevin S., Calkin, David E., Montgomery, Claire A., 2011. The Steiner Multigraph Problem: Wildlife Corridor Design for Multiple Species, in: *Proceedings of the Twenty-Fifth AAAI Conference on Artificial Intelligence*.

Lindborg, R., Eriksson, O., 2004. Historical Landscape Connectivity Affects Present Plant Species Diversity. *Ecology* 85, 1840–1845.

Lira, P.K., Tambosi, L.R., Ewers, R.M., Metzger, J.P., 2012. Land-use and land-cover change in Atlantic Forest landscapes. *Forest Ecology and Management* 278, 80–89.

Lloyd, H., Marsden, S.J., 2008. Bird community variation across Polylepis woodland fragments and matrix habitats: implications for biodiversity conservation within a high Andean landscape. *Biodiversity and Conservation* 17, 2645–2661.

Lunt, I.D., Winsemius, L.M., McDonald, S.P., Morgan, J.W., Dehaan, R.L., 2010. How widespread is woody plant encroachment in temperate Australia? Changes in woody vegetation cover in lowland woodland and coastal ecosystems in Victoria from 1989 to 2005. *Journal of Biogeography* 37, 722–732.

Magrach, A., Larrinaga, A.R., Santamaria, L., 2012. Effects of Matrix Characteristics and Interpatch Distance on Functional Connectivity in Fragmented Temperate Rainforests. *Conservervation Biology* 26, 238–247.

Malavasi, M., Santoro, R., Cutini, M., Acosta, A.T.R., Carranza, M.L., 2013. What has happened to coastal dunes in the last half century? A multi-temporal coastal landscape analysis in Central Italy. *Landscape and Urban Planning* 119, 54–63.

Marcantonio, M., Rocchini, D., Geri, F., Bacaro, G., Amici, V., 2013. Biodiversity, roads, and landscape fragmentation: Two Mediterranean cases. *Applied Geography* 42, 63–72.

Maron, M., Bowen, M., Fuller, R.A., Smith, G.C., Eyre, T.J., Mathieson, M., Watson, J.E.M., McAlpine, C.A., 2012. Spurious thresholds in the relationship between species richness and vegetation cover. *Global Ecology and Biogeography* 21, 682–692.

Martinuzzi, S., Gould, W.A., Ramos Gonzalez, O.M., Edwards, B.E., 2007. Development of a landforms model for Puerto Rico and its application for land cover change analysis. *Caribbean Journal of Science* 43, 161–171.

Mason, J., Moorman, C., Hess, G., Sinclair, K., 2007. Designing suburban greenways to provide habitat for forest-breeding birds. *Landscape and Urban Planning* 80, 153–164.

Matisziw, T.C., Murray, A.T., 2009. Connectivity change in habitat networks. *Landscape Ecology* 24, 89–100.

McAlpine, C. A., Fensham, R. J., Temple-Smith, D. E., 2002. Biodiversity conservation and vegetation clearing in Queensland: principles and thresholds. *The Rangeland Journal* 24, 36 – 55.

McRae, B.H., Beier, P., 2007. Circuit theory predicts gene flow in plant and animal populations. *PNAS* 104, 19885–19890.

McRae, B.H., Dickson, B.G., Keitt, T.H., Shah, V.B., 2008. Using Circuit Theory To Model Connectivity In Ecology, Evolution, and Conservation. *Ecology* 89, 2712–2724.

McRae, B.H., Hall, S.A., Beier, P., Theobald, D.M., 2012. Where to Restore Ecological Connectivity? Detecting Barriers and Quantifying Restoration Benefits. *PLoS ONE* 7,

Means, J.L., Medley, K.E., 2010. Old Regrowth Forest Patches as Habitat for the Conservation of Avian Diversity in a Southwest Ohio Landscape. *The Ohio Journal of Science* 110, 86–93.

Mellick, R., Lowe, A., Rossetto, M., 2011. Consequences of long- and short-term fragmentation on the genetic diversity and differentiation of a late successional rainforest conifer. *Australian Journal of Botany* 59, 351–362.

