Evaluating Biodiversity in Fragmented Landscapes: Principles

INFORMATION NOTE

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SUMMARY

UK forests and woodlands are often of considerable value to biodiversity. There is now a growing need to evaluate the impacts of forest management on biodiversity, in order to maintain and enhance the wildlife value at the landscape scale. The development of biodiversity evaluation tools will enable forest and land managers to make informed choices at this scale in order to provide sustainable forest landscapes for the future. This Information Note explains the scientific principles behind the approach being developed as *BEETLE – Biological and Environmental Evaluation Tools for Landscape Ecology*.

FORESTS AND BIODIVERSITY

Forests and woodlands support a large proportion of UK biological diversity, frequently referred to as biodiversity[1]. Over 40% of species within the UK Biodiversity Action Plan are associated with woodlands, and nearly 15% of habitats are specific woodland types (UK Biodiversity Steering Group, 1995b; Simonson and Thomas, 1999). Trees and forests play an important role in conserving biodiversity, providing a patchwork of wildlife-rich habitats and forming the building blocks for an ecologically sustainable landscape (Figure 1).

However, forest cover in the UK has become highly fragmented and much reduced in extent, declining from the 'wildwood', which covered approximately 75% of the country for long periods in the post-glacial until around 5000 BP, to approximately 11% today (Rackham, 1986; Forestry Commission, 2003). Total woodland cover has recently increased from a low of around 5% at the start of the 20th century, due largely to considerable afforestation with exotic coniferous species. However, many woods remain very small in scale and isolated from each other (Figure 2), especially those ancient native woods that have the highest biodiversity value (Peterken, 1993).

THREATS TO BIODIVERSITY

The fragmentation of woodland habitat into smaller isolated patches poses one of the key threats to forest biodiversity. This reduces the total amount of habitat *area*

Figure 1

Biodiversity-rich ancient woodland.

Figure 2

Aerial photograph showing broadleaved woodland (very dark green) within a highly fragmented agricultural landscape.

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[1] Biodiversity is the term given to the diversity at the different scales of ecosystem, habitat and species, including the genetic variation within them.
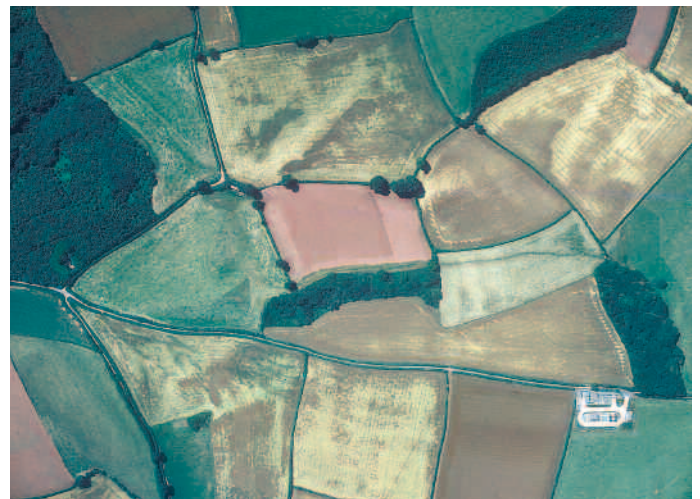
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(and particularly core habitat) and increases patch *isolation*. According to a number of scientific theories, such as island biogeography (MacArthur and Wilson, 1967) and metapopulation[2] dynamics (Hanski, 1998), the reduction in area may lead to increased local extinctions, while increased isolation may cause a reduction in the exchange of individuals between isolated patches, threatening their long-term viability. Intensification of land uses surrounding woodland patches may serve to exacerbate the effects of isolation. The surrounding matrix[3] has a significant impact on connectivity for many woodland species in general. Semi-natural and extensive habitats are considered to be more conducive, or permeable, to species movement, while intensive land uses are regarded as less permeable, thereby reducing connectivity and effectively increasing ecological isolation.

Table 1 illustrates the sensitivity of species to fragmentation based on simple differences in habitat area requirements and dispersal ability, which relates to species susceptibility to isolation. The top left cell of the table reflects the species which are most sensitive to fragmentation (e.g. extinct species with high area, specialist habitat requirements and low dispersal potential), while the bottom right cell reflects the least sensitive to fragmentation (e.g. potential pest species with low area, generalist habitat requirements and high

dispersal potential). The area of perceived conservation concern is indicated within the dashed line.

