No 10

REBUILDING THE ENGLISH COUNTRYSIDE:
habitat fragmentation and wildlife corridors as issues in practical conservation

English Nature Science

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SUMMARY

1. Many habitats in England are now more fragmented (the patches are smaller and more isolated from each other) than they were 50 years ago. There is sufficient evidence that this is potentially an important cause of species decline to justify opposition to further habitat fragmentation.

2. Linear (and non-linear) features that link up habitat patches have a conservation value in their own right whether or not they act as wildlife corridors. Such features should be protected and new ones created but not solely for their linking corridor value.

3. A key issue remains: how to identify those species which are of high nature conservation value and which are particularly sensitive to fragmentation or most likely to benefit from wildlife corridors. These may be few, but could be very important in particular situations.

4. Arguments against proposed fragmentation of sites should pay more attention to the effects of creating new edges and possible pollution impacts along such edges rather than the effects of reductions in patch size *per se* on particular species. Any special features of the area that may be lost should also be identified.

5. Proposals for new habitat creation, particularly where linkage of sites is proposed, must be viewed in their landscape context. Alternative ways of reducing fragmentation effects may be preferable.

6. Where the extent and diversity of semi-natural vegetation is high there is relatively little merit in putting a lot of effort into linking up the patches except to reduce edge effects.

7. Where semi-natural habitats are very sparse and within a hostile matrix the first priority is to build on to what exists already to make as compact a block as possible to reduce external influences and make the patches easier to manage.

8. It is desirable to develop more opportunities for species to move through and thrive in the whole countryside, not just in and around the areas that are currently species-rich. In many cases there is likely to be greater general wildlife benefit from putting the limited resources available into creating or encouraging the development of a series of small patches of new semi-natural habitat (stepping stones). The alternatives of putting the same total area into one single block or corridor may prove less cost-effective because specialist or slow-moving species do not in practice use them (even though they should do so in theory) or because these options are much more difficult to achieve.

9. Where the objective is to create a new extensive patch of a particular habitat (eg woodland, heath, or grassland), through concentrating the effort in one place, it may be necessary to introduce the key interior species that the habitat has been established to support.

10. It is unlikely that corridor networks will be of much value for species movement to escape the effects of climate change if the current predicted rates of climate change occur.

11. Further research and trials need to be evolved to translate fragmentation theories into the practical steps necessary to make the English countryside a more attractive place for wildlife and people.

PREFACE

Habitat fragmentation and wildlife corridors are popular ideas in the ecological and conservation literature at present (eg Andrews 1993; Rich 1994), but do they help us provide practical advice and support to those faced with yet another by-pass proposal or plans for the location of new woods? In 1992 English Nature established a small group to consider these issues and to commission research to support our discussions. This paper is derived from the discussions of the group, the research reports produced and two large seminars (one internal, one including people from the voluntary conservation movement, local authorities and consultants). The good ideas come from these reports and discussions, while I take full responsibility for any mistakes or inconsistencies that occur. The bias towards woodland examples also reflects my personal interests.

It is deliberately only lightly referenced and concentrates mainly on work relating to English conditions - the various review reports referred to go into the general ideas in far more detail than is possible here. Instead I have tried to provide a synthesis of where I think we stand now in our knowledge of fragmentation and linkage effects as they apply to the English countryside, ie with the species and habitats that English Nature is concerned to conserve (or control), at our particular landscape scales and timescales. I expect it to be rapidly overtaken by new knowledge. It is most unlikely that the conclusions would apply in North America, Australia or the Tropics, and they may apply only partially on Continental Europe where land use patterns differ. Recent work suggests, for example, that the avifauna of deciduous forests in Europe was pre-adapted to be better able to cope with fragmentation of the natural forest cover than its North American equivalent (Mönkönnen & Welsh 1994).

I have tried to provide a framework within which future discussion and research can take place. I hope that others will find this useful, particularly in guiding practical conservation. I would welcome any comments on the ideas expressed here.

ACKNOWLEDGEMENTS

I wish to thank members of the Habitat Fragmentation Group for their valuable contributions to this work and to all the others who helped with projects or comments on the draft report: George Barker, Leo Batten, Martin Drake, Andrew Farmer, Karen Goodwin, Gerry Hamersley, Stuart Hedley, Shelley Hinsley (ITE), Kate Holl (SNH), Jonathan Humphreys (CCW), Richard Jefferson, Stefa Kaznowska, Roger Key, Nick Michael, Tony Mitchell-Jones, Roger Morris, Des O'Halloran, Keith Porter, Heather Robertson, David Sheppard, Tom Tew (JNCC), Gavin Tudor (SNH), Chris Walker, Tony Whitbread and Corinna Woodall. In addition the reviews carried out by Ian Spellerberg and Martin Gaywood and by Dave Dawson provided essential background that I have mined unashamedly.

CONTENTS

INTRODUCTION

Numerous studies have documented the loss of semi-natural habitats in Britain over the last 40-50 years, but the surviving patches are also smaller and more isolated than previously. This raises questions about the effects on wildlife of habitat fragmentation: what difference does it make if the same total area of habitat is present as a few large patches or as many small ones; does it matter how far apart these patches are; and what value is there (if any) in their being linked by strips of habitat that might function as wildlife corridors? The location of the habitat lost may potentially be as important as its extent in terms of the changes in nature conservation value of the surviving patches. The significance of changes in land use at one place is thus affected by the nature of the surrounding landscape.

During the 1970s and early 1980s the main concern for conservation organisations was the loss of semi-natural vegetation to agricultural improvement, but the emphasis in the 1990s has changed. Habitat loss and degradation are still happening but shifts in agricultural and forestry policies have created opportunities to move beyond the siege walls of SSSI[1] defence. There is a need and the opportunity through a wide range of incentive schemes and other policy measures to restore some of the ground lost to wildlife (RSNC 1994). The Habitats and Species Directive refers to the need to promote the conservation of hedges, walls and other features that might act as stepping stones or corridors to promote species movement through the countryside and this has been adopted with only minor modification into the national conservation regulations needed to implement the directive. There is also support for these ideas within recent planning guidance from the Department of the Environment (Box 1).

At the same time the pressure on semi-natural areas from road schemes continues to focus attention on the impact of splitting up sites even where the total habitat loss is quite small. We must improve our understanding of what constitutes a corridor for or barrier to species movement and of the other effects of fragmentation, if our conservation policies are to have a sound scientific basis.

Box 1 Recent support for linear features in the countryside

(a) The Habitats and Species Directive
(Issued by the Council of the European Communities, Brussels, 1992.)

Article 10
Member states shall endeavour, where they consider it necessary, in their land use planning and development policies and, in particular, with a view to improving the ecological coherence of the Natura 2000 network, to encourage the management of features of the landscape which are of major importance for wild fauna and flora.

Such features are those which by virtue of their linear and continuous structure (such as rivers with their banks or the traditional systems for marking field boundaries) or their function as stepping stones (such as ponds or small woods), are essential for the migration, dispersal and genetic exchange of wide [ranging] species.

(b) The following is from Planning and Policy Procedure Guidance Note 9, issued by the Department of the Environment in October 1994.

Many sites of local nature conservation importance are given designations by local authorities and by local conservation organisations. These sites are important to local communities, often affording people the only opportunity of direct contact with nature, especially in urban areas. Statutory and non-statutory sites, together with countryside features which provide wildlife corridors, links or stepping stones from one habitat to another, all help to form a network necessary to ensure the maintenance of the current range and diversity of our flora, fauna, geological and landform features and the survival of important species.

[1] SSSI = Site of Special Scientific Interest

EN's Habitat Fragmentation Group

Generalisations derived from, for example, island biogeographic and metapopulation theories have been made about the effects of fragmentation or the value of wildlife corridors, but in practice the theoretical approach can only take us so far in trying to decide what is best for nature conservation on a particular site. Consequently in 1992 a group of English Nature staff was formed to consider in what circumstances we could rely on results from existing fragmentation studies and to identify what further work would be desirable to improve our knowledge on these subjects.

The group concentrated on species, habitats and landscape types in England, although inevitably we drew on experience and ideas from a much wider catchment. Effects on both scheduled sites and the wider countryside, and on both common and uncommon species were considered. Our goal was primarily the translation of existing ideas and experience into forms that would be directly useful to conservation workers in developing or implementing policies, in defending sites or deciding where new habitat patches are needed. The conclusions that we reached (albeit often tentative) are described in this report. We hope that they may help to prevent further national or regional species decline and provide a framework for restoring lost ground for wildlife. Those carrying out research on habitat fragmentation may be able to appreciate better how their work can be applied in nature conservation practice.

Box 2 illustrates the areas that we believe need to be tackled to build up our understanding of habitat fragmentation in England.

Box 2 A model (LYNX)[2] for gathering information about habitat fragmentation and using it to further nature conservation

INPUTS - These consist of ideas and experience from English Nature staff as well as from external sources

AREAS THAT NEED TO BE EXPLORED

↓

(a) Documentation of past/continuing fragmentation

(b) Identification of species at risk or which might act as indicators of fragmentation/linkage

(c) Reviews of fragmentation theory and process

(d) Reviews of habitat creation in practice and other mitigation measures as means of reducing fragmentation effects

(e) Reviews of the evidence for and significance of edge versus interior species and conditions

Feedback on usefulness or otherwise of guidance produced

(f) Studies of habitat selection and source-sink populations

(g) The practical implications of metapopulation studies and work on the genetics of small populations

(h) Experimental/field studies to test ideas from (a)-(e)

(i) Case studies of sites undergoing or which have undergone fragmentation/linkage

(j) Landscape rebuilding studies - looking at whether various countryside initiatives have helped to counteract fragmentation/restore links

(k) Reviews of cost-effectiveness of (i) and (j) and whether policy/practice should change as a consequence

The above are not one-off sequential steps (although the lower will tend to follow from the upper). There needs to be feedback between them leading to reiteration. Thus field studies (g) or case studies (h) may highlight a need for further review of how fragmented a particular habitat is (a) or of some aspect of fragmentation theory (c).

↓

OUTPUTS - These need to provide guidance on where fragmentation is a real problem and where it is not, on policy implications for SSSIs and the countryside in between, on ways of defending sites (both statutory and non-statutory) and opposing further fragmentation, as well as on ways of restoring links through habitat creation and other means where appropriate. The guidance must also be made available to those outside English Nature, both in the voluntary conservation sector and those involved with land use (planners, farmers, foresters, transport sectors).

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ULTIMATE GOAL - To prevent further regional/national extinctions from habitat fragmentation and to restore lost ground for wildlife.

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[2] The name is pure author's whimsy!

