FINAL REPORT

Forest Habitat Networks Scotland

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Contract report to Forestry Commission Scotland, Forestry Commission GB and Scottish Natural Heritage

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Executive Summary

1. Scotland's woodland habitat has reduced from an estimated 75% of the land area during the Atlantic period (8900-5700 BP) to less than 4% by the 17th century. Some of this loss results from a change to a wetter climate about 5-6000 years ago, and most to woodland clearance for agriculture. Since the 17th century reforestation policies have increased the woodland cover to about 17% at the beginning of 21st century.
2. Despite reforestation, woodland habitat - particularly the remnant ancient woodland (pre-1750) - remains severely fragmented as a result of spatially unconstrained expansion, particularly during the 20th century.
3. As a result of woodland habit loss and fragmentation Scotland's woodland specialist fauna has been severely depleted, including all the large mammalian predators.
4. The development of forest habitat networks and ecological networks in general, is of international importance, and has been recognised by the Convention on Biological Diversity (UNCED, 1992), and developed in subsequent initiatives, such as the Pan-European Ecological Network (PEEN) and article 10 of the Habitats Directive (European Commission, 1992).
5. Recent policy incentives have recognised how habitat networks might help reduce fragmentation *e.g.* UK Biodiversity Action Plan (BAP) (UK Government, 1994), the Scottish Biodiversity Strategy (Scottish Executive, 2004) and the Scottish Forestry Strategy (Forestry Commission, 2001).
6. This report describes a landscape ecology modelling study using least-cost methods (from the BEETLE suite of tools) within a Geographical Information System (GIS) to estimate the current distribution and extent of functionally connected woodland - "a habitat network". The method involves modelling the dispersal ability of woodland (and heathland) focal species between patches of habitat through the matrix (all non-habitat) within a land-cover spatial database.
7. It is assumed that a habitat network can function (in terms of landscape ecological processes) even though habitat may not be contiguous. Importantly, landscape ecological theory has shown that a landscape which is not structurally connected may have high functional connectivity (Farina, 1998).
8. Focal species can be real species or 'generic' in terms of their habitat and the way in which they respond to the matrix. There is very little published information about species-landscape ecological processes, such as dispersal ability and patch size requirements. Consequently modelling real species in the landscape is hindered by lack of data. To resolve this we have used a generic focal species (GFS) approach (Eycott *et al.*, 2007), which broadly encompasses the dispersal and patch size requirements of a conceptual species group. This is similar to using an umbrella species concept, except that the parameter profile of the model represents a combination of most species' needs.
9. Least-cost models were parameterised for a set of GFS that reflect broad woodland and heathland habitat types. However, it must be appreciated that the least-cost modelling approach is a generalisation. The approach simplifies landscape ecological principles using readily available land-cover data together with best-guestimate relationships to parameterise the model in a Delphi process. The parameterisation requires relationships between species, their habitat, and the matrix to be defined. Consequently the output approximates, in very broad terms, to the expected functional relationship of focal species in the landscape resulting from the arrangement of habitat patches and variations in matrix permeability.
10. The approach provides decision support for both policy implementation and land-use management (particularly forest managers). With the assumption and simplifications described, it must be realised that that map outputs are indicative. Maps should be treated carefully in developing plans for land-use change. In particular the digital datasets used in the analysis are limited in terms of the quality of the habitat defined. It is therefore very important that outputs are treated as possibilities, and that management options are checked carefully by site survey.
11. Habitat networks were calculated from national-scale digital land-cover data for the generic focal species associated with different woodland types, and heathlands. The inclusion of heathland provides an assessment (comparison and interaction) of a land-cover often associated with woodland in the landscape.
12. In addition to a national analysis, regional habitat network analyses were conducted on improved land-cover data for a wider range of regionally important woodland types. The

results show regional variation in functional connectivity in Scotland. Output maps indicate the location and extent of fragmentation for specific generic focal species. The report provides information and guidance on how foresters and land managers may use the habitat networks for strategic and operational planning and the targeting of management to consolidate and extend networks. The suggested priorities are:
   a. consolidate and expand the high quality core woodland fragments of antiquity,
   b. restore plantations on ancient woodland sites,
   c. convert key conifer stands to native woodland where biodiversity benefits exist from expanding the native woodland network,
   d. reforest open-ground to expand and link networks for woodland generalists.

13. Research suggests that habitat networks can maintain and improve the resilience of ecosystems to external pressures such as climate change (Peterken *et al.*, 1995). A fundamental objective of the development and expansion of the forest habitat network in Scotland is to maintain resilience of woodland ecosystems in the near future (as woodland ecosystems develop) at a time of rapid climate change, and in so doing provide a strategic objective of woodland expansion in a spatially constrained manner to sequester more carbon from the atmosphere, expand future resources for quality timber, construction timber and wood fuel.
14. The development of networks is good for society, providing opportunities for improving the well-being of people. This is particularly important for developing, expanding and linking forest habitat networks in and around Scotland's urban population.
15. In summary, this study underpins the strategic and landscape planning of forest habitat networks for Scotland in a way that is consistent with sustainable development, and in particular sustainable forest management.

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1 Objectives

Research aim

This project was funded by Forestry Commission Scotland, Scottish Natural Heritage and Forestry Commission GB. The overall aim of this project was to develop a plan to support the strategic development and integration of forest habitat networks and open habitat networks in Scotland. The project has produced ecologically based scenario maps, which will enable the Forestry Commission Scotland and Scottish Natural Heritage to advise on the expansion, improvement, and restoration of habitats to protect, and enhance, functional connectivity for woodland and open ground species.

Research approach

The specific objectives of the work described in this report were to:

i) Develop the theoretical basis for habitat networks based on the functional connectivity of focal species.

This objective investigates the applicability of the principles behind the BEETLE least-cost modelling approach to develop habitat networks for Scotland, at a range of scales.

ii) Produce a national map for Scotland showing existing woodland and open habitat networks.

The development of a national scale map in this objective demonstrates the scale of woodland and open ground fragmentation in Scotland, provided a tool to aid strategic decision making.

iii) Produce regional maps for Scotland showing existing woodland and open habitat networks that reflect the biophysical differences within Scotland.

Objective 3 describes the wider range of data sets and rules that were required to drive the detailed regional analyses.

iv) Produce a range of scenario maps for the different regions of Scotland indicating: expansion opportunities and constraints for focal species, and other management options to improve network function.

The fourth objective demonstrates how the habitat network maps can be applied to reduce the effects of habitat fragmentation at a range of scales, providing examples from the regional analyses.

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Checklist of outputs completed against project specification

Project plan output number	Notes on delivery
1. Short literature review	Completed and delivered in final report
2. Woodland generalists A national (Scotland) **'spatial' GIS based core area map** based upon generic focal species profiles representing woodland generalists, or as agreed with the steering group.	Completed analyses and report Jan2005 for: • Generic Focal species (GFS) for woodland generalists at dispersal distances of 5000, 1000, and 500 m • GFS analyses of Woodland specialists at 5000, 1000, and 500 m • GFS analysis of Heathland Generalists at 5000, 1000, and 500 m
3. Highland analysis Regional (Highland) analysis for broadleaved woodland specialists, ancient woodland specialist and Caledonian pinewood specialists, an assessment of key open-habitat focal species (to be agreed with the Steering Group). Add supporting **'graphical' and 'tabular' information** on existing core woodland areas, in terms of their carrying capacity, connectivity and viability.	Completed analyses and report Sept 2005 for: • Atlantic oakwood specialists • Ancient pinewood specialists • Plantation pinewood specialists BEETLE analysis of specialist networks assumes functional connectivity of minimum core habitat area of 1ha for species viability. Additionally delivered: • Atlantic oakwood paper for the Atlantic oakwoods conference proceedings: **Moseley, D.G., Ray, D. and Bryce, J. (2006). A Forest Habitat Network for the Atlantic Oakwoods in Highland Region, Scotland. Botanical Journal of Scotland, 57(1&2), 197-209.** • Article for Forestry and British Timber (January 2007) on the Highland Locational Premium Scheme use of FHN analyses.
4. Scottish Borders Regional (Scottish Borders) analysis for broadleaved woodland specialists, and ancient woodland specialist, an assessment of key open-habitat focal species (to be agreed with the Steering Group). Add supporting 'graphical' and 'tabular' information on existing core woodland areas, in terms of their carrying capacity, connectivity and viability.	Completed analyses and report May 2006 for Lothians and Scottish Borders and South West Scotland – all include: • Woodland generalists • Broadleaved woodland specialists • Heathland generalists Additionally delivered: • Riparian networks – regional application • Local application opportunities • Woodlands in and around communities • Integration of networks into LBAP • Potential interactions between woodland and heathland • Woodland management & expansion recommendations
5. Complete 75% of **'spatial' GIS based indicative linkage maps** based upon generic and focal species profiles at the regional/catchment scale, as agreed with the steering group, to identify target/priority areas.	Completed as part of 3) and 4)
6 – 75% of regional reports Show woodland HAP potential from Native Woodland Model & Ecological Site Classification (ESC). Show the	Completed in July 2006 for FC Scotland as part of the Scottish Forestry Strategy Phase 2 work

