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DO HABITAT CORRIDORS INCREASE POPULATION VIABILITY? PART A: DO HEDGEROW CORRIDORS INCREASE THE POPULATION VIABILITY OF WOODLAND SPECIES?

Systematic Review

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Protocol published on website: 2006 – Review posted on website: 2006-

Cite as: Davies, Z.G. & Pullin, A.S. (2006). Do hedgerow corridors increase the population viability of woodland species? CEE review 05-001 (SR8a). Collaboration for Environmental Evidence: www.environmentalevidence.org/SR8a.html.

CENTRE FOR EVIDENCE-BASED CONSERVATION

SYSTEMATIC REVIEW NO. 8: DO HABITAT CORRIDORS INCREASE POPULATION VIABILITY?

PART A: DO HEDGEROW CORRIDORS INCREASE THE POPULATION VIABILITY OF WOODLAND SPECIES?

REVIEW REPORT
(FINAL REPORT)

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Davies, Z.G. & Pullin, A.S. (2006). Do hedgerow corridors increase the population viability of woodland species? Systematic Review No. 8. Part A. Collaboration for Environmental Evidence.

SYSTEMATIC REVIEW SUMMARY

Background

To mitigate the effects of habitat fragmentation in the modern landscape, conservation biologists commonly advocate interventions that increase habitat connectivity in order to sustain, and enhance, the population viability of target species. The use of habitat corridors as a conservation tool to mediate such effects has been an area of considerable debate over the past two decades. To investigate whether habitat corridors represent effective conservation interventions, this initial systematic review has focused on whether hedgerow corridors mitigate woodland habitat fragmentation.

Primary Objective

To systematically collate and synthesise published and unpublished evidence in order to address the following two questions:

1. "Do hedgerows increase the population viability of target species occupying otherwise isolated fragments of woodland habitat?"
2. "Do hedgerows increase biodiversity within otherwise isolated fragments of woodland habitat?"

Search Strategy

Relevant studies were identified through computerised searches of the following electronic databases: ISI Web of Knowledge (including ISI Web of Science and ISI Proceedings), JSTOR, Science Direct, Directory of Open Access Journals (DOAJ), Copac, Scirus, Scopus, Index to Theses Online, Digital Dissertations Online, Agricola, English Nature's "WildLink" and the Countryside Council for Wales (CCW) library. Web searches were conducted using the internet meta-search engines Alltheweb and Google Scholar, in addition to inspecting the following statutory and non-governmental organisation websites: UK Department for Environment, Farming and Rural Affairs (Defra), Northern Ireland Department of Agriculture and Rural Development (DARD), European Union portal (Europa), Scottish Natural Heritage (SNH), The Royal Society for the Protection of Birds (RSPB), Birdlife International, Plantlife International, The Mammal Society and The National Trust. Bibliographies of traditional literature reviews and articles accepted into the systematic review at the full text stage were examined for studies that had not yet been identified by any other means.

Study Selection Criteria

The criteria, which studies had to meet for inclusion into the final stage of the systematic review, were:

1. *Subject*: any mammal, bird, invertebrate, amphibian or plant population or assemblage.
2. *Intervention*: a hedgerow, or hedgerow network, connecting two or more fragments of woodland habitat.
3. *Outcome*: desired primary outcomes were change in population density for a target species or change in species richness within assemblages. Nonetheless, studies were not rejected on the basis of outcome.
4. *Type of study*: any.

Data Collection and Data Analysis

Study inclusion assessments were performed and the observed agreement between the two independent reviewers was deemed to be "substantially good". Due to a lack of high quality data on changes in the long term persistence of populations or in species richness within assemblages, no formal statistical analysis was undertaken.

Main Results

The evidence currently available on the role of hedgerows as corridors is insufficient to definitively evaluate their effectiveness in regard to maintaining, or increasing, the population viability of species inhabiting woodland. However, although direct, high quality evidence is lacking, there were a number of studies that provided anecdotal evidence supporting the functional importance of corridors, reporting local and mechanistic effects within the system such as species movements. The research suggests that hedgerows with greater vegetational diversity and structural complexity are favourable for movement over hedgerows of a more basic composition.

Conclusions

In the absence of robust, high quality evidence, the management priority should be to improve the quality and continuity of existing hedgerow corridors and to monitor their value with regard to population persistence of target species in the long-term. The behaviour of species moving through hedgerows within agricultural landscape is likely to be influenced by the nature of the matrix, the type and spatial distribution of adjacent habitats, season, farming activities (e.g., herbicide and pesticide applications) and interaction between conspecifics and other species. Detailed information on the movement rates and specific movement behaviour of individuals therefore needs to be collated, if not for each species, then for those of conservation concern. The challenge for researchers is to integrate species' land-use behaviour and landscape configuration in order to determine whether hedgerow corridors can, or do, function between isolated fragments of woodland habitat.

1. BACKGROUND

1.1 Review Rationale

To mitigate the effects of habitat fragmentation in the modern landscape, conservation biologists commonly advocate interventions that increase habitat connectivity in order to sustain, and enhance, the population viability of target species (Simberloff 1988; Brussard et al. 1992; Hanski 1994; Wiens 1995; Thomas & Hanski 1997). The use of habitat corridors as a conservation tool to mediate such effects has been an area of considerable debate over the past two decades (e.g., Noss 1987; Simberloff & Cox 1987; Simberloff et al. 1992; Dawson 1994; Beier & Noss 1998; Haddad et al. 2000).

Conservationists frequently advocate the corridor value of strips of vegetation, but are seldom able to support these assertions with strong evidence (Dunning et al. 1992). Proponents of habitat corridors argue that they act as conduits, facilitating the movement of individuals between otherwise isolated habitat patches, thereby assisting the persistence of populations within the landscape. Sceptics have argued that habitat corridors may actually be deleterious to target species, potentially increasing edge-related predation risk, the spread of disease and the probability of catastrophic natural disturbance (Ogle & Wilson 1985; Forman 1991; Hobbs & Hopkins 1991; Simberloff et al. 1992).

A systematic review of all available empirical evidence was proposed by English Nature (the UK government’s conservation agency for England) to investigate whether habitat corridors represent effective conservation interventions. The rationale is that the review will allow both policy makers and practitioners to make informed decisions with regard to habitat corridor preservation and creation. In the absence of good quality and robust information, the systematic review serves to highlight the knowledge gaps in our ecological understanding of habitat corridor function, and to draw attention to areas where primary research is required.

Initially this systematic review has focused on whether hedgerows mitigate woodland habitat fragmentation. It is not the purpose of this systematic review to examine the importance of hedgerows as habitats. It is acknowledged that hedgerows are an integral part of the landscape and valuable habitats in their own right. For example, they provide bird species with nesting, roosting and foraging sites (e.g., Osborne 1984; Johnson & Beck 1988; Moles & Breen 1995; Dermers et al. 1995) and act as refugia for small mammals on arable farmland in the post harvest period (Tew & Macdonald 1993). Indeed, hedgerows often provide the only element of structure and biodiversity in landscapes that have otherwise lost most of their natural habitats to intensive agriculture (Burel 1996).

1.2 Habitat Fragmentation, Landscape Connectivity and Habitat Corridors

The extent of anthropogenic modification in the countryside means that virtually all of the modern terrestrial landscape consists of fragments of once continuous habitat (Groombridge 1992) interspersed by non-habitat, referred to as the matrix (Hanski & Simberloff 1997). The effects of fragmentation can be equally detrimental to the persistence of species as outright destruction, leading to isolated pockets of habitat that can no longer support viable populations in the long-term (Soulé 1987). A reduction in landscape connectivity decreases the probability that individuals can move successfully between habitat patches (Klein 1989; Thomas & Hanski 1997; Baguette et al. 2000), and lessens the chances of the population existing through rescue effects (Brown & Kodric-Brown 1977; Hill et al. 1996; Kuussaari et al. 1998). Connectivity of habitat patches within a landscape has therefore become a key issue in the conservation of biodiversity (Hanski 1999).

Connectivity is both a functional concept and a structural term. In structural terms, the distribution of habitat within the landscape is considered (i.e., Euclidean distances between habitat patches) independently of species movement behaviour (Tischendorf & Fahrig 2000). The functional approach explicitly takes into account the movement of individuals and how this may be modified by the landscape. For example, by consideration of the permeability of the matrix, which may either enhance or hinder movement (Tischendorf & Wissel 1997; Tischendorf & Fahrig 2000; Chardon et al. 2003). Highly vagile species may perceive a landscape as functionally connected, while species with limited dispersal capabilities may view the same landscape as totally disconnected (Klein 1989; With & Crist 1995).