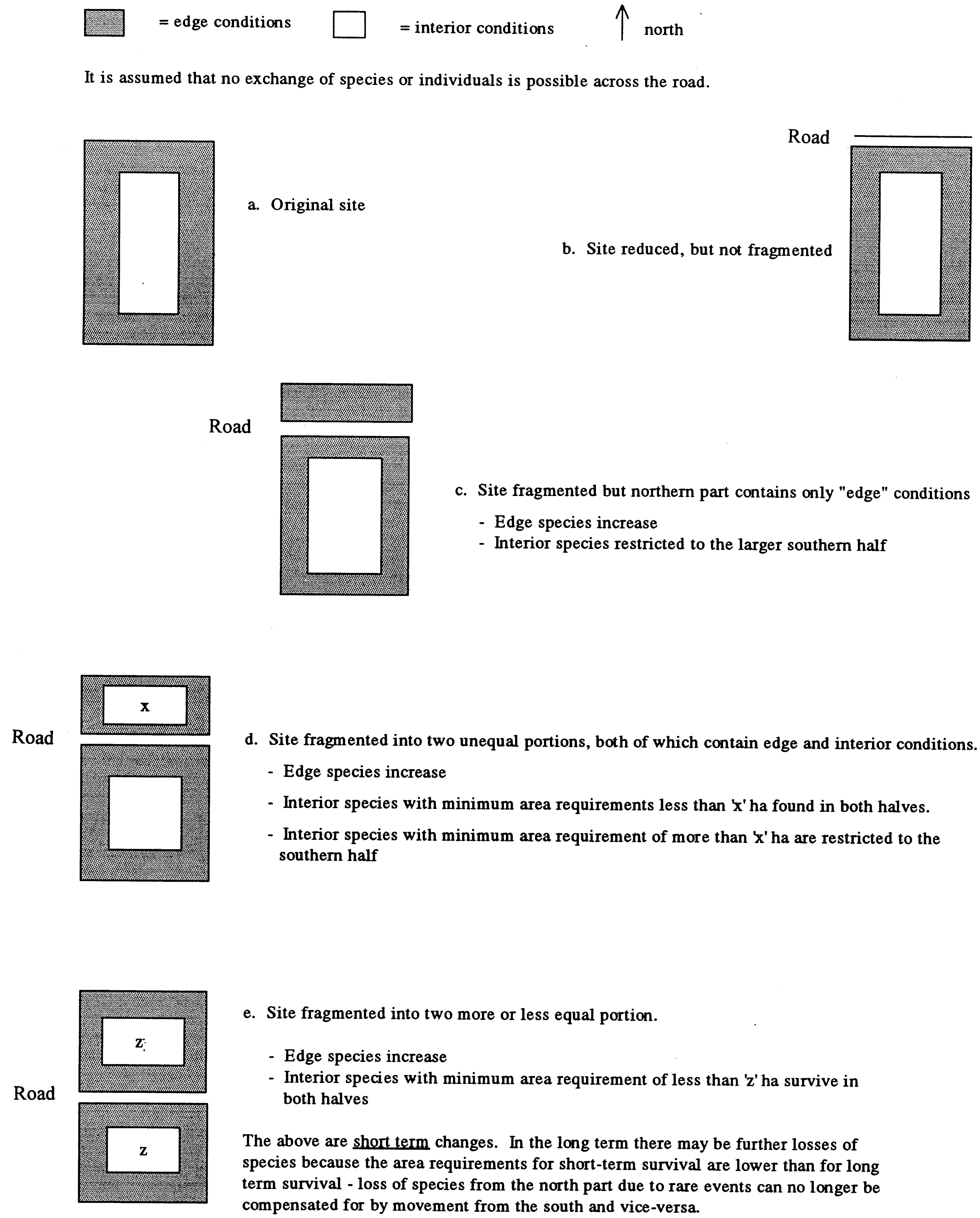


Figure 1. Possible effects of habitat fragmentation on species with different requirements, depending on how a site is split up.

Examples of fragmentation issues in nature conservation

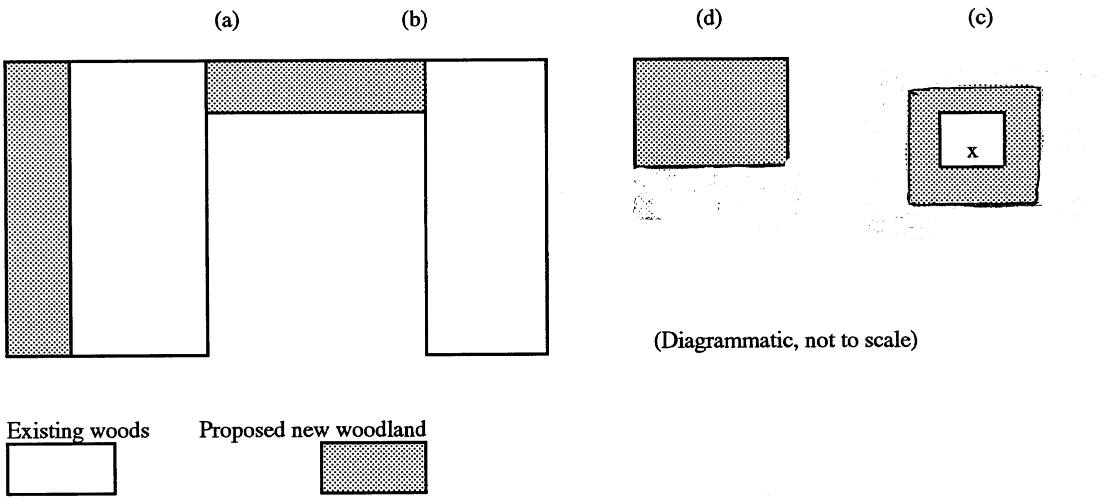
Where to put the road through a heath (or some other habitat patch)

Ideally new roads should be routed so as to avoid damaging semi-natural habitats, or so as to just clip their edges if they must be affected, but this does not always happen. Suppose you are faced with a road that is going to cut through a patch of heath, of uniform character apart from at its edge, in a "hostile" matrix of arable land. You may be concerned that many species of interest will be unable or unwilling to cross the road, such that the two heathland patches created function for these species as separate sites. Are there grounds from fragmentation theory for arguing that it is always better (other things being equal) to create one large and one small piece, as opposed to two more or less equal fragments? Unfortunately, as Figure 1 illustrates, the least damaging solution may depend, amongst other things, on the extent of the edge effect and whether `edge' species are more valuable than `interior' ones; and whether there are species with minimum habitat size requirements (and if so what these size requirements are).

Where to put new woodland

What is the best location (from a nature conservation point of view) for a new piece of woodland to maximise colonisation from nearby existing woods? Where might it have the most potential to reduce the isolation of the existing woods, to ease migration between them, albeit perhaps only over a long period? Again the example assumes that the existing woods are all uniform throughout and that the land in between is generally hostile to the movement of woodland species.

In Figure 2 the new wood is more likely to acquire species from the existing ancient wood if it is placed as a thin strip alongside one edge (a) but if that is done the relationship between the two main woods is hardly altered. An alternative location (b), connecting the two woods, may permit or improve species movement between them. Whether (a) or (b) is the better option for nature conservation depends on the value of the species that might spread along the connecting link and whether this movement affects the populations in the woods at either end, as opposed to the value of the species whose populations may be enhanced by enlarging the first wood. Other possibilities include using the new woodland to enlarge another small wood (c) or to create a new patch of habitat in currently species-poor ground (d). As in Figure 1 good arguments can be made for each option.



Two ten hectare ancient woods separated by 500 m of arable fields with no hedges. Several kilometres away is another isolated ancient wood (x) of only one hectare. A new wood of 2 ha is to be planted somewhere in associated with these woods. Possible options are:

(a) The new woodland (shaded) is created as a 40x500 m strip along the edge of one of the existing woods to act as a buffer between the existing wood and the fields and to give great opportunities for species from the existing wood to spread into the newly created area. The increase in area (from 10 to 12 ha) is unlikely to allow any new species to establish that are currently limited by the size of the wood, but may marginally reduce the risk of extinction of some species there.

(b) The new woodland is established as a 40 m wide strip to connect the two large woods. There may be species that can now spread from one wood to another. There may also be a few species that colonise the linked site (22 ha) but did not use either of the individual 10 ha blocks because they were each too small to support that species. However direct movement into the new woodland from the existing woods is only on an 40 m front with each wood (compared to 500 m in (a)).

(c) The new woodland is used to buffer and substantially increase the size of the one hectare wood (x). This is very likely to improve the potential for woodland species to survive in or colonise this patch, but it does little to reduce overall isolation of the three sites.

(d) A new two hectare wood is established halfway between the small wood (x) and the others to provide a potential stepping stone between them. This is in one sense the least satisfactory location in the short-term (no direct link to an existing wood by which colonization, particularly of plants and invertebrates, can occur), but in the medium- to long-term the new wood might form the focus for further habitat creation to link the woods directly.

Figure 2 - Different locations for a new piece of woodland and how it might influence and be influenced by existing woods

Corridors to allow species to escape the effects of climate change?

If climate change occurs then some of the places where species occur at present will not be suitable for them in future. Should we be advocating the creation of wildlife corridors that would permit species to move to more favourable areas in response to these changes?

The issue here becomes whether the species that need corridors or stepping stone patches of habitat to move through the countryside can actually do so fast enough in relation to the predicted rates of climate change. A recent review of the subject for English Nature (Hill *et al.* 1993) suggests that for the most part they could not. Hence the rest of this paper deals with smaller scale movements under present climatic conditions.

No single best solution?

The above examples suggest that there may be no single best solution that can be applied to all situations where habitat fragmentation is occurring or the opportunities for habitat creation are proposed. Instead we should explore in more detail what might constitute barriers to movement, what species (or processes) depend on large site areas, what is the significance of edges and over what scales in time and space do fragmentation processes operate. Even then our understanding of the problems and possible solutions is likely to be fairly simplistic.

FRAGMENTATION EFFECTS IN THE ENGLISH LANDSCAPE

It is sometimes claimed that in the wildwood, 7,000 year ago, a red squirrel could have gone from one side of the country to the other without touching the ground. Now woodland exists only as isolated patches separated by open land of various sorts. Does this open land constitute a barrier to movement of squirrels and other species? The presumption that barriers do exist is one of the fundamental ideas in assessing fragmentation effects. In Figures 1 and 2 the matrix around the patches was assumed to be very hostile to movement of heathland or woodland species respectively. This simplifies exploration of the basic ideas underlying concerns about habitat fragmentation, but is not a fair reflection of real life. Instead landscapes are a mixture of patches which may be more or less suitable for the species concerned either for movement through, or for living in or for both.

Barrier creation

Fragmentation of habitats and species populations occurs when some barrier is created that reduces existing flows of species, individuals, genes, nutrients or energy. It is important for nature conservation if it leads to potential or actual reductions in the long-term survival of some or all of the species present on either side of the barrier or their ability to respond to changed conditions. Effectively, the resilience (elasticity) of the ecosystem, the habitat or population is reduced.

- Barriers may be physical (stretches of unsuitable habitat which a species cannot cross) or they may be behavioural - a hedge or narrow road may effectively restrict movement of small animals from one field to the next, from one piece of wood to the next, even though they are physically capable of crossing it. Alternatively they may attempt to cross and suffer very high casualties in the process (Slater 1994).