Many forest species have evolved within a highly connected and extensive habitat, and fragmentation has inevitably had a major impact on them. Those with high habitat area requirements (e.g. wolf and bear) will become extinct rapidly, while wider biodiversity (e.g. woodland flora) exhibit a slow attrition. There are concerns that climate change may further compound these effects.

THE ROLE OF EVALUATION TOOLS IN FOREST LANDSCAPES

Biodiversity and forestry strategies for the UK countries (UK Biodiversity Steering Group, 1995a, c; Forestry Commission, 1999; 2000; 2001) currently emphasise the importance of designing and managing forest landscapes to improve their value for biodiversity. As there are insufficient resources or expertise to conserve everything, there is a need to prioritise and target conservation efforts. It is necessary therefore to develop tools to evaluate the effects of management within the existing forests and to be able to predict the benefits of habitat restoration and re-creation/creation – thereby enabling selection of the right methods and areas for action.

Table 1

Matrix indicating the sensitivity of species to fragmentation based on simple differences in habitat area requirements and dispersal ability (after Vos *et al.*, 2001).

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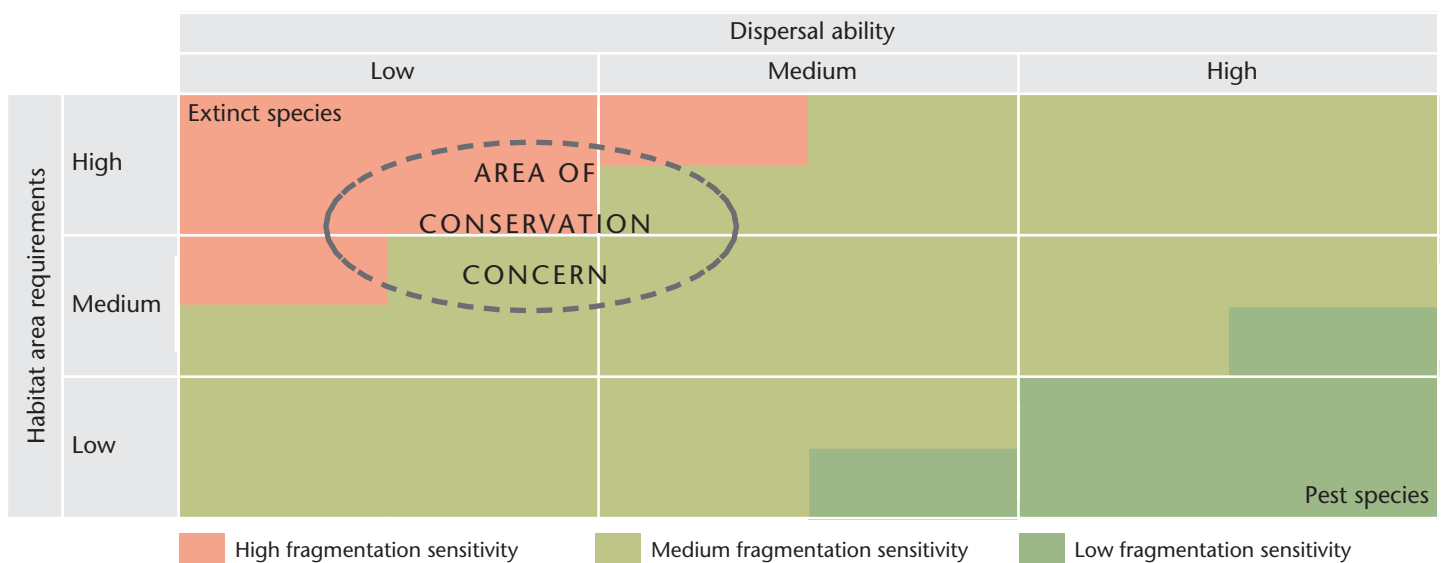
[2] A metapopulation is a set of sub-populations which are dynamically connected by immigration and emigration.
[3] The landscape matrix refers to the dominant component of the landscape, often the open, improved agricultural land surrounding semi-natural woodlands within a UK context.

