COLLABORATION FOR ENVIRONMENTAL EVIDENCE

SYSTEMATIC REVIEW No. 44

DOES STRUCTURAL CONNECTIVITY FACILITATE DISPERSAL OF NATIVE SPECIES IN AUSTRALIA'S FRAGMENTED TERRESTRIAL LANDSCAPES?

REVIEW PROTOCOL

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COVER SHEET

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1. BACKGROUND

The modification, loss and fragmentation of natural ecosystems are among the most serious threats to global biodiversity because the resulting altered landscapes invariably support smaller, more isolated populations of native species and increasingly degraded habitats, all of which are likely to reduce population viability and increase risk of extinction. Habitat fragmentation is thought to impact populations through three main effects: edge, area and isolation effects. Edge effects can include increased rates of predation and altered microclimates which may reduce survivorship and reproductive success. Due to the smaller habitat patches and thus smaller populations created by fragmentation, area effects may include increased levels of inbreeding, reduced genetic variability, and increased sensitivity to stochastic events. These area effects will be further intensified when combined with isolation effects, whereby the possibility of demographic or genetic rescue is reduced or eliminated because individuals cannot disperse between fragments through the matrix of unsuitable habitat. Extensive research has demonstrated these impacts of fragmentation, and numerous syntheses have been produced, so the basic problem is relatively well understood (e.g., Wilcove 1985; Wilcox & Murphy 1985; Rolstad 1991; Harrison & Bruna 1999, Debinski & Holt 2000; Villard 2002; McGarigal & Cushman 2002; Lindenmayer & Fischer 2006; Fischer & Lindenmayer 2007).

Fragmentation is an even more serious concern now that we know the planet's climate is changing, as global climate change is predicted to force species to locally adapt or move elsewhere in order to survive (Davis & Shaw 2001; Gitay et al. 2002; Parmesan 2006). Yet smaller populations will be less resilient to altered local conditions and therefore less able to adapt, and isolated populations will have difficulty shifting their ranges to track changing environments. This may be of particular concern in Australia, where extensive land clearing was conducted following European settlement, leaving fragments of remnant native vegetation within a matrix dominated by agricultural production systems (Saunders 1989; Bennett & Ford 1997). The long-term consequences of this fragmentation are expected to be serious with at least some researchers predicting that Australia will lose half of its bird species within the next century (Recher 1990).

Action is therefore urgently needed to reverse some of the effects of fragmentation—to reconnect small, isolated populations and restore their ability to function as larger, more resilient populations. Such actions need to occur at local, regional, and even continental scales to ensure benefits accrue at the population level but also that species can move to new areas as necessary under climate change. Fortunately, this need has captured the attention of government and the public. Connectivity restoration is frequently a goal of private revegetation efforts, local landcare groups, and incentive schemes administered by regional natural resource management bodies. Almost two decades ago, authors first proposed large networks of connected habitats in North America (Harris & Gallagher 1989) and Australia (Hobbs & Hopkins 1991), and the Australian Government and non-governmental organisations have recently initiated a number of major projects involving continental scale connectivity restoration such as Gondwana Link and the Great Eastern Ranges Initiative (formerly known as Alps to Atherton), including its component projects such as Kosciusko-to-Coast and Slopes-to-Summit.

The difficulty is that it is unclear exactly what actions should be taken to restore connectivity to our landscapes, aside from trying to recreate vast swaths of native ecosystems (which would not be practicable given the need for other land uses). By definition, a connected landscape is one in which individuals of all species (or their propagules or genes) can move or disperse from one resource patch to another (see Appendix B for definitions of terms used in this protocol). So how much habitat, what kind of habitat, and in what spatial configuration might be required to facilitate such dispersal? Unfortunately, the many syntheses of the problems of habitat fragmentation tell us relatively little about dispersal, and thus about the appropriate *solutions* to the problem, and new research and syntheses specifically focused on connectivity, as opposed to fragmentation, are required.

