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REVIEW

Are hedgerows effective corridors between fragments of woodland habitat? An evidence-based approach

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Abstract Anthropogenic modification of the countryside has resulted in much of the landscape consisting of fragments of once continuous habitat. Increasing habitat connectivity at the landscape-scale has a vital role to play in the conservation of species restricted to such remnant patches, especially as species may attempt to track zones of habitat that satisfy their niche requirements as the climate changes. Conservation policies and management strategies frequently advocate corridor creation as one approach to restore connectivity and to facilitate species movements through the landscape. Here we examine the utility of hedgerows as corridors between woodland habitat patches using rigorous systematic review methodology. Systematic searching yielded 26 studies which satisfied the review inclusion criteria. The empirical evidence currently available is insufficient to evaluate the effectiveness of hedgerow corridors as a conservation tool to promote the population viability of woodland fauna. However, the studies did provide anecdotal evidence of positive local population effects and indicated that some species use hedgerows as movement conduits. More replicated and controlled field investigations or long-term monitoring are required in order to allow practitioners and policy makers to make better informed decisions about hedgerow corridor creation and preservation. The benefits of such corridors in regard to increasing habitat connectivity remain equivocal, and the role of corridors in mitigating the effects of climate change at the landscape-scale is even less well understood.

Keywords Climate change · Connectivity · Conservation · Habitat fragmentation · Habitat loss · Landscape-scale · Movement · Population · Systematic review · Woodland fauna

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Introduction

The extent of anthropogenic modification in the countryside means that virtually all of the modern terrestrial landscape consists of fragments of once continuous habitat interspersed by non-habitat (Groombridge 1992). The effects of habitat loss and fragmentation can be highly detrimental to the persistence of species, leading to isolated pockets of habitat that can no longer support viable populations in the long-term (Soulé 1987; Fahrig 2003). A reduction in landscape connectivity decreases the probability of individuals successfully moving between habitat patches (Klein 1989; Thomas and Hanski 1997; Baguette et al. 2000; Hanski et al. 2000; Brooker and Brooker 2002) and lessens the chances of populations existing through rescue effects (Brown and 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).

To mitigate the effects of habitat fragmentation, 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 and 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 and Cox 1987; Simberloff et al. 1992; Dawson 1994; Beier and Noss 1998; Haddad et al. 2000). Proponents of corridors argue that they act as conduits, facilitating the movement of individuals between otherwise isolated patches of remnant habitat, thereby promoting gene flow, reducing population fluctuations and decreasing extinction risk. Their role in assisting the movement of species is widely accepted from a theoretical perspective (Bridgewater and Woodin 1990; Forman 1995a; Hudgens and Haddad 2003) and supported by modelled simulation studies (e.g., Anderson and Danielson 1997; Hargrove et al. 2004; Ovaskainen 2004). However, sceptics point out that these assertions are seldom supported by strong empirical evidence (Simberloff and Cox 1987; Dunning et al. 1992) and go so far as to advise that corridors may actually be deleterious to target species, potentially acting as population sinks, increasing edge-related predation risk, the spread of disease and the probability of catastrophic natural disturbance (Ogle and Wilson 1985; Henein and Merriam 1990; Forman 1991; Hobbs and Hopkins 1991; Simberloff et al. 1992; Hess 1994).

Further interest in restoring landscape connectivity has been stimulated by the acceptance that climate change leads to shifts in the locations of climatically suitable habitats that satisfy the niche requirements of species (Bridgewater and Woodin 1990; Parmesan 1996; Thomas and Lennon 1999; Parmesan et al. 1999; Berry et al. 2002; Parmesan and Yohe 2003; Thomas et al. 2004; Hulme 2005). The many species constrained by habitat fragmentation will not be able to track suitable climates (Parmesan 2001; Warren et al. 2001; Travis 2003; Opdam and Wascher 2004) and will effectively get 'left behind' and face extinction.