Mita, D., DeKeyser, E., Kirby, D., Easson, G., 2007. Developing a wetland condition prediction model using landscape structure variability. *Wetlands* 27, 1124–1133.

Mitchell, M.G.E., Bennett, E.M., Gonzalez, A., 2013. Linking Landscape Connectivity and Ecosystem Service Provision: Current Knowledge and Research Gaps. *Ecosystems* 16, 894–908.

Muratet, A., Lorrilliere, R., Clergeau, P., Fontaine, C., 2013. Evaluation of landscape connectivity at community level using satellite-derived NDVI. *Landscape Ecology* 28, 95–105.

Oliver, I., Jones, H., Schmoldt, D.L., 2007. Expert panel assessment of attributes for natural variability benchmarks for biodiversity. *Australian Ecology* 32, 453–475.

Packett, D.L., Dunning, J.B., 2009. Stopover Habitat Selection by Migrant Landbirds in a Fragmented Forest-Agricultural Landscape. *The Auk* 126, 579–589.

Panzacchi, M., Linnell, J.D.C., Melis, C., Odden, M., Odden, J., Gorini, L., Andersen, R., 2010. Effect of land-use on small mammal abundance and diversity in a forest–farmland mosaic landscape in south-eastern Norway. *Forest Ecology and Management* 259, 1536–1545.

Pascual-Hortal, L., Saura, S., 2006. Comparison and development of new graph-based landscape connectivity indices: towards the priorization of habitat patches and corridors for conservation. *Landscape Ecology* 21, 959–967.

Pascual-Hortal, L., Saura, S., 2007. Impact of spatial scale on the identification of critical habitat patches for the maintenance of landscape connectivity. *Landscape and Urban Planning* 83, 176–186.

Pascual-Hortal, L., Saura, S., 2008. Integrating landscape connectivity in broad-scale forest planning through a new graph-based habitat availability methodology: application to capercaillie (Tetrao urogallus) in Catalonia (NE Spain). *European Journal of Forest Research* 127, 23–31.

Pavlova, A., Amos, J.N., Goretskaia, M.I., Beme, I.R., Buchanan, K.L., Takeuchi, N., Radford, J.Q., Sunnucks, P., 2012. Genes and song?: genetic and social connections in fragmented habitat in a woodland bird with limited dispersal. *Ecology* 93, 1717–1727.

Pino, J., Marull, J., 2012. Ecological networks: Are they enough for connectivity conservation? A case study in the Barcelona Metropolitan Region (NE Spain). *Land Use Policy* 29, 684–690.

Pinto, N., Keitt, T.H., 2009. Beyond the least-cost path: evaluating corridor redundancy using a graph-theoretic approach. *Landscape Ecology* 24, 253–266.

Piquer-Rodríguez, M., Kuemmerle, T., Alcaraz-Segura, D., Zurita-Milla, R., Cabello, J., 2012. Future land use effects on the connectivity of protected area networks in southeastern Spain. *Journal for Nature Conservation* 20, 326–336.

Rayfield, B., Fortin, M.-J., Fall, A., 2010. The sensitivity of least-cost habitat graphs to relative cost surface values. *Landscape Ecology* 25, 519–532.

Rocchini, D., Perry, G.L.W., Salerno, M., Maccherini, S., Chiarucci, A., 2006. Landscape change and the dynamics of open formations in a natural reserve. *Landscape and Urban Planning* 77, 167–177.

Rocha, C.F.D., Bergallo, H.G., Van Sluys, M., Alves, M. a. S., Jamel, C.E., 2007. The remnants of restinga habitats in the Brazilian Atlantic Forest of Rio de Janeiro state, Brazil: habitat loss and risk of disappearance. *Brazilian Journal of Biology* 67, 263–273.

Rouget, M., Cowling, R.M., Lombard, A.T., Knight, A.T., Graham, I.H.K., 2006. Designing large-scale conservation corridors for pattern and process. Conservation *Biology* 20, 549–561.