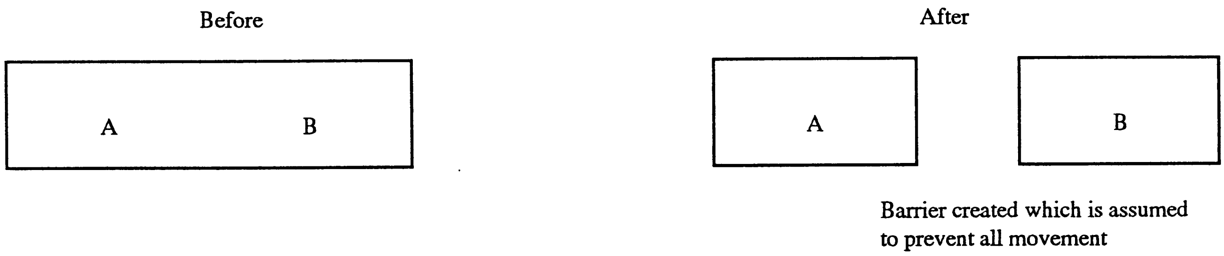
- Barriers are not the same for all species - what is a barrier to one species may be a partial barrier to another, or no barrier at all to a third. Populations in different parts of the country or in different years may cross barriers where otherwise they did not. Perhaps a sieve whose hole size may vary is a better analogy than a barrier (although for convenience barrier is retained as a term in the rest of the paper). Equally what counts as a corridor for one species may not work for another, indeed may even be a barrier for the second species. In Norway Fry and Main (1993) found that hedgerows could restrict movement of some butterfly species between meadows where they were breeding; movement of carabid beetles between fields may be slower where a hedge has to be crossed than where it does not (Mauremooto *et al.* 1995).

- If no flows occur between two areas then the creation of a barrier does not produce effective fragmentation. Small fen areas may be limited by the pattern of water movement, so a county may contain several isolated patches of this habitat type. However if these have never been connected, and if there were never any significant flows of species between them, then they are not fragmented.

- Fragmentation effects may be important on only one side of the barrier (as when a block of habitat is cut into one very large and one very small part) (Figure 1c). They may be insignificant in nature conservation terms, if both halves are large enough to function more-or-less as before despite the interruption of flows by the barrier.

Fragmentation operates at different scales for different species and for different habitats; a fragmented landscape for one species is continuous to another. Deer may treat the whole of a woodland as one habitat patch; for butterflies of the open stages in a coppice each coupe is the habitat patch and they may be discouraged from moving from one coupe to the next by walls of trees. Furthermore while barriers are usually seen as a negative feature, they may bring conservation benefits if they stop the movement of undesirable species or processes such as fire and disease.

Figures 3, 4 and 5 illustrate some of the above points in the context of situations that occur commonly in the English countryside.



a. Various butterflies are associated with recently cut areas in a wood and rely on movement from one to another, as each coupe is suitable only for very short periods. Immediately prior to the creation of the barrier all the recently cut areas and hence the associated species happened to be in section A. After the barrier is created these species still survive as before in newly cut areas in A, but are much less likely to colonise such stands created in B.

b. A large mammal (eg badger, deer) nests (dens, lies up) in A, but individuals rely on B as a key feeding area for at least part of the year. After the barrier is created this use is prevented resulting in their population in A being reduced as well as disappearing completely from B.

c. The populations of small mammals in sections A and B of the habitat are more or less self-contained, but occasionally individuals move from one population to the other. This helps maintain the level of genetic variability in the populations. After the barrier is created this exchange is reduced. The species survive in both halves but there may be changes in the genetic make-up of the two populations. Whether this would matter in nature conservation terms is hard to judge.

d. Initially a stream flows from A to B. The barrier may restrict the channel or stop the water flow altogether (perhaps leading to ponding in A, drying out in B, and consequent vegetation change in both) or it may lead to changes in the nutrients and organic matter it carries such that downstream communities in B only are affected.

Figure 3 Examples of how a barrier might affect movement of species, individuals, genes and nutrients/energy between two habitat fragments

In the mosaic of rough grassland and woodland illustrated below, the obvious place to link the two woods would be by planting field A, the point where the two woods come closest. This could however create a barrier to movement of species between the two areas of rough grassland. A better overall solution might be therefore to put field A into set-aside or more positively to try to make it a herb-rich meadow, and to create the woodland links across arable fields B and C. Alternatively field A could be developed as a mosaic of open scrub and grassland that might provide a suitable link for both woodland and grassland species.

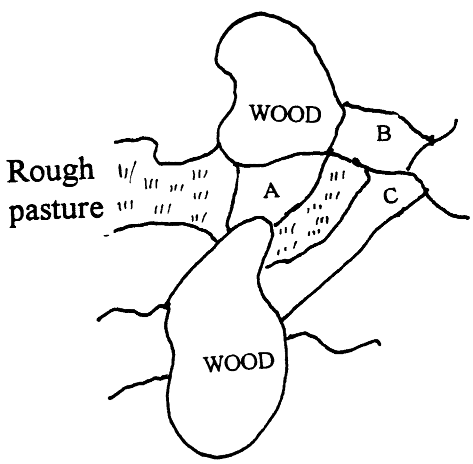


Figure 4 - Corridor or barrier?

In many landscapes patches of habitat are clustered (in the following example clusters of ancient woods are indicated by dotted lines in Figure 5). The space between the woods and the clusters may be more or less of a barrier according to the mobility of the species concerned. In this example the effects on removing different woods or parts of woods are examined for three contrasting species; species I is a plant with a likely movement range of about 25 m; species II is a butterfly likely to move about 500 m; and species III is a small mammal which usually moves only about 2 km.

Most of the time therefore species I is confined to the woods in which it occurs except in cluster (c) where colonisation between the two large woods is possible. Species II moves between woods in a cluster, but not between clusters. Species III can move between all woods (eventually). Removing wood X disrupts movement in cluster (d) for species II, but does not alter the potential movement in the other woods for the other species. Removing cluster (c) affects only the movement of species III; removing wood Y has no affect on the movement patterns of any of the species in the remaining woods. However most species may move much longer distances under rare circumstances. Therefore given a long enough time period even a relatively immobile species such as species I could potentially spread directly between for example the wood in cluster (a) and one in cluster (d).

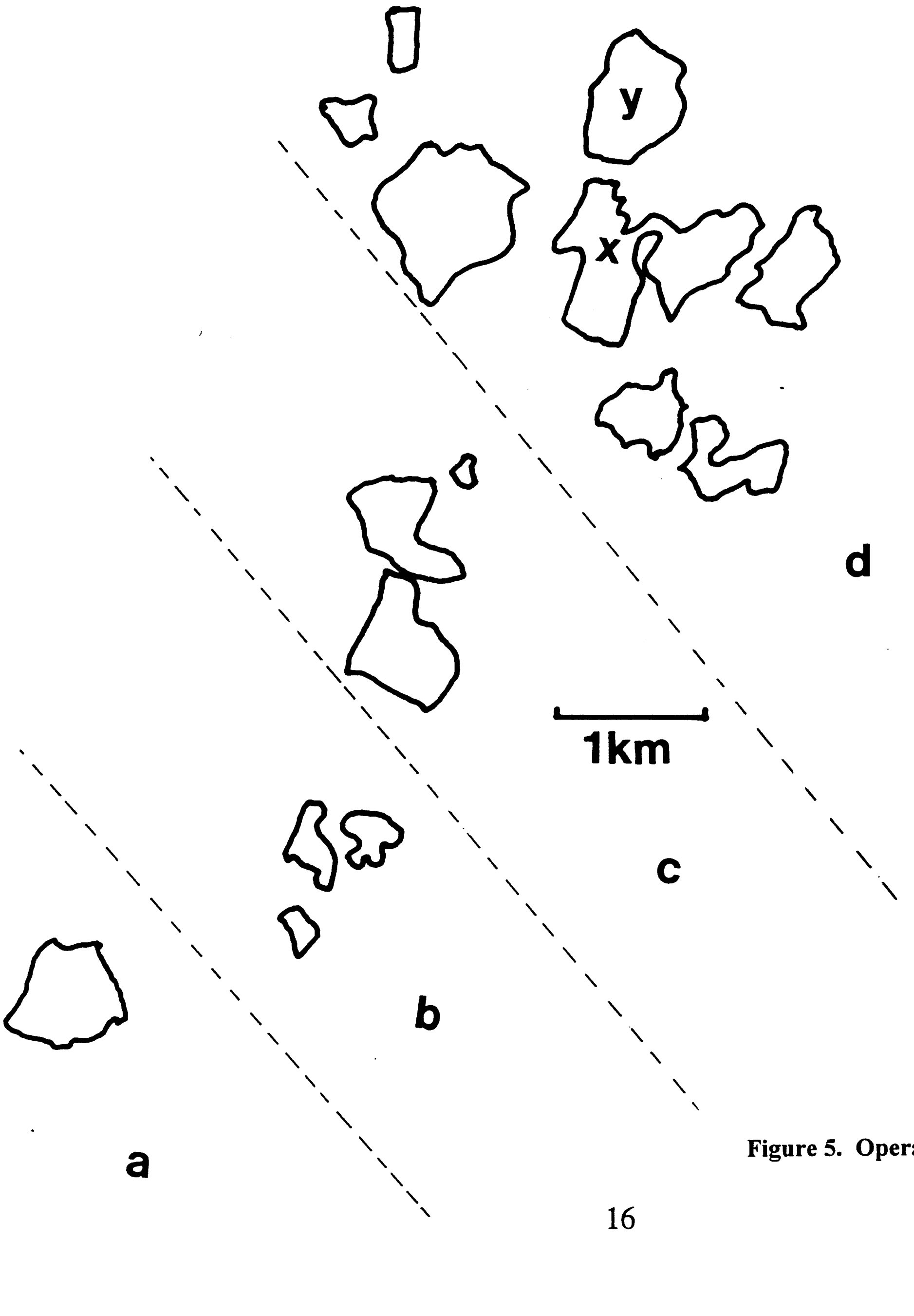
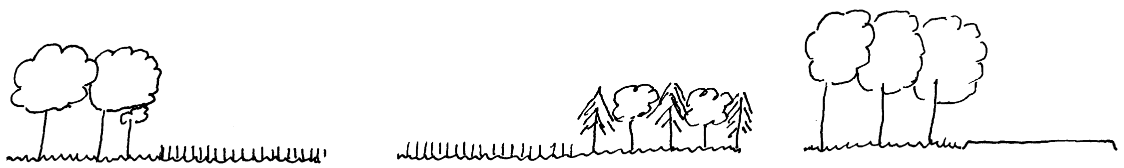


Figure 5. Operation of barriers at different scales.