Such evaluation tools must be applicable at a range of scales: at habitat/forest scale to guide management at an operational level; at larger landscape scales to direct strategic planning and policy making. Effects at the larger forest and landscape scale are hard to predict, yet it is at this scale that policy makers and land managers are increasingly required to take decisions.

It is anticipated that such tools could be equally applicable to large woodlands within a primarily forested landscape and small woodlands within an open matrix. This will make it possible for forest and land managers to assess the biodiversity impacts of their plans, and make informed choices, in both space and time. Such knowledge can be combined with other environmental, economic and social factors in order to plan for multiple benefits within sustainable forest landscapes.

APPROACHES TO LANDSCAPE EVALUATION

Land management activities, principally forestry, agriculture and development, which *change* landscapes, will have an impact on both the *structure* and *function* of the landscape. It is predicted that such changes will influence the ability of biodiversity to survive within, and move through, the landscape. In terms of evaluating biodiversity, it is thus necessary to assess the impact of changes from both structure and function.

The *structural* element refers to the spatial arrangement and organisation of distinct landscape elements. Analysis is often focused towards the physical composition and configuration of particular habitat patches within a landscape.

Landscape *function* is concerned with the interactions between these structural elements, through ecological processes and the flow of energy. In terms of biodiversity, landscape function is often related to the movement and viability of particular species within these structures.
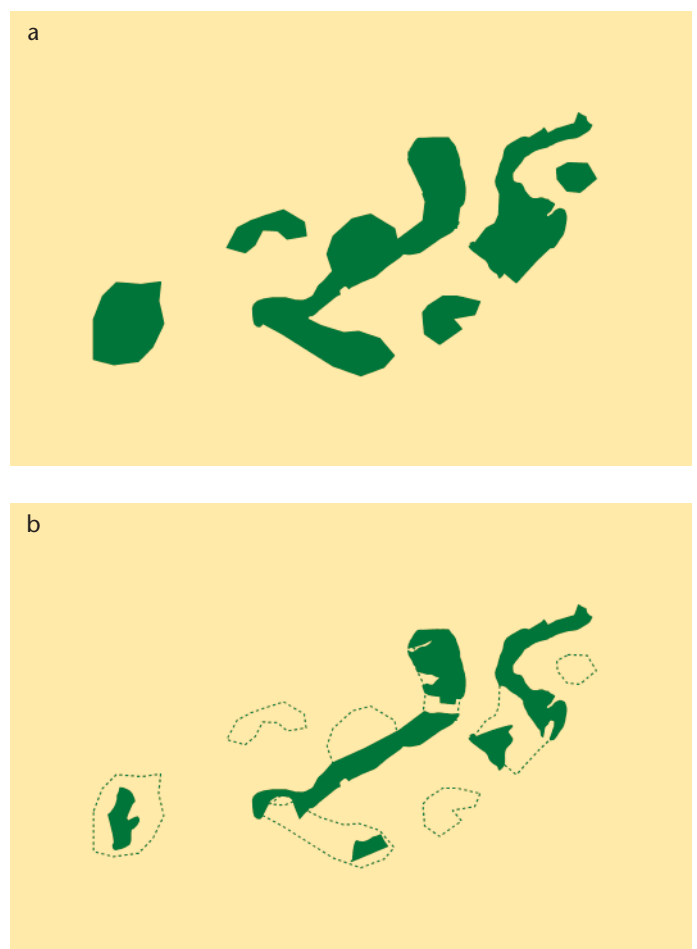
Analysis of landscape structure

Techniques for the analysis of landscape structure have developed rapidly and are increasingly used to aid forest management and forest design. Landscape metrics[4] are commonly used to quantify landscape structure and to

assess change. The most basic metrics examine the size, number and spatial arrangement of habitat patches. In calculating landscape metrics, the assumption is that the resulting value will give some useful insights into underlying ecological functions and their impact on biodiversity.

Figure 3 illustrates a simple fragmented landscape, with patches of woodland within a present and a future landscape; the size and number of woodland patches has reduced and the ecological isolation between them has increased. The biodiversity in the future landscape will be threatened by increased local extinctions of individuals and species, due to a decline in habitat area, and a reduced exchange of individuals between increasingly isolated habitat patches.