suitability of the selected target/priority areas for woodland creation/restoration (native and commercial) with predicted yield estimates and habitat management options. Add supporting 'graphical' and 'tabular' information on potential linkages and revised core areas, in terms of their carrying capacity, connectivity and viability.	
7 – Highland and Scottish Borders local/regional 'spatial' prioritised/classified GIS based maps completed. Develop core area and linkage maps and supporting analysis, and the potential areas, patterns and woodland thresholds that will not significantly damage the biodiversity of key open-habitats of the existing landscape.	Completed as part of 3) and 4)
8 - Completion of prioritised/classified GIS based maps developed from the core area; linkage maps and supporting analysis; the potential areas, patterns and woodland thresholds that will not significantly damage the biodiversity of key open-habitats of the cultural/existing landscape, including supporting 'graphical' and 'tabular' information	Remaining areas of Scotland completed and summarised in the final report. Including re-analysis of SW Scotland Broadleaved woodland specialists at 250m, and the completion of the FHN analysis of Perth and Argyll at 250, 500 and 1000m for woodland generalists, broadleaved woodland specialists, pinewood specialists, and Heathland specialists, following an update to the land-cover data for Perth and Argyll. New land-cover data includes: FESCD, SFGS,WGS, SSNWI, and OS Strategi roads on top of original LCS88 and NIWT . Report still to be completed for Perth and Argyll.
9 – Report of secondary outputs such as the assessment of non-ecological benefits from FHNs – e.g. visual, social etc.	Analysis of woodland accessibility according Woodland Trust's 'woodlands for people' criteria - completed and included in regional reports

2 Background

Habitat fragmentation in Scotland

Scotland's woodland has been subject to large changes in terms of size and management; from a post glacial extent of around 75% woodland cover, land use pressure reduced this to less than 4% by the 17th Century, resulting in fragmented and isolated remnants. Afforestation throughout the 19th Century and particularly the 20th Century increased woodland cover to 17.1% of the total land area of Scotland. However, the ancient semi-natural remnant woodlands remain largely fragmented, because new planting has been spatially unconstrained (Watts & Griffiths, 2004).

The fragmentation process involves the break up of a few large patches of habitat into an increased number of smaller patches; reducing the area of available habitat; increasing patch isolation; and reducing the amount of core habitat area due to edge effects.

The reduction in area (or core area) may lead to increased local extinctions, whilst increased isolation may cause a reduction in the exchange of individuals between isolated patches, threatening their long-term viability (Fahrig, 2001). Many forest species have evolved within a highly connected and extensive habitat, and fragmentation has inevitably had a major impact on them. In Scotland, specialist forest species with a very large home-range became extinct rapidly. The continued chronic interruption of dispersal, migration and metapopulation dynamics of many species will cause a slow attrition of biodiversity. There are concerns that climate change will compound these effects, as species will not be able to track their climatic envelope across landscapes and so will become more susceptible to extinction (Opdam & Wascher, 2004).

> **Habitat fragmentation** reduces the amount of habitat ***area*** and ***core habitat*** and increases patch ***isolation*** posing a major threat to biodiversity conservation

Habitat networks – a potential solution

The negative impacts of fragmentation are increasingly recognised within the nature conservation community, and consequently there is much interest in developing habitat networks to provide a solution. Habitat networks are intended to reverse the deleterious effects of fragmentation by linking existing habitat to provide large connected areas which are capable of sustaining a greater biodiversity. It is now becoming apparent that piecemeal approaches to biodiversity conservation and enhancement are not effective (Anon, 2004). That isolated conservation measures taken at the local, often site-based, scale may not be adequate in tackling the wider problems caused by habitat fragmentation (Hawkins & Selman, 2002, Lee et al., 2002, Lee, 2001, Thompson et al., 1999, Thompson et al., 2001). In the future, site conservation measures will be increasingly complemented with actions to sustain habitat quality and wildlife in the wider landscape (Humphrey et al., 2003a, Townshend et al., 2004). Habitat network strategies place particular emphasis on the development of plans for the creation of large-scale habitat networks, to provide a framework for the maintenance, improvement and restoration of biodiversity.

> **Habitat networks** are intended to **reverse** the effects of **fragmentation** by expanding and linking isolated habitats

The importance of habitat networks and ecological networks to address habitat fragmentation and conserve biodiversity at international, European, national and local scales was recognised at the Convention on Biological Diversity (UNCED, 1992), and developed in subsequent initiatives, such as the Pan-European Ecological Network (PEEN) (Bennett, 1994, Bouwma et al., 2002, Foppen et al., 2000) and article 10 of the Habitats Directive (European Commission, 1992). The directive charges member states with endeavouring to encourage landscape management of features which are essential for the migration, dispersal and genetic exchange of wild species. Habitat networks are also formally recognised within the UK through a number of nature conservation programmes and forestry strategies, *e.g.* UK Biodiversity Action Plan (BAP) (UK Government, 1994), the Scottish Biodiversity Strategy (Anon, 2004) and the Wales Woodland Strategy (Forestry Commission, 2001). Habitat networks are also being seen as essential landscape features for the protection and enhancement of biodiversity, particularly with the uncertainties posed by climate change in the current Scottish Forestry Strategy (Anon, 2006).

Approaches to developing habitat networks

Habitat networks based on habitat distribution and its functional connectivity have been developed particularly by Forest Research (http://www.forestresearch.gov.uk/habitatnetworks) and ALTERRA (http://www.alterra.wur.nl/UK/). The adoption of FHNs in Scotland was recommended by Scottish Natural Heritage (SNH) (Peterken *et al.*, 1995) to reverse fragmentation and rebuild significant areas of native woodland, primarily to conserve and enhance woodland biodiversity. It was suggested that FHNs should exist at a range of scales, comprised of 'nodes' and 'links'. Core areas are retained, expanded and developed within existing clusters, while linear woodlands are developed into linkages to connect these core areas. Although it has been emphasised that woodland should not take precedence over other scarce or important habitats (Peterken, 2002). Inherent in Peterken's vision is the assumption that a FHN, as a simple network of woodland habitat patches, will facilitate the dispersal of all woodland species. This leads to general principles interpreted as simple rules for woodland patch design. Generalisation will tend to mean that some species will benefit from the policy while others will not.

Hampson & Peterken (1998) recognised that the implementation of FHNs in Scotland would occur only through a national programme to develop and publicise the concept. This has happened using national scale policies (*e.g.* the Scottish Forestry Strategy (Anon, 2006), publicity (Fowler and Stiven, 2003) and incentives (*e.g.* Scottish Forestry Grant Scheme (SFGS) (Anon, 2003)). The initial conceptual work was followed by case studies to apply guiding principles tailored to local biophysical conditions and existing woodland cover (Peterken *et al.*, 1995): Cairngorms (Towers *et al.*, 1999), Loch Lomond (Anon, 2002), Clyde Valley (Peterken, 2000a), Highland Perthshire (Worrell *et al.*, 2003), and by this national study to develop a common framework linking regional and local objectives and priorities.

Habitat networks have been successfully developed and applied to woodlands in Wales (Watts *et al.*, 2005a) and Scotland (Ray *et al.*, 2005). The long-term goal of habitat network strategies developed by Forest Research has been to protect, manage, restore, improve, and recreate woodland habitats in the most effective manner ((Peterken, 2003, Peterken et al., 1995), as opposed to large scale, spatially unconstrained, untargeted and reactive schemes. The approach has focused on local and national scale studies (Watts *et al.*, 2005a; 2007b) and on the interaction with open habitat networks (Humphrey *et al.*, 2007; Watts *et al.*, 2007b).