Edge Effects

A second major effect of fragmentation is the increase in the ratio of edge to interior habitat. The smaller the fragments created and the more irregular the new boundaries the greater is the relative increase in the amount of edge. In some cases small fragments may become entirely edge (as in Figure 1c) where their width is less than twice that of the zone where edge effects occur. What species, if any, respond to or are affected by the difference in the composition of or conditions at the edge compared to in the interior? Are there many real interior species still left in England, given the long history of habitat modification and fragmentation that has occurred? There may be those that show a preference for interior conditions but few vertebrates are confined to such situations. Interior species are therefore most likely to be found among invertebrates, for example those of the forest canopy or specialist heathland species.

How wide is the edge zone and how does this vary for different groups of species and different habitats? Some types of pollutant may be trapped in just a few metres of edge habitat; the effect of increased noise disturbance along the edge of a road may take tens or hundreds of metres to dissipate (Reijnen & Foppen 1994). At the edge of a wood and open ground one effect is the increased light reaching the ground just inside the new woodland edge but this is not an issue where a heathland meets a grassland (Figure 6).



(a) Open edge created next to wood	**(b) Wood developed next to open ground**	**(c) Wood/road edge**
Increased light, reduced humidity	Increased shade	Increased noise disturbance
Invasion by open ground species	Increased invasion of open ground by trees	Air, water, salt and particulate pollution
Possible spray drift	Increased predation on ground nesting birds	Increased access disturbance
Increased wind throw of edge trees	Reduced sight lines for species needing open country	Rubbish dumping
Increased populations of wood edge species	Competition for water and nutrients from the trees	Direct mortality of animals crossing the road

The original habitat is in each case on the left-hand side, the new edge conditions on the right. Not all impacts will occur or be important in nature conservation terms in every case.

The following references illustrate some of the potential adverse edge effects.

Pesticide drift (Cooke 1993)
Noise disturbance and roads (Reijnen & Thissen 1987; Reijnen & Foppen 1994; Reijnen *et al.* 1994)
Edge-interior differences in invertebrate populations (Webb & Hopkins 1984)
Edge related bird distributions (Hinsley *et al.* 1994)
Effects of roads generally (English Nature 1993a; Angold 1994)

Figure 6 Examples of possible impacts associated with the creation of new edges

Creating new edges is not always undesirable in nature conservation terms however. There are species that depend on mosaics of habitats with abundant edges. Most edges show increased species richness compared to the interior. The species that increase may be only common or even undesirable ones, but there are important species that are generally associated with particular types of edges, for example ridesides in woodland (Warren & Fuller 1990). Edge creation may therefore be beneficial for nature conservation, but often it is not (Figure 6). The quality as well as nature of the edge and the species associated with it are therefore important.

Indirect consequences of fragmentation on management

Small patches of habitat left isolated by fragmentation may be more vulnerable to subsequent deliberate destruction or loss through neglect. Small patches of grassland are less likely to be grazed because it is more difficult and costly to arrange such management on small patches. Patches left in urban areas may be subject to very intense recreational pressure. Outliers of land may be sold off, increasing the risks of at least a temporary disruption in their treatment, if not a permanent change. Small woods may just be left because it is not worthwhile to manage them. (This is an undesirable condition if maintenance of some open space in the wood is important but probably beneficial to species that require closed canopy high forest with a humid microclimate and an accumulation of dead wood). The range of management options may be reduced in small isolated patches because certain treatments are ineffective or will not achieve the desired result if carried out at too small a scale. This is illustrated with respect to possible woodland management in Box 3.

Box 3 Possible implications for management in woods of different sizes

The objective is to have at least 0.5 ha of open space created each year to maintain populations of a particular butterfly. The natural rate of gap creation ie without any management is approximately 1% of the area per annum for the woods as they are at present.

Size of wood		Options for management
1 ha		The objective cannot be achieved and still retain the site as woodland.
10 ha		A coppice rotation of up to 20 years would be possible with coupe size $\leq$ 0.5 ha.
50 ha	a.	Coppice with a choice of rotation lengths and coupe sizes is possible.
	b.	High forest on up to 100 year rotation would also allow 0.5 ha to be cut each year.
	c.	Theoretically minimum intervention should on average produce 0.5 ha of natural gap per annum (1% of area) but natural gap creation is unlikely to be regular enough to guarantee meeting the objective.
200 ha	a.	A wide range of coppice and high forest rotations would be possible.
	b.	With an average gap production of 2 ha per annum there is a good chance that at least 0.5 ha would be produced each year under a minimum intervention regime.

(The above assume that the butterfly has no problems locating the gap, wherever it is in the wood, and that all the woods start with a similar age class mix.)

This is a hypothetical situation but it illustrates the greater flexibility of management and conditions that are possible on large sites. Similarly on large grassland areas different grazing regimes may allow both short and long grass specialists to be present on the site as well as those that may require a mixture of conditions.

WHAT HABITATS AND SPECIES ARE SENSITIVE TO FRAGMENTATION?

Describing habitat fragmentation effects - patch size and isolation

Descriptions of the size distribution of different types of habitat (including the way large areas have been broken down into several smaller units over the last 50 years) illustrate the potential impact of habitat fragmentation. Heathland loss is particularly well-documented (Moore 1962; Webb & Haskins 1980) as is change in ancient woodland (Spencer & Kirby 1992; Kirby & Thomas 1994). In areas which appear to be fairly continuous, such as upland moors, disruption of species movement and behaviour may still be occurring through creation of new tracks, conifer plantations and conversion of heather moor to grassland. Habitats that at a national scale may be considered as relatively unfragmented - upland blanket mire for example - may show high levels of fragmentation at a local level. It also depends on what date is taken to be the baseline against which fragmentation is judged.

Beechwoods and western oakwoods still survive through much of their range as fairly large blocks. Thus they have a much lower level of fragmentation compared to say old parkland or the mixed deciduous woods of East Anglia. This difference is however trivial if the current extent and size distribution of all these types of woodland are compared to their probable extent in the wildwood 7,000 year ago. Conversely chalk grassland must have been very scarce 7,000 years ago; there could be more now and in larger blocks than there was then, but equally there is much less than 100 years ago. Chalk grassland is not a particularly fragmented resource if you are on Salisbury Plain; it is in Cambridgeshire.

Documentation of patch size and distances between patches provides, therefore, important background information in understanding fragmentation effects but the precise location as well as the amount of the change needs to be known. Surveys such as the Countryside Survey in 1990 (Barr *et al.* 1993) are in this respect less useful as baselines than inventory type surveys such as those already produced (and being revised) for woodland, grassland and heathland (English Nature 1994a, Evans *et al.* 1994, Spencer & Kirby 1992). The Institute of Terrestrial Ecology's Land Cover Map, though at a coarser scale, may also be useful where patterns at a national scale are being investigated. The more such data can be linked to Geographic Information Systems (GIS) systems the better. Even so these do not by themselves progress very far our ideas on the effects of fragmentation and whether such effects are important in nature conservation terms. Data on change in habitat location and extent need to be linked to studies of species or assemblages believed to be at risk from fragmentation.

There is usually, for a variety of reasons, a positive relationship between the number of species found and patch area, but usually with a wide scatter about the regression line. However the combined species total from several small patches may be more than from an equivalent area which is a single large patch eg for woods in Lincolnshire (Peterken & Game 1984) and limestone grassland (Higgs & Usher 1980). Frequently this occurs because patches are not uniform in their composition, structure, past or present treatment. Thus a single large wood may cover a narrower range of soil conditions than several small woods of the same (combined) area. This can apply even if generalist or edge species are excluded from the species count. Therefore while large patches generally contain more species, and particularly more of the specialist species for that habitat, even very small patches should not be written-off as of no value (e.g. Eversham & Telfer 1994). For species that depend on mosaics - perhaps of trees and grassland -the relevant patch size is that which contains both elements and so large uniform blocks of either are undesirable for these species.

Where once continuous patches have become fragmented, what is the nature of the barriers created between them (how absolute are they and for what species) and will the now-isolated populations suffer if no future flows occur? For a particular species and population how do current patch sizes relate to minimum viable population size, colonisation and extinction processes, including regular population fluctuations? How important are `rare' events (exceptional storm, drought, disease etc) and refugia where a species hangs on or retreats to under adverse conditions? Refugia are not always the sites where the species is most abundant under normal conditions. For example a species may, in normal years, grow best on mid slopes, but in drought years survive only in the moister, lower slopes. Patches where the species is currently absent must also be considered: are they used periodically, particularly at critical times; did the species formerly occur there; could the species occur there in future (Figure 7)? The dynamics of species occurrence in relation to patch size, isolation and habitat quality are as important as the current distribution pattern but very rarely do we have such information. Even in areas where there is long-term monitoring of species occurrence the conditions over the time period considered are likely to change. In addition in Figure 7 the survey methods adopted on both occasions must be good enough to be sure that the species definitely is or is not present in a particular patch and the timescale must be appropriate to the likely dynamics of the system - for invertebrates a few years might be sufficient to assess the general trend; for large mammals a decade might be needed; for trees several centuries. The effect of rare events might still be missed. The pinhole borer (*Platypus cylindrus*) had for many years been considered rare and a potential candidate for Red Data Book status - until the 1987 storm in south-east England (estimated return time 200 years) provided an abundance of habitat (fallen oak trees) and it has since appeared in many places where it was not previously recorded.

	Time (1)		Time (2)	Possible interpretation of changing distribution
(a)	● ● ● ● ○ ○	(b)	● ● ● ● ○ ○	There may really be something wrong with the empty patches that we have not identified, or the species may not be able to reach them, or the population doesn't produce enough surplus individuals to need to spread to the empty sites.
		(c)	● ● ● ● ● ●	Population appears to be expanding (this may be either temporary or permanent).
		(d)	● ● ○ ○ ○ ○	Population appears to be contracting (this may be either temporary or permanent).

If the changes in (c) and (d) are only temporary then it may be particularly important to look at the characteristics of the sites occupied when populations are low (ie those in (a) (d)) to see if these are refugia or chance survivals. If the change is part of a general trend across the country then it may be necessary to look for explanations beyond the sites under review.

		(e)	● ○ ○ ● ● ●	Population stable, but it appears that in any one patch the species will periodically go extinct only to be recolonised from a nearby occupied patch. All patches whether currently occupied or not are important for long term survival and maintenance of population levels.

Figure 7 How important are the patches where a species is not present (○) compared to where it is (●)? Do the patches where a species occurs change over time?

Identifying sensitive species

Some species are much more sensitive to fragmentation at a particular scale than others (cf Figure 5), but there are too many to assess the impact of fragmentation for each individually. Instead we must look for ways of identifying groups or types of species, or species associated with particular conditions that are likely to be more susceptible to fragmentation than others. These may serve as indicators for what is happening in the system as a whole. They might be targeted in experimental or field studies; in case studies of areas that are undergoing fragmentation or where the landscape is being restored; and in environmental assessments. Badgers and amphibians are already often picked out as sensitive because of their regular patterns of daily or seasonal movements. Several other approaches to identifying possible indicators are considered below.