Biodiversity conservation strategies recently produced for Europe, as part of the EU Habitat and Species Directive adopted in 1992, propose that connectivity should be increased via corridors and stepping stones of habitat (EEC 1992). As a result, most European countries now have policies and management schemes in place to promote landscape-scale habitat connectivity (Jongman et al. 2004). Further interest in restoring connectivity has been stimulated by the acceptance that climate change leads to shifts in the location of climatically suitable habitats that satisfy the niche requirements of species (Parmesan 1996; Thomas & Lennon 1999; Parmesan et al. 1999; Berry 2002; Parmesan & Yohe 2003). The many species constrained by habitat fragmentation may not be able to track suitable climates (Parmesan 2001; Warren et al. 2001; Travis 2003), and will effectively get “left behind” and face extinction. Habitat specialists are particularly vulnerable as they are likely to show a large lag in their abilities to exploit new areas and may fail to shift their distributions at all; in addition to having specific ecological requirements to satisfy, a majority exhibit relatively poor colonisation ability (Peterken 1993; Warren et al. 2001; Hill et al. 2002; Travis 2003).

1.3 Woodland Fragmentation

During recent times, the most important change in the rural landscape concerns land-use patterns and the fragmentation of forests (Hobbs & Saunders 1993). In Britain, woodland once covered 90% of land area, but has now been reduced to a mere 15% (Rackham 1980). In the eastern US, most of the forest area was cleared for agriculture during the eighteenth and nineteenth century; in some areas of New England and New York, over 80% of the original forest was cleared by the late 1800s (Glitzenstein et al. 1990; Foster 1992; Smith et al. 1993). Many governmental policies now aim to promote substantially extended areas of woodland (Peterken 2000). For instance, in the UK, the Department of the Environment, Farming and Rural Affairs (Defra) is currently financially supporting farmers who plant woodlands on their land under the Farm Woodland Premium Scheme (FWPS) (Moore et al. 2003). In Ireland, the rate of afforestation is currently one of the highest in Europe, with projected planting of 20 000 ha of woodland per year, until 2030 (Anon 1996).

The creation of new woodland and other semi-natural habitats, such as hedgerows, in suitable locations are thought to reduce the detrimental effects of fragmentation on the biodiversity of woodlands by providing stepping stones or corridors of habitat between isolated species populations (Kirby 1995; Peterken 1995; Bennett 1999; Peterken 2000; Spellerberg 1995). The utility of woodland corridors has received reasonable attention from the research and conservation communities (Wiens 2002, Catchpole 2004) and this is the primary reason for choosing hedgerow corridors as the initial "model" for this systematic review.

1.4 Hedgerows

Hedgerows consist of lines of scrub and/or trees which demarcate field boundaries, contributing to a chequerboard landscape that is characteristic of much of lowland Britain and other parts of western Europe (Pollard et al. 1974; Burel & Baudry 1995). Hedgerows have a wide distribution, occurring on every continent with the exception of Antarctica (McCollin 2000). Traditionally, they are regularly managed to provide a relatively compact and sustainable stock-proof barrier but they are, however, extremely variable in structure. British hedgerows are generally low (often less than 2 m in height), continuous lines of trimmed bushes (Pollard et al. 1974). Hedgerows in other parts of the world are frequently much larger and less subject to management (e.g., in the North America, Forman & Godron 1986; and in South Africa and Australia, Bennett 1991). Bates (1937) defined a "hedge" as the woody upright component of the field boundary and a "hedgerow" as the entire structure, including the vegetation at the bottom of the hedge. This convention is still widely used today (Barr & Gillespie 2000) although, in North America, the term fencerow is often used as a synonym for hedgerow (McCollin 2000).

Over the past 30 years, the loss of hedgerows in the UK is largely a result of neglect, as opposed to deliberate removal (Barr & Gillespie 2000). As a consequence of agricultural intensification, they rarely function as originally intended and have commonly been replaced by temporary fencing (e.g., electric fence), which is both more effective and economical to maintain (Baudry et al. 2000). The biodiversity value of hedgerows only became a "hot" topic in the 1970s when the importance of older hedgerows as refuge for restricted woody plant species became apparent (McCollin 2000). The UK government reacted to the rate of hedgerow decline in 1997, when Defra proposed legislation to protect the hedgerows within the landscape that are considered to be most valuable. The Hedgerows Regulations (Anon 1997) set out explicit criteria concerning which hedgerows are judged worthy of protection and, by implication, those that are not. The ecological component of this evaluation places an emphasis on biodiversity, in particular that of plants (McCollin 2000). The UK government has also responded by providing financial incentives to plant hedgerows on farmland under the Countryside Stewardship (agri-environment) Scheme (Moore et al. 2003). Similar concern with regard to the conservation, restoration and management of hedgerows is reflected in many parts of Europe, but less so in North America where hedgerows are not credited with the same ecological or social importance (de Blois et al. 2002).

2. OBJECTIVES

2.1 Primary Objective

To systematically collate and synthesise published and unpublished evidence in order to address the following two questions:

1. "Do hedgerows increase the population viability of target species occupying otherwise isolated fragments of woodland habitat?"
2. "Do hedgerows increase biodiversity within otherwise isolated fragments of woodland habitat?"

2.2 Secondary Objective

To investigate whether the factors listed below influence the effectiveness of hedgerows as habitat corridors between woodland fragments:

1. Physical structure of the hedgerow.
2. Species composition of the hedgerow.
3. Nature of the arable matrix.
4. Size and quality of the woodland fragments.
5. Whether the hedgerow is supporting a breeding population of the target species.
6. Time of year of the study.
7. Life history stage of the target species (e.g., dispersing juveniles).
8. Altitude and latitude of the study area.

3. METHODS

3.1 Question Formulation

English Nature identified the need for a systematic review to evaluate the effectiveness of habitat corridors in promoting population viability of target species and biodiversity within fragments of remnant habitat. It was decided that a "model" system should be used to examine the utility of habitat corridors as conservation tools, and hedgerows were identified as the initial system to be investigated using the systematic review process.

The specific nature of the question to be addressed was formulated via iterative discussion between the CEBC and UK-based stakeholder organisations (i.e., those with an interest in the result of the review). In total, 25 stakeholder organisations were contacted and invited to comment on a draft of the proposed methodological protocol, prior to finalisation and initiating the research.

The question composed of three key elements:

1. *Subject (i.e., the unit of study to which the intervention is to be applied)*: any mammal, bird, invertebrate, amphibian or plant populations or assemblages.

2. *Intervention (i.e., the policy or management action under scrutiny)*: a hedgerow, or hedgerow network, connecting two or more woodland habitat fragments.
3. *Outcome*: change in population density for a target species or change in species richness within assemblages.

3.2 Search Strategy

Relevant studies were identified through computerised searches of the following electronic databases:

- ISI Web of Knowledge
  - ISI Web of Science: Science Citation Index Expanded (1945-present)
  - ISI Proceedings: Science and Technology Proceedings (1990-present)
- JSTOR
- Science Direct
- Directory of Open Access Journals (DOAJ)
- Copac
- Scirus
- Scopus
- Index to Theses Online (1970-present)
- Digital Dissertations Online
- Agricola
- English Nature's "WildLink"
- Countryside Council of Wales (CCW) library

The search terms used were:

- Hedgerow* AND corridor*
- Hedgerow* AND movement*
- Hedgerow* AND dispersal
- Hedgerow* AND colonisation
- Hedgerow* AND colonization
- Hedgerow* AND connectivity
- Hedgerow* AND population*
- Hedgerow* AND communit*
- Hedgerow* AND mammal*
- Hedgerow* AND bird*
- Hedgerow* AND invertebrate*
- Hedgerow* AND plant*
- Hedgerow* AND amphibian*

Publication searches were also conducted using the internet meta-search engines Alltheweb and Google Scholar; the first 50 word document or PDF hits from each website were examined for appropriate literature and data. In addition, the following statutory and non-governmental organisation websites were inspected: UK Department for Environment, Farming and Rural Affairs (Defra), Northern Ireland Department of Agriculture and Rural Development (DARD), European Union portal (Europa), Scottish Natural Heritage (SNH), The Royal Society for the Protection of

Birds (RSPB), Birdlife International, Plantlife International, The Mammal Society and The National Trust. Bibliographies of articles accepted into the systematic review at the full text stage and traditional literature reviews were searched for studies that had not yet been identified by any other means. Recognised experts and practitioners were contacted and asked to recommend any additional sources of potentially relevant information.