The most commonly proposed solution is to retain or restore habitat corridors. While the interpretation of this term varies (see Simberloff et al. 1992 for six different definitions), we define a corridor as a relatively unbroken (contiguous) linear strip of habitat that connects two or more patches of habitat that are otherwise surrounded by unsuitable areas for the species or community in question (Saunders & de Rebeira 1991; Hobbs 1992; Beier & Noss 1998). We believe this matches the operational definition used by most Australian land managers and by members of the public. The theory behind corridors is that individuals will be exchanged and/or genes will flow between connected patches or populations either because the corridor is occupied by the species or community and thus the corridor creates a continuous population between the two patches, or because dispersing individuals (or seed dispersers or pollinators) will use the corridor to move from one patch to the other. However, the ability of corridors to achieve this goal, and provide for dispersal just as much as continuous habitat would, may depend very much on the dispersal behaviour of the species involved as well as many other characteristics of the corridors themselves, the habitat patches, and the surrounding matrix (Tischendorf & Wissel 1997; Lindenmayer 1998; St Clair et al. 1998; Heinz et al. 2007). As a result, the effectiveness of corridors has been the subject of considerable debate (Noss 1987; Simberloff & Cox 1987; Simberloff et al. 1992; Beier & Noss 1998; Haddad et al. 2000; Hannon & Schmiegelow 2002; Damschen et al. 2006), and there is an imperative to determine which characteristics might make them most effective across different species and even different ecosystems, and whether there are alternatives.

There are a number of ecological reasons which suggest that alternatives to corridors need to be seriously considered. First, if corridors are to provide for gene flow by providing occupied habitat, then there may be costs to the populations involved, so a thorough weighing of the balance between benefits and costs is required. In particular, edge effects in narrow habitat strips may mean that population sinks may be created when corridors are occupied (Lynch et al. 1995; Cale 1999; Hess & Fischer 2001). Such sinks could potentially decrease both the likelihood of dispersal between patches and the overall viability of the population, even though the corridor might appear to be a success because it is occupied. Second, the corridor concept is based on a binary patch/matrix model of the landscape—that there are distinct, suitable parts of a landscape (patches) and unsuitable parts (matrix), but nothing in between. However, ecologists now recognise that there are other valid landscape models, including the variegated model (McIntyre & Barrett 1992; McIntyre & Hobbs 1999) and continuum models (Manning et al. 2004; Fischer & Lindemayer 2006), in which different parts of the landscape may vary in their suitability for any given species, resulting in different densities or patterns of use. These models are particularly important in Australia, as many of Australia's ecosystems naturally form a patchy mosaic (e.g., Bentley & Catterall 1997), so native species may have evolved to take advantage of that heterogeneity during dispersal. This means that individuals may not require continuous strips of habitat for dispersal, and also that suitable habitat for dispersal might actually have a very different composition and structure than habitat suitable for long-term survival and reproduction.

The increased appreciation of these ecological concepts has led scientists to broaden their thinking about connectivity restoration beyond corridors and into the paradigm of structural vs. functional connectivity (With et al. 1999; Uezu et al. 2005; Crooks & Sanjayan 2006; Hilty et al. 2006). Under this new paradigm, structural connectivity is anything that physically links separate populations, and it may consist of just about any kind of landscape heterogeneity in between occupied patches of habitat. Examples of structural connectivity include corridors and partially vegetated drainage lines or fence lines, but it may also consist of more subtle habitat elements such as scattered trees or shrubs, or even scattered clumps of tussock grass or coarse woody debris. In contrast, functional connectivity refers to the outcome we desire from these structural features—the degree to which movement and dispersal actually occur. Research is now focused on trying to understand the relationships between structural and functional connectivity, which includes work on corridors but is more broadly focused on movement and gene flow in heterogeneous landscapes. In other words, we need to know exactly which types of structural connectivity really do provide functional connectivity (dispersal in the landscape) for the majority of species in an ecosystem.

