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WHAT IS THE EVIDENCE FOR THE DEVELOPMENT OF CONNECTIVITY TO IMPROVE SPECIES MOVEMENT, AS AN ADAPTATION TO CLIMATE CHANGE?

Systematic Review Protocol

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1. BACKGROUND

1.1 Policy context and need for review:

In the context of commitments to halt the loss of biodiversity and meet other targets in the UK Biodiversity Action Plan, there is a need to consider the impacts of climate change on species, for understanding of their response and provision of potential adaptation measures (UK Biodiversity Partnership 2007). This is in addition to commitments in place which require reduction of the impacts of fragmentation. The EU Habitats Directive (EEC, 1992; transposed into law as the Habitats Regulations 1994) obliges the UK to endeavour to improve the ecological coherence of Natura 2000 sites (see Box 1) and maintain or restore favourable conservation status to species of community importance, many of which have been adversely affected by fragmentation. The England Biodiversity Strategy (EBS) Climate Change Adaptation workstream is currently engaged in promoting adaptation, and developing an adaptation strategy across all sectors of the EBS in recognition of the threat of climate change to meeting their biodiversity objectives.

1.2 Connectivity and climate change

There is a growing body of evidence of impacts of climate change on biodiversity, which include:

- Changes in phenology, which may lead to loss of synchrony between species (e.g. Visser *et al.*, 1998)
- Changes in species distribution (including arrival of non-native species and potentially loss of species for which suitable climate conditions disappear, e.g. Wilson *et al.*, 2005)
- Subsequent changes in community composition and interspecific interactions (e.g. Klanderud, 2005)
- Changes in ecosystem function (e.g. Fay *et al.*, 2008)
- Loss of physical space due to sea level rise and increased storminess (e.g. Desantis *et al.*, 2007)

Projected shifts in suitable climate space may force species to adjust their ranges if they are to survive (Walmsley *et al.*, 2007) and many species groups are already showing range margin movement (Parmesan, 2006). Many species may not be able to move rapidly enough to track their future climate space and this problem is further compounded by fragmentation (Travis, 2003).

Habitat isolation, urbanisation and agricultural intensification may all inhibit species movement. Dispersal can become energetically more costly and have higher mortality risks (Pearson & Dawson, 2005; Warren *et al.*, 2001; Thomas *et al.*, 2006). Even mobile species such as butterflies have been shown to encounter difficulty moving quickly enough in response to climate change (Gutierrez & Thomas, 2000).

A contrasting impact of climate change is that invasive species may be able to spread further. In order to protect native species assemblages, conservation interventions may be required to reduce connectivity for invasive species (Manchester & Bullock, 2000).

Box 1

Article 10 of the Habitats directive
'*Member States shall endeavour, where they consider it necessary, in their landuse planning and development policies and, in particular, with a view to improving the ecological coherence of the Natura 2000 network, to encourage the management of features of the landscape which are of major importance for wild fauna and flora. Such features are those which, by virtue of their linear and continuous structure (such as rivers with their banks or the traditional systems for marking field boundaries) or their function as stepping stones (such as ponds or small woods), are essential for the migration, dispersal and genetic exchange of wild species*.'

Article 3 of the Birds directive
'…*Member States shall take the requisite measures to preserve, maintain or re-establish a sufficient diversity and area of habitats for all the species of birds referred to in Article 1. 2. The preservation, maintenance and re-establishment of biotopes and habitats shall include […] (b) upkeep and management in accordance with the ecological needs of habitats inside and outside the protected zones*…'

1.3 (Re)Building connectivity as an adaptation measure

Measures to increase species' resilience and their speed of response are both important to limit the consequences of climate change (Hannah *et al*., 2002; Hulme, 2005; Pearson & Dawson, 2005). Measures proposed to increase resilience in the face of biodiversity threats include protected areas, varied and functional ecosystems and good habitat quality (Hopkins *et al*., 2007; Mitchell *et al*., 2007).