Rare/endangered species

A wide range of factors may contribute to a species becoming rare/endangered. However if fragmentation effects are among the principal causes for their rarity then we might postulate that species in these categories in habitats that have suffered recent fragmentation would be more likely than common species (or those in unfragmented habitats) to have the following characteristics:

- large minimum area requirement
- poor mobility outside habitat
- dependence on habitats that tend to be (or were) continuously present in time or space on sites rather than occurring sporadically in widely dispersed locations
- interior rather than edge species.

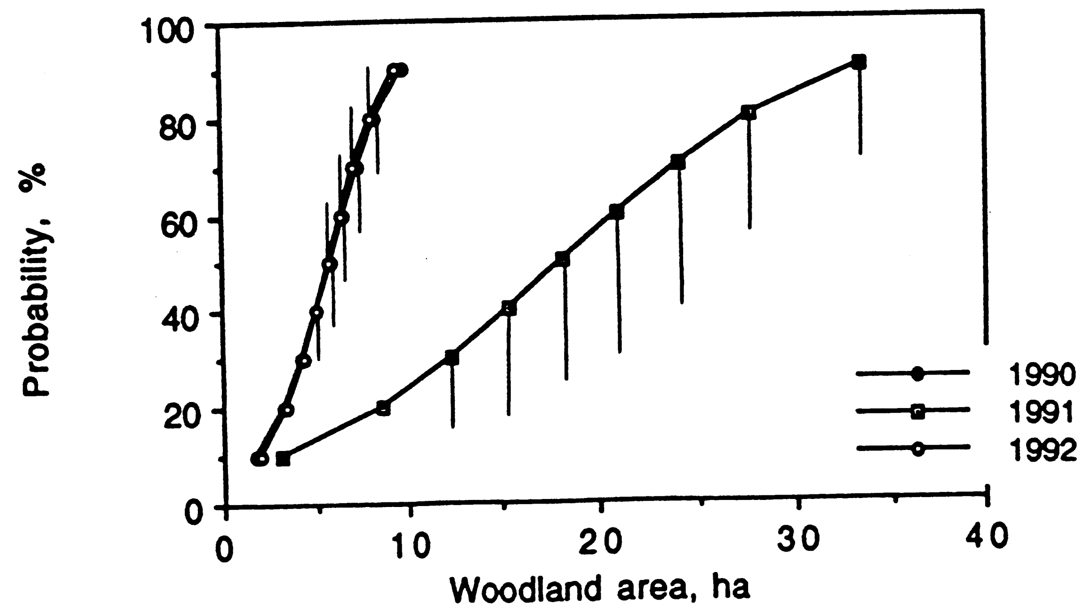
These attributes were reviewed for a range of rare and vulnerable invertebrates (Kirby 1994). To be useful for monitoring the effects of fragmentation the species must also be relatively easy to study and not likely to be greatly affected by other changes that take place at the same time as the fragmentation process. Thus invertebrates associated with dead wood may be sensitive to fragmentation but most such species are difficult to sample in a non-destructive way. Dung beetles, because they use a widely scattered resource, may depend on large sites for the maintenance of rich faunas and could be sampled in standard ways using bait traps. However their occurrence on a site will be tied to the presence or absence of grazing animals and so may be affected far more by management than by fragmentation. Their dependence on a temporary resource may also mean that they are likely to be very mobile. Many scarce and declining bees and wasps appear to require a combination of features, typically sunny dead wood with beetle holes in which to nest and nearby tall flower-rich vegetation in which to find food. This mixture can occur in a variety of situations but is particularly a feature of the countryside in general rather than just special sites. Bees and wasps are thus potentially suitable for the study of the decline and traditional countryside patterns as a whole (Falk 1994).

Incidence functions

Incidence functions describe the probability of finding a particular species in patches of different sizes and may be useful as a guide to which species are sensitive to fragmentation. Recent work that looks at the occurrence of particular British species across a range of patch sizes includes Hinsley *et al.* (1994) on woodland birds, Bright *et al.* (1992) on dormice; and Thomas *et al.* (1992) on butterflies.

Size of patches as viewed by people however may not be the same as the habitat patch size from the point of view of the individual species concerned. For bees and wasps that nest in bare sand in heathland, it is the extent of open sandy patches, not the total area of heath, that is important and the two areas are not necessarily correlated. Great spotted woodpeckers need a minimum area of woodland in which to breed (about 8-10 ha) but this could be composed of several patches separated by fields. Furthermore, for some species, the relationship between patch size and its occurrence may change from year to year depending on the regional population size. If many species in England show similar year-to-year fluctuations then recommendations of "minimum site size" based on studies of one-or-two year's duration could be very misleading (Figure 8). Incidence functions by themselves therefore do not help us decide whether species are limited by barriers between patches, the size of the patch or some aspect of habitat quality that may tend to be associated more with large patches.

Much of the theory for interpreting the minimum patch size needed by a species has been developed for birds in `natural' or unmanaged conditions. British experience is that many species, particularly perennial plants, can be maintained for long periods in areas of just a few hectares provided the management is right, and the appropriate range of structural conditions is maintained. Many lowland meadows and pastures for example remain diverse despite their small size. On the other hand species may be lost from large areas if the management is wrong. Thomas (1994) stresses that while chance factors may be the immediate cause of extinction of a population, far more often deterministic factors such as site management are responsible for the species being at risk. Coppicing for example has enabled many open stage species to survive in woods that are very much smaller than would be needed if these species had to rely on the outcome of natural gap formation processes (Box 3). Abandonment of coppicing rather than any other factor is the main threat to their future. Fragmentation may still affect species survival because the population sizes overall might be smaller in several fragmented patches, compared to one continuous patch of the same total extent. Good examples of this need however to be produced before it could be accepted as generally true in English conditions. Somewhat easier to asses may be the higher risks and costs attached to maintaining a species in fragmented areas compared to those for a large continuous habitat block. In practical conservation terms it may be more effective sometimes to use resources to improve the management of an area rather than to increase its extent or to reduce isolation.



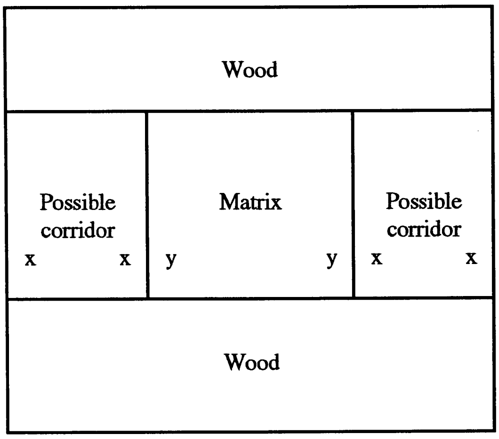
The probability of breeding occurring increased with site area, but following a hard winter (1990/91) the relationship changed with many small woods remaining unoccupied in 1991. They were however recolonised in 1992. The bars represent standard errors.

Figure 8 Incidence function for bullfinch in Cambridgeshire woods 1990-92. (From Hinsley *et al.*)

Species mobility

Three broad classes of species are likely to exist (Dawson 1994). Highly mobile species may find fragmentation of their habitat a relatively minor problem as long as the total area available to them is not greatly reduced. For highly immobile species with small minimum area requirements for self-sustaining populations (eg many plants and some invertebrates), habitat fragmentation may be irrelevant - they survive where they are, more or less indefinitely, and are unlikely to spread elsewhere whether they are part of a 1 ha or 20 ha unit. In between are a third group of species, with varying abilities to spread by crossing gaps or using corridors. What proportion of species falls into this third set in different landscapes and regions? How can these species or at least their general characteristics be specified? For each individual species there may be a range of distances over which movement is very easy; a second band where it is difficult but sometimes occurs; and a third where it is virtually impossible. Thomas *et al.* (1992) have, for a series of rare butterflies, drawn together data illustrating the relationship between isolation of sites and probability of occupancy. They quote (from other sources) maximum single step colonisation distances of between 0.6-1.00 km for black hairstreak and 8.65 km for the silver spotted skipper.

Corridors (or stepping stones) may be of benefit to conservation if movement of desirable species is facilitated by the existence of a linear feature even though some movement occurs outwith it (Figure 9). Increased spread of undesirable species and increased predation in the corridor should also be considered however. Showing that spread occurs along a linking feature is not by itself proof that it is important as a corridor (Dawson 1994), it must be shown that spread is greater than that through (or over) the adjacent land. Where there are costs involved in maintaining or creating a corridor the increased probability of movement must be high enough to justify those costs.



(a)

Corridor | Adjacent land | Corridor

x↓↓↓↓x | y y | x↓↓↓↓x

All movement in corridors

↓ = species movement

(b)

x↓↓↓↓x y↓ y x↓↓↓↓x

Most movement in corridor, some in the matrix

(c)

x↓↓ x y↓↓ y x↓↓ x

No difference in movement between corridor and matrix

(d)

x x y y x x

No movement at all

For species (a) the connecting feature acts as a corridor and is essential for movement (↓); for (b) the feature also acts as a corridor and there are conservation benefits from its existence as a connecting link, even though some movement occurs through the adjacent land. For species (c) the feature does not function as a corridor - movement is as easy through the matrix. For (d) no movement occurs through either habitat. No conclusions about the value of the linking feature as a corridor can be drawn by sampling only in the corridor at x-x because movement will be recorded for all three species (a, b, c) even though for species (c) no corridor effect exists. Comparative data must be available for the matrix y-y to separate which species benefit from the existence of the linear features.

Figure 9 - Hypothetical movement patterns through a linking feature that might be acting as a corridor and through the matrix.

Habitat characteristics

Patches and sites that have only recently become fragmented may be more likely to contain species that are sensitive to fragmentation than those that have been isolated for long periods. However, even with habitats that have long existed as apparently isolated patches, changes in the countryside in the last 50 years may represent a new phase of fragmentation, with the barriers being created more quickly and those barriers being more extreme and permanent than they were in the past. Woods, for example, were formerly much more interconnected by hedgerows. While we commonly think of barriers being formed by deliberate positive actions (eg a road being built), neglect and ending of management can also create them, as for example when abandonment of grazing leads to scrub growth that breaks up grassland patches.

Fragmentation effects may be easier to describe (and appear more quickly) in early successional stage habitats or those with a high proportion of short-lived species. Effects may be more difficult to detect or be slower to appear in habitats with a high proportion of long-lived individuals, like many grassland plants, since these may remain on site long after conditions for regeneration have ceased to exist. An important distinction is therefore between population size and effective (ie reproducing) population size. Thus effects are more likely to be detectable in the invertebrate populations in a patch than in the populations of perennial plants.

An integrated assessment for mammals

For British mammals sufficient is known about the ecology of the individual species to try to produce an overall sensitivity analysis (Box 4, derived from Bright 1993). Even with the most potentially vulnerable group however other factors may be far more important as factors affecting species survival than habitat fragmentation, competition effects and disease for red squirrel for example, past persecution for the larger carnivores.