Forest loss and fragmentation has been one of the most important alterations to the global landscape (Hobbs and Saunders 1993). For example, in Britain, woodland once covered 90% of land area, but has now been reduced to 15% as a result of changing land-use (Rackham 1980). The preservation and creation of hedgerows in suitable locations is thought to reduce the detrimental effects of fragmentation on the woodland fauna (Forman and Baudry 1984; Kirby 1995; Peterken 1995, 2000; Bennett 1999; Spellerberg 1995). English Nature (EN), the UK government conservation agency for England, identified the need for a systematic review to evaluate the effectiveness of hedgerow corridors in promoting population viability of target species and biodiversity within remnant woodland habitat patches. The rationale for undertaking the review was that it would allow both policy makers and practitioners to make better informed decisions with regard to hedgerow corridor preservation and creation, which may be especially pertinent in the face of climate change. In the absence of good quality and robust information, a systematic review serves to highlight the knowledge gaps in our understanding and to draw attention to areas where further primary research is required.

Methods

Systematic reviews locate information from published and unpublished sources, critically appraise methodology and synthesise evidence to provide empirical answers to scientific research questions. They differ from conventional literature reviews as they follow a strict methodological protocol and provide a comprehensive assessment of available empirical evidence (Khan et al. 2003). Therefore, they are extensive, repeatable and minimise the chance of incorporating bias into the review process, whereas a conventional review may reflect the personal view of author(s) and may be based on a (potentially biased) selection of literature. The utility and value of systematic review and the evidence-based approach is well established in the medical and public health sectors (Stevens and Milne 1997; Egger et al. 2003), and is now widely recognised in other research disciplines, including conservation and environmental management (Pullin and Knight 2001; Sutherland et al. 2004; Pullin and Stewart 2006; further details of the methodology and completed systematic reviews can be found at www.cebc.bham.ac.uk).

Question formulation

The specific nature of the question to be addressed by the systematic review was formulated via iterative discussion between English Nature and other UK statutory and non-governmental conservation organisations. The question was constructed of three key elements (Khan et al. 2001; Pullin and Stewart 2006):

1. Subject (i.e., the unit of study to which the intervention is to be applied): any faunal population or assemblage.
2. Intervention (i.e., the policy or management action under scrutiny): a hedgerow, or hedgerow network, connecting two or more patches of woodland habitat.
3. Outcome (i.e., the measured result from a study on the effectiveness of the intervention): the desired 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.

Identification of relevant studies

Relevant studies were identified through computerised searches of the following electronic databases: ISI Web of Knowledge (comprising of ISI Web of Science: Science Citation Index Expanded 1945–present and ISI Proceedings: Science and Technology Proceedings 1990–present), JSTOR, Science Direct, Directory of Open Access Journals (DOAJ), Copac, Scirus, Scopus (1960–2005), Index to Theses Online (1970–2005), Digital Dissertations Online, Agricola, English Nature's 'WildLink' and Countryside Council of Wales (CCW) library (providing access to grey literature of relevance to EN and CCW, the Welsh government conservation agency, respectively). Couplets of key words were used for searching, consisting of 'hedgerow' combined with the following: corridor, movement, dispersal, colonisation, colonization, connectivity, population, community, mammal, invertebrate, amphibian and bird (wildcards were used where supported by the database).

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 or 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, The Mammal Society and The National Trust. Bibliographies of articles accepted into the systematic review at the full text stage of the process and conventional literature reviews were searched for studies that had not yet been identified by any other means. Finally, recognised experts and practitioners were contacted and asked to recommend any additional sources of potentially relevant information.

Non-English language searches were not conducted in this systematic review. However, the search did identify studies on a global scale (e.g., research 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.

Studies underwent a 3-fold filter process before being accepted into the final systematic review.

Initially, all articles were filtered by title and any obviously irrelevant studies were removed from the list of captured articles. Subsequently, the abstracts of the remaining studies were examined, by two independent reviewers, with regard to possible relevance to the systematic review question, using inclusion criteria based on the subject and intervention elements of the systematic review question. No study was rejected due to the outcome measure (i.e., irrespective of whether it recorded change in population density, individual animal movements, etc.). Articles 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. Finally, all remaining studies were read at full text and either rejected or accepted into the final review.

Data extraction and analysis

Information related to each of the systematic review question elements was extracted from the studies and collated in a qualitative table. The broad variation in type of investigation and range of outcome measures adopted in the studies precluded the use of formal meta-analytical techniques for quantitative analysis.