However, a key measure for increasing the speed at which species are able to respond to climate change is probably ensuring landscapes are permeable to species movement. There are a number of complex links and feedback processes in moving from increasing individuals' movement to predicting changes in the ranges of populations as a climate response. The link between increased species movement and (meta) population persistence has strong foundations in ecological theory (Hanski & Gaggiotti, 2004) but the importance of dispersal on population dynamics can vary with the spatial structure of the population (Thomas & Kunin, 1999).

Landscape scale interventions such as the development of functional ecological networks are often proposed as a measure to limit the consequences of habitat fragmentation and so help species adapt to the impacts of climate change. Functional ecological networks are based on functional connectivity, as contrasted to networks based purely on structural connectedness. For individual species, a landscape is functional if it allows a species to carry out all its ecological functions including movement for foraging, mate finding and dispersal. For all but the most immobile and most mobile species, functional connectivity will be affected by the availability and spatial arrangement of habitat and the composition and arrangement of intervening landscape (Tischendorf & Fahrig, 2000; Murphy & Lovett-Doust, 2004). A basic principle of functional connectivity is that some land covers or land uses are more permeable than others (Donald & Evans, 2006). The implication of this definition of connectivity is that different species will respond in different ways so connectivity can only be defined from each species viewpoint (Tischendorf & Fahrig, 2000).

Management, expansion, restoration and creation of suitable habitat, provision of buffer zones around habitat, provision of corridors and stepping-stones between habitats and improving matrix permeability, are the 'building blocks' for functional ecological networks. From a practical perspective, in the UK there may be limited potential for creation of structural networks based on large core areas and corridors of near-continuous habitat applied elsewhere in the world (e.g. North and South America and Europe; Jongman & Pungetti, 2004). This is due to the limited scale of land tenure, current landscape use and the current species composition (Bennett, 2004). However, each kind of network aims to incorporate core breeding areas with permeable elements between them.

Functional ecological network models have already been used throughout the UK to target and evaluate conservation options at various spatial scales (Catchpole 2007; Watts *et al*., 2007). This reflects recognition of a potential limitation of site-based conservation systems. For example, the recent UK Biodiversity Partnership publication '*Conserving Biodiversity in a changing climate: guidance on building capacity to adapt*' advocates provision of ecological networks as one of several measures that can be taken to encourage adaptation (Hopkins *et al*., 2007, p.18).

Functional ecological networks are based on first principles derived from ecological theory (e.g. island biogeography, MacArthur & Wilson 1967; metapopulation dynamics, Hanski 1999). However some authors have noted that there is little supporting empirical evidence to demonstrate the practicality and effectiveness of ecological networks in general (e.g. Jongman & Pungetti, 2004) or to guide design features such as size, shape, spacing, or structure.

With the current focus on evidenced-based policies, it is important to test links between general principles of functional connectivity and specific species-based studies. This systematic review will help ensure that any further development and application of ecological networks as an adaptation to climate change would be:

- Based on the best available evidence
- Refined and applied, to benefit species or groups of species
- Accepted by the wider policy, planning and conservation communities.

2. OBJECTIVE OF THE REVIEW

The overall objective was to review evidence that supports (or does not support) the principles of landscape functional connectivity. This is in order to help ensure that policies and actions taken in the UK to increase (or decrease) species movement by changing landscape connectivity are supported by robust scientific evidence. A key secondary objective was to identify knowledge gaps.

2.1 Research question

Which landscape features affect species movement?

The specific question for this review was developed through iterative discussion between the review team and the steering group, which consisted of key policy stakeholders for the UK, both NGO and statutory agencies. This broad initial question was broken into components based on potential subjects, interventions, outcomes, and study format and design.

As the question begins ‘what landscape features…’ (the intervention component) a broad range of landscape features and characteristics associated with connectivity was searched initially. The steering group discussed a range of options to broaden or narrow the scope of each of the subject, outcome, study format and study design aspects, depending on the evidence available, which are given in Table 1.

As a large number of articles are obtained by the search, the review was be limited to subjects, interventions and outcomes ranked higher in the table. The review is intended to support conservation policy and activity in the UK, so there was a focus on UK studies and species, as a secondary question.