Several approaches to modelling habitat networks from a landscape ecology perspective were considered, ranging from simple analyses of physically derived metrics (*e.g.* patch size or shape indices) through to individual species-based modelling techniques. Of these approaches, the least-cost focal species approach was identified as a convenient way of mapping and analysing forest habitat networks, as it represents in a model how species may be considered to disperse through different patches of land cover in the matrix. The use of focal species as surrogates or indicators of wider biodiversity avoids the need to carry out large numbers of individual species analyses for which there is very little, or no information on dispersal and land-cover preferences. However, each approach has different limitations. The focal species approach requires assumptions to be made on dispersal ability through a range of habitat types. Validation of the results is difficult, but two studies are currently focussing on this. Uncertainties regarding the dispersal ability of species can be reduced through a Delphi analysis, or discussion with a group of assembled experts. The objective being to discuss species-landscape preferences and dispersal constraints, and to agree on the relative preferences between land-cover types within and between species.

3 Methods

3.1 The modelling framework

The approach uses a GIS-based model (accumulated cost-distance) from 'BEETLE' (Biological and Environmental Evaluation Tools for Landscape Ecology) developed by Forest Research (Humphrey et al., 2003b, Latham et al., 2004, Ray et al., 2004, Watts, 2003). Part of this model is a focal species (see Brooker, 2002, see Lambeck, 1997) tool that utilises habitat area requirements and dispersal characteristics to identify functional habitat networks for a given species. Generic focal species (GFS – see 3.2.2 Focal species module) (Eycott et al., 2007), rather than specific focal species were selected to represent national and regional land cover types. The use of focal species as surrogates or indicators of wider biodiversity negates the need to carry out a vast number of individual species analyses. The approach also has the advantage of allowing the user to model how species may disperse through each of the different elements of the land cover matrix. In addition, the modelling does not require extensive autecological data for parameterisation. Such data are often lacking, preventing the use of more complex species-based approaches. The basic principles of the focal species tool are similar to the LARCH model developed in the Netherlands, which has also been used to examine habitat networks (Bolck et al., 2004, Opdam, 2002, Rooij et al., 2001, Verboom & Pouwels, 2004).

The Scotland FHN study used the GFS approach with accumulated cost-distance modelling to address the regional differences (geographic variation, habitat types, land management practices) of Scotland. For the national, and each regional analysis, a range of data sets describing land-cover were interrogated to produce a unified data set to allow the GIS analysis to be undertaken. This data set was re-coded to reflect each GFS' dispersal ability by applying a series of dispersal 'costs' (see 3.2.3 Connectivity module), which have been determined by woodland and open ground experts. The GFS profile costs described are an attempt at representing the availability of cover, opportunity for dispersal, and likely disturbance to dispersal across a range of land cover types. However, it must be noted that this approach is very much an approximation and a generalisation. Without a huge investment in autecological research for very many species, it not possible to quantitatively parameterise this or any other tool that assesses landscape-scale ecological processes. Despite these limitations, we believe the approach is cost effective, simple, accessible, and fit for purpose.

3.2 Key elements of the BEETLE least-cost approach

The BEETLE accumulated least-cost approach (referred to as 'BEETLE' throughout) is implemented through a set of modules that represent and process input data. The use of modules allows a flexible framework allowing the incorporation of a range of data inputs, and provides an analysis varying in complexity and landscape ecology focus. The modules used within the woodland habitat network analysis are outlined below and their elements and interactions are identified in Figure 1.

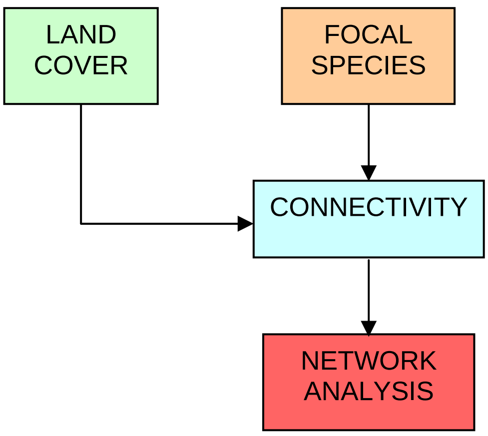


Figure 1. Key modules of the BEETLE model

3.2.1 Land cover module

The following data sets were used to build the land cover used in the analysis (some are region specific) and were assembled in 10 metre resolution raster grids.

- Land Cover Scotland (LCS88)
- Land Cover Map 2000 (LCM2000) for 15km England buffer and areas of missing data in LCS88
- National Inventory of Woods and Trees (NIWT)
- Scottish Semi Natural Woodland Inventory (SSNWI)
- Phase 1 habitat data
- Forestry Commission sub-compartment database
- Woodland Grant Scheme 3 (WGS3)
- Scottish Forestry Grant Scheme (SFGS)
- Scottish Ancient Woodland from the Scottish Inventory of Ancient and Long-established Woodland Sites (v3) and the Scottish Inventory of Semi-natural Woodlands (v3)
- Caledonian Pinewood Inventory (CPI)
- Riparian and wet (Carr) woodland indicator dataset (derived from North East Scotland Biological Record Centre (NESBReC) data)
- Lowland Zone from the national analysis
- Elevation Mask from the national analysis showing areas above and below 500 m, based on the Ordnance Survey 50 metre resolution Digital Elevation Model (DEM)
- Flood risk areas derived from the Ordnance Survey 50 metre resolution DEM
- Designated areas: Natura 2000 Special Areas of Conservation (SAC), Special Site of Scientific Interest (SSSI)
- Ordnance Survey® Strategi ® infrastructure data for roads and rail

 The background mapping used in this report comes from either the OS raster mini-scale digital data at a scale of 1:250 000, or OS raster 1:50 000 scale and 1:10 000 scale.

Elevation modifier
Areas with a minimum 500 metres elevation were identified on the DEM. An elevation factor of 2 was applied to the cost matrix for these areas, doubling the cost of species dispersal at higher elevation.

Refining land cover data

The regional studies provide an assessment of the biodiversity contribution made by woodlands and other land cover types at the landscape scale. For pinewoods, broadleaved, and mixed woodlands, this was undertaken to identify woodland areas of potential high biodiversity quality and improve the detail of the land cover matrix. Two approaches to quality assessment were used: interview, where local knowledge was available; coincidence mapping, to identify woodlands on the basis of plant indicator species occurrence.

Quality assessment by interview
The Highland, Borders (Moseley *et al.*, 2005; 2006) and southwest Scotland (Grieve *et al.*, 2006) analyses employed a series of interviews with local woodland officers and foresters to 'broadly' categorise woodland quality wherever possible. The scope, scale and resources of the FHN project do not permit a very detailed description of woodlands at the sub-compartment level, therefore the interview and interpretation focused on an overall score for woodland blocks. For the purposes of woodland assessment, areas under 2 ha were not considered - as most would be eliminated in the GIS analysis during the removal of the 50 m internal buffer.

Three factors of quality (structure, deadwood, and field layer composition) were considered in the survey to provide a surrogate for biodiversity value. In order for a high quality designation to be ascribed to a woodland block, each criterion had to be well represented. From this analysis an overall score was derived for each woodland (Table 1).

1. Structure
1.a. 'Good' structural composition will include: tree species mix suited to the site, multi-layer canopy, gaps in the canopy. The majority of the trees would be at least 100 years old.
1.b. 'Moderate' composition will include two of the factors described in 1.a.
1.c. 'Poor' composition will include one or none of the factors described in 1.a.

2. Deadwood
2.a. 'Good' deadwood component will include the following elements in varying stages of decay: some standing deadwood – snags (and hung broken branches), sap runs, fallen deadwood.
2.b. 'Moderate' deadwood will include two of the factors described in 2.a.
2.c. 'Poor' deadwood will include one or none of the factors described in 2.a.

3. Field layer
3.a. 'Good' field layer component will include roughly 50% cover or more of the woodland floor, a representative sample (5 or so) of plants associated with that woodland type, evidence of low deer browsing pressure.
3.b. 'Moderate' field layer will include two of the factors described in 3.a.
3.c. 'Poor' field layer will include one or none of the factors described in 3.a.