These general principles for connectivity restoration—recommendations for what is likely to work for most species in most systems—can only come from syntheses of many empirical studies. A synthesis that incorporates a variety of types of structural connectivity, not just corridors, has yet to be performed. While the utility of corridors has been tested using theoretical modelling (e.g., Hanson et al. 1990; Tilman et al. 1997), and empirical evidence for use of corridors has been accumulating for a number of years (Saunders & Hobbs 1991; Beier & Noss 1998; Bennett 1998; Haddad et al. 2003; Davies & Pullin 2007), research on other types of structural connectivity is relatively recent. Furthermore, recent evidence comes from a variety of different types of studies (survey, mark-recapture, genetic, radiotracking, etc.), which can make the resulting conclusions difficult to interpret *across* studies. Thus, the time is ripe to attempt a synthesis of the relationships between structural and functional connectivity, particularly in Australia where there may be considerable variation in structural connectivity and how it is used by native species. The systematic review approach may be especially useful, as it provides a rigorous framework in which to attempt a formal comparison of the different types of evidence produced by different types of studies. These are our goals in this review, with the ultimate aim of providing clearer, science-based information to natural resource planners and managers about how best to invest in connectivity, and to identify critical knowledge gaps that will guide future research to ensure that Australia's significant on-ground expenditures achieve their goals of restoring functional connectivity in Australian landscapes.

2. OBJECTIVE OF THE REVIEW

To evaluate whether structural connectivity (i.e., habitat elements of any sort in an otherwise unoccupied/unsuitable matrix) physically linking patches of occupied habitat facilitates functional connectivity (i.e., dispersal of native species) in fragmented terrestrial landscapes in Australia, and to identify which characteristics of structural connectivity increase the probability of dispersal. While different characteristics may be important for different species or in different landscapes or ecosystems, we aim to identify principles for natural resource managers that will be as generally applicable as possible, while also distilling recommendations for specific taxa or communities where more general insights do not emerge.

2.1 Primary question

Do the various landscape elements that provide structural connectivity in Australian fragmented terrestrial landscapes facilitate dispersal of native species between habitat patches or populations? i.e., do they provide true functional connectivity? This question is broken down into 'subject-intervention-outcome' components (Table 1).

Table 1. Components of the primary systematic review question. See Appendix A for definitions of the systematic review terminology and Appendix B for definitions of ecological terms.

Subject (population)	Intervention (comparison)	Primary Outcome	Secondary Outcome	Types of Study
Any terrestrial native Australian species	Patches of occupied habitat, surrounded by a dissimilar unoccupied matrix, with some form of structural connectivity between the patches *vs* Patches of occupied habitat, surrounded by dissimilar unoccupied matrix, without or with less structural connectivity between the patches	Relative movement* rates of individuals or propagules (observed or inferred) between patches	Binary variable describing whether or not there is evidence of movement* of individuals or propagules (observed or inferred) between patches	Survey data on abundance or even presence/absence in patches or elements of structural connectivity, genetic studies including population genetic analyses and assignment tests, mark-recapture or resighting data, translocation and gap-crossing studies, radiotelemetry studies

* Note that while we are ultimately interested in dispersal, this is difficult to observe and quantify, and not all studies of movement are explicit about why the animals are moving. In some studies, the movement is even experimentally induced. Thus, we will include all studies with evidence of inter-patch movement, regardless of whether the purpose of the movement is known or unknown. Where the purpose of the movement is known but is related to migration or even daily foraging movements, we will still retain the study in the review because elements of structural connectivity that assist with these movements are likely to also be beneficial to dispersal. However, we will include these differences among studies as a source of heterogeneity (see Section 3.6 below), so we will be able to analyse whether our results differ depending on the purpose of the movements. Depending on the data presented in a particular study, movement rates may be presented in terms of proportions of individuals moving, frequencies of movements, migrants per generation, etc. To achieve comparability between studies, we will assess the percent difference between rates with and without structural connectivity.

2.2 Secondary question

Do the various landscape elements that provide structural connectivity differ in how well they facilitate dispersal of individuals between habitat patches or populations, and what characteristics make structural connectivity elements most effective? This is actually the question of greatest interest for this review. Data permitting, we will examine the relative benefits of different types of structural connectivity (e.g., scattered trees, drainage lines, messy pastures—whatever types of heterogeneity exist between populations), not just traditional linear corridors. We will also attempt to analyse structural connectivity based on quantitative characteristics such as length, width, vegetation density, composition and structure, and maximum gaps to be crossed.