Results

Search statistics

Searching was completed in May 2005. From over 7500 initial hits (including duplicates) from all searches, 205 unique studies remained in the systematic review after the abstract filter stage; 183 from electronic database searches and 22 from other sources. Twenty-two of the 205 studies could not be obtained at full text for further examination, as they were unavailable from the British Library, author(s) or publishers. Following assessment at full text, the final review incorporated 14 studies on mammals (52% of the 27 studies in total), 6 studies on birds (22%) and 7 on invertebrates (26%) (Table 1).

Review outcome

The empirical evidence that is currently available on hedgerow 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 was lacking (i.e., long-term fully replicated and controlled field-based investigations), there were a number of studies that provided anecdotal evidence of positive local population effects related to hedgerow variables, such as structural complexity and density within the landscape. The studies also indicated that species were using continuous, unbroken 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 (Table 2). Conversely, it must be stressed that the evidence collated in this review 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 included into the systematic review 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

Table 1 Summary of each study satisfying the inclusion criteria of a systematic review evaluating the effectiveness of hedgerow corridors in promoting population viability of woodland fauna

Study	Country	Taxonomic group	Study species	Matrix	Type of study (*sampling effort*)	Study system (*range of wood area in ha*)	Utility of hedgerow corridors
Merriam and Lanoue (1990)	Canada	Mammal	White-footed mouse (*Peromyscus leucopus*)	Arable and pastoral	Radio-tracking (*18 individuals, twice for 2 days in summer and autumn*)	Small woodland network	Structurally 'complex' hedgerows (>2 m wide with unlimited shrub cover, but <10% of hedgerow length with trees taller than 10 m) were preferred for movement
Zhang and Usher (1991)	UK	Mammal	Wood mouse (*Apodemus sylvaticus*)	Arable	Live-trapping (*four 10-day sessions in 3 months*)	3 woods	Hedgerows were used for movement between woods. Dispersal rate between woods was greater between those connected by hedgerows than those that were not (sample size too small to test statistically)
van der Zee et al. (1992)	Netherlands	Mammal	Badger (*Meles meles*)	Arable and pastoral	Sett occupancy survey (*twice in 20 years*)	Woodland network	Setts that changed occupancy status were associated with lower than average numbers of hedgerows. Setts with consistent occupancy were associated with the largest number of hedgerows in a 1 × 1 km square surrounding the sett
Fitzgibbon (1993)	UK	Mammal	Grey squirrel (*Sciurus carolinensis*)	Arable	Population density survey (*over 3 months*)	68 woods (*0.2–12.5*)	Squirrel presence was positively related to hedgerow density within 400 m radius of the wood
Bennett et al. (1994)	Canada	Mammal	Chipmunk (*Tamias striatus*)	Arable and pastoral	Live-trapping (*four sessions within 5 months*)	4 woods	Hedgerow use by woodland residents was positively correlated with tall tree (> 10 m), small tree (4–10 m) and shrub cover (1.5–4 m). Hedgerow use was negatively correlated with hedgerow length and proportion of gaps along the length
Entwistle et al. (1996)	UK	Mammal	Brown long-eared bat (*Plecotus auritus*)	Pastoral	Radio-tracking (*16 individuals, for a total of 68.5 bat nights over 2 years*)	Woodland network	Hedgerows were used as commuting routes between roost and feeding sites. Bats travelled significantly longer distances via these routes than Euclidean distance between woods
Kotzageogis and Mason (1996)	UK	Mammal	Yellow-necked mouse (*Apodemus flavicollis*)	Arable	Radio-tracking (*6 individuals for 3–7 days*)	3 woods	All individuals stayed within the hedgerows and did not enter the matrix