Table 1. Options for scope of question: Subject, outcome, study format and design

Subject	Intervention	Outcome	Study format	Study design
1. UK species 2. Defra potential invasives 3. Temperate Europe species 4. Other species in comparable landscapes[1] 5. All species	See section 3.1.1 for comprehensive list	1. Change in dispersal rate 2. Change in movement distance 3. (Re)colonization of vacant patches (inc. increase in proportion of patches occupied) 4. Increased range 5. Genetic evidence of dispersal/ isolation	1. Empirical evidence of movement 2. Genetic evidence 3. Anecdotal or qualitative evidence 4. Modelling/ simulations	1. Land use/habitat change(before and after/control and intervention designs - BACI) 2. Habitat change without BACI design but including a spatial OR a temporal comparator 3. Comparison between different landscape structures or compositions

[1]Similarity of landscape structure for this analysis will refer to studies with patches of semi-natural habitat within a primarily agricultural and/or urban matrix.

Habitat creation or restoration may not have the exact opposite impact of degradation, therefore if before/after studies were retrieved it would be important to keep evidence from creative/positive changes and destructive/negative intervention separate.

3. METHODS

3.1 Question formulation

Following scoping searches and initial assessments of retrieved references, the review question was further developed in consultation with the steering group. Question elements were agreed as follows:

- Subject: all species
- Intervention: landscape features - natural and man-made (including for example: corridors, stepping stones, 'green bridges', barriers, matrix permeability, spatial pattern)
- Comparator: absence of (or quantitatively less of) the above features in the landscape
- Outcome: a recorded change in movement in individuals of study species

3.2 Search strategy

The development of an appropriate set of key words to be used in the searching phase of the review was driven by a steering group and further guided by 'scoping' searches to allow the identification of the most useful sets of words. These were grouped into sub-sets, based on the intervention and outcome elements of the question. The formulation of additional subsets of spatial and subject context words helped to ensure that only the most relevant studies were identified. Thus the search terms were as follows:

- **Intervention**: corridor*, barrier*, bridge*, "stepping stone*", highway*, link*, network*, "buffer zone*", patch*, edge*, connect*, mosaic*, "spatial pattern*", heterogen*, permeab*
- **Outcome**: movement, dispersal, isolation, migration, coloni*, invasion, immigration, emigration
- **Spatial context**: habitat, landscape, matrix, fragment*
- **Subject context**: biodiversity, conservation, species, population*, metapopulation*.

Definitions of these search terms are in the Glossary of the systematic review report. An asterisk (*) indicates a 'wildcard', which allows the database or search engine to look for multiple words that have different endings, e.g. connect* captures [connect OR connected OR connection OR connectivity OR connectedness]. Speech marks ("") around two words restricts the search to where that phrase occurs (for example, "buffer zone*" picks up 'buffer zone' and 'buffer zones' but not 'buffer the zone'.

The search strategy was designed to capture as many relevant references as possible, both published and unpublished ('grey literature'). First, relevant studies were identified through searches of the following electronic databases:

- ISI Web of Science
- CAB Abstracts
- Directory of Open Access Journals
- Index to Theses Online
- Conservation Evidence.com

For these searches, the individual key words were combined using 'Boolean' operators (restricting or expanding the searches using 'AND', 'OR' and 'NOT' indicators) to maximise the efficiency of searching. All terms from the 'outcome', 'spatial' and 'subject' context word lists were combined with a single 'intervention' word per search, for example:

"((movement OR dispersal OR isolation OR migration OR coloni* OR invasion OR immigration OR emigration) AND (habitat OR landscape OR matrix OR fragment*) AND (biodiversity OR conservation OR species OR population* OR metapopulation*) AND corridor*)"

In addition to the online databases, general internet searches were conducted to identify further studies and unpublished literature. Three search engines were used in the web searching phase: www.alltheweb.com, www.scirus.com, and www.google.com. The first 50 hits (restricted to .doc .txt .xls and .pdf documents, where this could be separated) for each search were examined for studies meeting the inclusion criteria. No further links from the captured documents were followed. To allow for the variation in search engine capability, a standardised search was used for each engine, utilising their advanced search options, as follows:

- Using the "find any of the words" feature (or "at least one of the words"), the following terms were entered: "species, metapopulation, habitat, landscape, fragmentation, dispersal".