Box 4 Mammals that may be most vulnerable to fragmentation (from Bright 1993)

Most vulnerable--Least vulnerable

(a)	(b)	(c)	(d)
Water shrew	Field vole	Serotine bat	Hedgehog
Greater horseshoe bat	Orkney vole	Noctule bat	Mole
Lesser horseshoe bat	Yellow-necked mouse	Pipistrelle bat	Common shrew
Whiskered bat		Common long-eared bat	Pigmy shrew
Natterer's bat		Brown hare	Rabbit
Daubenton's bat		Grey squirrel	Bank vole
Mountain hare		Polecat	Wood mouse
Red squirrel		Badger	Harvest mouse
Water vole		Red deer	House mouse
Dormouse		Sika deer	Brown rat
Edible dormouse		Fallow deer	Black rat
Pine marten		Roe deer	Fox
Mink		Muntjac	Stoat
Otter			Weasel
Wildcat			

COLONISATION, CORRIDORS AND MITIGATION

Where barriers to movement are a major constraint on the conservation of species or communities the following options may help to alleviate the situation:

- restoring direct habitat links (wildlife corridors, tunnels under roads);

- creation of stepping stones, so that, although there is no direct link between habitat patches, colonisation distances are shortened;

- creating a more wildlife-friendly matrix between habitat patches - for some species creating a link (or stepping stones) of exactly the same habitat between two patches may not be necessary, as long as it's a reasonably friendly habitat: it might for example provide food and shelter but not breeding habitat;

- managing a site to give optimal conditions for what is judged to be the key species, thereby boosting the effective population of a species in the source site, so that there is more likelihood that dispersal to a new site will occur and be successful without any change in the intervening ground;

- increasing the area of small isolated habitat patches by habitat creation or restoration to increase population size and thus reduce the risks of local species extinction;

- direct translocation of species from one patch to another where conditions are (and will remain) suitable but the distances or behavioural limitations prevent natural recolonisation.

The literature on wildlife corridors and the value of linear features has been reviewed critically to see how far it is applicable to English conditions and species, (Spellerberg & Gaywood 1993; Dawson 1994) including in relation to climate change (Hill *et al.* 1993). The effects of habitat fragmentation and the creation of links through corridors or stepping stones depend on the particular species, the particular habitats, the particular landscape context and the spatial and temporal scales involved. Not surprisingly therefore, for every general rule that has been formulated it is possible to find exceptions.

Translocation and habitat creation

Overall, translocation is considered the least desirable approach, because of the difficulties that can be involved and because only limited numbers of species are ever likely to be moved in this way. Nevertheless it has long been used, for example, in tree planting schemes, and is increasingly being considered and practised elsewhere for example in the red kite and various butterflies projects within English Nature's Species Recovery Programme. There is a need to review the situations where re-introductions and translocations are desirable, acceptable or not acceptable as a conservation mechanism in England taking account of IUCN criteria.

There may be risks in reducing the isolation of populations (or sites) directly or indirectly so it should not automatically be assumed to be beneficial. This is especially so where the populations have been isolated for a long time. There may be a loss of genetically distinct local populations and this has been a major argument used for the restrictions placed on where particular provenances of native pine may be used in Scotland (Forestry Commission 1989). We may also inadvertently assist the spread of invasive species. Grey squirrels may use broadleaved strips to spread into large coniferous forests where red squirrels survive; Japanese knotweed spreads along river corridors and displaces the native bankside vegetation; the ruddy duck, a North American species accidentally introduced to Europe now threatens through interbreeding the survival of white-headed ducks in Spain, a globally endangered species. The contrary argument may also be used where local populations that formerly all belonged to one gene pool are believed to have become distinct, through isolation and inbreeding of small populations. Genetic mixing, such as occurs through translocation, might then be desirable. An accidental interbreeding with a German kite may, for example, have contributed to recent improved breeding success in the Welsh red kite population.

Other options involve the development of new habitat areas (Buckley 1989). In some cases this may be possible entirely by natural regeneration, but often some extra work will be needed. Habitat creation and restoration in a broad sense (which might involve removing trees from former heath for example) thus have a part to play in mitigating the effects of fragmentation. The potential for this is very variable: only certain soils have the potential to carry heathland so identifying where these occur close to existing heathland patches is a useful approach (Veitch *et al.* 1995). The cost-effectiveness of different options is important, including how long it will take for the proposed benefits to show. In some situations it will be better to put the effort into expanding (or improving the management of) the habitat patch rather than trying to link it to the next nearest patch. The latter may not be a realistic option anyway with very isolated blocks. As with earlier discussions about the effects of fragmentation, the `quality' of the species/habitats that can be created/restored is as important as the mere number of species that turn up on the new site.

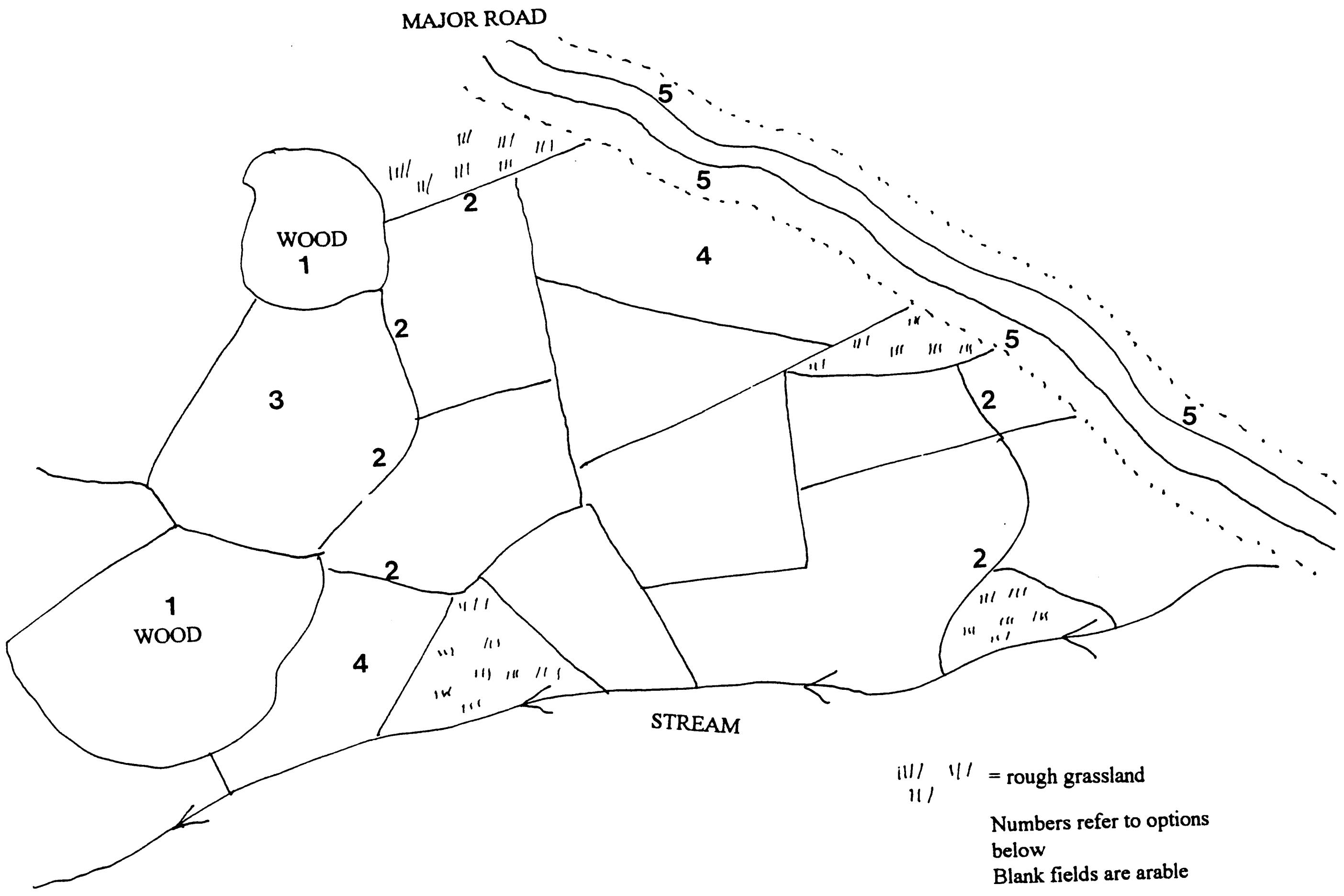
Recent work in this field includes a review of work associated with road schemes (English Nature 1993a) and of the results from a number of more general habitat recreation schemes (Parker 1995). Detailed studies of ways of treating field margins have also been described (Smith *et al.* 1993; Boatman 1994) as have approaches to new woodland creation (Rodwell & Patterson 1994; Watkins 1991; Ferris-Kaan, 1995). Work is also under way setting out English Nature's position on re-introduction with respect to different species groups (English Nature 1994b).

In habitat creation/restoration projects where the <u>prime</u> aim is to restore a direct or indirect link between existing patches, how purist should conservation workers be? Is wildlife gardening more acceptable in these circumstances than elsewhere? There is a need to define the role and limits of habitat creation for nature conservation.

An integrated approach to landscape restoration

In practice a combination of approaches will be needed within a landscape, with the emphasis in parts being on linkage and elsewhere on expansion of isolated patches; some of this will be by natural regeneration and recolonisation and a small amount by intensive species introduction/translocation (Figure 10). The action must be fitted to the landscape, habitats and species of concern in particular circumstances as well as the availability of support through the various countryside schemes and initiatives (Box 5) (LUC 1994).

Other countryside initiatives/ideas include the Heathland Restoration Programme; promotion of uncropped margins to fields; the planting of short rotation coppice for energy production; the development of community woodland and the new national forest; restructuring of many big upland forests; suggestions for restoration of flood plain forests (Peterken 1992); and creation of new native woodland in the uplands. Strategic approaches to the planning of land use (Indicative Forestry Strategies, Integrated Catchment Plans and "Natural Areas" (English Nature 1993b)) may provide other frameworks for encouraging the right habitats in the right place. Targeting of all these schemes to particular situations or regions is likely to increase (Webster & Felton 1993).



1. Improve management for conservation of existing woods, eg use the Forestry Commission's special management grant to help pay for ride management, glade creation and increased structural diversity.

2. Improve state of existing hedges (or create new ones), particularly those that link semi-natural or uncultivated ground, under Hedgerow Improvement Scheme or perhaps through Countryside Stewardship. Supplement this with Conservation Headland treatments under set-aside.

3. Create new woodland to link existing woods using the Farm Wood Premium Scheme (including better land supplement).

4. Use set aside to create at least temporary refuges within the arable system. Sites in the middle of or next to an area of uncultivated ground would be particularly appropriate for long-term set-aside options.

5. The highway authority should be encouraged to see road verges as contributing to the wildlife potential of this landscape.