Table 1 continued

Study	Country	Taxonomic group	Study species	Matrix	Type of study (*sampling effort*)	Study system (*range of wood area in ha*)	Utility of hedgerow corridors
Fitzgibbon (1997)	UK	Mammal	Wood mouse Bank vole (*Clethrionomys glareolus*)	Arable	Live-trapping (*two 4-day sessions in spring and late summer*)	38 woods (*0.05–4.45*)	Wood mouse presence in spring was positively related to hedgerow density within 400 m of the wood. Wood mouse and bank vole autumn abundance was positively related to hedgerow 'connectedness' (interaction of hedgerow length with number of connected hedgerows)
Verboom and Huitema (1997)	Netherlands	Mammal	Pipistrelle bat (*Pipistrellus pipistrellus*) Serotine bat (*Eptesicus serotinus*)	Arable and pastoral	Activity observations (*over 5 months*)	Woodland network (<2)	Pipistrelle activity was proportionally related to hedgerow density and hedgerow height (not recorded if <6 m high). Serotine activity was more than proportionally related to hedgerow density
Bright (1998)	UK	Mammal	Common dormouse (*Muscardinus avellanarius*)	Pastoral	Radio-tracking (*12 individuals*)	Small wood	Dormice did significantly more about-turns, travelled further and faster in cut hedgerow than uncut hedgerow. There was a significant difference in the frequency with which hedgerow gaps were crossed: gaps of 1 m were crossed on 55% of approaches, 3 m gaps were only crossed on 6% approaches and 6 m gaps were never crossed. Movement in hedgerows was not oriented in any direction other than that imposed by the hedgerow. Dormice in the grassland spent significantly less time stationary than those in hedgerows, moved further on each move and lost more body mass than those in hedgerows. Movement in grassland was always oriented towards woodland
Marsh and Harris (2000)	UK	Mammal	Yellow-necked mouse Wood mouse	Pastoral	Live-trapping (*two 6-week sessions in autumn and spring*)	19 woods (*2.2–113.5*)	Number of hedgerows connected to each wood was highly intercorrelated with woodland area; it contributed least to the multiple regression model and was therefore excluded from further analysis
Capizzi et al. (2002)	Italy	Mammal	Common dormouse	Arable	Presence/absence survey (*over 3 months*)	38 woods (*1–120*)	Dormouse presence was positively related to the number of hedgerows into the wood

Table 1 continued

Study	Country	Taxonomic group	Study species	Matrix	Type of study (*sampling effort*)	Study system (*range of wood area in ha*)	Utility of hedgerow corridors
Motte and Libois (2002)	Belgium	Mammal	Lesser horseshoe bat (*Rhinolophus hipposideros*)	Pastoral	Radio-tracking (*1 individual, once for 11 days*)	Woodland network	Hedgerows were used as commuting routes from roost to woodland foraging area
Capizzi et al. (2003)	Italy	Mammal	Edible dormouse (*Glis glis*)	Arable	Presence/absence survey (*over 11 months*)	38 woods (*1–120*)	Dormouse presence was not related to the number of hedgerows into the wood
Hinsley et al. (1995)	UK	Bird	Resident and migrant woodland bird assemblages	Arable	Bird census counts (*four sessions per wood each breeding season, for 3 years*)	151 woods (*0.02–30*)	Length of hedgerow in the surrounding landscape within 0.5 km of a wood was positively related to the breeding presence of long-tailed tits (*Aegithalos caudatus*), garden warblers (*Sylvia borin*) and blackcaps (*Sylvia atricapilla*). Length of hedgerow in the surrounding landscape within 1 km of a wood was positively related to the breeding presence of robins (*Erithacus rubecula*) and bullfinches (*Pyrrhula pyrrhula*). Number of hedgerows connected to the wood was positively related to the breeding presence of wrens (*Troglodytes troglodytes*), great tits (*Parus major*), blue tits (*Parus caeruleus*) and willow warblers (*Phylloscopus trochilus*). Hedgerow as an integral part of the wood was positively related to the breeding presence of song thrushes (*Turdus philomelos*)
Hinsley et al. (1998)	UK	Bird	Resident and migrant woodland bird assemblages	Arable	Bird census counts (*over 3 years*)	150 woods (< 15)	'Species-rich' woods (> 1 species more than expected from woodland area) were more connected by hedgerows than 'species-poor' woodlands (2 species less than expected from woodland area)