Rubio, L., Rodriguez-Freire, M., Mateo-Sanchez, M.C., Estreguil, C., Saura, S., 2012. Sustaining forest landscape connectivity under different land cover change scenarios. *Forest Systems* 21, 223–235.

Rubio, L., Saura, S., 2012. Assessing the importance of individual habitat patches as irreplaceable connecting elements: An analysis of simulated and real landscape data. *Ecological Complexity* 11, 28–37.

Rudnick, D.A., Ryan, S.J., Beier, P., Cushman, S.A., Dieffenbach, F., Epps, C.W., Gerber, L.R., Hartter, J., Jenness, J.S., Kintsch, J., Merenlender, A.M., Perkl, R.M., Preziosi, D.V., Trombulak, S.C., 2012. The role of landscape connectivity in planning and implementing conservation and restoration priorities. *Issues in Ecology* 16, 1–20.

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. *Landscape and Urban Planning* 83, 91–103.

Saura, S., Rubio, L., 2010. A common currency for the different ways in which patches and links can contribute to habitat availability and connectivity in the landscape. *Ecography* 33, 523–537.

Saura, S., Vogt, P., Velázquez, J., Hernando, A., Tejera, R., 2011. Key structural forest connectors can be identified by combining landscape spatial pattern and network analyses. *Forest Ecology and Management, Environmental Stress and Forest Ecosystems: Case studies from Estonia* 262, 150–160.

Savage, J., Wheeler, T.A., Moores, A.M.A., Taillefer, A.G., 2011. Effects of Habitat Size, Vegetation Cover, and Surrounding Land Use on Diptera Diversity in Temperate Nearctic Bogs. *Wetlands* 31, 125–135.

Sesnie, S.E., Hagell, S.E., Otterstrom, S. m., Chambers, C.L., Dickson, B.G., 2008. SRTM-DEM and LANDSAT ETM+ data for mapping tropical dry forest cover and biodiversity assessment in Nicaragua. *Revista Geográfica Acadêmica* 2, 53–65.

Shanahan, D.F., Possingham, H.P., 2009. Predicting avian patch occupancy in a fragmented landscape: do we know more than we think? *Journal of Applied Ecology 46*, 1026–1035.

Sinclair, K.E., Hess, G.R., Moorman, C.E., Mason, J.H., 2005. Mammalian nest predators respond to greenway width, landscape context and habitat structure. *Landscape and Urban Planning* 71, 277–293.

Sirami, C., Nespoulous, A., Cheylan, J.-P., Marty, P., Hvenegaard, G.T., Geniez, P., Schatz, B., Martin, J.-L., 2010. Long-term anthropogenic and ecological dynamics of a Mediterranean landscape: Impacts on multiple taxa. *Landscape and Urban Planning* 96, 214–223.

Sork, V.L., Smouse, P.E., 2006. Genetic analysis of landscape connectivity in tree populations. *Landscape Ecology* 21, 821–836.

Spear, S.F., Balkenhol, N., Fortin, M.J., McRae, B.H., Scribner, K., 2010. Use of resistance surfaces for landscape genetic studies: considerations for parameterization and analysis. *Molecular Ecology* 19, 3576–3591.

Spencer, W.D., Beier, P., Penrod, K., Winters, K., Paulman, C., Rustigian-Romsos, H., Strittholt, J., Parisi, M., Pettler, A., 2010. *California Essential Habitat Connectivity Project: a Strategy for Conserving a Connected California.* Prepared for California Department of Transportation, California Department of Fish and Game, and Federal Highways Administration.

Theobald, D.M., Crooks, K.R., Norman, J.B., 2011. Assessing effects of land use on landscape connectivity: loss and fragmentation of western U.S. forests. *Ecological Applications* 21, 2445–2458.

Townsend, P.A., Levey, D.J., 2005. An Experimental Test of Whether Habitat Corridors Affect Pollen Transfer. *Ecology* 86, 466–475.

Tucker, N.I.J., Simmons, T., 2009. Restoring a rainforest habitat linkage in north Queensland: Donaghy's Corridor. *Ecological Management and Restoration* 10, 98–112.