Figure 3

The structural impact of habitat fragmentation on patches of woodland (green) within a non-woodland matrix (yellow) for (a) a present and (b) a future landscape. The dotted line depicts previous extent of woodland in future landscape.

[4] Landscape metrics, or landscape indices, are quantifiable descriptions of landscape structure or pattern.

Analysis of landscape function

Species may respond quite differently to changes in forest landscapes, depending on their ecological requirements and attributes. The creation of open areas within a large forest may create important habitat for one species (e.g. black grouse), but may inadvertently isolate a population of a species restricted to woodland (e.g. red squirrel). This makes it extremely difficult to objectively evaluate the impacts of management in forest landscapes on biodiversity in general, as there is unlikely to be an optimal landscape design – there will often be winners and losers.

Developing the example in Figure 3b, the future landscape may represent five habitat patches for a generalist woodland species (e.g. tree sparrow) able to utilise small patches (shown in Figure 4a). However, a specialist species (e.g. dormouse), requiring large core areas, may be

Figure 4

The functional impact of habitat fragmentation (as shown in Figure 3b) on the extent of suitable habitat for (a) a generalist and (b) a specialist woodland species (green) within the same future landscape. The dotted line depicts unsuitable habitat patches for specialist woodland species requiring larger core areas.

restricted to the two largest high quality patches, which are increasingly isolated (Figure 4b). This example illustrates how a change in the structure of a landscape can have different functional impacts on biodiversity. Note that Figure 4 could represent small woodlands within a landscape of several kilometres or very large woodlands at catchment, region or country scale.

DEVELOPING EVALUATION TOOLS FOR FOREST LANDSCAPES

Forest Research is currently developing a suite of evaluation tools under the name BEETLE – Biological and Environmental Evaluation Tools for Landscape Ecology. These tools are intended to range from those that produce *simple* measures, or indicators, of landscape structure to more *complex* tools that measure landscape function. The latter is related to the characteristics and requirements of a variety of ecologically representative *focal* species. The appropriateness of each approach will vary with the particular research or management question, the scale of analysis and the availability of spatial and species data.

Focal species approach

Focal species are selected/considered as representatives of the wider elements of the woodland community and key ecological processes (Lambeck, 1997). Such an approach has received much attention, being easy to understand and readily applicable to management problems. It is also necessary as species may respond quite differently to landscape changes and knowledge is limited. Focal species should be regarded as part of the evaluation toolkit, which allows an assessment of the relative merits of landscape change, rather than as direct targets for conservation action in themselves. This objective information can then be used within the wider decision-making process.

This approach utilises the habitat area requirements and dispersal characteristics for a range of focal species, primarily targeted on woodland habitats and species. The aim is to increase our understanding of habitat fragmentation, associated with land management activities, in particular changes to the *area* of habitat and ecological *isolation*.

In addition to *specific focal species* (e.g. dormouse), it has been desirable, or considered necessary, to create a

number of *generic focal species* (e.g. ancient woodland specialist with high area requirements and limited dispersal) in order to represent the bulk of species for which insufficient spatial data and autecological knowledge exist. This further reinforces the focus on wider biodiversity and landscape processes as opposed to single species conservation.

Modelling functional connectivity

In order to assess ecological isolation it is necessary to model functional connectivity. As distinct from connectedness, which is based simply on physical distance or proximity, connectivity is a functional attribute of the landscape related to ecological processes such as the predicted movement of particular species between habitat patches.

Connectivity is modelled on the dispersal ability of a focal species and the ease of movement, or permeability, through the surrounding landscape (Adriaensen *et al.*, 2003). In the typical situation of limited spatial and species data, an intelligent estimate should be achievable given adequate information on the species characteristics. The connectivity modelling process is illustrated in Figure 5.

In an analysis of connectedness of the woodland patches first introduced in Figure 3b, four of the six habitat patches (1, 2, 3 and 6) in Figure 5a appear to be connected in one potentially large network, while patches 4 and 5 appear isolated. This analysis uses a buffer based on the dispersal distance for a focal species but disregards the permeability of the surrounding landscape.

Figure 5b illustrates the permeability of the surrounding landscape matrix based on the potential ease of movement for a typical woodland species: yellow represents high permeability, light brown moderate permeability and dark brown low permeability.