Table 1 continued

Study	Country	Taxonomic group	Study species	Matrix	Type of study (*sampling effort*)	Study system (*range of wood area in ha*)	Utility of hedgerow corridors
Vanhinsbergh et al. (2002)	UK	Bird	Resident and migrant woodland bird assemblages	Arable and pastoral	Bird census counts (*each wood in winter and breeding season, within a year*)	64 woods	Woodlands connected by dense hedgerows with trees were more likely to contain the following species, than woodlands connected by hedgerows that were dense but without/sparsely vegetated with trees: blue tit, chaffinch (*Fringilla coelebs*), robin, song thrush, yellowhammer (*Emberiza citrinella*) and garden warbler. Species richness was greater in woods connected with dense hedgerows that contained trees, than in woods connected to hedgerows without trees
Bennett et al. (2004)	UK	Bird	Specialist and migrant woodland bird assemblages	Arable	Bird census counts (*four sessions per wood each breeding season, for 3 years*)	88 woods (*0.5*)	Woodland-dependent species abundance was greater in woods with higher hedgerow density within a 1 km radius. Hedgerows did not affect turnover of either type of species. Assemblage composition (determined by ordination scales of frequency of each species in each wood) was positively related to hedgerow density within a 1 km radius of the wood
Browne et al. (2004)	UK	Bird	Turtle dove (*Streptopelia turtur*)	Arable, horticultural and pastoral	Bird census counts (*at least 10 sessions per wood, over 30 years*)	Woodland network (*majority >10*)	Change in annual territory density was positively correlated to an index of ‘hedginess’ (ratio of hedgerow length, woodland and scrub edge to farmland area). No other correlation was observed between population density and any of the habitat/landscape variables

Table 1 continued

Study	Country	Taxonomic group	Study species	Matrix	Type of study (*sampling effort*)	Study system (*range of wood area in ha*)	Utility of hedgerow corridors
Bellamy and Hinsley (2005)	UK	Bird	Resident and migrant woodland bird species	Agricultural	Activity observations (*over 3 months*)	31 pairs of woods (*0.1–157*)	Three times more bird movements were made along hedgerows than across open fields. Total number of movements along hedgerows was positively related to structural complexity (based on height, width, number of trees present and continuity). A greater percentage of the birds crossed between woods via the open fields when the proportion of gap in the length of the hedgerow was high. Blue tits and great tits were significantly more likely to use hedgerows to cross between woods, whereas green woodpeckers (*Picus viridis*) were significantly more likely to cross via the open fields and chaffinches showed no preference for either route. The use of the hedgerows to cross between woods increased as mean body mass of the bird species decreased. There was no relationship between birds crossing the open fields and the ratio of hedgerow length to Euclidean distance between woods
Plat et al. (1995)	Netherlands	Invertebrate	Carabid beetle (*Calathus rotundicollis*)	Agricultural	Mark-release recapture (*2 14-day sessions within 3 months*)	2 woods	No beetles were re-captured within the matrix. Individuals released at the wood/hedgerow interface moved into the wood and along the hedgerow away from the wood. No individuals crossed any gap within the hedgerow
Charrier et al. (1997)	France	Invertebrate	Carabid beetle (*Abax parallelepidus*)	Pastoral	Radio-tracking (*8 individuals four times*)	1 wood	Mean distance covered per unit time and area occupied during the study were highest in the wood, decreasing in hedgerows with reduced vegetation cover. No individuals died within the wood. Mortality was highest among individuals who left the hedgerow at some stage; >50% of these individuals died whilst still within the matrix