Uuemaa, E., Mander, U., Marja, R., 2013. Trends in the use of landscape spatial metrics as landscape indicators: A review. *Ecological Indicators* 28, 100–106.

Vallecillo, S., Brotons, L., Thuiller, W., 2009. Dangers of predicting bird species distributions in response to land-cover changes. *Ecological Applications* 19, 538–549.

Wang, Y.-H., Yang, K.-C., Bridgman, C.L., Lin, L.-K., 2008. Habitat suitability modelling to correlate gene flow with landscape connectivity. *Landscape Ecology* 23, 989–1000.

Watts, K., Handley, P., 2010. Developing a functional connectivity indicator to detect change in fragmented landscapes. *Ecological Indicators* 10, 552–557.

Williams, J.C., Snyder, S.A., 2005. Restoring habitat corridors in fragmented landscapes using optimization and percolation models. *Environmental Model Assessment* 10, 239–250.

Winfree, R., Dushoff, J., Crone, E.E., Schultz, C.B., Budny, R.V., Williams, N.M., Kremen, C., 2005. Testing simple indices of habitat proximity. *The American Naturalist* 165, 707–717.

Yadav, P. K., Kapoor, Mohnish, Sarma, Kiranmay, 2012. Land Use Land Cover Mapping, Change Detection and Conflict Analysis of Nagzira-Navegaon Corridor, Central India Using Geospatial Technology. *International Journal of Remote Sensing and GIS* 1.

Report References

Bureau of Meteorology 2013. *Guide to environmental accounting in Australia*, Environmental Information Programme, Publication Series no.3, Bureau of Meteorology, Canberra, Australia, 122p.

Bureau of Meteorology 2013. *Environmental account framing workbook*, Bureau of Meteorology, Canberra, Australia.

Bureau of Meteorology (in prep.) *Methods for evidence based conceptual modelling for environmental accounting: a technical note*, Bureau of Meteorology, Canberra, Australia.

European Commission, Organisation for Economic Co-operation and Development, United Nations, World Bank, 2013. *System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting*.

Fitzsimons, J., Pulsford, I., Wescott, G., 2013. *Linking Australia's Landscapes: Lessons and Opportunities from Large-scale Conservation Networks*. CSIRO.

Hansson, L. 1991. Dispersal and connectivity in metapopulations. Pages 89–103 in M. Gilpin and I. Hanski, editors. *Metapopulation dynamics: empirical and theoretical investigations.* Academic Press, London, UK.

Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Synthesis*. Washington D.C.

United Nations Statistics Division, 2014. The System of Environmental-Economic Accounts (SEEA) Briefing Note [www Document]. System of Environmental-Economic Accounting (SEEA). URL https://unstats.un.org/unsd/envaccounting/Brochure.pdf (accessed 25.4.14).

Appendix 1 Search result statistics

Table 1: Numbers of relevant items of evidence resulting from a stated search phrase and source.

Search Phrases Used	Science Direct	TROVE	CSIRO Publishing	Web of Science (core collection)	Google Scholar
('vegetation connectivity' OR 'landscape changes' OR 'landscape connectivity' OR 'vegetation clearing' OR 'landscape fragment*' OR corridor* OR 'land cover') AND ((habitat*) OR (biodiversity OR divers* OR wildlife))	85/1,193 of first 250	53/31,453 of first 250 (4) (from journals, articles and datasets)	Not searched	Not searched	Not searched
('vegetation connectivity' OR 'spatial metrics' OR 'landscape changes' OR 'landscape connectivity' OR 'vegetation clearing' OR 'landscape fragment*' OR corridor* OR 'land cover') AND ((habitat*) OR (biodiversity OR divers* OR wildlife))	Not searched	Not searched	13/58 of total 58	103/468,329 (28) of first 250	84/17,800 (15) of first 250

NB. The second search phrase used was a copy of the first search phrase, with the term 'spatial metrics' added. It was decided to replace the first search phrase with the second during the search process, after the search of the Science Direct and TROVE databases had been completed.