Foreign language searches were not conducted in this systematic review. However, the search did identify studies on a global scale (e.g., studies conducted in North America, Europe and Australia) and all suitable studies were included into the start of the systematic review process, irrespective of geographic location.

3.3 Study Inclusion Criteria

Studies were initially filtered by title and any obviously irrelevant articles were removed from the list of captured articles. Subsequently, the abstracts of the remaining studies were examined with regard to possible relevance to the systematic review question. A subset of approximately 25% of these articles ($n = 189$) was also assessed for relevance by a second independent reviewer; agreement on inclusion between the reviewers was deemed to be "substantially good" (Cohen's Kappa test: $K = 0.738$). Studies were accepted for viewing at full text if it appeared that they may contain information pertinent to the review question, or if the abstract was ambiguous and did not allow inferences to be drawn about the content of the article (i.e., if there was insufficient information to determine that the study was inappropriate for systematic review).

The criteria, which studies had to meet for inclusion into the final stage of the systematic review, were:

1. *Subject*: any mammal, bird, invertebrate, amphibian or plant population or assemblage.
2. *Intervention*: a hedgerow, or hedgerow network, connecting two or more fragments of woodland habitat.
3. *Outcome*: desired primary outcomes were change in population density for a target species or change in species richness within assemblages. Nonetheless, studies were not rejected on the basis of outcome.
4. *Type of study*: any. No comparator was necessary for inclusion, although appropriate spatial or temporal controls (e.g., monitoring of species within woodland fragments before and after hedgerows were planted or removed) were a prerequisite for studies to be included in any subsequent meta-analysis.

Studies accepted into the review at full text were considered for relevance by two additional independent reviewers. Any disagreement on inclusion was discussed and resolved by consensus.

3.4 Study Quality Assessment

Study quality assessments were not performed on the studies accepted into this systematic review. This was because the quality of the studies fell below the *a priori* defined quality threshold and the review would, therefore, not included quantitative synthesis.

3.5 Data Extraction & Data Synthesis

Any information related to the systematic review question was extracted from the studies and collated in qualitative tables. The variation in type of investigation and range of outcome measures adopted in the studies precluded the use of formal meta-analytical techniques.

4. RESULTS

4.1 Review Summary Statistics

Searching was completed in May 2005. Two hundred and four studies remained in the systematic review after the abstract filter stage (Table 1); 183 were captured using electronic database searches and 21 were found via other sources. Twenty two of the 204 studies could not be obtained at full text for further examination, as they were unavailable from the British Library and the author(s)/publisher.

Table 1: Number of studies included during each of the systematic review filtering stages.

Systematic review stage	No. studies
Studies captured using search terms in electronic databases* (including duplicates)	7455
Studies captured using search terms in electronic databases* (excluding duplicates)	2537
Studies remaining after title filter	747
Studies remaining after abstract filter	204
Studies remaining after full text filter	51

* *(excludes studies captured in English Nature's WildLink database and hits from internet searches)*

Approximately 50 studies were accepted into the final stages of the systematic review and their progression is summarised in Table 2.

Table 2: Progression of studies through the final stages of the systematic review process, grouped by taxon.

Taxon	No. studies accepted for full text evaluation	No. studies rejected at full text evaluation	No. studies accepted into the systematic review
Mammals	18	4	14
Birds	8	3	5
Invertebrates	14	7	7
Amphibians	2	2	0
Plants	9	*	*

* *(Further consultation required with stakeholders to complete this stages of the systematic review process. Please refer to section 4.2.5)*

4.2 Outcome of the Review

The evidence that is currently available on the role of hedgerows as habitat corridors is insufficient to definitively evaluate their effectiveness in regard to increasing the population viability of species inhabiting woodland. However, although direct, high quality evidence is lacking, there were a number of studies that provided anecdotal evidence of local population effects and indicated that species were using hedgerows as movement conduits. By their very definition, corridors can only function if they facilitate movement of the biota, so these studies were included in the systematic review. Conversely, it must be stressed that this evidence cannot be regarded as substantive, as the apparent positive benefits of hedgerow corridors may be confounded by other variables. For example, large numbers of hedgerow connections into a wood may be confounded by greater habitat diversity in the surrounding landscape (i.e., several small fields with associated field margins that may promote species presence), or hedgerows may function as additional areas of habitat for species to inhabit thereby increasing population densities within the woodland fragments.

Studies were grouped by taxon because the efficiency of corridors depends on the relationship between space-use behaviour and landscape configuration for each particular taxonomic group (Collinge 2000; Berggren et al. 2001). Ideally, qualitative "vote-counting" assessment (i.e., scoring the results of each study as positive, neutral or negative in relation to the effect of hedgerow presence on the outcome measure, and then adding them up to provide an overall summary of effect) should be undertaken on the studies accepted into a qualitative systematic review. However, in this instance, it was deemed to be inappropriate due to publication bias by the consensus of the review team. Many of the studies examine the influence of a variety of different habitat and landscape variables, over a range of spatial scales, and do not report those that have a negative or neutral effect on the population/assemblage of interest. For example, in a number of studies, the hedgerow variables were lost from multivariate analyses due to co-linearity with other predictor variables that had more significant effects on the outcome measure. The following summaries provide a brief insight into the nature of the findings across each taxonomic group, but please refer to the appendices for detailed itemisation of the methods and outcomes for the individual studies.

4.2.1 Mammals

The majority of the studies used rodents as study species. Species' presence and abundance were positively related to hedgerow density within the landscape and the number of hedgerow connections into the study wood (Fitzgibbon 1993; Fitzgibbon 1997; Verboom & Huitema 1997; Capizzi et al. 2002). The exception to this was the edible dormouse (*Glis glis*); presence of the species in a wood was not related to the number of hedgerows connected to the wood (Cappizzi et al. 2003). Movement in hedgerows was positively related to increased levels of vegetation cover and structural complexity (Merriam & Lanoue 1990; Bennett et al. 1994; Bright 1998), and hedgerow presence was shown to increase the dispersal rates of individuals between woods (Bennett et al. 1994). Please refer to appendix one for a breakdown of the methodology and results of each individual study.

4.2.2 Birds

Outcome measures investigated consisted of species' presence/absence, population densities, annual species turnover and species richness and assemblage composition. The results of the studies suggest that species' presence, abundance and richness were positively related to the number of hedgerows connected into the study wood, greater hedgerow structural complexity and hedgerow density within the surrounding landscape (Hinsley et al. 1995; Hinsely et al. 1998; Vanhinsbergh et al. 2002; Bennett et al. 2004; Browne et al. 2004). There was no evidence that species turnover was affected by any hedgerow variable (Bennett et al. 2004). Please refer to appendix two for a breakdown of the methodology and results of each individual study.

4.2.3 Invertebrates

All invertebrate studies included in the systematic review focused on assemblages or individual species of carabid beetle. The results of the studies indicated that species' abundance and species' presence were positively related to the vegetation cover and structural complexity of the hedgerows (Petit & Burel 1998a; Aviron et al. 2005). Movement of individuals was inhibited by gaps in the hedgerow and improved with increasing vegetation cover (Plat et al. 1995); the matrix was avoided and mortality was high for those that travelled into the farmland, even if they subsequently returned to the hedgerow (Charrier et al. 1997). Please refer to appendix three for a breakdown of the methodology and results of each individual study.

4.2.4 Amphibians

Two studies examining amphibian movement were examined at full text, but were subsequently rejected from the systematic review for not satisfying the inclusion criteria. However, although the species were not using hedgerows as conduits between woodland fragments, they may serve as a corridor between the two types of habitat essential for the species life history. Jehle & Arntzen (2000) observed the post breeding migrations of 2 species of newt (*Triturus cristatus* and *T.marmoratus*), away from the fishponds used for breeding, back to fragments of woodland habitat utilised for aestivation and hibernation. Individual newts were radio tracked and were more frequently observed in hedgerows than expected, based on the availability of hedgerows within the predominately pastoral landscape. In contrast, Joly et al. (2001) found the abundance of the three newt species (*Triturus helveticus, T. alpestris* and *T. cristatus*) was negatively related to the length of hedgerow in a 50 ha area around each focal breeding pond where individuals were captured. Both studies were conducted in France.