AND

- Using the "find all the words" feature, the following terms were used individually: 'connectivity', 'barrier', 'bridge', 'corridor', 'stepping stone', 'network', 'link', 'spatial pattern', 'highway', 'mosaic', 'permeability', 'buffer zone', 'heterogeneity', 'patch', 'edge'.

The total number of search term combinations (or 'search strings') to be searched in each engine was fifteen. The number of words per search string was necessarily different from that used in the electronic database to reflect the increased ambiguity of particular words in a search of the World Wide Web compared to scientific publication databases.

The websites of the following organisations were inspected for further relevant material including useful grey literature or unpublished datasets: Natural England, Scottish Natural Heritage, Countryside Council for Wales, Department of Agriculture and Development Northern Ireland, Joint Nature and Conservation Committee, US

Forest Service, Environment Canada (including Canadian Wildlife Service) and The Commonwealth Scientific and Industrial Research Organisation (CSIRO).

References listed in the search results were then checked for duplicates. Searching was completed in February 2008.

3.3 Study inclusion criteria

3.3.1 Inclusion in review library

References retrieved underwent a three-stage iterative filtering process to assess their relevance for inclusion into the analyses. First the titles of all articles were assessed for relevance by a single reviewer (AE). Any titles in the field of whole-organism biology were included, as the search terms had been quite specific. Examples of studies retrieved in the searches that were rejected at title stage included palaeontology, molecular biology, chemistry, and other fields that use similar words to landscape ecology to mean very different things (particularly ‘matrix’ and ‘species’). References were accepted into the next stage when there was any uncertainty, as article title often did not accurately reflect content.

A more stringent set of inclusion and exclusion criteria was formulated for the second, abstract level assessment. The criteria were tested using kappa analysis and refined before being applied.

At the abstract inclusion stage it became apparent that there was a larger than expected body of evidence looking at matrix features. As it was not possible to review patch size, isolation by distance and also matrix feature data in the time available, the latter group was chosen to reflect the increased interest in the effects of matrix features in both scientific and policy contexts (e.g. Kupfer *et al.*, 2006 and the England Biodiversity Strategy, Mitchell *et al*., 2007, respectively). Studies concerning patch size or distance were saved in a separate list for potential further investigation in the future.

Included were all studies presenting primary data concerning <u>directly-measured</u> movement (i.e. not inferred movement) in relation to:

- landscape features outside of habitat patches
- the shape of habitat patches.

Only studies with appropriate spatial or temporal controls or comparators were included in the review. Specific exclusions were:

- Studies of colonisation/invasion where the source (i.e. distance moved) is not known
- Studies of seed movement by animals or disease/parasite movement – any form of ‘lift-hitching’ (though dispersal of seeds by animals is very important, the effect of landscape features on the seeds vs. the ‘carriers’ is difficult to separate)

Studies that did not fit the inclusion criteria that were rejected at this stage included:

- Studies that inferred dispersal from measures of species abundance/density (as opposed to direct measurement)
- Articles in which movements measured were within a single habitat patch
- Modelling studies which did not present field data used for model validation/parameterisation
- Genetic studies (except where precise identification and location of parents was possible)
- Studies examining pollen dispersal (this is a means of genetic dispersal but not population dispersal)
- Studies of the effect of inter-patch distance or patch size.

The third, full text assessment stage was conducted by a single reviewer (AE). The same inclusion and exclusion criteria as for the abstract assessment were used, with input and agreement from other review authors in cases of uncertainty.

3.3.2 Study characterisation & organisation into pools

The articles remaining after full-text assessment varied greatly, both in terms of the landscape feature tested and the way the outcome was measured. To assist synthesis they were further organised by division into pools (Figure 1) according to experimental design, particularly the type of matrix feature tested and the type of movement (between specific patches or around heterogeneous landscapes). This allowed us to look for pools of studies large enough and consistent enough to extract data for meta-analysis.