Search phrases and sources

The above table lists the search phrases and sources used to identify evidence for this review. The search results for each search are provided in the format X/Y (Z) of 1st A where:

X = the number of relevant evidence items found

Y= the total number of search returns

Z = the number of relevant returns that had already been found in a previous search

A = the total number of search returns viewed until the relevance of evidence items becomes significantly reduced

Appendix 2 Search method

Overview

The search method aims to capture an unbiased representative sample of the literature as comprehensively as the available resources of the study will enable. Published and unpublished literature will be sourced and used. Search sources will be broad including web based grey literature, universities, government and non-government organisations. References provided in studies assessed will also be used to search for further relevant studies.

Search strategy

Databases

The search aims to include the following databases:

1. Science Direct

2. Web of Science

3. TROVE

4. CSIRO publishing

Web sites

An internet search was performed using the following web sites:

www.googlescholar.com

The first 250 hits from each search will be assessed for relevance.

Key search elements

The following search terms were located in relevant studies found during the scoping search, and relate to the three key elements of the secondary questions – Landscape vegetation connectivity, vegetation habitat and biodiversity.

Landscape vegetation connectivity elements:

landscape vegetation connectivity, landscape changes, vegetation connectivity, landscape connectivity, patch connectivity, ecological connectivity, functional connectivity, vegetation clearing, revegetation, landscape fragmentation, landscape structure, corridor, ecological networks, connectivity corridor, vegetation corridor, riparian vegetation, riparian corridor, forest connectivity, forest fragmentation, land cover.

Vegetation habitat elements:

habitat, habitat connectivity, habitat network, fragmented habitat, habitat loss, habitat patch, habitat extent, habitat condition, habitat quality, wildlife habitat, habitat cover, habitat configuration.

Biodiversity elements:

biodiversity, species diversity, genetic diversity, genetic variation, variety, floral diversity, faunal diversity, biological diversity, ecosystem diversity, wildlife.

Final search phrase

The following search phrases are what were used to conduct the search in the selected databases.

('vegetation connectivity' OR 'landscape changes' OR 'landscape connectivity' OR 'vegetation clearing' OR 'landscape fragment*' OR corridor* OR 'land cover') AND ((habitat*) OR (biodiversity OR divers* OR wildlife))

('vegetation connectivity' OR 'spatial metrics' OR 'landscape changes' OR 'landscape connectivity' OR 'vegetation clearing' OR 'landscape fragment*' OR corridor* OR 'land cover') AND ((habitat*) OR (biodiversity OR divers* OR wildlife))

Appendix 1 outlines the number of relevant evidence items found in each database using this final search phrase.

Study inclusion and exclusion criteria

It is necessary to apply study inclusion criteria in order to ensure that only the most relevant items of evidence are used hence increasing the efficiency of the search process. The inclusion criteria used are related to the key syntax elements of the primary and secondary questions. These elements are the subject, types of interventions, types of comparator and types of outcomes.

Search returns were initially screened on title for relevance and then screened on abstract after viewing the item.

All relevant search returns will be stored in an electronic bibliographic management library – Zotero (http://www.zotero.org/).

Relevant subject(s)

- Ecosystems world-wide
- All types of ecosystem (not restricted to 'pristine' ecosystems)
- Landscape scale vegetation connectivity but contributions at all scales. For example patch scale connectivity contributes to functional landscape scale connectivity.

Excluded subjects

- Aquatic and marine underwater ecosystems including rivers, lakes, estuary and marine environments
- Studies prior to 2004. An assumption has been made here, that given the broad nature of the search topics i.e. 'habitat', 'landscape connectivity' and 'biodiversity' that studies captured by the search (post 2004) will reflect prior scientific understanding to 2004. It is assumed that the maturity of science reflects all knowledge to date.
- Single species studies from other countries. This will ensure that studies included are more directly relevant to the development of an Australian account.

Types of articles

Only articles published in English will be used. Both quantitative and qualitative literature will be used.

Types of studies

Evidence items involving case studies, as opposed to theory, will be the focus of the search.