Table 1. Scoring system used to derive an overall stand quality score from structure, deadwood, and field layer components.

	Component Quality		
Overall quality	High	Good	Average
High	3	-	-
High	2	1	-
Good	2	-	1
Good	1	2	-
Good	1	1	1
Good	-	3	-
Good	-	2	1
Average	1	-	2
Average	-	1	2
Average	-	-	3

Quality assessment using coincidence mapping

The process of interviewing local woodland officers and foresters to confirm woodland type and identify quality information is a time consuming process and does not identify all woodlands as it is restricted to those which the interviewee is most familiar with. To supplement this survey, a procedure for identifying woodlands remotely using coincidence mapping was designed.

The methodology involves making an assumption that the best quality woodlands will contain more organisms associated with ancient woodlands. As woodlands mature they develop structurally, providing a greater range of micro-habitats, and a longer time frame for organisms to establish. This concept has led to the development of a list of plants which are thought, and have been shown (Peterken, 2000b, Rose, 1999), to indicate ancient woodland conditions. Certainly, woodlands which contain many of these plants tend to be structurally diverse and more likely to provide conditions for a rich assemblage of organisms, from all taxonomic groups.

Whilst the presence of one species may occur by chance or could have been introduced, the presence of additional species strengthens the argument (Peterken, 2000). The presence of four species was considered a suitable minimum number to rate an area of associated woodland as good quality, whilst eight or more species was considered to represent particularly rich woodlands of high biodiversity quality. However, the records are open to false negative results, since 'no records' cannot be assumed to mean 'not present', only 'not recorded'. We have tested 21 species to try and minimise non-recording of certain species, however woodlands that are infrequently visited are perhaps less likely to have complete records. Three standards of woodland quality were developed for the study. Woodland that contained:

- less than 4 ancient woodland indicator plants = average quality woodlands
- 4 to 7 ancient woodland indicator plants = good quality woodlands
- 8 or more ancient woodland indicator plants = high quality woodlands

A list of ancient woodland indicator plants was selected, and their point data distribution was queried from the digital data held by local Biological Records Centres. Since the site quality of woodlands varies spatially with bioclimatic factors, the list included species associated with poor to rich soil nutrient regimes, and very moist to slightly dry soil moisture regimes (Pyatt *et al.*, 2001).

Woodland polygons intersecting these points were selected and designated as high, good, or average biodiversity quality as appropriate. Occasionally some of the data points could not be referenced to a broadleaved or mixed woodland polygon with a reasonable degree of confidence. In such cases, and where the distance from the data point was still within 1km, the designation was downgraded to a lower category, *i.e.* high quality to good quality, good quality to average quality. This approach means that downgraded woodlands are not classified as core habitat, and consequently cannot form the basis for a network. However, if such woodlands are subsequently surveyed and found to be of a high quality, the land cover can be amended to reflect this.

If no polygon could be ascribed to a data point within the 1km specified distance, the data point was noted and used to suggest areas where additional woodland or conversion to broadleaved woodland may be appropriate.

3.2.2 Focal species module

Some approaches to protect and enhance biodiversity have produced a single optimal network design, principally based upon landscape structure but "there is no single optimum design that suits 'biodiversity' generally, as each species has distinctive spatial requirements" (Hawkins & Selman, 2002). Where the availability of detailed species data is limited recent approaches have tended to use GFS as a complement to actual species (Eycott *et al.*, 2007).

Habitat Networks aim to protect and enhance biodiversity. They are based on ecologically representative focal species

A GFS is a conceptual or virtual species, whose profile consists of a set of ecological requirements reflecting the likely needs of real species where species data are unavailable. GFS are selected to represent particular species, groups of species, habitats, important landscape features or specific policy objectives. GFS are best developed with key stakeholders involved in strategic planning and management as well as relevant habitat and species experts. Rather than being prescriptive, the focal species approach is intended to act as an indicative aid to integrated landscape planning by assessing the relative merits of a landscape for particular representative focal species.

The structure of the GFS profiles is not based on empirical science (there is very little evidence to help define the profiles) although this area is currently under investigation through a DEFRA contract. The profiles have been developed through a Delphi process which attempts to find agreement between experts on the likely differences between GFS profiles. This is easy to do with a GFS, since the profile does not have to match any single species. However, having developed the profile to parameterise the model for the GFS, it is easier to then link a specific species with a likely GFS model.

The GFS for the national scale analyses were chosen to represent habitats that are commonly found in Scotland to allow consistency across the country. Here some ideas on the species associated with different GFS models are provided. These are the kinds of species discussed in the Delphi process for particular GFS or woodland habitat types. The examples are indicative of the GFS or woodland type, they are not exclusive to the category allocated, and they have been included here to suggest a guide to the habitat size requirements or dispersal range of each GFS category. It is also necessary to have some idea of the amount of time allowed for dispersal. The time domain for colonisation of new woodland is not considered in the model. For woodland generalists that can walk or fly, the time domain could be 1 year or less. For less mobile generalists (not able to fly or walk) - 2 to 50 years. For specialists that are more sedentary the time domain might be 50 to 150 years or more. However these are approximations to provide a reference to the likelihood of colonisation within a rotation.

- Woodland Generalist – representing species which may disperse easily, that are not specifically associated with woodland, but may need woodland for a part of their life cycle, or partly within their range, *e.g.* badger, spotted flycatcher, greater-spotted woodpecker, great woodrush, *Amanita submembranacea* – a fungus.
- Heathland Generalist – representing species associated with heathland, but often found in (open) woodlands or glades and rides in woodlands on poor soils. Sites may be recognised by a significant presence of heather, *e.g.* purple moor-grass, curlew, brown hare.
- Broadleaved specialist – representing species specifically associated with broadleaved woodland, may be found in mixed woodland to a lesser degree and occasionally in conifer. The term specialist signifies a rather reduced dispersal and a more exacting habitat requirement, *e.g. Limnophila pulchella* (a cranefly), *Dicrostema gracilicornis* (a sawfly), bluebell (*Hyacinthoides non-scripta*), wood anemone (*Anemone nemorosa)*.

In addition to the GFS used in the national analysis, the regional analyses also reflect important woodland types associated with that region, *e.g.* pinewood in Highland, riparian and wet woodland in Grampian, ancient broadleaved woodland in the Scottish Borders.

- Pinewood specialist – representing species specifically associated with pine woodland, *e.g.* red squirrel, crested tit, hairy woodant, *Cladonia botryes* (a stump lichen), creeping ladies tresses.
- High biodiversity pinewood specialist– representing species specifically associated with high biodiversity (often ancient & long established) pine woodland that has a well-developed ground flora and a good vertical structure & deadwood component. Examples include: Scottish crossbill, twinflower, ostrich-plume feather moss, blue-tooth fungi.
- Atlantic oakwood specialist – representing species specifically associated with sessile oakwoods (NVC identifiers 70 to 75, 80 to 84, 122, 125, 126) occurring below 200m. Examples include: *Adelanthus decipiens* (a liverwort), *Killarney featherwort*, with species such as the Pied flycatcher and Tree lungwort also using Atlantic oakwoods as habitat.
- High quality broadleaved woodland specialist – representing those species only associated with ancient and long established woodlands. The species may additionally be present in conifer plantations on ancient woodland sites (PAWS), but PAWS have not been classified as habitat in the analysis. The important issue is antiquity, which provides a long period of woodland cover. Species in this category might be less mobile than broadleaved specialists and include: bluebell, dog's mercury, saproxylic fungi.
- High quality mixed/broadleaved woodland specialist GFS – species requiring woodlands of antiquity, but not as exacting in their need for only broadleaved species. These woods would normally have a relatively high broadleaved tree component (30% or more). Again the species may additionally be present in conifer plantations on ancient woodland sites (PAWS), but PAWS have not been classified as habitat in the analysis. Examples include: ramsons, nuthatch.
- Riparian woodland specialist – representing those species only associated with riparian woodlands. Sites are located adjacent to rivers and streams. Species in this category are generally limited to riparian areas and include: otter, Daubenton's bat, Pipistrelle bat goldeneye, *Brachyptera putata* (a stonefly).
- Wet (Carr) woodland specialist – representing species requiring wet woodland areas, typified by the presence of willow and adjacent fen. These woods would normally have a relatively high broadleaved tree component (30% or more). Again the species may additionally be present in conifer plantations on ancient woodland sites (PAWS), but PAWS have not been classified as habitat in the analysis. Examples include: *Lipsothrix ecucullata* (a cranefly), coral-root orchid, alder hoverfly

Defining 'home habitat' for each GFS

'Home habitat' represents land cover that is considered habitat for each of the GFS; these areas of land cover are detailed below. A modification has been made by factoring an edge effect into the analysis for woodland specialists. The edge effect is assumed to extend 50m into woodland. This distance represents a distance of 2 tree heights, considered to be the normal extent of the edge effect (Bennett, 2003), beyond which the woodland core area is encountered. A 50 metre internal buffer was removed from the habitat layer. Although the 50 metre edge was not considered as source habitat, it was assigned a cost of 1 in the land cover matrix. A smaller edge effect of 20 metres was used for riparian woodlands.