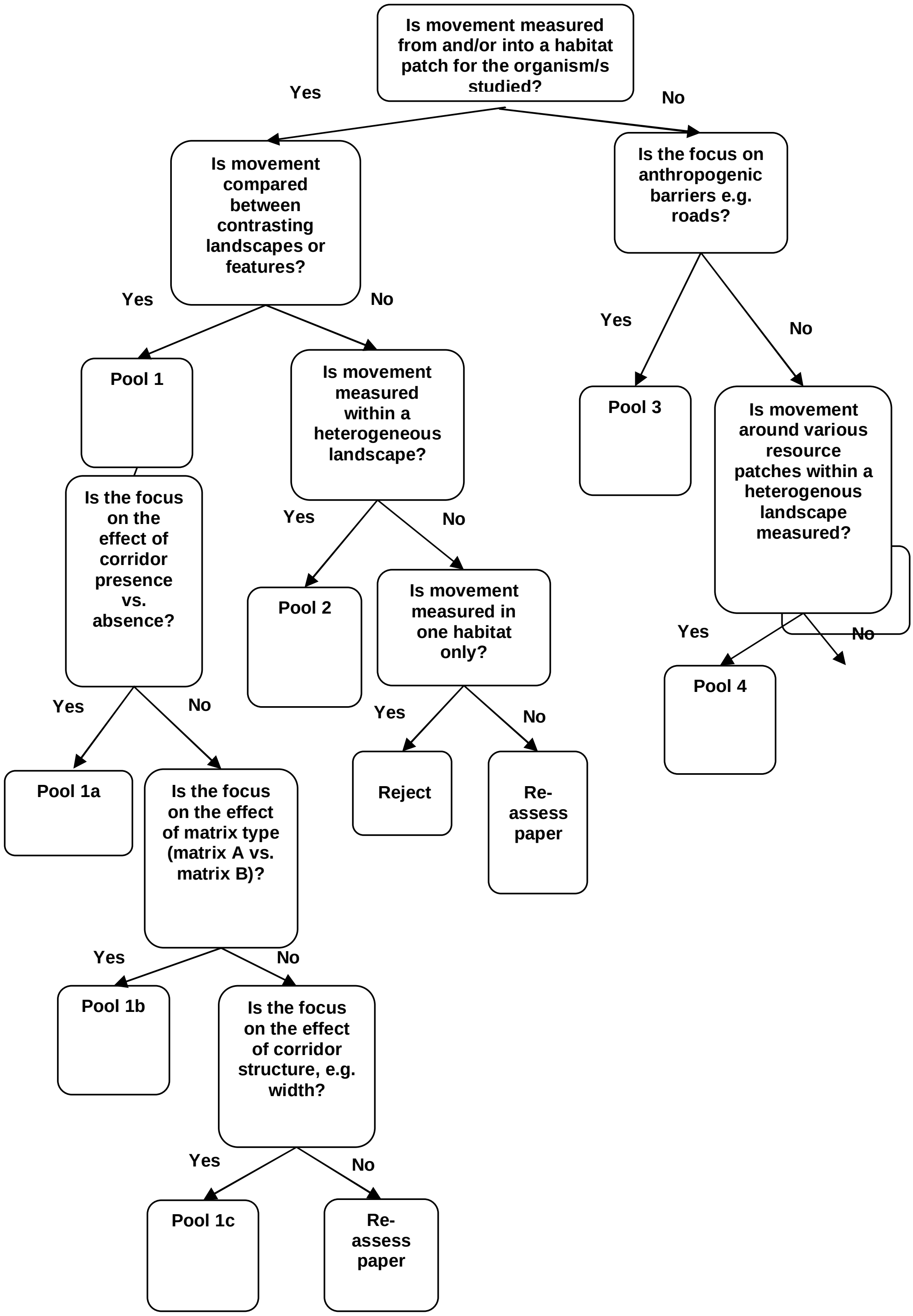

Figure 1. Criteria for the division of studies accepted at the full text stage into pools.