Finally, Figure 5c, which takes into account the permeability of the surrounding matrix, indicates that patches 1, 2 and 5, and 3 and 6, form two discrete networks, in contrast to the single large network comprising patches 1, 2, 3 and 6 in Figure 5a. The link between patches 2 and 5 demonstrates the concept of a permeable corridor, whereas patches 3 and 6 are isolated by a landscape feature with low permeability.

This example makes it clear that it is possible to have high connectivity in an apparently fragmented landscape with low connectedness. Conversely, patches that appear likely to be connected, based on close proximity, may in fact be functionally isolated. Much depends on the wider matrix and whether it provides an opportunity for the particular ecological process, in this case species movement, to occur. This type of analysis can help identify the most appropriate location for conservation within a landscape.

Figure 5

Connectivity modelling: (a) habitat patches (from Figure 3b) buffered in light green to reflect dispersal distance; (b) permeability of the landscape matrix – yellow high permeability to dark brown low permeability for potential movement; (c) modelled connectivity between patches.
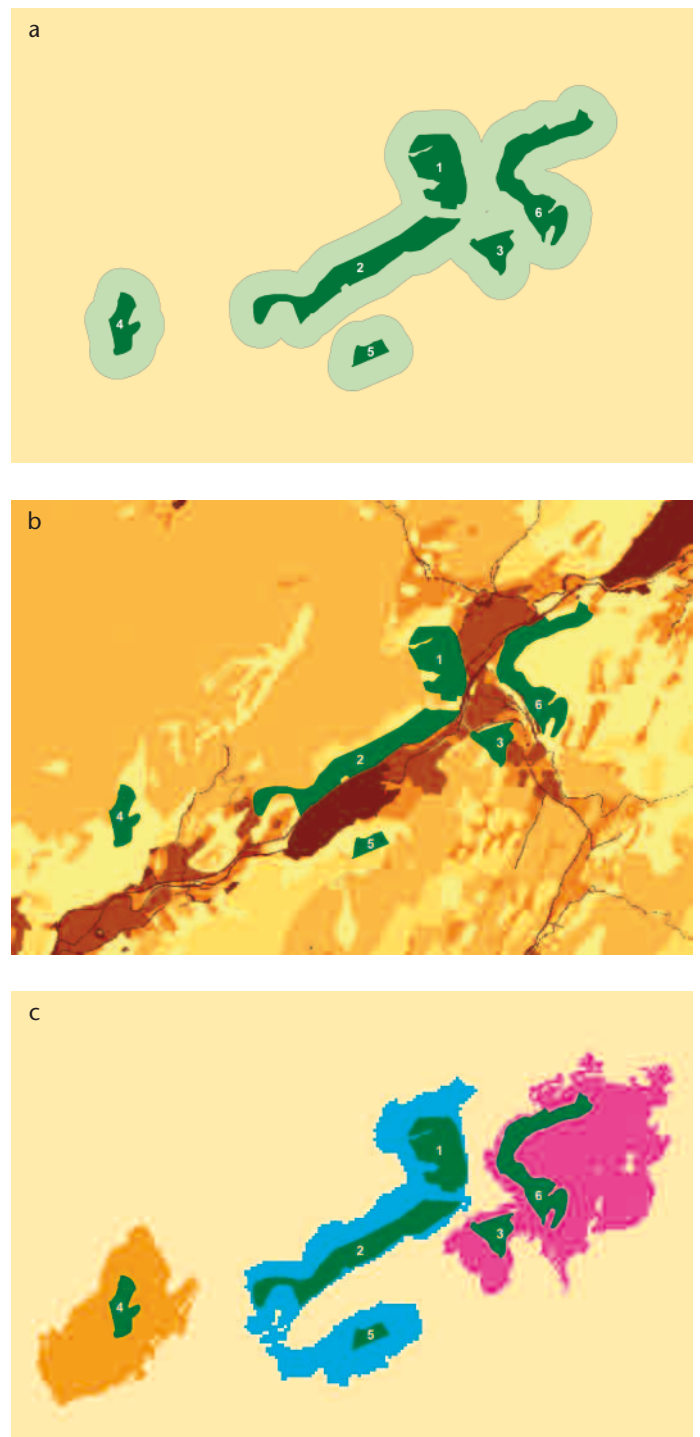
Implementing BEETLE

This focal species-based evaluation process is being developed within a Geographical Information System (GIS), and implemented through a set of modules that organise and process data. Figure 6 illustrates the process of evaluating biodiversity in fragmented landscapes through the use of focal species.