Woodland generalists
All SSNWI data except "farm and parkland" mainly scattered trees along field boundaries, and also woodland with a canopy cover of less than 50%. Qualifying SSNWI habitat was combined with the complete NIWT dataset. The SSNWI woodland excluded as habitat was added to the land cover matrix.

Broadleaved woodland specialists
Identified from NIWT (where indicative forest type is broadleaved) and from SSNWI, using the 80% broadleaved and broadleaved woodland categories, where canopy cover was greater than 50%. The SSNWI woodland excluded as habitat was added to the land cover matrix.

Heathland generalists
Identified from the LCS88 categories wet, dry, or undifferentiated heather moor without trees. The LCS88 categories wet, dry, or undifferentiated heather moor with trees were not considered habitat, but heathland generalists can freely dispersal through these areas.

High biodiversity pine woodland specialists
Identified from NIWT (where indicative forest type is semi-natural coniferous), from SSNWI, using the conifer categories with a naturalness category of either semi-natural, 80 to 90% semi-natural, or mixed semi-natural/planted where canopy cover was greater than 50%, FE where species = pine, and from CPI where the description was Caledonian pinewood. Each of these datasets was qualified by forest managers and other experts in each of the districts within Highland Conservancy with regard to the quality of the ancient pine woodland. Unknown areas were designated as unqualified pinewood and given a higher dispersal costs.

Pine woodland specialists
Identified from NIWT (where indicative forest type is semi-natural coniferous), from SSNWI, using the conifer categories with a naturalness category of semi-natural, 80 to 90% semi-natural, or mixed semi-natural/planted, FE where species = pine, and from CPI where the description was Caledonian pinewood. The SSNWI woodland excluded as habitat was added to the land cover matrix. The WGS3, Fplan, and SFGS datasets and the ancient woodland inventory was used to identify new planting, or restocking, of pine stands not captured by the SSNWI or NIWT datasets.

Atlantic oakwood specialists
Identified from SSNWI, using the 80% broadleaved and broadleaved woodland categories that were 80 to 90% semi-natural or semi-natural, with a minimum canopy cover of 10% and spatially corresponding to NWM sessile oak sites under 200 m elevation. FE and estate sub-compartment databases were qualified by forest managers and other experts in each of the districts within Highland Conservancy with regard to the quality of the Atlantic oakwood.

High biodiversity broadleaved woodland specialists
Identified as for broadleaved woodland specialists, but spatially corresponding with the distribution of twenty-one ancient woodland indicator plants. Sites with eight or more indicators were designated as high quality broadleaved woodland. Sites with between four and seven indicators were designated as good quality woodland in the land cover matrix, and sites with less than four indicators, poor quality woodland.

High biodiversity *mixed / broadleaved woodland specialists*
Identified as for high quality broadleaved woodland specialists, but also included sites of mixed woodlands as many of these woodlands have a high component of broadleaved woodland.

Riparian woodland specialists
Identified from SSNWI = watercourse woodland, FE = Alder or Willow; SSNWI = 80 to 90% broadleaved or broadleaved, mixed broadleaf/conifer, with a minimum canopy cover of 10%; NIWT = Broadleaved or mixed; FE = Broadleaved or mixed, where the sites have either been qualified by an expert as riparian woodland or they spatially correspond to: sites with at least 8 riparian woodland indicator plants; derived flood risk areas; NWM wet woodland areas; or.

Wet (Carr) woodland specialists
Identified from FE = Alder or Willow; SSNWI = 80 to 90% broadleaved or broadleaved, mixed broadleaf/conifer, with a minimum canopy cover of 10%; NIWT = Broadleaved or mixed; FE = Broadleaved or mixed, where the sites have either been qualified by an expert as wet (Carr) woodland or they spatially correspond to: sites with at least 8 wet (Carr) woodland indicator plants; derived flood risk areas; NWM wet woodland areas.

A series of rules were applied to derive habitat patches for each of the GFS from the land cover data sets; Figure 2 shows an example for ancient pinewood specialists, the logic and rules applied to other GFS are shown in Appendix A.

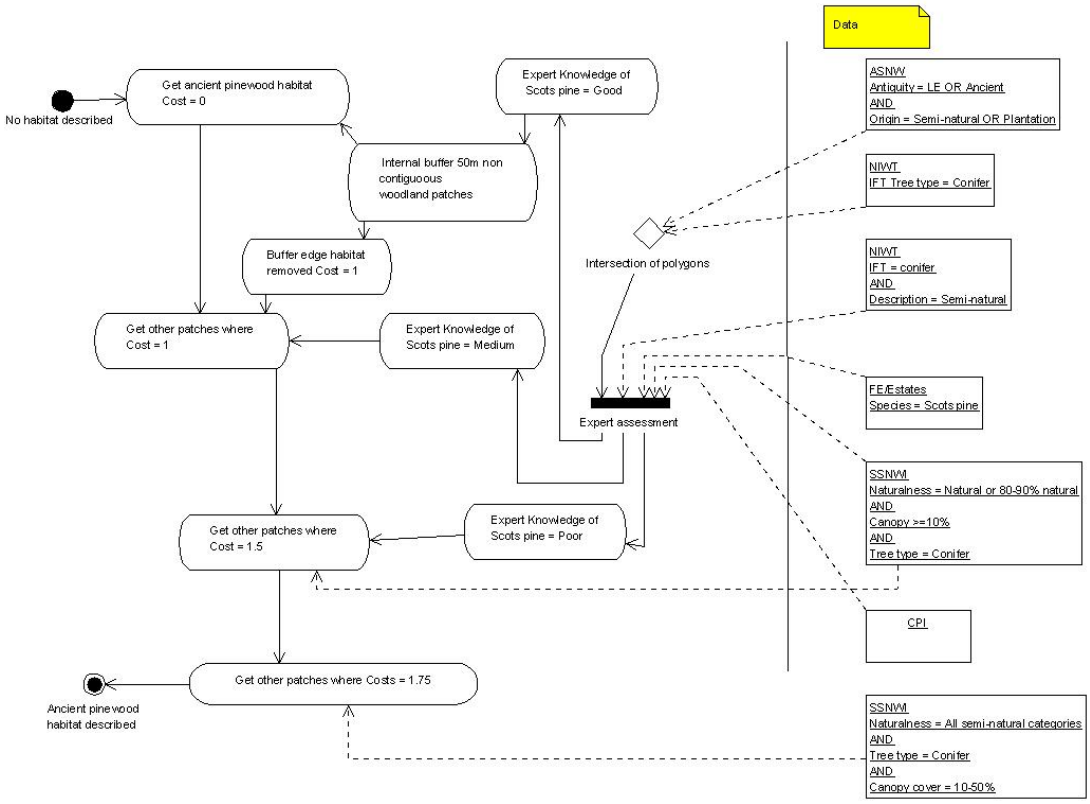


Figure 2. Flow diagram of sources and rules used to derive ancient pinewood specialist data

3.2.3 Connectivity module

The BEETLE tool takes into account the probability of movement across the wider landscape matrix, and so does not require woodland to be contiguous to be functionally connected. It is possible to have high functional connectivity in a physically fragmented landscape with low structural connectivity, as long as the wider matrix supports landscape ecological processes such as species dispersal. This enables investigation of the implications of habitat fragmentation, in particular alterations to habitat area, ecological isolation and matrix quality; explicitly making the distinction between connectedness and connectivity. It is therefore likely to generate recommendations for relatively discrete new areas of woodland and a reduction in the intensive management of other land. This may be more acceptable and compatible with the conservation of a range of woodland and open-ground habitats than application of approaches based on landscape structure.