2.3 Tertiary questions

As indicated in 2. Objective of the Review, whether or not any type of structural connectivity is effective at facilitating dispersal may simply depend—on the species, the ecosystem type, the characteristics of the rest of the landscape, etc. Yet in practice, land managers are unlikely to be managing for single species in single locations. Instead, they need to know when we can distil some general principles among all this variation (e.g., habitat specialists respond similarly, or scattered trees are more effective when they connect woodlands as opposed to forests). Thus, we need to analyse whether these sources of heterogeneity among studies affect our overall conclusions. While there are many potential sources of heterogeneity among connectivity studies that we may need to control for in our analyses (see 3.6 below), we are particularly interested in: 1) determining if different taxonomic groups (e.g., birds, mammals, invertebrates, etc.) respond differently to different forms of structural connectivity, and 2) evaluating whether the interactions between landscape structure and connectivity are the same across Australia's diverse terrestrial ecosystems, particularly temperate vs. tropical and forest vs. woodland vs. grassland systems.

3. METHODS

3.1 Search strategy

The following electronic databases will be searched for studies to be included in the review:

1. ISI Web of Knowledge
    i. ISI Web of Science
    ii. ISI Proceedings
    iii. Current Contents
    iv. CAB Abstracts
    v. Zoological Record
    vi. Web Citation Index
2. Directory of Open Access Journals
3. Scopus
4. Australian Agriculture and Natural Resources Online (AANRO)
5. CSPubList (via EnCompass; official CSIRO publications)
6. CSIRO Library Catalogue (Voyager)
7. Australasian Digital Theses Program
8. ProQuest Dissertations and Theses

We will search using two terms: one movement-related term and one term relating to landscape context. We will conduct searches of each database using all possible two-term searches based on the movement and landscape terms below.

Movement-related terms:

1. colonisation OR colonization
2. dispersal
3. migration
4. movement*

Landscape-context terms:

5. connectivity
6. corridor*
7. fragment*
8. isolat *
9. landscape*
10. matrix
11. paddock tree*
12. patch*
13. stepping stone*

We will also search for the following single terms:

14. interpatch*
15. gap-crossing

We will experiment with incorporating NOT operators into searches to limit the number of hits on unrelated topics. Where possible, we will use the following NOT terms: alloy*, aquatic, bacter*, brain, Campylobacter, capital, cell*, clinical, corrosion, cortex *, cultur*, deep-sea, disease*, evangel*, eye-movement*, fluvial, fung*, gas*, Holocene, ion, medicine, molec*, neur*, marine, motion, patient, phylogenetic, Pleistocene, politic*, polymer*, protein, river*, Salmonella, scripture, sediment, social movement, soil*, speciation, stent, stream*, thermal sensor, train, transport, virus*.

No foreign language searches will be conducted, as we anticipate that all research on connectivity management in Australia will be published in English.

Searches will also be conducted using the internet-based search engines Google Scholar and Alltheweb, using the two single-term searches and the five most prolific two-term searches from the Web of Science search listed above. The first 100 hits from each search on each website will be examined for possible inclusion in the review.

One of the difficulties with searching for relevant studies in Australia is that much of the research done in Australia is performed by or for government departments and results are often only available in government reports, not peer-reviewed publications. Unfortunately, there are no searchable databases of these reports in Australia. In addition, The Australasian Digital Theses Program database catalogues Masters and PhD theses from every university in Australia, but the extent of chronological coverage seems to vary among institutions. Furthermore, this database does not include Honours theses, which are generally only catalogued at the department level. Thus, we have developed a novel systematic search strategy specifically for these types of data sources. We will contact the following:

1. the main library of every research university in Australia

2. every research university department that includes the words biology, zoology, botany, ecology, evolution, ecosystem, conservation, environment*, forestry or natural resources in its department name
3. any other university school or department recommended by a university library but not identified by us using the terms listed above
4. every state government department that conducts or funds environmental research
5. every federal government department that conducts or funds environmental research

We will request all theses or reports that have any of the following terms in their titles or as keywords: dispersal, corridor*, connectivity, fragment*, remnant*. Where possible, we will target our requests to specific individuals in these organisations in order to improve the probability that they will respond to our requests.