4.2.5 Plants

Forman (1991) reviewed the evidence of plant dispersal along corridors and concluded that there is no direct evidence that plants disperse progressively along hedgerows, despite the large number of studies on the topic; he surmised that certain plant species may be moved via vertebrate dispersers, rather than plants migrating along corridors. As there is debate within the literature regarding movement in plants and how it relates to determining corridor use (McCollin et al. 2000), further consultation with the stakeholders is required prior to data extraction. The definition of what is considered to be appropriate movement along a hedgerow, and the associated outcome measure, relevant to this systematic review must be confirmed. Please refer to appendix four for a list of plant studies accepted into the review for full text evaluation.

5. DISCUSSION

Although highly controversial, it has become an ecological paradigm that habitat corridors connecting isolated patches of habitat will increase the abundance and diversity of species within those patches, by facilitating increased rates of movement. This perception was exacerbated by many studies merely reporting the presence of biota in a habitat corridor and subsequently surmising that it is, therefore, acting as a movement conduit in the fragmented landscape (MacClintock et al. 1977). At best, such observations can only be useful as an indicator of corridor utility for sedentary species.

The objective of this systematic review was to collate and synthesise published and unpublished evidence on whether hedgerows are effective habitat corridors, increasing the population viability of target species occupying otherwise isolated fragments of woodland habitat. Unfortunately, there was no clear high quality evidence (i.e., long-term fully replicated and controlled field-based experiments or investigations) to provide any firm conclusions on their utility and value as a conservation tool; none of the studies demonstrated either a positive, or a negative, effect on long-term population persistence. However, there was some evidence supporting the functional importance of corridors, reporting local and mechanistic effects within the system, such as species movements. The research suggested that hedgerows with greater vegetational diversity and structural complexity are favourable for movement over hedgerows of a more basic composition. At this stage, given the present lack of a firm evidence-base, we should not reject the general hypothesis that continuous and heterogeneous hedgerow corridors are most likely to foster movements.

There are considerable difficulties and ethical stumbling blocks in the undertaking of robust primary research on such a topic, which may give reason to their paucity. Large numbers of confounding variables operate in such field-based systems and it is hard to find suitable analogous controls in close proximity within a study area (i.e., two systems with similarly structured and spatially configured woodland fragments, one system interconnected with hedgerows and the other not). Temporal experimentation might necessitate activities that are detrimental or inappropriate for the conservation of species (e.g., hedgerow removal or species translocations to isolated areas of habitat), resulting in a conflict of interest between knowledge acquisition and conservation.

5.1 Implications for management and policy

In light of our findings it might be argued that there is insufficient evidence that hedgerow corridors enhance the population viability of species occupying isolated woodlands, or indeed facilitate movement of biota, for us to devote limited financial resources to their provision. Equally, the best available evidence is inadequate for us to reject the hypothesis that that they are cost effective conservation tools. Consequently, it is better to maintain and monitor the value of existing hedgerow corridors in the years to come, rather than neglect their potential benefits with regard to population persistence and then discover their worth when irreversible losses have occurred. Current resources directed at conservation of potential hedgerow corridors already present within the landscape should, therefore, be sustained. It has been suggested that a large proportion of UK hedgerows are either under-managed or over-managed (MacDonald & Johnson 1995), and their potential as corridors may be substantially enhanced with the application of suitable management regimes. This would also be an added advantage to some species, potentially providing them with additional habitat (Hinsley & Bellamy 2000; Haddad & Tewksbury 2005). However, management strategies should not necessarily focus on corridors at the expense of other potentially suitable management solutions, such as maintaining 'stepping stones' of remnant or restored woodland habitat (Simberloff et al. 1992; Hulme 2005) or increasing the permeability of the arable matrix and wider landscape (Baum et al. 2004; Revilla et al. 2004).

The seductive power of the corridor paradigm has influenced policy recommendations aimed at conserving biological diversity, on both a national and international scale. For example, the 2002 World Summit on Suitable Development called for the promotion of 'national and regional ecological networks and corridors' as conservation interventions to reduce current rates of biodiversity loss. This stance has also been mirrored by the Convention for Biological Diversity. In 2002, the Conference of the Parties to the Convention proposed that 'ecological corridors' should be developed on a national and regional basis in order to protect forest biological diversity (Bennett 2004). A report published by the Intergovernmental Panel on Climate Change provided an overview of the adaptation possibilities that could be adopted to conserve biodiversity as the climate warms. It suggested that, in Europe, a 'network of habitats and habitat corridors will be required to facilitate migration through the landscape' where large-scale range changes are predicted to occur (IPCC 2001). In response to such recommendations, hedgerow corridors may well be advocated as a means of assisting the movement of woodland biota through the fragmented landscape as they attempt to track climatically suitable habitat. However, this study has demonstrated that the effectiveness of corridors in relation to increasing habitat connectivity is not yet established, and that the potential role of corridors in mitigating the effects of climate change is even less well understood.

5.2 Implications for research

Little can be inferred from the available empirical evidence with regard to the breadth and type of species (e.g., habitat specialists or type of autoecology) that would benefit from hedgerow corridors. Conjecture from existing studies to general questions about which species corridors may benefit at the population-level is limited by the number and types of species that have been studied, despite the fact that corridors may impact on hundreds of species within a landscape. To begin to understand the cumulative effects of corridors, researchers need to consider more complex interactions between species that, to date, have not been commonly investigated in corridor systems (Tewksbury et al. 2002; Hudgens and Haddad 2003). For example, if corridors facilitate animal movements then they should also, indirectly, increase the movement of plant pollen and seed. This more holistic approach is of particular importance if the motivation behind corridor protection or creation is preserving biodiversity.

An understanding of how species move through the landscape, including habitat corridors, is vital for species management. To achieve this understanding, detailed information on the movement rates and specific movement behaviour of individuals in different ecosystems needs to be collated, if not for each species, then for those of conservation concern. However, the rate of dispersal between habitat fragments needed to decrease extinction risk and increase gene flow may be extremely low, and detecting individuals moving could therefore be difficult, even within a functioning corridor (Haddad & Tewksbury 2005). The behaviour of species moving through hedgerows within agricultural landscapes is likely to be influenced by the nature of the matrix, the type and spatial distribution of adjacent habitats, season, farming activities (e.g., herbicide and pesticide applications) and interaction between conspecifics and other species.

To address the question of whether the presence of hedgerows, or indeed any type of habitat corridor, promotes population viability may require long-term monitoring at a landscape-scale. For example, the result of monitoring population persistence in a study system where hedgerows have been lost, maybe confounded by time lags between when the landscape changed and the reaction of species to the change (Petit & Burel 1998b). Integrating land-use behaviour and landscape configuration of such systems to determine whether hedgerow corridors really do work represents a considerable challenge for conservation biologists, especially when, to complicate matters, different sections of the population (e.g., dispersing juveniles) may have different requirements for movement. The principle aim for ecologists and conservationists in the future must be to assemble the high quality evidence-base necessary to enable policy makers, and practitioners, to make informed decisions with regard to habitat corridor preservation and creation.

6. ACKNOWLEDGEMENTS

We would like to thank all the stakeholder organisations and individuals for their support and valuable contributions throughout the systematic review process, but most notably Phoebe Carter (The Mammal Society), Paul Donald (RSPB), Heather Robertson (English Nature), Fiona Sanderson (RSPB) and Robert Wolton (English Nature) for their useful comments on the initial draft of this systematic review report. We are also grateful to colleagues at the Centre for Evidence-Based Conservation for their assistance during the review, particularly Claire Tyler for undertaking an independent assessment of study relevance at the abstract filter stage, and both Claire and Gavin Stewart for discussions with regard to study inclusion at the full text stage of the review.

This systematic review was funded by English Nature.

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8. APPENDICES

Appendix One: Mammal studies satisfying the inclusion criteria of the systematic review (studies are presented in chronological order).