Habitat patches were identified for each species and the permeability of the intervening matrix was scored for species movement and dispersal (Watts *et al.*, 2005). The permeability scores were used to calibrate dispersal distances and create buffers of varying distance around habitat patches. Functional connectivity between habitat patches occurs where buffers intersect and habitat networks are defined as areas of connected habitat (Figure 3).

The inherent assumptions within this modelling approach; habitat preference, area requirements, dispersal distance and matrix permeability are based on sound ecological theories and have been developed through consultation with the project steering group and are explicit within the modelling approach. BEETLE has been designed as an adaptive management tool to guide and support management action, based on landscape ecological theory, rather than a tool to model and predict actual species dispersal and viability.

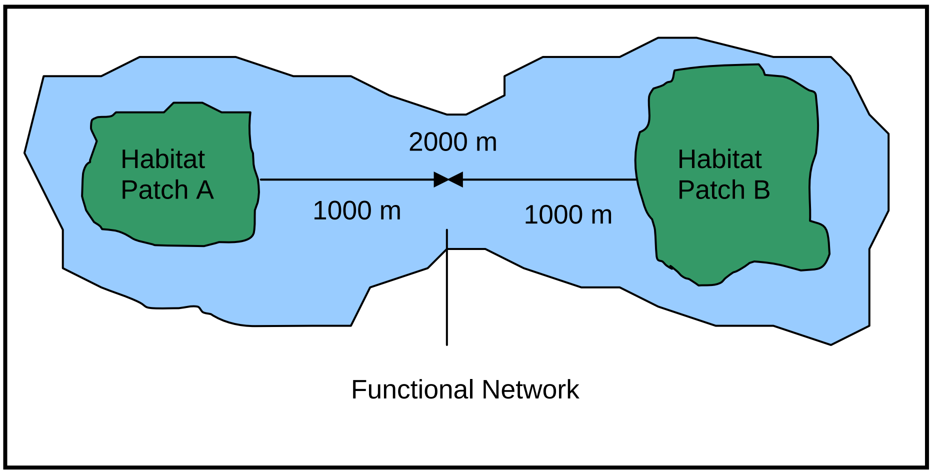


Figure 3. Illustration of functional habitat network in relation to habitat patches

Accounting for geographic differences in land management

The analysis makes an allowance for differences in land management by increasing the dispersal cost (reducing the permeability) of intensively managed land, such as improved grassland and arable areas, which are generally considered more hostile for biodiversity (Table 2). The basis for this is that intensively managed land has: less structure – therefore providing less cover for dispersing organisms able to walk, greater disturbance – thereby damaging plants or destroying plants that are only able to colonise and disperse through successive generations. A reduction in permeability takes more account of chemical inputs, greater disturbance and generally lower woodland/hedgerow habitat. A reduction in dispersal cost (increased permeability) recognises that a woodland, or open habitat, is less intensively managed, or is semi-natural, and therefore less hostile to biodiversity.

Farm and parkland is often described as wood pasture in the uplands with high biodiversity value as it is extensively managed, whereas in the lowlands, it often signifies degraded shelter belt woodland of low biodiversity value, consisting largely of highly modified and managed land. We also attempted to take account of regional differences in the coniferous plantations of Scotland, which are mainly pine (relatively open canopy and therefore more permeable to woodland species) in the north and east, and mainly of spruce (often even-aged close spacing Sitka spruce and therefore less permeable) in the west and south.

Table 2. The landscape permeability of a selection of land cover types used to determine forest habitat networks for Scotland (costs for woodland generalists, other generic focal species has different costs).

	Habitat characteristics (*modification/structure*)	Examples	Dispersal cost *(movement as a function of dispersal distance and cost)*
Low dispersal cost	Quasi-woodland habitats; relatively unmodified with strong 3-D structure and known to readily accommodate woodland species	Semi-natural scrub, bracken	**1 – high permeability** dispersal distance = **1000** dispersal cost = **1** movement 1000/1=**1000m**
Intermediate dispersal cost	Unimproved semi-natural habitats; little modification with well developed structure	Acid grassland bracken, heathland with trees	**3** dispersal distance = **1000** dispersal cost = **3** movement 1000/3= **333m**
	Unimproved semi-natural habitats; little modification but with limited structure	Unimproved grasslands, wetlands with trees	**5** dispersal distance = **1000** dispersal cost = **5** movement 1000/5= **200m**
	Semi-improved habitats; moderate modification and limited structure	Semi-improved grassland, modified heathland, bogs	**10** dispersal distance = **1000** dispersal cost = **10** movement 1000/10= **100m**
High dispersal cost	Heavily modified habitats with very little structure	Improved grassland, arable, amenity grassland	**20** dispersal distance = **1000** dispersal cost = **20** movement 1000/20= **50m**
	Artificial and hostile habitats	Water, buildings, roads	**50 – low permeability** dispersal distance = **1000** dispersal cost = **50** movement 1000/50= **20m**

3.2.4 Network analysis

Forest habitat networks

Woodland generalist and broadleaved specialist network analyses have been undertaken nationally and regionally, allowing strategic usage of the outputs. At a regional scale, the analyses have focused on the most important/relevant habitats resulting in different habitat networks and suggestions for their usage.

Open habitat networks

The main focus of this work has been forest habitat networks, as the scientific principles began examining methods to address woodland habitat fragmentation. However, there is a requirement for applying the same principles to open ground, *e.g.* the development of Lowland Habitat Networks (Humphrey *et al.*, 2007). There is also a need to examine woodland and open ground networks together to determine the best approach to enhance habitat for a range of species. Due to time limitations, if was not possible to undertake an analysis of a wide range of open ground habitat networks, so this project has focused on heathland generalists. Where FHNs and open habitat networks overlap, it is recognised there is a requirement to prioritise important habitat. Overlapping networks signify the presence of semi-natural open ground adjacent to woodland, through which species of the woodland edge and of open ground may occur, and disperse.

Each analysis was undertaken to represent dispersal distances of: 500 m, 1000 m, and 5000 m for the national analyses; 250 m, 500 m, and 1000 m for the regional analyses.

- dispersal restricted species able to disperse 250 metres
- dispersal limited species able to disperse 500 metres
- relatively mobile species able to disperse 1000 metres
- very mobile species able to disperse 5000 metres

The national scale analysis was undertaken to develop a theoretical basis for constructing habitat networks in Scotland and to indicate the existing networks for species with: general woodland habitat preferences; those requiring a more specialist woodland habitat, and species requiring open habitat. The generic focal species chosen to meet these criteria were woodland generalists, broadleaved woodland specialists, and heathland generalists (Table 3).

The outputs from the national analysis (indicative maps, GIS shapefiles, and tabular information) can be used to inform and refine the targets and scale for woodland creation, restoration and habitat management. This can be undertaken according preferences and ambitions for particular assemblages of species and the regional priorities identified through the BAP process.

Table 3. National and regional scale dataset availability, listing generic focal species type and dispersal distance.