Figure 10 - Possible ways of reducing/counteracting habitat fragmentation in a lowland landscape

Box 5 Countryside schemes (run by various authorities and departments) which may include an element of habitat creation/restoration in a broad sense and so be used to reduce habitat fragmentation

(a) Countryside Stewardship
- Habitat types covered include:
  heathland, upland, coastal, calcareous grassland, wetland, old meadows and pastures.
- Habitat creation is a possibility.
- Some targeting of agreements possible through advice on suitability or otherwise of individual proposals.

(b) Hedgerows Incentive Scheme (part of Stewardship)
- Includes creation and restoration of hedges.

(c) ESAs
- Various regions and habitats.
- Allow for habitat restoration and some re-creation.
- Targeting of agreements possible within the ESA boundaries.

(d) Woodland Grant Schemes.
- Establish woodland.
- Guidance on avoiding certain habitats in farm woodland schemes.
- Supplements for better land, community forest areas.

(e) Landscape Conservation Grants.
- Creation of features in the landscape.

(f) Farm Conservation Grants.
- Various habitat management opportunities including creation of new features.
- Farm waste controls.

(g) National Park grants.
- Various grants for habitat creation and management.

(h) Wildlife Enhancement Scheme
- Standard payments are available from English Nature for positive management to improve the quality of habitats within and around SSSI (trial areas only at present).

(i) Habitat Scheme.

(j) Set-aside wildlife derogation.

Further research and monitoring

The various reviews referred to in this report (eg Dawson 1994; Hill *et al.* 1993; Spellerberg & Gaywood 1993) draw together much of the general information on fragmentation effects but this research field is rapidly expanding and there is a need for more specific information about particular species, patch and landscape types. From an English Nature perspective both specialist and local team staff need to update and maintain knowledge of relevant fragmentation studies.

Studies of the relationships and dynamics of populations in clusters of sites and the genetics of small populations are starting to move out of the realms of academic ecology and into practical nature conservation debates. English Nature has for example commissioned a study on the use of DNA to test how closely related different populations of butterflies are and hence the likely degree of past interchange of individuals. The results of this should be available in 1995/96. The main need is for a much closer link between theoretical and field-based studies. The concepts are currently useful in descriptive studies, but it is not clear whether their predictive power is strong enough to be a guide in situations where heterogeneity within and between sites and the overriding influence of management are common.

Much of the field evidence to support or refute theories on fragmentation and linkage is anecdotal, from one-off studies or may be open to other possible interpretations (Dawson 1994). More rigorous studies should be made to back up the existing field evidence. Short-term work (1-2 years), for example can test how readily small mammals and invertebrates cross different types of barrier under normal conditions and whether linking features really are used as corridors, preferably using species relevant to nature conservation concerns. How different are the matrices of fields and semi-natural patches from the point of view of most of the species in them? These studies may be experimental or carefully designed surveys (eg Shreeve 1995). The problems of such work are reviewed by Dawson (1994) who discusses the strengths and weaknesses of previous studies (see also Figure 9). There remains the fundamental issue of how to identify and assess the importance of rare events which may be all that is needed for populations and gene flow to be maintained. However, applying the precautionary principle, if short-term work suggests that fragmentation may be an issue for a particular species or in a particular landscape type, then actions should be taken to counteract such effects.

Case studies of sites that are undergoing/have undergone fragmentation seem at first sight an attractive approach but it is (i) likely to be expensive and (ii) likely to yield ambiguous results unless both the sites and the species to be monitored are very carefully chosen at the outset. Direct and indirect effects of fragmentation are likely to be involved in any particular case. Despite these drawbacks, developers should be encouraged to monitor sites that are being unavoidably affected by fragmentation through road schemes etc.

We need to move away from only considering the very special sites that are affected to considering the overall impact of a development on habitat and species diversity, including any mitigation measures. Figure 11 outlines a possible approach which could also be taken with any major development. Retrospective studies may also be valuable. Moore (1962) predicted that continued loss of key species was likely to occur from the smaller Dorset heaths studied. While fragmentation cannot be proved to be the sole cause his predictions appear to be borne out by recent surveys (Webb & Rose 1994). We might predict that more "woodland" ground flora species should be present in motorway plantings next to existing woods than in those bordering open land; can such a relationship be shown along the motorways built during the 1960s where any planting should now be old enough to have created a woodland micro-climate?

Work on edge versus interior species is potentially a very useful area of research into the implications of fragmentation because edge effects should be relatively easy to detect and are likely to show up much quicker than, for example, impacts on population genetics. In addition increased edge effects will be a feature of almost all cases of fragmentation even where there are no effects arising from the changes in site size. Relatively little seems however to have been done in Britain that can be used directly in habitat fragmentation debates.

New countryside initiatives, such as those in Box 5, may create valuable habitat patches but how much effort is it worth to encourage their location in areas that may lead to a reduction in fragmentation effects? Is the same effect achieved by simply leaving the location to a land-owner's or planner's discretion? No studies (to our knowledge) have looked at the new patterns actually created by set-aside, new woodland planting and the like to determine how far, with or without guidance, they correspond to ecologists' ideas as to what would be the best locations.

One possibility would be to identify areas in contrasting landscape types eg an urban area, an area with a relatively high cover at present of semi-natural vegetation, an area with only very isolated semi-natural patches. In each of these areas there would be a coordinated effort over 3-5 years among the various government and voluntary bodies to try to decrease the fragmentation of habitats accompanied by appropriate monitoring measures to be compared with areas which did not receive such concentrated attention.

I suggest that areas of about 10 x 10 km or 5 x 5 km would be appropriate. These are small enough that it is likely that only a relatively few landowners involved. Hence the chances of being able to get a coordinated change of land use are increased. On the other hand it is large enough that significant changes over this sort of area would have an impact on the landscape in general. Over the timescale of this sort of project direct impact on most species populations would be difficult to assess, but it would be possible to show the change in area of semi-natural vegetation, changes in inter-patch distance and in crude measures of the "wildlife-friendliness" of the countryside in the areas targeted compared to the controls (Baalman & Kirby 1995).

Figure 11 An integrated approach to monitoring the effects of habitat fragmentation and associated mitigation measures for a major new transport link

(a) It is assumed that all appropriate procedures have been gone through to ensure that the final route is the least damaging; that unavoidable fragmentation of existing habitats is minimised; that as part of the package mitigation work will be carried out; and that the developers are committed to ensuring through a monitoring programme that the long-term impact is at least minimised, and preferably that there are longer-term benefits.

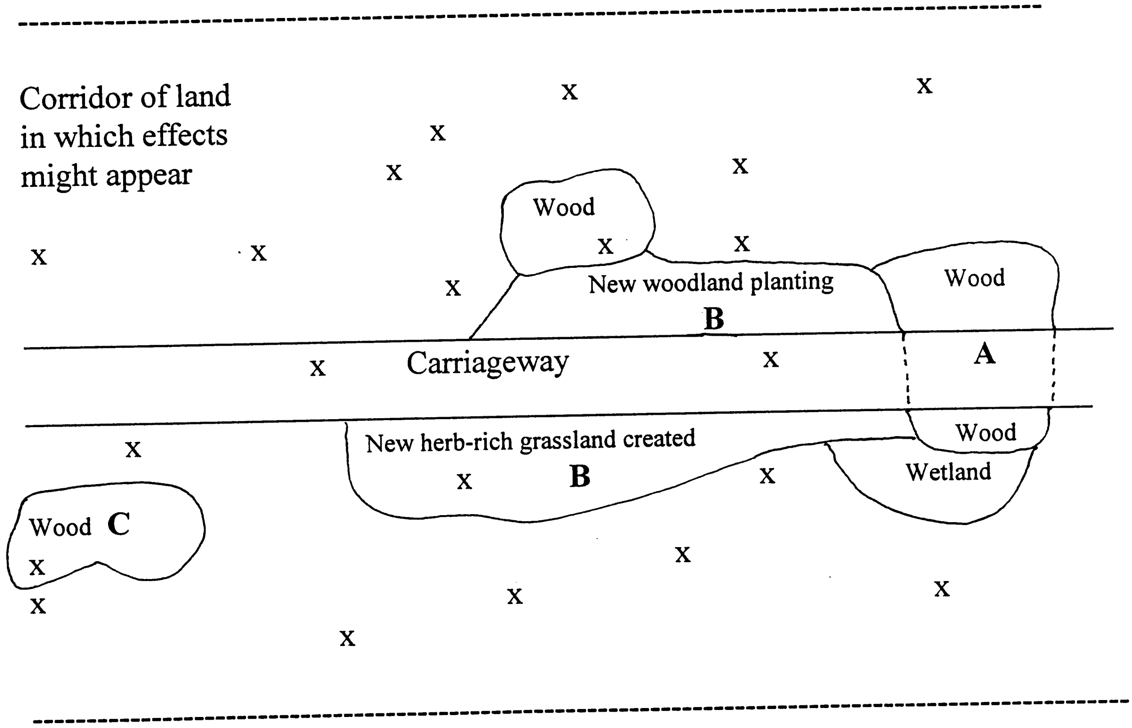
(b) The habitat profile (extent of woodland, grassland etc) should be compared before and after construction. The profile quality should be maintained.

(c) A structured sampling of all land within the corridor (not just semi-natural areas) should be carried out to provide a measure of the species content of the corridor. The Countryside Survey 1990 methodology (Barr *et al.* 1993) provides a model.

(d) Monitoring should also assess directly the impact on a sample of existing key habitat patches fragmented or otherwise affected by the route (1) and the development of new habitats created as part of the mitigation programme (2) to assess the quality changes in these habitats.

(e) Key species groups eg badgers, bats, dragonflies identified as important in the initial surveys should be monitored across a range of sites. (Both key habitats and species may vary according to the characteristics of the particular corridor.)

(f) A comparable area unaffected by the development should also be studied as a control.



Examples of surveys needed.

X = stratified random sample plot points to allow assessment of the overall impact of the road on the adjacent corridor (recorded before and after construction). The corridor might need to be 1km wide.

A = location for transect sampling to assess short distance effects (and new edge creation) in habitat patches that are fragmented by the carriageway.

B = sample plots set up to record development in new habitats created as part of the mitigation package.

C = home-base for badger population (or other wide-ranging animal) that could be affected by the road and so needs to be monitored.

Possible comparisons: frequency/extent of different habitats and species pre- and post-construction; size of key species populations.

CONCLUSIONS

The previous sections have thrown up more questions than answers. English Nature, with very limited funds, cannot expect to deal with them entirely by its own research. We need to draw on as wide a range of existing knowledge and experience as possible, both within and outside the organisation, to narrow down the new work that needs to be done to that which is most cost-effective. Any comments on this paper and how to progress the ideas in it would therefore be welcomed.

In addition we believe the following conclusions about habitat fragmentation can be applied now to conservation practice.