Pool 1 - Direct comparisons of matrix elements: Comprised studies providing explicit, direct comparisons of movement to, from or between patches (i.e. emigration or immigration or both). This was restricted to studies where two (or more) distinct matrices were compared. To reflect the heterogeneity in study focus within this relatively broad category, pool 1 was further divided into:

- 1a: Corridor presence/absence (note: a corridor in this project was defined as a linear element of the same vegetation type as the habitat patch (see glossary) and not capable of supporting a breeding population according to the study text)
- 1b: Two kinds of matrix
- 1c: Two kinds of corridor, e.g. narrow/wide or continuous / discontinuous.

Pool 2 - Interpatch movement: Consisted of studies of movement to or from patches in heterogeneous landscapes. These included, for example, mark-recapture studies relating the number of individuals moving between patches to matrix composition in agricultural-forest mosaics.

Pool 3 - Anthropogenic barrier features: Comprised studies of movement rates across anthropogenic barriers (predominantly roads) where at least two types of barrier or two types of crossing are compared. These were separated out into an individual pool because they have a potentially valuable practical application to the UK where the road density is high.

Pool 4 - Movement around complex landscapes: Comprised studies of movement (especially home-range movement) without a specific ‘home’ habitat patch being defined, and where species utilise a range of patches in a landscape.

Pool 5 - The remainder: Comprised those remaining studies that passed the inclusion criteria but did not fit into any of the above pools, e.g. studies of patch-edge shape, speed of movement, and movement compared between habitat patches and one matrix type.

Note: where single articles reported two different studies/datasets, each was included in the most appropriate pool.

3.4 Study quality assessment

Methodological characteristics of the included studies were tabulated to enable the differences in approach to be described and to ensure that potentially interesting information on methodological quality was not excluded from the analyses.

3.5 Quantitative data extraction

Data from those studies selected for meta-analyses were extracted into spreadsheets. In addition to data on movement rates, extraction spreadsheets also included inter-patch distance, taxonomic group, matrix types (woody vegetation, grassy vegetation, bare or made ground, aquatic), and whether the physical design of the experiment was a comparison or a ‘choice’ structure. Where it was not possible to extract data, authors were contacted with a request to provide missing information.

The data extraction and study characteristics are described in detail in Appendix 1.

In some cases, data were extracted by multiplication of proportions shown in graphs with numbers of individuals in the experiment (see Appendix 1 for details). Multiple non-independent data points were extracted from the same study where:

- more than one species or subspecies was examined ,sexes or ages were separated or different matrix habitats or inter-patch distances were used.

Zero values for movement rates were substituted with one in to permit calculation of the risk ratio (Lipsey & Wilson, 2001). Data points were excluded from studies where the movement rate was zero in both treatment and control.

3.6 Quantitative data synthesis

To conduct a meta-analysis of the quantitative data we used risk ratio as an effect size metric and also ‘number needed to treat’ (NNT), defined as the expected number of individuals who need to receive the experimental rather than the comparator intervention for one additional individual to either incur (or avoid) an event in a given time frame.

3.6.1. Exploration of heterogeneity

Cochran’s Q tests were used to examine heterogeneity among effect sizes. Subgroup analysis and meta-regression were undertaken, where enough information on covariates was available.

3.6.2. Robustness of analyses

Sensitivity analyses were carried out by comparing the risk ratios to risk differences and also odds ratios, to investigate whether choice of effect size metric was critical to the conclusions of the meta-analysis.

Multiple points from the same study were initially disaggregated (i.e. included as separate points in the analysis) to explore reasons for variation between them, but were also aggregated to test for effects due to potential non-independence of data from the same study (quasireplication).

The presence of publication bias was investigated by means of funnel plots (Sterne, 2001).

3.7 Narrative synthesis of studies

Qualitative assessment (narrative synthesis) was used to examine the effects of different matrix features on the movement of species currently present in the wild in the UK. Available information was summarised by habitat type, landscape feature, experimental design and taxonomic group. The narrative synthesis was based on outcomes as reported by authors without considering whether the outcome reported is reflected in the data presented. Unlike meta-analysis, this qualitative synthesis does not consider effect sizes.

4. POTENTIAL CONFLICTS OF INTEREST AND SOURCES OF SUPPORT

This project was commissioned by Defra and is funded by the Forestry Commission, Countryside Council for Wales, Defra , Scottish Natural Heritage and the Woodland Trust.

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