Region	Generic focal species	Dispersal distances (m)
National	Heathland generalist	500, 1000, 5000
	Woodland generalist	500, 1000, 5000
	Broadleaved woodland specialist	500, 1000, 5000
Borders & Lothians	Heathland generalist	250, 500, 1000
	Woodland generalist	250, 500, 1000
	Broadleaved woodland specialist	250, 500, 1000
	High quality broadleaved woodland specialist	250, 500, 1000
	High quality mixed woodland / broadleaved woodland specialist	250, 500, 1000
Grampian	Heathland generalist	250, 500, 1000
	Woodland generalist	250, 500, 1000
	Broadleaved woodland specialist	250, 500, 1000
	Riparian woodland specialist	250, 500, 1000
	Wet (Carr) woodland specialist	250, 500, 1000
	Pine woodland specialist	250, 500, 1000
	High biodiversity quality pinewood specialist	250, 500, 1000
Highland	Heathland generalist	250, 500, 1000
	Woodland generalist	250, 500, 1000
	Broadleaved woodland specialist	250, 500, 1000
	Atlantic oakwood specialist	250, 500, 1000
	Pine woodland specialist	250, 500, 1000
	High biodiversity quality pinewood specialist	250, 500, 1000
Perth, Argyll & Fife	Heathland generalist	250, 500, 1000
	Woodland generalist	250, 500, 1000
	Broadleaved woodland specialist	250, 500, 1000
	Pine woodland specialist	250, 500, 1000
SW Scotland	Heathland generalist	250, 500, 1000
	Woodland generalist	250, 500, 1000
	Broadleaved woodland specialist	250, 500, 1000
	High quality broadleaved woodland specialist	250, 500, 1000

The national network outputs were used as an aid to direct the regional analyses. Regional variations have led to the development of networks for habitats that are indicative of the region. This report brings together the regional analyses into a consistent format that can be viewed at the national scale, but it should be emphasised that local knowledge is an essential aspect of FHN development. The regional analyses benefit from the use of improved datasets using, where available, phase 1 survey data, qualified data from interview or coincidence mapping of plant indicator species records, or methodologies to identify habitat types, *e.g*. Atlantic oakwood. Consequently there will be some difference in the size and extent of national and regional networks due to the use of additional, more detailed, data in the regional analyses. The network datasets produced in the analyses are listed in Table 3.

3.3 Sensitivity analysis

Since actual and generic focal species do not represent “real populations” it is difficult to test model outputs (Freudenberger & Brooker, 2004, Lindenmayer et al., 2002, Melbourne et al., 2004). For example, if field survey revealed that species were not present in the habitat they were predicted to occur in, would this be a failure of the model, or simply an indication of poor understanding of the habitat requirements of the species? (Melbourne *et al.*, 2004) suggest that the best way of testing the models is to run a range of simulations to test the sensitivity of the model parameters to changes in value.

A series of sensitivity analyses were performed to determine the change in network area metrics calculated for a generic focal species were sensitive to dispersal ‘cost’ (land cover permeability values) adjustments of a relatively large amount, 20%. The analyses were undertaken for Atlantic oakwood specialists and ancient pinewood specialists in Highland, and broadleaved specialists and woodland generalists for randomly selected areas of Perth, Argyll & Fife and Grampian.

4. Results

The national and regional scale habitat network outputs indicate possibilities for application of the analyses at strategic, regional, and local levels (Figure 5 and Figure 6). Comparison of the networks developed at the national scale with those subsequently developed using more detailed data for the regional scale provides an indication of the opportunities for improving biodiversity across a range of habitats.

National scale

The national scale analysis was undertaken to develop the theoretical basis for constructing habitat networks in Scotland and to indicate existing networks for species with: general woodland habitat preferences; those requiring a more specialist woodland habitat, and species requiring open habitat. The GFS chosen to meet these criteria were woodland generalists, broadleaved woodland specialists, and heathland generalists. Habitat networks were identified for at dispersal distances of 500 m, 1000 m, and 5000 m (Table 4) to represent species with limited, moderate, and high dispersal ability. Although there is a large increase in network area and a reduction in habitat isolation when considering the largest dispersal distance, few species will disperse this far and it would be more appropriate to consider dispersal distances of 500 m or 1000 m.

The results indicate that heathland networks are less fragmented than the woodland networks, with larger individual networks, although the overall extent of the heathland networks is not much greater than woodland networks. Figure 6 shows that there are a small number of very large heathland networks, particularly in the highlands.

Table 4. Summary statistics for: (a) woodland generalists; (b) broadleaved woodland specialists; (c) heathland generalists.

(a)

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)
500	75 690	1 866 825	24	113 016
1000	59 186	2 059 657	34	210 436
5000	14 657	3 331 822	227	1 330 356

(b)

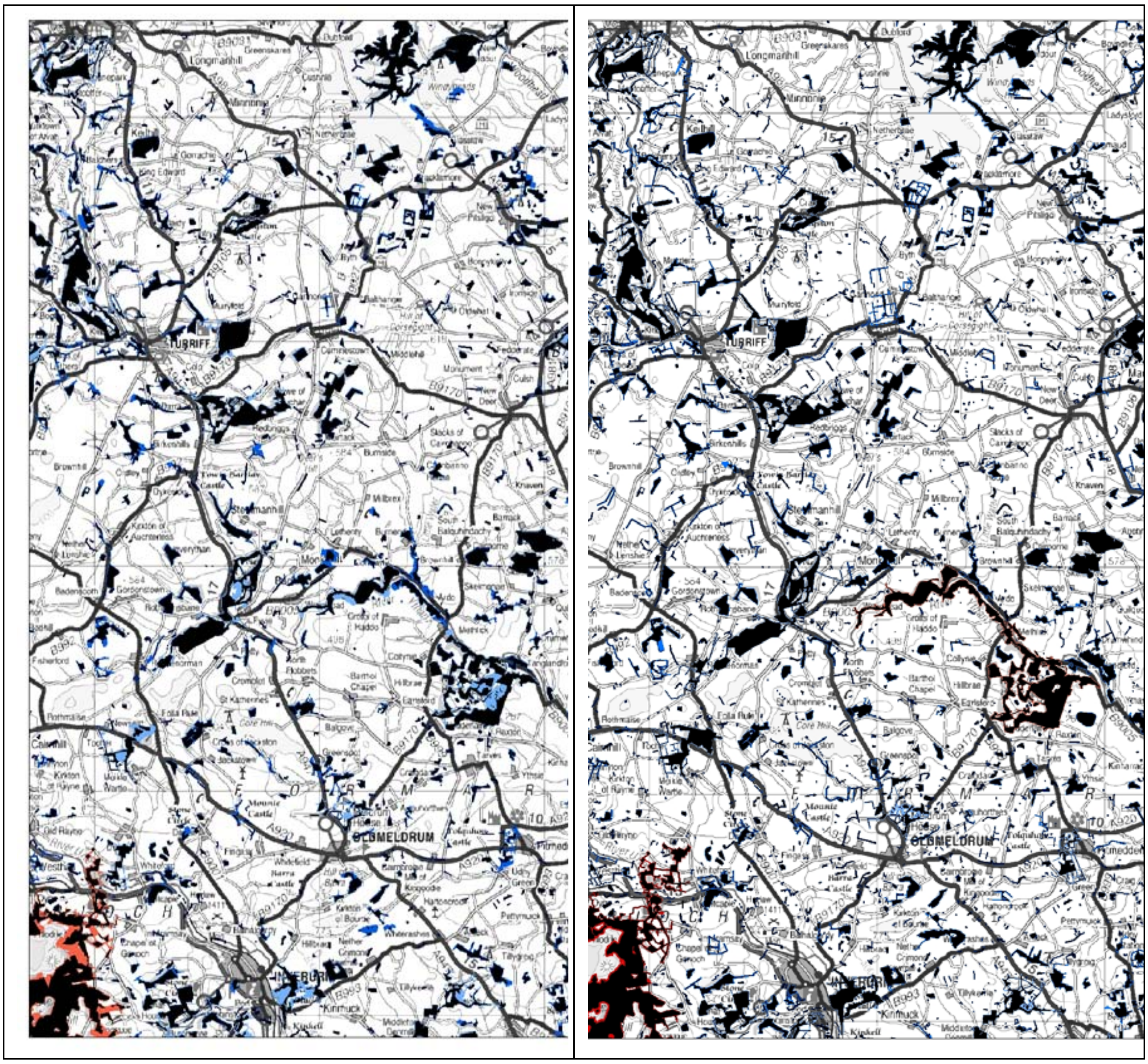
Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)
500	8980	160 825	18	1965
1000	7867	213 250	27	2054
5000	5034	535 577	106	10 122

(c)

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)
500	4520	2 396 949	530	726 581
1000	3265	2 699 558	826	955 855
5000	1302	3 866 485	2 969	1 432 364

The development and analysis of the networks allowed for refinement of the modelling process to be undertaken to reflect: additional datasets (the addition of SSNWI data to complement NIWT); the variation in the biodiversity value of regional land cover types (upland and lowland ecological and management differences). This approach was crucial to gaining a more accurate representation of the current forest habitat network extent and is particularly important for areas with low woodland cover. The effect of both of these factors is apparent on the Buchan plains where there is an increase in both the number and size of networks (Figure 4a and 4b).