3.2 Study inclusion criteria

We will include in the review any and all studies that meet the following criteria:

- **Relevant subject(s):** The study provides data on any terrestrial native Australian species including mammals, birds, reptiles, invertebrates and plants (including seeds and pollen).
- **Types of intervention:** The study site contains any type of structural connectivity between otherwise isolated patches of native habitat or, even more broadly, landscapes with significant spatial heterogeneity in structure and occupancy by the subject.
- **Types of comparator:** The study compares patches connected by any type of structural connectivity vs. patches with less or no connectivity. No comparator is necessary for inclusion in the review; however, comparators are required for studies to be included in some meta-analyses.
- **Types of outcome:** The study contains data on relative movement rates of individuals between patches, or at least evidence (direct or inferred—see 3.3 Study quality assessment) of movement within a heterogeneous landscape.
- **Types of study:** A wide variety of types of study are often conducted in dispersal and connectivity research (see Section 3.3 below) and we will attempt to include as many types as possible, including presence/absence studies, abundance surveys, mark-recapture or resighting data, genetic studies (including population-level analyses as well as more detailed analyses like assignment tests), and more direct observations of movement such as radiotelemetry studies.

References returned by all searches (database, internet search-engines, universities and departments) will be filtered in several stages to determine whether they will be included in the review or not. First, title filtering will be performed to remove references that are clearly irrelevant to this review. Second, abstract filtering will be performed to remove references that, based on the abstract, do not meet the above study inclusion criteria. Finally, full text filtering will be performed to remove references that may have appeared relevant from the abstract, but do not actually meet the study inclusion criteria. When it is unclear whether a reference should be included in the next stage of the review, it will be included. At each of these stages, two reviewers will independently examine a subset of references (about 10-15% of the studies) and results will be compared via a Kappa Test. If the Kappa value is <0.6, the filtering strategy will be revised and repeated until Kappa >0.6 is achieved. Two reviewers will also independently review references whose status remains unclear and any disagreements will be resolved via consensus or by a third reviewer.

All references accepted after the full text filter will be accepted into the review and will be evaluated for data extraction (see Section 3.4 below).

3.3 Study quality assessment

The quality of each study accepted into the final review will be assigned two scores to rank its quality according to two distinct sets of criteria. One set of scores relates to the experimental design employed in each study. We will use the hierarchy of evidence table presented in Pullin and Knight (2003), which is modified from systematic reviews in medical research (Table 2).

Table 2. Hierarchy of evidence based on the experimental design of research undertaken. Modified for conservation use by Pullin and Knight (2003).

Quality of evidence – Conservation	
I	Strong evidence obtained from at least one properly designed; randomised controlled trial of appropriate size.
II-1	Evidence from well designed controlled trials without randomisation.
II-2	Evidence from a comparison of differences between sites with and without (controls) a desired species or community.
II-3	Evidence obtained from multiple time series or from dramatic results in uncontrolled experiments.
III	Opinions of respected authorities based on qualitative field evidence, descriptive studies or reports of expert committees.
IV	Evidence inadequate owing to problems of methodology e.g. sample size, length or comprehensiveness of monitoring, or conflicts of evidence.

Because we are particularly interested in assessing the value of different landscape elements at providing functional connectivity, our “gold standard” will be data that document movement paths between patches (so we know which landscape elements were actually used) and which document successful reproduction following successful dispersal. This first point is particularly important because data showing that individuals have transferred between patches that are connected by a corridor (e.g., through mark-recapture data) does not necessarily prove that movement has occurred *through* the corridor. The second point is important because dispersal without reproduction will not ultimately affect levels of gene flow or “rescue” populations from extinction. Very few studies will meet this gold standard by providing data on both of these aspects of dispersal (and most will have data on neither). Instead, most studies use a variety of different surrogates, including everything from following dispersal movements until settlement or observing part of the dispersal (or other movement) process, to inferring dispersal using genetic data or even presence/absence of a species. Thus, we also intend to use a hierarchy of evidence approach to distinguish between studies that fully documented paths leading to effective dispersal versus those that inferred that dispersal occurred using a variety of methods, some of which are better surrogates for dispersal and make fewer assumptions than others (Table 3).