Table 1 continued

Study	Country	Taxonomic group	Study species	Matrix	Type of study (*sampling effort*)	Study system (*range of wood area in ha*)	Utility of hedgerow corridors
Burel (1998)	France	Invertebrate	Carabid beetle assemblages	Pastoral	Pitfall-trapping (*3-day sessions each fortnight, for 10 trapping months*)	1 wood	Not all hedgerows were favoured by 'corridor' species (those found throughout the hedgerow network); abundance in hedgerows was positively related to a dense herbaceous layer and presence of a tree layer
Petit and Burel (1998a)	France	Invertebrate	Carabid beetle (*A. parallelepidus*)	Pastoral	Pitfall-trapping (*over 5 months*)	Woodland network	Beetle abundance was positively correlated with all examined measures of connectivity; Euclidean distance showed the lowest significance, distance along the hedgerow network had the strongest significance
Petit and Usher (1998)	UK	Invertebrate	Carabid beetles assemblages	Arable and pastoral	Pitfall-trapping	19 woods	Woodland specialist species were found in hedgerows; spatial isolation was not the primary factor in determining their distribution, although it did have an effect (local conditions were more important)
Butterweck (2000)	Germany	Invertebrate	Carabid beetles (*A. parallele-pipedus* and *Abax parallelus*)	Arable and pastoral	Mark-release recapture	2 woods	Hedgerows had lower densities of the carabids than the woods. Three of 143 released *A. parallelepipedus* individuals were re-caught within the matrix, 15 emigrated from the wood into the hedgerow and a further 8 had crossed into the other wood. Insufficient *A. parallelus* were re-caught to determine whether the species used the hedgerow for movement between woods
Aviron et al. (2005)	France	Invertebrate	Carabid beetle assemblages	Arable and pastoral	Pitfall-trapping (*weekly for 14 weeks over 5 trapping months*)	Small woodland network	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

Table 2 Summary of the broad research focus of the literature accepted into the systematic review. Percentages are given in relation to the total of 27 studies

Total number of studies	27 (100%)
Mammal	14 (52%)
Bird	6 (22%)
Invertebrate	7 (26%)
Multiple taxonomic groups	0 (0%)
Population/assemblage studies	*15 (56%)*
Mammal	6 (22%)
Bird	5 (19%)
Invertebrate	4 (15%)
Movement studies	*12 (44%)*
Mammal	8 (29%)
Bird	1 (4%)
Invertebrate	3 (11%)

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.

Mammals

The majority of the studies included used rodents as study species (71% of the 14 studies). 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, 1997; Verboom and 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 and 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).

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). Movement via hedgerows was positively related to their structural complexity and continuity. However, birds of a larger body mass were more likely to fly across open fields to move between patches of woodland (Bellamy and Hinsley 2005).

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 and 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 non-habitat 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).

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 and Arntzen (2000) observed the post-breeding migrations of two 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.

Discussion

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 has been exacerbated by many studies merely reporting the presence of species within a corridor and subsequently surmising that it is, therefore, acting as a movement conduit in the fragmented landscape (MacClintock et al. 1977). At best, observations such as these can only be useful as an indicator of corridor utility for sedentary species.

The objective of this systematic review was to collate, critically appraise and synthesise published and unpublished evidence on whether hedgerows are effective corridors for fauna, increasing the population viability of target species occupying otherwise isolated fragments of woodland habitat. Unfortunately, there was insufficient evidence 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 hedgerow corridors, with local population effects reported within the system and species movements recorded between habitat patches. The research suggests that hedgerows with greater diversity of vegetation 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 logistical and ethical difficulties in undertaking robust primary research on such a topic, which may give reason to their paucity (Dover and Fry 2001; Tewksbury et al. 2002; Bowne and Bowers 2004). 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.

Implications for management and policy

The specific purpose of the systematic review was not to examine the importance of hedgerows as habitats. Hedgerows are acknowledged as 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 (Osborne 1984; Johnson and Beck 1988; Moles and Breen 1995; Dermers et al. 1995; Hinsley and Bellamy 2000) and act as refugia for small mammals on arable farmland in the post harvest period (Tew and 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).

In light of our findings some might argue that there is insufficient evidence that hedgerow corridors enhance the population viability of species occupying isolated woodlands, or indeed facilitate movement of fauna, for us to devote limited financial resources to their provision, and that they are not a cost effective conservation tool. Regrettably, therefore, even after decades of debate regarding the utility of corridors, practitioners and policy makers are still left to make best judgement decisions on appropriate courses of action and face the uncertainty of the consequences. Management strategies should not, therefore, be necessarily focused 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; Fahrig 2003; Hulme 2005) or increasing the permeability of the agricultural matrix and wider landscape (Baum et al. 2004; Revilla et al. 2004).