There are two primary data inputs: a *land cover module* and a *focal species module*. The land cover module represents the landscape change and controls the model's behaviour, while the parameters of the focal species module are selected based on knowledge of the ecology of the area and the type of decision being considered. The

Figure 6

Using focal species to evaluate biodiversity in fragmented landscapes.
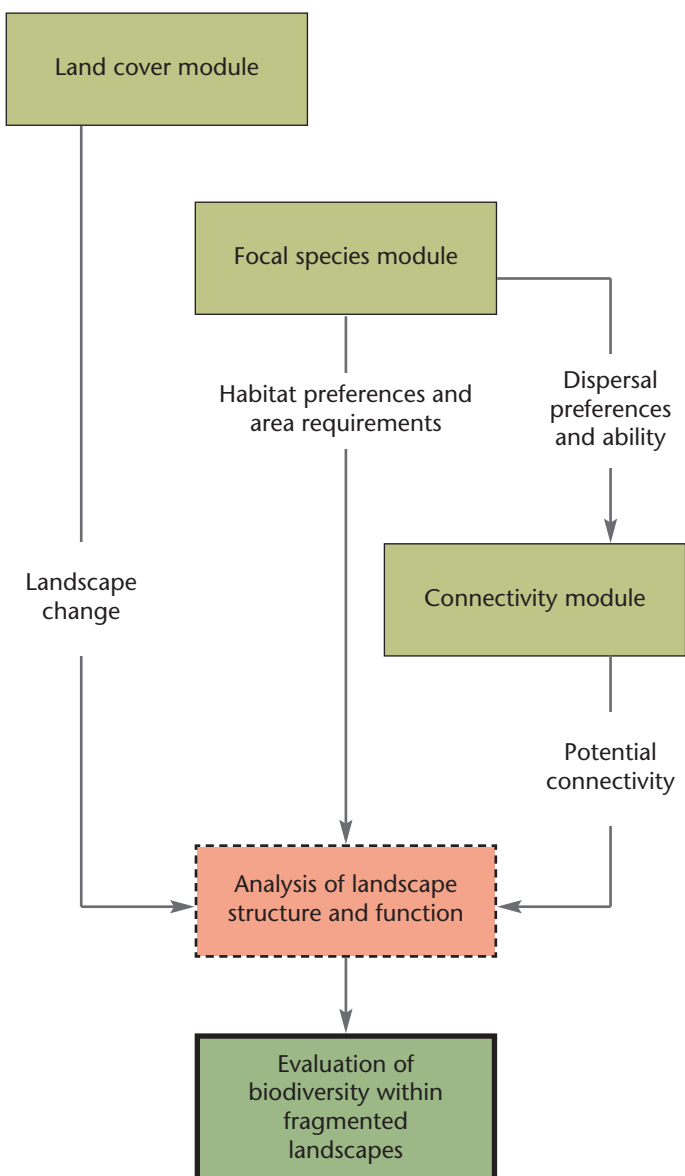
connectivity module models the mobility of the focal species, based on their dispersal preferences and dispersal ability. This allows the *analysis* of the potential connectivity across the landscape between the defined habitat patches, allowing the identification of potential habitat networks.

An example of using BEETLE to define habitat networks

Figure 7 demonstrates the evaluation process in action in a fragmented landscape in northwest Wales. Data from the land cover module are represented in Figure 7a. The focal species module is used to define the areas of suitable habitat; in this example broadleaf woodlands are selected to represent habitat for a generic woodland species (Figure 7b). This module also provides the necessary data for use in the connectivity module to assess landscape permeability; in this example high permeability is illustrated with light colours while dark colours signify low permeability in Figure 7c. The permeability is principally based on the degree of habitat modification, ranging from semi-natural habitats with high permeability (e.g. scrub and bracken) to heavily modified or artificial with low permeability (e.g. arable and urban). This allows the identification of potential networks of habitat patches for selected focal species, defined by different colours (Figure 7d).