Study	Country and Location	Species Investigated	Brief Summary of Methodology	Brief Summary of Results
Merriam, G. & Lanoue, A. (1990). Corridor use by small mammals: field measurement for three experimental types of *Peromyscus leucopus*. *Landscape Ecology* **4**: 123-131.	Country: Canada Location: Ottawa	White-footed mouse (*Peromyscus leucopus*)	Woodland: network of small deciduous and mixed wood fragments within the landscape. Hedgerows: 3 types were examined. "Simple" fencerows (with <10% trees and shrubs and other structural elements and <1 m wide), "intermediate" fencerows (consisting of unlimited tree cover, but with trees taller than 10 m covering only <10% of their length, and <2 m wide) and "complex" fencerows (with any vegetation structure and >2 m wide). Matrix: arable and pastoral. Data collected: 18 mice were radio tracked in the fencerows for 48 hours, during the summer and autumn. Study design/analysis: examined whether movement of individuals was related to the type of fencerow structure.	The mice spent 90% of their time within the hedgerow. Structurally "complex" hedgerows were significantly preferred for movement.
Zhang, Z.B. & Usher, M.B. (1991). Dispersal of wood mice and bank voles in an agricultural	Country: UK Location: northern England (York).	Wood mouse (*Apodemus sylvaticus*) Bank vole (*Clethrionomys glareolus*)	Woodland: 3 small woods. Hedgerows: 4 hedgerows. Matrix: arable.	A lack of data for bank vole movement meant that only wood mouse movements were examined. There were 66 movements in total. Hedgerows were used to move between woods. Movement was

landscape. *Acta Theriologica* **36**: 239-245.			Data collected: species were surveyed by live trapping within the woods, hedgerows and matrix between August and October. 10 traps were placed in 3 of the hedgerows, 15 in the largest hedgerow, at 15 m intervals. 40 traps were placed in 2 of the woods, in a grid of 4 rows of 10 traps, spaced at 15 m intervals. 50 traps were used in the largest wood. Trapping was conducted over 4 10 day periods. Study design/analysis: examined whether movement of individuals was associated with hedgerow, wood and landscape variables.	observed within the matrix (6 movements), but only for short distances. Dispersal rate between woods were greater between woods connected by hedgerows, than the 2 woods that were not connected (sample size too small to test statistically).
van der Zee, F.F., Wiertz, J., Ter Braak, C.J.F. & van Alpeldoorn, R.C. (1992). Landscape change as a possible cause of the badger *Meles meles* L. decline in The Netherlands. *Biological Conservation* **92**: 17-22.	Country: Netherlands Location: unknown	Badger (*Meles meles*)	Woodland: <90 ha area of tree cover around the sett. Hedgerows: network within the landscape. Matrix: arable and pastoral. Data collected: condition of the setts within the landscape was censured in 1960 and again in 1980. Condition was then classified as "improved" (not used or non-existent in 1960, used by 1980), "consistent" (in the same state of use in 1960 and 1980) or "declining" (used in 1960, but not in 1980). Length of hedgerow in a 1 x 1 m square around the sett was recorded. Study design/analysis: examined whether badger sett condition was associated with surrounding habitat/landscape variables.	Both "deteriorated" and "improved" setts were associated with lower than average numbers of hedgerows. Badger setts that were "consistent" in condition were associated with the largest number of hedgerows in a 1x1 km square surrounding the sett.
Fitzgibbon, C.D. (1993). The distribution of	Country: UK Location: eastern	Grey squirrel (*Sciurus carolinensis*)	Woodland: network of 68 deciduous woods within the landscape, ranging from 0.2-12.5 ha in size.	Presence of squirrels was positively related to the density of hedgerow within 400 m radius of the wood.

grey squirrel dreys in farm woodland - the influence of wood area, isolation and management. *Journal of Applied Ecology* **30**: 736-742.	England.		Hedgerows: network within the landscape. Matrix: arable. Data collected: drey densities were calculated by using transect data collected between January and March, and used to generate a population index of the number of squirrels present. Length of hedgerow within 400 m of each wood, and whether the hedgerow linked the survey wood to another wood of either 0.5-5 ha in size, or a wood greater than 5ha in size, was also recorded. Study design/analysis: examined whether species presence/absence was related to surrounding habitat/landscape variables.	
Bennett, A.F., Henein, K. & Merriam, G. (1994). Corridor use and the elements of corridor quality: chipmunks and fencerows in a farmland mosaic. *Biological Conservation* **68**: 155-165.	Country: Canada Location: Manotick, 20 km south of Ottawa.	Chipmunk (*Tamias striatus*) (only transient individuals, normally resident in woodland, were considered for this review)	Woodland: network of small, broadleaved woods within the landscape. Hedgerows: fencerows that vary in structure from consisting of shrubs and vines, through to mature trees. Matrix: 200 ha area of pastoral and arable farmland. Data collected: 4 live trapping sessions, between May and September, within 4 woods and 18 fencerows. Hedgerow habitat variables including, floristic composition, structure, fencerow width, linear continuity were recorded. Study design/analysis: examined whether movement of individuals was associated with fencerow occurrence and the fencerow habitat variables.	Individuals of all age and sex classes were recorded in fencerows. Movements between landscape elements (excluding within fencerow or wood) were made by 56% of chipmunks using fencerows. Out of 80 recorded movements, 71% were between wood and fencerow, 26% fencerow to fencerow and 3% wood to wood. Fencerow use was positively correlated with tall tree cover (>10 m tall), small tree cover (4-10 m tall) and shrub cover (1.5-4 m tall).

				Fencerow use was negatively correlated with fencerow length and proportion of gaps along the fencerow length.
Entwistle, A.C., Racey, P.A. & Speakman, J.R. (1996). Habitat exploitation by a gleaning bat, *Plecotus auritus*. *Philosophical Transactions: Biological Sciences* **351**: 921-931.	Country: UK Location: north-east Scotland.	Brown long-eared bat (*Plecotus auritus*)	Woodland: network of deciduous and coniferous woods within the landscape. Hedgerows: network within the landscape. Matrix: pastoral. Data collected: 16 individuals (consisting of males, non-reproductive and lactating females) were radio tracked from 6 roost sites, for 2 years between May and August. In total, 65 full bat nights and 7 additional half nights activities were recorded. Study design/analysis: examined whether movement of the individual was associated with surrounding habitat/landscape variables.	Used hedgerows as commuting routes between roosts and feeding sites, even though the bats travelled significantly longer distances via these routes than if they travelled Euclidean distance between woods.
Kotzageorgis, G.C. & Mason, C.F. (1996). Range use, determined by telemetry, of yellow-necked mice (*Apodemus flavicollis*) in hedgerows. *Journal of Zoology* **240**:	Country: UK Location: southern England (Essex).	Yellow-necked mouse (*Apodemus flavicollis*)	Woodland: network within the landscape. Consisted of ancient, deciduous woods. Hedgerows: 2 hedgerows linking blocks of woodland, ranging between 2-4.5 m wide and 4-6 m tall, with a diverse shrub flora, dense ground cover and standard trees. Matrix: arable. Data collected: 6 individuals (3 males, 3 females: 1 pregnant and 2 lactating) were radio-tracked in August for 3-7 days.	All individuals stayed within the fencerows and did not move into the arable matrix. Females move shorter distances than males.

773-777.			Study design/analysis: examined whether movement of individuals was related to fencerow presence.	
Fitzgibbon, C.D. (1997). Small mammals in farm woodlands: the effects of habitat, isolation and surrounding land-use patterns. *Journal of Applied Ecology* **34**: 530-539.	Country: UK Location: eastern England (Cambridgeshire and Peterborough).	Wood mouse (*Apodemus sylvaticus*) Bank vole (*Clethrionomys glareolus*)	Woodland: network of 38 deciduous woods within the landscape, ranging from 0.05-4.45 ha in size. Hedgerows: network within the landscape. length of hedgerow within 400m of each wood and number of hedgerows connected to the wood. Matrix: arable. Data collected: species were surveyed by live trapping twice for 4 days, once during April/May and again in August/September. A variable trapping grid was used (as different woods were of different area), with single traps placed 10 m intervals across each wood in rows. Length of hedgerow within 400 m of each wood and number of hedgerow connections to each surveyed wood were also recorded. Study design/analysis: examined whether species presence/absence and abundance was related to surrounding habitat/landscape variables.	Presence of wood mice in spring was positively related to the density of hedgerow within 400 m of the wood. Wood mouse and bank vole autumn abundance was related to hedgerow connectedness (interaction of length of hedgerow with number of connected hedgerows).
Verboom, B. & Huitema, H. (1997). The importance of linear landscape elements for the pipistrelle *Pipistrellus*	Country: Netherlands Location: Overijssel province (northern Twente).	Pipistrelle bat (*Pipistrellus pipistrellus*) Serotine bat (*Eptesicus serotinus*)	Woodland: network of small woodlots, <2 ha in size, within the landscape. Hedgerows: network within the landscape. Matrix: arable and pastoral. Data collected: observations were recorded from 5-8	Pipistrelle presence was strongly associated with linear elements. Serotines showed no preference. Number of serotine bat passes (activity) was more than proportionally related to hedgerow density, whereas for pipstrelle