Many habitats in England have become more fragmented in recent years, but the evidence for direct and indirect effects of such fragmentation (as distinct from habitat loss) on species populations is limited. Our initial concern was to draw together and interpret what was already going on and to identify where fragmentation is likely to be a significant problem. *There is sufficient evidence that it is potentially an important cause of species decline to justify opposition to further habitat fragmentation.*

Linear habitats have a conservation value in their own right (Spellerberg & Gaywood 1993; Barr et al. 1993) whether or not they act as wildlife corridors. In a recent Public Inquiry in Bristol the Inspector ruled that he was satisfied that an area did "make a valuable contribution to the passage of wildlife between different parts of the urban area" even though this was not conclusively proved. There are other ways in which the effects of habitat fragmentation may be ameliorated in particular circumstances, which in some conditions may be more cost effective than creating corridors. *Linking features should be encouraged and protected, but we should not rely solely on their corridor value to justify our actions.*

A key issue remains how to identify those species which are of high nature conservation value and are most likely to be particularly sensitive to fragmentation or conversely most likely to benefit from wildlife corridors. Careful autecological work is needed for this. Bees and wasps appear to be a group that would repay further study in this respect.

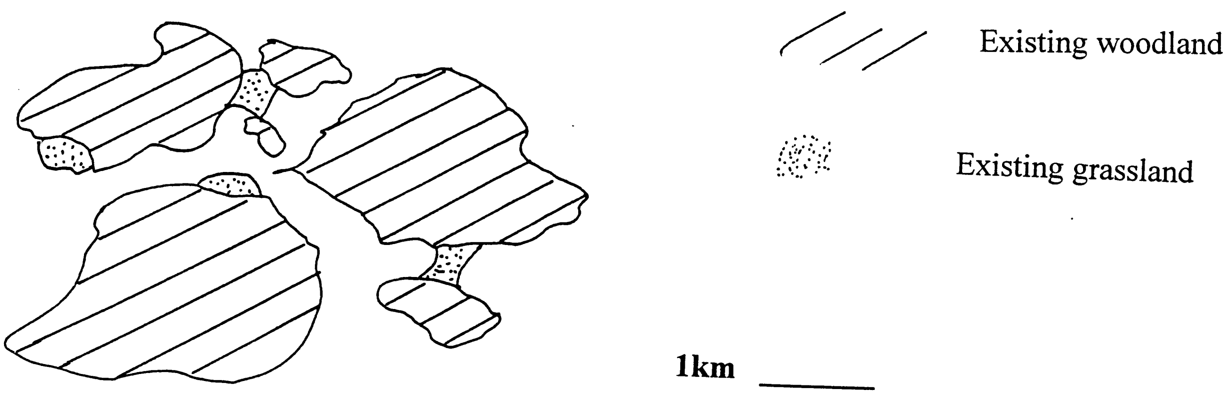
Arguments against proposed fragmentation of sites should pay more attention to the effects of creating new edges and possible pollution impacts along such edges rather than the effects of reductions in patch size per se on particular species. The former may be easier to demonstrate than the latter and are likely to apply even where no size effect does.

Proposals for new habitat creation, particularly where linkage of sites is proposed, must be viewed in their landscape context. The development of corridors and consolidation of existing sites is a more appropriate strategy where there are isolated clusters within a very hostile landscape than where the habitat is already very extensive. Four different landscape scenarios are considered below in an attempt to indicate where different approaches may be most appropriate.

Where the extent and diversity of semi-natural vegetation is high (Figure 12) there is relatively little merit in putting a lot of effort into linking up the patches except to reduce edge effects. Concentrate on increasing the overall area of semi-natural vegetation wherever it is convenient and improving the management for nature conservation of existing areas. Most species in these circumstances are likely to colonise rapidly, with or without complete corridors. Indeed in these circumstances corridors of one habitat are most likely to start to act as a barrier to species of another habitat type. Any appropriate new habitat patch is likely to acquire a reasonable range of species.

Figure 12 **High semi-natural cover regions**

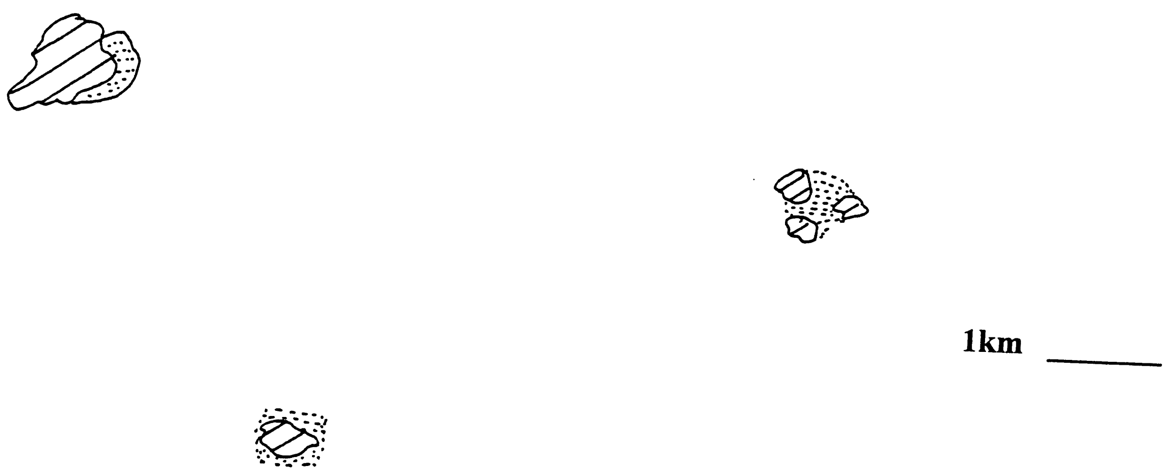
Linkage between existing woodland is not critical because colonisation rates are likely to be high for most species. In addition direct linkage of woodland patches may create barriers between the grassland patches.



Where semi-natural habitats are very sparse indeed (Figure 13) (and the matrix is generally "hostile") the first priority is to build on to what exists already to make as compact a block as possible to reduce external influences and make the enlarged patches easier to manage. The best additions are those of a similar habitat type to that which exists already, to build up and buffer the existing populations. In these circumstances it is unlikely that effective corridor or stepping stone links can be established in the short-term to the next major block of habitat.

Figure 13 **Isolated clusters or individual patches**

Build on to (:::) or link existing heathland patches (////) to consolidate their interest.



It is also desirable to develop more opportunities for species to move through and thrive in the whole countryside, not just in and around the areas that are currently species-rich. In many cases there is, in practice, likely to be greater general wildlife benefit from creating or encouraging the development of a series of small patches of new semi-natural habitat than from putting the same total area into one single block or corridor (Figure 14). This goes against some conservation advice in the past and so needs further justification as follows:

- Several small blocks may be more effective as stepping stones than a single large one because inter-step distances are smaller.

- The several small blocks will be less suitable for interior species than a single large block, but such species tend to be the least mobile so might not get to the single large block anyway and would be unlikely to spread along a very long thin corridor. A different strategy is likely to be needed for these (see below).

- On the other hand the small blocks will support a higher proportion of edge species per unit area than a single large block and these do tend to have good mobility, and so will colonize the small blocks. The argument that edge species are all very common anyway does not apply in much of England where almost the whole countryside has become impoverished. A series of small blocks may also provide more opportunities for species that need mosaics of different habitat types.

- Several small blocks are likely to cover a wider range of environmental conditions than a single large one (and hence be more diverse) because they are spread about and because there is greater flexibility in where they can be put without compromising other land uses or habitats.

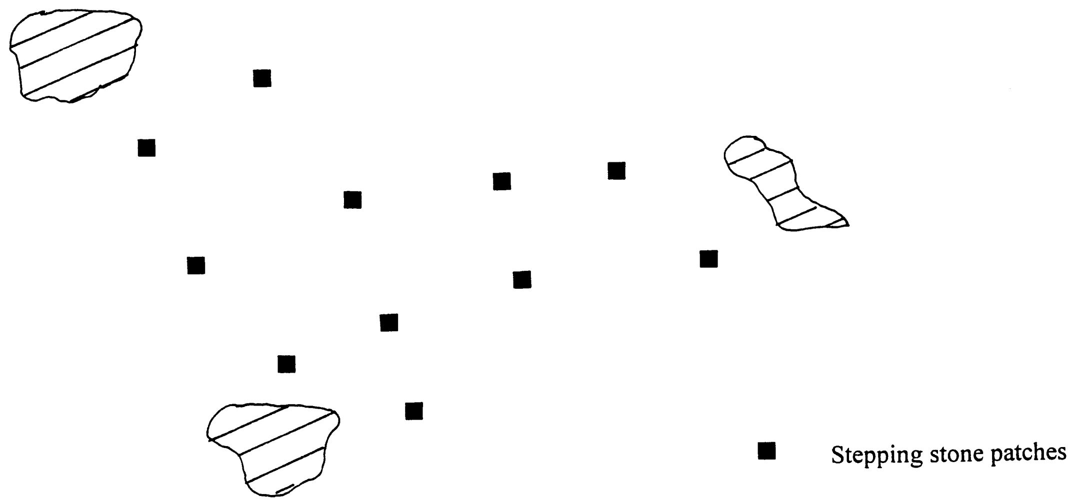
- Small "stepping stone" patches can be used to enhance scattered features that already exist within the landscape since seldom is the matrix completely hostile.

- The total costs of establishing a series of small "stepping stone" patches are likely to be intermediate between those for a single large patch (lowest) and those for a continuous linking feature (highest). However, in most situations the matrix land where these stepping stones will be created is in multiple ownership. The chances of persuading a series of owners each to establish a stepping stone patch are very much greater than either trying to find one owner willing and able to establish the single large patch, or trying to coordinate the establishment of a continuous linking feature across several ownerships.

Bibby *et al.* (1989) showed that even very small groups of broadleaf trees scattered through an upland conifer plantation could increase the woodland bird diversity, although the mobility of birds means that for them it is not the relative isolation of the broadleaved patches that is the critical feature. A better, historical analogy might be the value we now place on hedgerow networks: these contribute to the wildlife of the general countryside over a much wider area than would an equivalent extent of woodland.

Figure 14 **Creating opportunities for movement between existing blocks (////) through "hostile" territory.**

A series of small stepping stones is likely to be more effective than a single stone or a very thin corridor.



Where the objective is to create a new extensive patch of a particular habitat (eg woodland, heath, or grassland) through concentrating the effort in a single place it may be necessary to consider introducing the key "interior" species that the habitat has been established to support. They are generally unlikely to colonize the patch otherwise in a reasonable timescale (the next 60 years).

Finally it is unlikely that corridor networks will be of much value for species movement to escape the effects of climate change if the current predicted rates of climate change occur (Hill et al. 1993). The stepping stone system may be slightly more useful but only for a limited range of species.

There are tremendous opportunities to create, restore and renew links between the remnant patches of semi-natural habitat not just in the lowlands but in the uplands as well. The ideas of "Capability" Brown, Repton and others led to the establishment of new patterns in many landscapes in the eighteenth century. In a similar way *there is a chance in the next few years, not to set rigid rules for what habitats should be created where, but to evolve criteria, procedures and practices that will help us and others to make the countryside a richer and more attractive place for wildlife and for people.*

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