Evaluating biodiversity using the BEETLE approach

Using the BEETLE approach it is possible to assess fragmented landscapes for a range of focal species, based upon habitat availability, the number and size of networks, and the size and distribution of habitat patches within them. Habitat patches within large networks are considered to be more robust than small isolated patches surrounded by an intensive landscape with low permeability.

Detailed examination of such outputs can identify key areas for habitat protection, management, restoration and re-creation/creation that produce potential gains in habitat networks. The overall *biodiversity value* of the landscape is assessed by comparing networks for a range of focal species. Often this process will illustrate trade-offs between different species and can be useful in comparing the effects of forest and landscape planning options. Alternative future landscape change scenarios, particularly those aimed at combating habitat fragmentation through restoration and re-creation/creation, can also be modelled.

Figure 7

BEETLE modelling approach applied to a wooded landscape in northwest Wales: (a) output from land cover data; (b) core habitat for generic woodland focal species; (c) permeability of landscape matrix to dispersal – green is habitat, permeability ranges from high (yellow) to low (reddish-brown); (d) identification of habitat (green) within potential habitat networks (reproduced from Watts *et al.*, 2005).
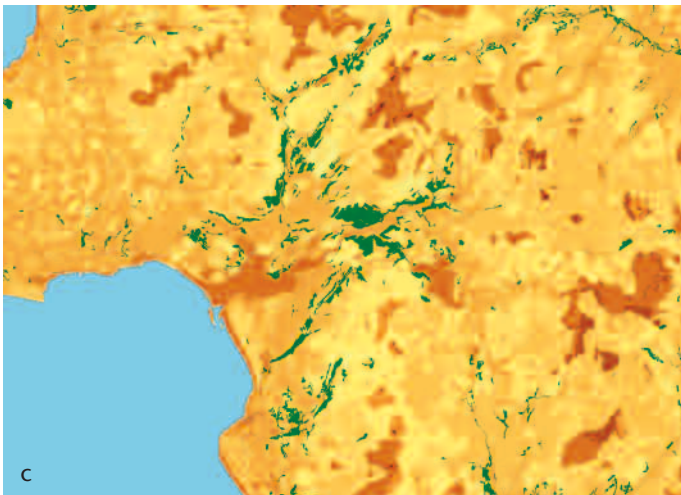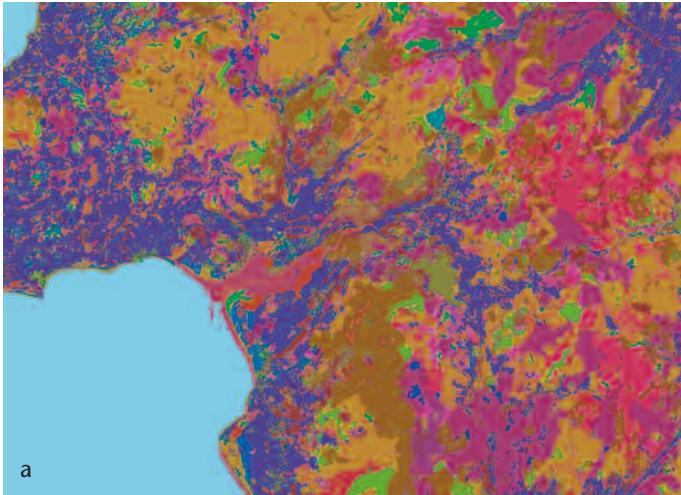
CONCLUSION

Our approach to biodiversity evaluation in fragmented landscapes is designed to provide tools to guide and support management action, rather than predict actual species dispersal and viability. These tools are intended to provide a framework within which to objectively model those landscape ecological processes which may impact on biodiversity. This provides a mechanism to consider the impact of management on biodiversity within the wider sustainable forestry and landscape decision-making processes, particularly when combined with other environmental, economic and social information. There are a number of assumptions inherent within these evaluation tools but these are based on sound ecological theories and principles and are explicit within the modelling approach. The particular evaluation approach will vary in relation to the particular research or management question, the scale of analysis and the availability of spatial and species data.

BEETLE is designed to be an adaptive evaluation tool which will be refined by ongoing monitoring and research. Further validation of the model will be achieved from the continued improvement of both spatial and species data.

FUTURE INFORMATION

This Information Note is the first in a series on biodiversity evaluation in fragmented landscapes; future Notes will explore issues on the application, refinement and future development of these principles.

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