Table 3. Hierarchy of quality of evidence based on the degree to which dispersal was actually observed versus inferred from different types of data.

Quality of evidence – Measuring Effective Dispersal	
I-1	Individuals followed directly so dispersal paths known—individuals followed until death or successful reproduction.
I-2	Individuals followed directly so dispersal paths known but only followed until settlement.
I-3	Individuals followed directly so dispersal paths known but only for part of dispersal search path.
I-4	Movement path known but unknown whether for dispersal or other purposes.
II-1	Between-patch dispersal (path inferred) known from mark-recapture data, genetic assignment tests, or radiotelemetry data where movement path not known.
II-2	Between-patch dispersal inferred from population genetic data.
III-1	Between-patch dispersal inferred from presence in connecting landscape element (e.g. in corridor or stepping stone between patches)
III-2	Between-patch dispersal inferred from presence/absence data in patches.

Two reviewers will independently assess a random subset of accepted articles (approximately 15 % of the studies accepted at full text); any disagreement on study quality will be resolved by consensus and referred to a third reviewer if necessary.

3.4 Data extraction strategy

For each study accepted into the final review, a reviewer will record data regarding the study characteristics (subject, intervention, and outcomes measured), study quality, and sources of heterogeneity (see Section 3.6 below) in a format suitable for meta-analysis where possible on a specially designed data extraction form. Data extraction will be repeated by a second reviewer for a random subset of studies (approximately 15%) to check accuracy and repeatability. The forms may be amended after piloting the data extraction process.

3.5 Data synthesis

We will produce a narrative synthesis of the results of all studies included in the final review based on the data extraction summary tables. Quantitative analyses will be undertaken on any data that are suitable for formal statistical treatment. Meta-analysis including random effects will be employed if suitable data are available. If there are insufficient quantitative data for a meta-analysis then a vote-counting procedure will be employed to synthesize results. Any analyses performed will be carried out as two versions – one with studies weighted according to the hierarchies of evidence above (Tables 2 and 3) and one with unweighted data.

3.6 Potential sources of heterogeneity

Effects of structural connectivity may differ between studies for a number of reasons. As noted above, our data extraction strategy will include quantifying possible sources of heterogeneity that may explain variation among different studies. Such sources will obviously include the factors addressed by our secondary and tertiary questions (see 2.2 and 2.3 above), differences in study design (see Tables 2 and 3), as well as other potential ecological or methodological differences. Thus, possible sources of heterogeneity to be considered wherever possible (and analysed through meta-analysis where sufficient data exist) will include:

1. Taxonomic group of study organism
2. Ecology, behaviour, and dispersal mechanism of study organism
3. Life history of study species and specifically the life-history stage of individuals included in the study
4. Size of study organism and spatial scale of movements
5. Type of community or ecosystem (e.g., temperate vs. tropical)
6. Size, number and habitat quality of patches being connected
7. Type of connectivity – e.g., continuous corridor, disjunct corridor, stepping stones, etc.
8. Quantitative characteristics of connectivity – e.g., width, length, species composition, age, vegetation complexity, gap distances, etc.
9. Characteristics of the intervening matrix (crop, pasture, pine plantation, etc.)
10. Whether the connectivity and/or patches are remnant or restored habitat
11. Landscape level characteristics (e.g., total percent cover of native vegetation)
12. Disturbance history of study areas
13. Climatic conditions during study (e.g., drought)
14. Type/purpose of movements studied (home-range movements vs. foraging trips vs. dispersal vs. migratory or nomadic movements)
15. Study design (replicated comparisons, etc.)
16. Type of study (tracking, mark/recapture, population genetic, etc)

4. POTENTIAL CONFLICTS OF INTEREST AND SOURCES OF SUPPORT

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Appendix A – Glossary of systematic review terminology*

Systematic Review – "a review of a clearly formulated question that uses systematic and explicit methods to identify, select and critically appraise relevant research, and to collect and analyse data from the studies that are included within the review. Statistical methods (meta-analysis) may or may not be used to analyse and summarise the results of the included studies."