pipistrellus and the serotine bat *Eptesicus serotinus*. *Landscape Ecology* **12**: 117-125.			points within a 1 km x 1 km square. There were 15 grid squares within the landscape, each consisting of a range of habitats types. Observations were made between May and September. 5 observations were made from each individual point, equally spaced over the investigation period each night. Bat activity was the number of bat passes recorded, via bat detector, in a 5 minute interval. Study design/analysis: examined whether movement of the individual was related to surrounding habitat/landscape variables.	activity was only proportionally related to hedgerow density (a mathematical effect due the habitat associations of the species). The number of pipistrelle passes was significantly related to the height of the hedgerow. They were not recorded along landscape elements that were <6 m high.
Bright, P.W. (1998). Behaviour of specialist species in habitat corridors: arboreal dormice avoid corridor gaps. *Animal Behaviour* **56**:1485-1490.	Country: UK Location: southern England (Isle of Wight).	Common dormouse (*Muscardinus avellanarius*)	Woodland: small woods. Hedgerows: one cut hedgerow and one uncut hedgerow. No resident individuals were present in either hedgerow. Matrix: pastoral (grass maintained at a height of 20-30 cm tall, livestock not present). Data collected: 12 individuals were radio-tracked moving in the grassland, cut and uncut hedgerows. Study design/analysis: controlled experimental investigation. Movement responses of individuals were compared within the two differently managed hedgerows and the grassland control.	Dormice did significantly more about-turns, travelled further and faster in the cut hedgerow than uncut hedgerow. Dormice in the grassland spent significantly less time stationary than those individuals in hedgerows, moved further on each move and lost more body mass than those in hedgerows. Movement in hedgerows was not oriented in any particular direction, other than that imposed by the hedgerow. Movement in grassland was always oriented towards woodland. There was a significant difference in

				the frequency with which gaps in the hedgerows were crossed: gaps of 1 m were crossed on 55% of approaches, 3 m wide gaps were only crossed on 6% approaches and gaps of 6 m were never crossed.
Marsh, A.C.W. & Harris, S. (2000). Partitioning of woodland habitat resources by two sympatric species of *Apodemus*: lessons for the conservation of the yellow-necked mouse (*A. flavicollis*) in Britain. *Biological Conservation* **92**: 275-283.	Country: UK Location: southwest England (Gloucestershire).	Yellow-necked mouse (*Apodemus flavicollis*) Wood mouse (*Apodemus sylvaticus*)	Woodland: network of 19 deciduous woods within the landscape, ranging in size from 2.2-113.5 ha. Hedgerows: network within the landscape. Matrix: pastoral. Data collected: species were surveyed by live trapping, during 2 six week periods, in September and the following April. Trapping effort was scaled to the size of woodland, and traps placed along transects 15 m intervals. Study design/analysis: examined whether species abundance was related to surrounding habitat/landscape variables.	Number of hedgerows connected to each wood was highly intercorrelated with woodland area. The number of hedgerows contributed least to the multiple regression model and was therefore excluded from further analysis.
Capizzi, D., Battistini, M. & Amori, G. (2002). Analysis of the hazel dormouse, *Muscardinus avellanarius,*	Country: Italy Location: province of Viterbo (Latium).	Common dormouse (*Muscardinus avellanarius*)	Woodland: network of 38 broadleaved woodlots, randomly selected from within a 1240km^2 area within the landscape. Woodlot area ranged between 1 and 120 ha. Hedgerows: vegetated fencerows between woodlots. Matrix: arable.	Presence of the dormouse was significantly related to the number of fencerows into the woodlot.

distribution in a Mediterranean fragmented woodland. *Italian Journal of Zoology* **69**: 25-31.			Data collected: presence/absence of the species in the woodlots between September and November was determined by hair-tube transects and nest searches. Study design/analysis: examined whether species presence/absence was related to surrounding habitat/landscape variables.	
Motte, G. & Libois, R. (2002). Conservation of the lesser horseshoe bat (*Rhinolophus hipposideros* Bechstein, 1800) (Mammalia: Chiroptera) in Belgium. A case study of feeding habitat requirements. *Belgian Journal of Zoology* **132**: 49-54.	Country: Belgium Location: Famenne region (Revogne).	Lesser horseshoe bat (*Rhinolophus hipposideros*)	Woodland: network of deciduous and mixed pine woods within the landscape. Hedgerows: dense network within the landscape. Matrix: pastoral. Data collected: 1 female was radio tracked for 11 nights in August. Study design/analysis: examined whether movement of the individual was associated with surrounding habitat/landscape variables.	Hedgerows were used as commuting routes from the roost to woodland foraging area. Only very limited foraging was observed while travelling along the hedgerows.
Capizzi, D., Battistini, M. & Amori, G. (2003). Effects of habitat fragmentation and forest	Country: Italy Location: province of Viterbo (Latium).	Edible dormouse (*Glis glis*)	Woodland: network of 38 broadleaved woodlots, randomly selected from within a 1240km^2 area within the landscape. Woodlot area ranged between 1 and 120 ha. Hedgerows: vegetated fencerows between woodlots. Matrix: arable.	Presence of the dormouse was not related to the number of fencerows into the woodlot.

management on the distribution of the edible dormouse *Glis glis*. *Acta Theriologica* **48**: 359-371.	Data collected: presence/absence of the species in the woodlots between September and July the following year, determined by nocturnal call and movement surveys. Study design/analysis: examined whether species presence/absence was associated with surrounding habitat/landscape variables.

Appendix Two: Bird studies satisfying the inclusion criteria of the systematic review (studies are presented in chronological order).

Study	**Country and Location**	**Species Investigated**	**Brief Summary of Methodology**	**Brief Summary of Results**
Hinsley, S.A., Bellamy, P.E., Newton, I. & Sparks, T.H. (1995). Habitat and landscape factors influencing the presence of individual breeding bird species in woodland fragments. *Journal of Avian Biology* **26**: 94-104.	Country: UK Location: eastern England (within Cambridgeshire and Lincolnshire).	Residents: Blackbird (*Turdus merula*) Dunnock (*Prunella modularis*) Wren*** (*Troglodytes troglodytes*) Robin** (*Erithacus rubecula*) Sparrowhawk (*Accipiter nisus*) Stock dove (*Columba oenas*) Woodpigeon (*Columba palumbus*) Bullfinch** (*Pyrrhula pyrrhula*) Great-spotted woodpecker (*Dendrocopus major*) Song thrush**** (*Turdus philomelos*) Long-tailed tit* (*Aegithalos caudatus*) Marsh tit (*Parus palustris*) Great tit*** (*Parus major*) Blue tit*** (*Parus caeruleus*) Nuthatch (*Sitta europaea*) Treecreeper (*Certhia familiaris*) Jay (*Garrulus glandarius*) Yellowhammer (*Emberiza citrinella*) Goldfinch (*Carduelis carduelis*) Greenfinch (*Carduelis chloris*) Chaffinch (*Fringilla coelebs*) Tree sparrow (*Passer montanus*) Starling (*Sturnus vulgaris*) Carrion crow (*Corvus corone corone*)	Woodland: network within the landscape. Majority of woods were deciduous, but a few contained mixed conifers and broadleaved trees. The 151 small woods ranged from 0.02 to 30 ha in size. Hedgerows: network within the landscape. Matrix: arable. Data collected: Bird census counts over 3 years. Each wood was visited 4 times during breeding season. Study design/analysis: examined whether species presences was related to woodland variables and surrounding habitat/landscape variables.	Length of hedgerow in the surrounding landscape within 0.5 km of the wood was positively related to the breeding presence of species marked with an asterisk (*). Length of hedgerow in the surrounding landscape within 1 km of the wood was positively related to the breeding presence of species marked with two asterisks (**). The number of hedgerows connected to the wood was positively related to the breeding presence of species marked with three asterisks (***). Hedgerow as an integral part of the wood was positively related to the breeding presence of species marked with four asterisks (****).