Resolving the dispute on corridor use is likely to be both time consuming and costly. However, conservation biologists have to act now to ensure that adequate landscape-scale habitat connectivity is retained (Hobbs 1992; Beier and Noss 1998; Bennett 1999; Opdam and Wascher 2004). It is better to maintain and monitor the value of existing hedgerow corridors in the years to come, than neglect their potential benefits with regard to population persistence and then discover their worth when irreversible losses have occurred. A suitable compromise may be to focus on the landscape connections already present, improving the quality of the corridor and preserving their continuity between habitat fragments, the importance of which has been demonstrated in this systematic review. It has been suggested that a large proportion of UK hedgerows are either neglected or over-managed (MacDonald and Johnson 1995; Barr and Gillespie 2000) 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 and Bellamy 2000; Haddad and Tewksbury 2005).

Environmental management at a landscape-scale has a crucial role to play in the mitigation of climate change impacts (Opdam and Wascher 2004; Hulme 2005). Nevertheless, although there has been extensive research on climate impacts, particularly in regard to predicting shifts in species' spatial distributions, little work has focused on the implications for conservation planning and the practical application of strategies for adaptation (Opdam and Wascher 2004; King 2005). Given that it is widely acknowledged that biodiversity will be significantly impacted by climate change (Thomas et al. 2004), a move towards adaptive habitat and species management is long overdue (Hulme 2005).

Hedgerow corridors may well be advocated as a means of assisting the movement of woodland fauna through the fragmented landscape as they attempt to track climatically suitable habitat. Despite the seductive power of the corridor paradigm, this study has shown that there is no empirical evidence to substantiate their effectiveness at the landscape-scale. If hedgerows are to be planted in order to facilitate the movement of species as they respond to the changing climate, one might presume that they should be strategically positioned within the landscape and orientated parallel to existing climatic gradients (i.e., aligned low to high elevation or poleward; Hobbs and Hopkins 1991). However, these assumptions are based on temperature changes alone, and may not accommodate significant changes in precipitation patterns, other climate-related variables or increased frequency of large-scale disturbances caused by extreme weather events (Opdam and Wascher 2004). This simplistic corridor orientation strategy may actually limit the possible benefits of corridors for the shifting populations. The optimum orientation of hedgerow corridors will differ according to the distribution of woodland habitat within the landscape, as the direction of a species range expansion will depend on movements into and through regions that can support (meta)populations (Opdam and Wascher 2004; Davies et al. 2005). The effectiveness of corridors in relation to increasing habitat connectivity is not yet established, and the potential role of corridors in mitigating the effects of climate change is even less well understood.

Implications for research

Advice on the creation and preservation of corridors is urgently required by practitioners and policy makers, even though the information available is insufficient to make adequate recommendations. Nonetheless, the lack of evidence with regard to their utility should not exclude them from use and is not a case for the rejection of the concept, but a reason to initiate primary research projects and gather high quality evidence on their function.

The conventional types of study required to unequivocally establish the importance of hedgerow corridors are difficult to design, slow to gather data and expensive to implement (Dover and Fry 2001; Tewksbury et al. 2002; Bowne and Bowers 2004). As a result, empirical studies addressing the impact of corridors have tended to be small-scale and have frequently failed to isolate the effects of corridor function *per se* from the confounding effects of increased habitat area. Nicholls and Margules (1991) and Inglis and Underwood (1992) both stress the need for controlled field experiments to thoroughly evaluate the consequences of corridors between isolated fragments of habitat for donor/recipient populations. However, randomised and fully replicated studies may be a practical impossibility within the hedgerow system. As the implementation of robust experiments would be costly and labour intensive, it is essential that problems of independence, pseudoreplication and confounding factors are given serious consideration *a priori* (Inglis and Underwood 1992). Interpretation of the results must be clear and unambiguous, otherwise subsequent management decisions may be compromised.