Subject – defined by the CEBC as "the unit of study to which the intervention is to be applied" (i.e., the community, group, species, or population being studied)

Intervention – defined by the CEBC as "the policy or management action under scrutiny within the systematic review", but, for the purpose of this review, more broadly defined as the independent variable of interest.

Outcome –defined by the CEBC as "the effect of the intervention in a form that can be reliably measured", but, for the purpose of this review, more broadly defined as the dependent variable of interest. The Primary Outcome is the most informative and most suited to meta-analysis. The Secondary Outcome is less informative but provides an alternative way to analyse data across studies.

Meta-analysis – statistical techniques used to integrate and summarise results from a number of independent studies.

Primary, Secondary and Tertiary Questions – questions to be addressed by the review in order of breadth, rather than order of importance or interest. Thus, the Primary Question represents the broadest possible comparison (all types of intervention vs. no intervention), and the Secondary and Tertiary Questions represent variation within that broader comparison.

Study Inclusion Criteria – the information contained in references that determines whether they will be included in the systematic review or rejected. These are established *a priori* to minimise subjectivity in the decisions about what references to include.

* definitions quoted from the CEBC website (http://www.cebc.bangor.ac.uk/terminology)

Appendix B – Glossary of other important terms **

Structural Connectivity – habitat features in a fragmented or heterogeneous landscape that physically link other features, especially discrete areas of habitat occupied by any species in question (e.g., patches)

Functional Connectivity – the degree to which organisms actually move through the landscape, especially between discrete areas of occupied habitat (e.g., patches) and especially for dispersal & gene flow

Connectivity – we adopt the definition of landscape connectivity first proposed by Taylor et al (1993), who defined it as "the degree to which the landscape facilitates or impedes movement among resource patches"; thus, a landscape with high connectivity is one that provides functional connectivity regardless of what it looks like in terms of structural connectivity

Corridor – a landscape element that connects two or more patches in a relatively unbroken (contiguous) line; thus, a form of structural connectivity

Dispersal – movement of organisms or propagules that may potentially result in gene flow, including the movement of individuals from their place of birth to the site of their first breeding (natal dispersal), movement from one breeding site to another breeding site (breeding dispersal), movement of seeds (seed dispersal), and movement of pollen (pollen dispersal)

Effective dispersal – occurs when dispersal movements result in actual gene flow (e.g., natal dispersal followed by successful reproduction, seed dispersal followed by successful establishment and reproduction, etc.)

Patch – a discrete area of habitat occupied by a species, surrounded by areas not occupied by that species that are known or thought to be unsuitable as habitat (e.g., matrix); note therefore that a patch may not be clearly observable in a structural sense to researchers, and thus this definition of patch is compatible with landscape models such as the variegated model and continuum model as well as the patch-matrix model

Matrix – unoccupied region, thought or known to be unsuitable as habitat, surrounding patches of suitable habitat

Habitat – a place suitable for survival and/or reproduction of a particular plant or animal species; note that different structural and compositional characteristics may be associated with habitat used for long-term survival, reproduction, and short-term survival during dispersal

Stepping stone – a landscape element that is located between but not contiguous with two or more patches; thus, a form of structural connectivity

Gap-crossing – movement across matrix (e.g., from a patch to a stepping stone). Gap-crossing studies typically involve experimental translocation of individuals across gaps and observing their behaviour after release.

** Note: ALL of these terms are likely to be species specific (i.e., what is suitable habitat for one species is not for another), but an overarching goal of the review is to uncover general principles in how the *landscape structure* of habitat influences functional connectivity.