		Migrants: Nightingale (*Luscinia megarhynchos*) Garden warbler* (*Sylvia borin*) Blackcap* (*Sylvia atricapilla*) Chiffchaff (*Phylloscopus collybita*) Turtle dove (*Streptopelia turtur*) Willow warbler*** (*Phylloscopus trochilus*) Whitethroat (*Sylvia communis*) Spotted flycatcher (*Muscicapa striata*)		
Hinsley, S.A., Bellamy, P.E. & Rothery, P. (1998). *Co-occurrence of Bird Species-Richness and the Abundance of Individual Bird Species in Highly Fragmented Farm Woods in Eastern England*, pp. 227-232. In Key Concepts in Landscape Ecology. IALE (UK) International Association of Landscape Ecology, Lymm, UK.	Country: UK Location: eastern England (a 2500 km^2 area within Cambridgeshire and Lincolnshire).	Resident: Blackbird (*Turdus merula*) Robin (*Erithacus rubecula*) Dunnock (*Prunella modularis*) Wren (*Troglodytes troglodytes*) Great tit (*Parus major*) Blue tit (*Pardus caeruleus*) Chaffinch (*Fringilla coelebs*) Long distance summer migrants: Willow warbler (*Phylloscopus trochilus*) Blackcap* (*Sylvia atricapilla*)	Woodland: network within the landscape. Majority of woods were deciduous, but a few contained mixed conifers and broadleaved trees. All 150 were small (<15 ha in size). Hedgerows: network within the landscape. Matrix: arable. Data collected: bird census counts of breeding pairs collected over 3 years. Study design/analysis: examined whether species richness and population sizes were related to woodland variables and surrounding habitat/landscape variables.	"Species-rich" woods (at least 2 species more than expected from woodland area) were more connected (by hedgerows) than "species-poor" woodlands (2 species less than expected from woodland area). "Species-rich" woods also had, on average, greater diversity of vegetation in the shrub layer and contained more habitat types, both within-wood and in the surrounding landscape, than "species-poor" woods. "Species-rich" woods supported higher population densities of all species.
Vanhinsbergh, D., Gough, S., Fuller, R.J. & Brierley, E.D.R.	Country: UK Location:	Residents: Blackbird (*Turdus merula*) Blue tit* (*Pardus caeruleus*)	Woodland: network within the landscape. Hedgerows: network within the landscape.	Woodlands connected by dense hedgerows with trees were more likely to contain

(2002). Summer and winter bird communities in recently established farm woodlands in lowland England. *Agriculture, Ecosystems & Environment* **92**: 123-136.	central and eastern England (majority of sites within a 60 mile radius of Silsoe, Bedfordshire).	Chaffinch* (*Fringilla coelebs*) Great tit (*Parus major*) Robin* (*Erithacus rubecula*) Song thrush* (*Turdus philomelos*) Woodpigeon (*Columba palumbus*) Yellowhammer* (*Emberiza citronella*) Dunnock (*Prunella modularis*) Wren (*Troglodytes troglodytes*) Long distance summer migrants: Willow warbler (*Phylloscopus trochilus*) Blackcap* (*Sylvia atricapilla*) Chiffchaff (*Phylloscopus collybita*)	Matrix: arable and pastoral. Data collected: bird census counts collected from 64 sites during winter (Jan/March) and breeding season (April/May). All woods included in the study were joined by at least one hedgerow. Study design/analysis: examined whether species richness and population sizes were related to woodland variables and surrounding habitat/landscape variables.	populations of the species marked with an asterisk (*), than woodlands connected by hedgerows that were dense but without tress or sparsely vegetated with trees. Species richness was greater in woods connected with dense hedgerows that contained trees, than in woods connected to hedgerows without trees in both seasons.
Bennett, A.F., Hinsley, S.A., Bellamy, P.E., Swetman, R.D. & MacNally, R. (2004). Do regional gradients in land-use influence richness, composition and turnover of bird assemblages in small woods? *Biological Conservation* **119**: 191-206.	Country: UK Location: eastern England (a 2100 km^2 area within Cambridgeshire and Lincolnshire).	Woodland migrants: Nightingale (*Luscinia megarhynchos*) Garden warbler (*Sylvia borin)* Blackcap (*Sylvia atricapilla*) Willow warbler (*Phylloscopus trochilus*) Chiffchaff (*Phylloscopus collybita*) Woodland dependents: Great-spotted woodpecker (*Dendrocopus major*) Nightingale (*Luscinia megarhynchos*) Song thrush (*Turdus philomelos*) Blackcap (*Sylvia atricapilla*) Chiffchaff (*Phylloscopus collybita*) Goldcrest (*Regulus regulus*) Long-tailed tit (*Aegithalos caudatus*) Marsh tit (*Parus palustris*) Willow tit (*Parus mountanus*)	Woodland: network within the landscape. Majority of woods were deciduous, but a few contained mixed conifers and broadleaved trees. All 88 woods were >0.5 ha, but most were <15 ha in size. Hedgerows: network within the landscape. Matrix: arable. Data collected: bird census counts collected over 3 years. Each wood was visited 4 times during breeding season. Study area was divided up into 84 landscape units (5 km x 5 km). Woodland, local-scale and regional-scale variables were recorded. Study design/analysis: examined whether	There were more woodland dependent species in woods with a greater extent of hedgerow within a 1 km radius. There was no evidence of hedgerows affecting the turnover of either type of woodland species. Composition of the avian assemblage was positively related to amounts of hedgerow within a 1 km radius of the wood.

		Coal tit (*Parus ater*) Great tit (*Parus major*) Nuthatch (*Sitta europaea*) Treecreeper (*Certhia familiaris*) Jay (*Garrulus glandarius*)	species richness, annual turnover (relative to the number of species present) and composition of the avifauna were related to woodland, local-scale and regional-scale habitat/landscape variables.	
Browne, S.J., Aebischer, N.J., Yfantis, G. & Marchant (2004). Habitat availability and use by turtle doves *Streptopelia turtur* between 1965 and 1995: an analysis of Common Birds Census data. *Bird Study* **51**: 1-11.	Country: UK Location: eastern England (a 2500 km^2 area within Cambridgeshire and Lincolnshire).	Turtle dove (*Streptopelia turtur*)	Woodland: network within the landscape. Consisted of semi-natural broadleaved and mixed woods. Majority were >10 ha in size. Hedgerows: index of “hedginess” derived from ratio of hedgerow length, woodland and scrub edge (m) to farmland plot area (ha). Matrix: arable, horticultural and pastoral. Data collected: bird census counts from between 1965 and 1995 in 30 farmland plots (all plots included were surveyed for at least 10 years). Study design/analysis: examined whether species population density was associated with surrounding habitat/landscape variables.	Population density fluctuated over the time period. There was a significant positive correlation between change in annual territory density and change in the index of “hedginess”. No other correlation was observed between population density and any of the habitat/landscape variables.

Appendix Three: Invertebrate studies satisfying the inclusion criteria of the systematic review (studies are presented in chronological order).

Study	**Country and Location**	**Species Investigated**	**Brief Summary of Methodology**	**Brief Summary of Results**
Burel, F. (1989). Landscape structure effects on carabid beetles spatial patterns in western France. *Landscape Ecology* **2**: 215-226.	Country: France Location: Western France (Liffre Forest, 15km east of Rennes).	Carabid beetle assemblages	Woodland: dense hornbeam coppice and tall oak/beech timber wood. Hedgerows: network within the landscape. Matrix: pastoral. Data collected: assemblages were surveyed using pitfall traps (sampling for 3 days every 2 weeks) between April and October, and then again between the following May and July. 35 traps were placed at 50 m intervals along the hedgerow network. Study design/analysis: examined whether carabid diversity and abundance was related to surrounding habitat/landscape variables and distance away from the wood.	The abundance of all species is significantly affected by distance from the forest block. Five of the woodland carabids were found to be "core forest" species, being limited to the forest and only up to 50 m from its periphery. Four were considered to be "peninsular forest" species, as their abundances declined in relation to distance away from the forest. Three further species were found throughout the hedgerow network and deemed to be "corridor" species. Not all hedgerows were favoured by "corridor" species; abundance in hedgerows was positively related to a dense herbaceous layer and presence of a tree layer.
Plat, S., Kuivenhoven, P. & van Dijk, T.S. (1995). *Hedgerows: suitable corridors for ground dwelling forest carabid beetles?*, pp. 73-75. In Proceedings of the	Country: Netherlands Location: unknown.	Carabid beetle (*Calathus rotundicollis*)	Woodland: 2 fragments of woodland. Hedgerows: network within the landscape. Matrix: agricultural. Data collected: the species was surveyed using barrier traps	No beetles were re-captured within the matrix. Individuals released at the hedgerow entry point moved further into the wood, and moved along the hedgerow away for the wood. No individuals crossed a break