Tewksbury et al. (2002) advocate the use of large-scale experimental approaches in conjunction with investigations in unmanipulated landscapes, so that the potential biases of natural studies can be tested. This echoes a previous call by Hobbs and Wilson (1998) for a range of research techniques to be adopted to test the value of corridors, which should include novel approaches to gathering data, in addition to existing modelling, experimental and observation methodologies. Dover and Fry (2001) explored the mechanisms that underpin corridor function, using two model structures to mimic the physical presence and visual cues of hedgerows within an agricultural landscape, and concluded that simple structural traits in landscape elements can indeed modify species movement behaviour. Tewksbury et al. (2002) created eight experimental landscapes to examine the effectiveness of corridors in facilitating plant-animal interactions (seed dispersal and pollination) and whether corridors can intercept species movements within the matrix, diverting them into connected patches. The results demonstrated that although the corridors did not influence individuals within the matrix, they increased interpatch movement and assisted these two key processes which rely on plant-animal interactions. In both examples, the hypotheses would have been problematic to test within the framework of a controlled and replicated experiment in a natural system, yet the studies complement such conventionally designed investigations into corridor-use.

An understanding of how species move through fragmented landscapes, using elements such as corridors and stepping stones, is vital for species management at a landscape-scale (Brooker and Brooker 2002; Bowne and Bowers 2004). To achieve this objective, 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 in a natural setting can often be difficult (Ims and Yoccoz 1997; Bowne and Bowers 2004; Haddad and Tewksbury 2005). This is further complicated by the fact that the behaviour of species moving through hedgerows within agricultural landscapes is likely to be influenced by the nature of the matrix (Ricketts 2001; Baum et al. 2004), the type and spatial distribution of adjacent habitats, season, farming activities (e.g., herbicide and pesticide applications) and interaction between conspecifics and other species.

A recent review of the literature investigating interpatch movements in spatially structured populations found that less that half of empirical studies (33 out of 89 in total) reported on the population-level consequences of such movements (Bowne and Bowers 2004). The relationship between immigration/emigration rates through corridors and population dynamics at a landscape-scale needs to be clearly demonstrated by further research before proponents of corridors can state that they serve to promote population viability by facilitating interpatch movements. Long-term monitoring of population persistence is also required in systems where hedgerows have been lost, replanted or restored, as apparent population-level effects may be confounded by time lags between when the landscape change has occurred, and when local populations begin to react to the change (Petit and Burel 1998b).

Future conservation planning research must attempt to unify the fields of (meta)population ecology and landscape ecology if conservation measures to increase landscape connectivity, in order to promote long-term population viability, are to be effective. Although the two concepts are both concerned with the spatial arrangement of habitat patches within the landscape, they have evolved independently and essentially differ with regard to how habitat and the matrix are viewed; (meta)population ecology views habitat within a featureless matrix, where interpatch distances are Euclidean, whereas landscape ecology is concerned with the complex environmental heterogeneity found within the real landscape (Forman and Godron 1986; Forman 1995b; Wiens 1995, 1997; Hanski and Simberloff 1997). However, landscape ecology is highly relevant to species (meta)population dynamics, especially when considering how variation in the landscape can influence the movement of individuals through the matrix and therefore the likelihood of habitat patch occupancy (Wiens 1997; Ricketts 2001). For instance, Roland et al. (2000) examined the dispersal behaviour of a butterfly species that occupies alpine meadows in Canada. Dispersal declined with distance as expected, but the trend was modified by the nature of the matrix, with the species travelling further through open but unsuitable grassland than through areas of woodland. With recent technological advances (e.g., in Geographical Information Systems), the gap between the two approaches is being bridged. Details of landscape elements that may impede or assist movement through the matrix, such as stepping stones, barriers and corridors, are now being used in conjunction with (meta)population models (Akçakaya 1994; Gustafson and Gardner 1996) to develop conservation strategies for species and assemblages (Wiens 1996).

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 profit 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 which, to date, have not been commonly investigated in corridor systems (Tewksbury et al. 2002; Hudgens and Haddad 2003). Indeed, no such study was identified within this systematic review (Table 2). A more community-orientated approach is of particular importance if the motivation behind corridor protection or creation is to preserve biodiversity.

The principle aim for conservation biologists 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 corridor preservation and creation. A more holistic view of the landscape needs to be taken when undertaking such research, especially if we are to develop adaptive management strategies to conserve species and biodiversity in the face of climate change.

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