Section Experimental and Applied Entomology of the Netherlands Entomological Society (N.E.V.) **6**. Nederlandse Entomologische Verniging, Amsterdam, The Netherlands.			(for two fortnight long sessions) between August and October. Individuals were caught and released at 3 points (one central to the wood, one at entry point to the hedgerow and one within the hedgerow). Eight barrier traps were then equally distributed 12.5 m around each release point. Study design/analysis: 735 marked beetles were released in the forest. Beetles were re-caught in neighbouring habitats, including hedgerows.	(ditch or pathway) within the hedgerow.
Charrier, S., Petit, S. & Burel, F. (1997). Movements of *Abax parallelepipedus* (Coleoptera, Carabidae) in woody habitats of a hedgerow network landscape: a radio-tracing study. *Agriculture, Ecosystems & Environment* **61**: 133-144.	Country: France Location: Brittany (60 km north of Rennes).	Carabid beetle (*Abax parallelepidus*)	Woodland: a mixed deciduous woodlot, 870 m^2 in size. Hedgerows: an old lane boarded by parallel hedgerows, with similar tree composition to woodlot, and two individual hedgerows were used. The first of these two hedgerows was dense with trees and a shurb layer, the second was less well vegetated. Matrix: pastoral. Data collected: 8 individuals were radio-tracked each of the four habitat types between May and July. Study design/analysis: Movement responses of individuals were compared within the four habitat types.	Mean distance covered per unit time and the area occupied during the study were highest in the woodlot, and decreased in the different types of hedgerow in relation to the extent of vegetation cover. Individuals that left the woody habitats and entered the matrix, within the shadow of the trees, moved between 1 and 6 times faster than in meadow. No individuals died within the woodlot. Mortality was highest among individuals who had left the linear habitats at some point in time, and more than 50% of individuals died within the meadow.
Petit, S. & Burel, F. (1998a). Connectivity in fragmented populations: *Abax parallelepipedus* in a hedgerow network landscape. *Comptes Rendus de l'Academie*	Country: France Location: Brittany (60km north of Rennes).	Carabid beetle (*Abax parallelepidus*)	Woodland: network of deciduous woods in the landscape. Hedgerows: network within the landscape. Matrix: pastoral. Data collected: individuals were collected using pitfall	The beetle was present in 65% of woodland sites, 40% of parallel hedgerow lane sites and 35% of hedgerows sites. The abundance of the species was positively correlated with all examined measures of “connectivity”. Euclidean

des Sciences - *Series III* - *Sciences de la Vie* **321**: 55-61.			traps, during eight 7 day sampling periods between May and September. 97 sites were surveyed within the landscape (30 woods, 20 hedgerow lanes and 47 hedgerows). Study design/analysis: examined whether abundance was associated with "connectivity" (distance to the nearest site where the species occurs) and "viscosity"* (degree to which movement is facilitated or impeded) of the landscape. **"Viscosity" measures are non independent as they were determined from the results of Charrier et al. (1997) and are therefore excluded from the systematic review.*	distance between two sample sites showed the lowest significance. Estimating "connectivity" along the woody network was far better correlated with abundance.
Petit, S. & Usher, M.B. (1998). Biodiversity in agricultural landscapes: the ground beetle communities of woody uncultivated habitats. *Biodiversity and Conservation* **7**: 1549-1561.	Country: UK Location: Scotland (West Lothian, 28km west of Edinburgh).	Carabid beetles assemblages	Woodland: network of 19 woods, predominately deciduous but a few coniferous, within the landscape. Hedgerows: network of 24 hedgerows within the landscape. Matrix: arable (18%) and unimproved pasture. Data collected: the woods and hedgerows were sampled from April to August. Each sample site was a row of 7 pitfall traps spaced at 1 m intervals. Study design/analysis: examined whether carabid diversity and abundance was related to surrounding habitat/landscape variables and distance away from the wood.	41 species trapped; 29 species found in both the woods and hedgerows, 2 were restricted to woodland and 9 to hedgerows. Diversity indices were comparable for the two habitat types. 3 species caught were woodland specialists. For these species, spatial isolation was not the primary factor in determining their distribution, although it did have an effect (local conditions were more important).
Butterweck, M.D. (2000). *Do Corridors Increase Movements Between Forest Patches? A Study on Between Habitat Migration of Ground*	Country: Germany Location: northern Bavaria (Wurzburg)	Carabid beetles (*Abax parallelepipedus* and *Abax parallelus*)	Woodland: 2 woodlots. Hedgerows: one hedgerow linking the woodlots. Matrix: arable and pastoral. Data collected: Individuals were caught and released at 3	Significantly more *A. parellelepidus* were re-captured in the woodlots and hedgerow than expected by chance. The hedgerow had significantly lower densities of the carabids than the woodlots.

Beetles (Coleoptera : Carabidae), pp. 35-43. In Workshop on Ecological Corridors for Invertebrates: Strategies of Dispersal and Recolonisation in Today's Agricultural and Forestry Landscapes. Council Europe Proceedings, Strasbourg, France.			points (one at entry point to the hedgerow and one close to the forest edge, opposite to the matrix). Trapping grids (consisting of 10 traps) were place 14 m into the matrix, within the hedgerow and at the woodlot edge. Study design/analysis: compared the abundance of the two carabid species trapped in the woodlots and hedgerow to those trapped in the matrix.	Three of 143 released *Abax parallelepipedus* individuals were re-caught within the matrix. Fifteen had emigrated from the forest into the hedgerow and a further 8 individuals had crossed into the other woodlot. Insufficient *A. parallelus* were re-caught to determine whether the species used the hedgerow for movement between woodlots.
Aviron, S., Burel, F., Baudry, J. & Schermann, N. (2005). Carabid assemblages in agricultural landscapes: impacts of habitat features, landscape context at different spatial scales and farming intensity. *Agriculture, Ecosystems & Environment* **108**: 205-217.	Country: France Location: western France.	Carabid beetle assemblages	Woodland: network of small woods within the landscape. Hedgerows: network within the landscape. Matrix: arable and pastoral. Data collected: assemblages were surveyed using pitfall traps between June and August (weekly for 9 weeks), and again between the following April and May (weekly for 5 weeks). Three 25 km^2 landscape units were demarked, and the core 16 km^2 of each unit was sampled at 16 randomly selected points. Landscape variability at three different grain sizes (50 x 50 m, 250 x 250 m and 500 x 500 m) each sampling point. Study design/analysis: examined whether carabid diversity was related to surrounding habitat/landscape variables.	Habitat type explained 17.9% of the variability in carabid assemblage, with hedgerow density accounting for 4.6% of variability. Carabid beetles were most abundant in landscapes with high woodland and hedgerow density. Hedgerows mainly contained field carabid species, although woodland species often present as well.

Appendix Four: Plant studies accepted into the systematic review for full text evaluation (studies are presented in chronological order).

Helliwell, D.R. (1975). The distribution of woodland plant species in some Shropshire hedgerows. *Biological Conservation* **7**: 61-72.

Fritz, R. & Merriam, G. (1993). Fencerow habitats for plants moving between farmland forests. *Biological Conservation* **64**: 141-148.

Corbit, M., Marks, P.L. & Gardescu, S. (1999). Hedgerows as habitat corridors for forest herbs in central New York, USA. *Journal of Ecology* **87**: 220-232.

Sarlöv Herlin, I.L. & Fry, G.L.A. (2000). Dispersal of woody plants in forest edges and hedgerows in a Southern Swedish agricultural area: the role of site and landscape structure. *Landscape Ecology* **15**: 229-242.

Smart, S.M., Bunce, R.G.H. & Stuart, R.C. (2001). *An Assessment of the Potential of British Hedges to Act as Corridors and Refuges for Ancient Woodland Indicator Plants*. In Hedgerows of the World: their ecological functions in different landscapes, pp. 3-16. IALE (UK) International Association of Landscape Ecology, Lymm, UK.

Schmucki, R., de Blois, S., Bouchard, A. & Domon, G. (2002). Spatial and temporal dynamics of hedgerows in three agricultural landscapes of southern Quebec, Canada. *Environmental Management* **30**: 651-664.

Deckers, B., Hermy, M. & Muys, B. (2004). Factors affecting plant species composition of hedgerows: relative importance and hierarchy. *Acta Oecologica* **26**: 23-37.

Endels, P., Adriaens, D., Verheyen, K. & Hermy, M. (2004). Population structure and adult plant performance of forest herbs in three contrasting habitats. *Ecography* **27**: 225-241.

Petit, S., Griffiths, L., Smart, S.S., Smith, G.M., Stuart, R.C. & Wright, S.M. (2004). Effects of area and isolation of woodland patches on herbaceous plant species richness across Great Britain. *Landscape Ecology* **19**: 463-471.