(a) (b)



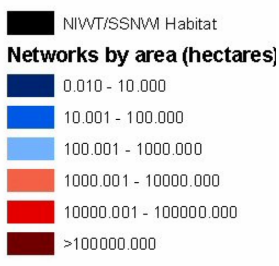
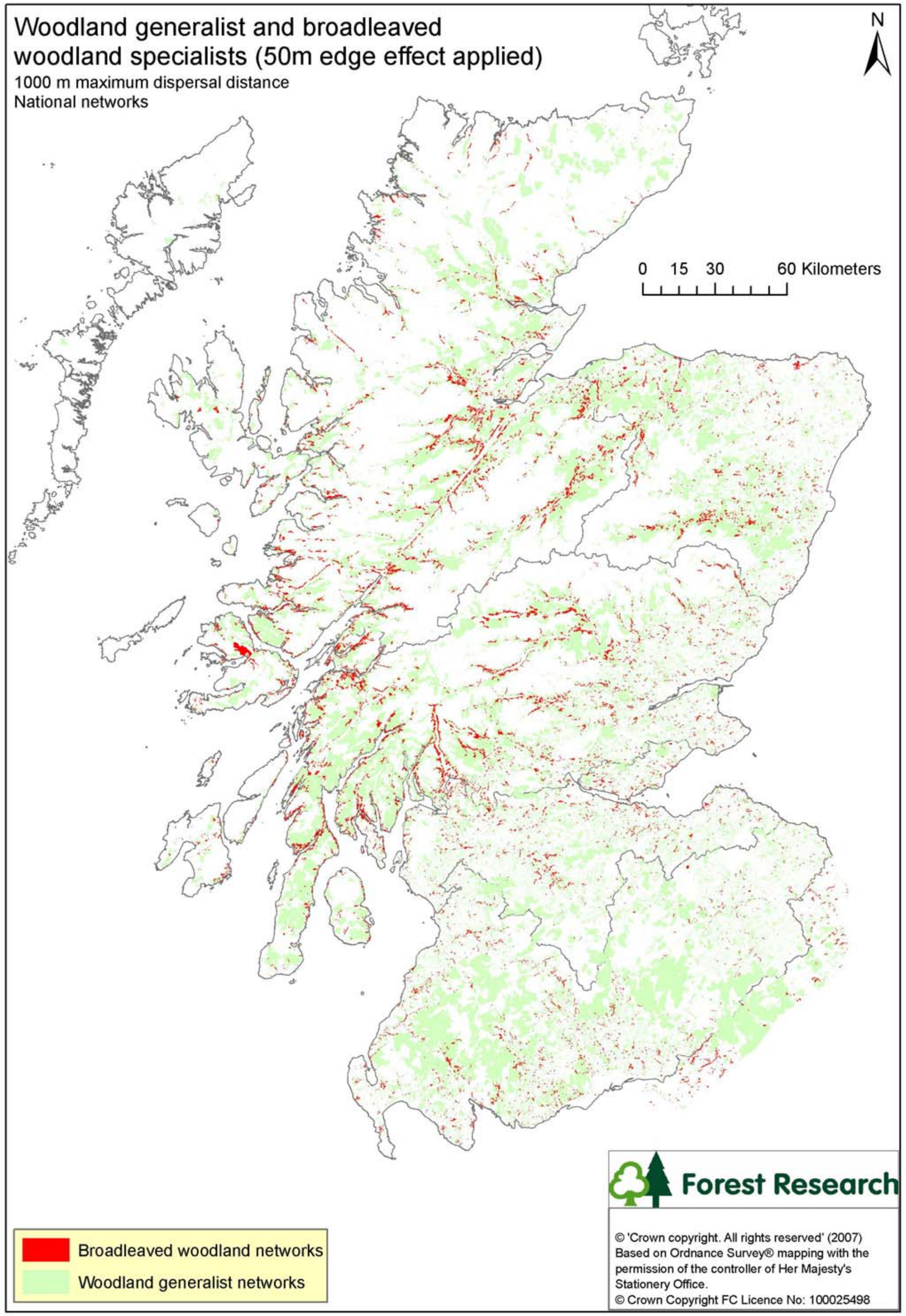


Figure 4. Woodland generalist networks in the Buchan plains, showing (a) the original networks and (b) the revised networks.



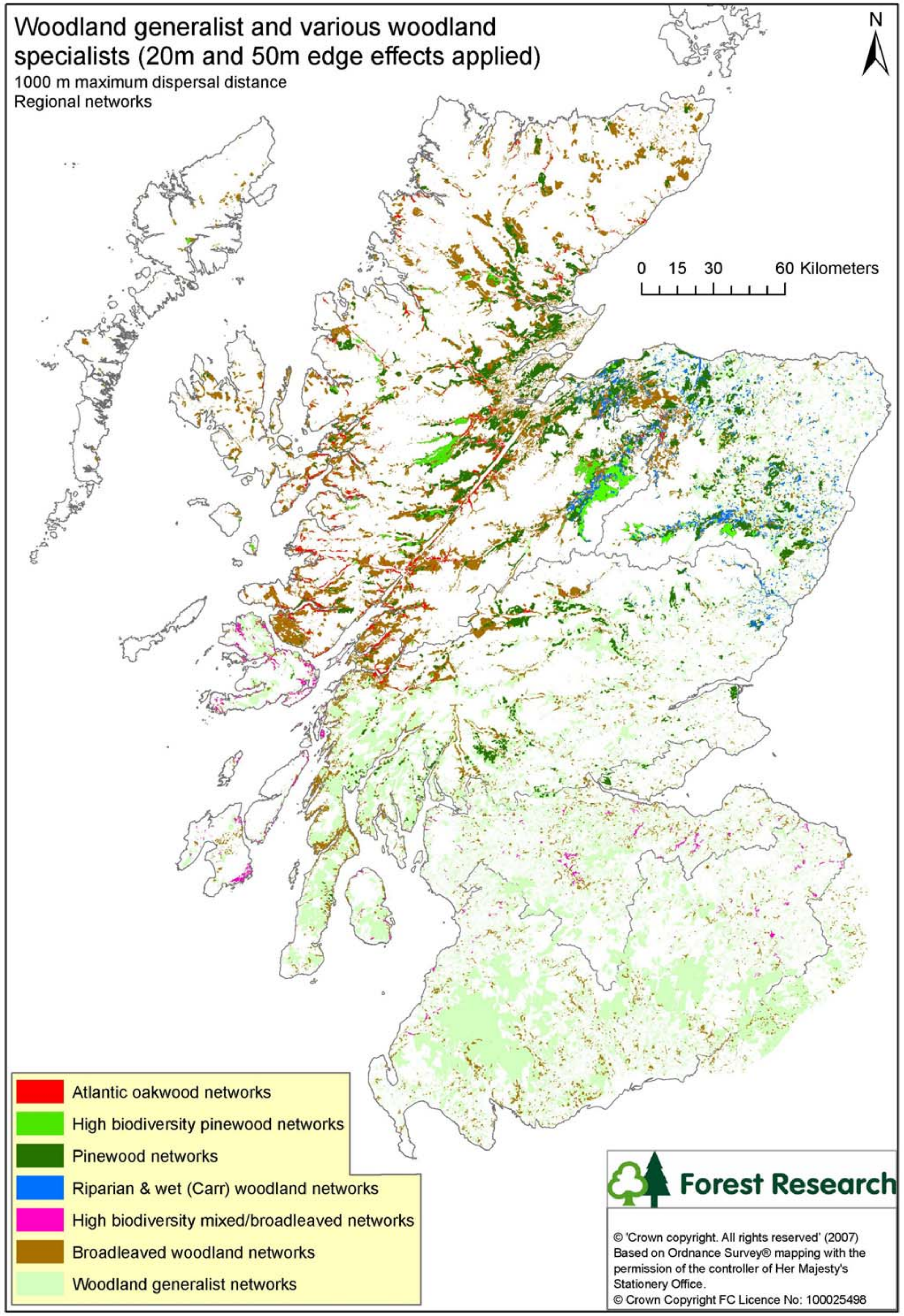


Figure 5. Forest habitat network analyses at (a) national and (b) regional scales, the latter allowing focus on the important regional habitat types.

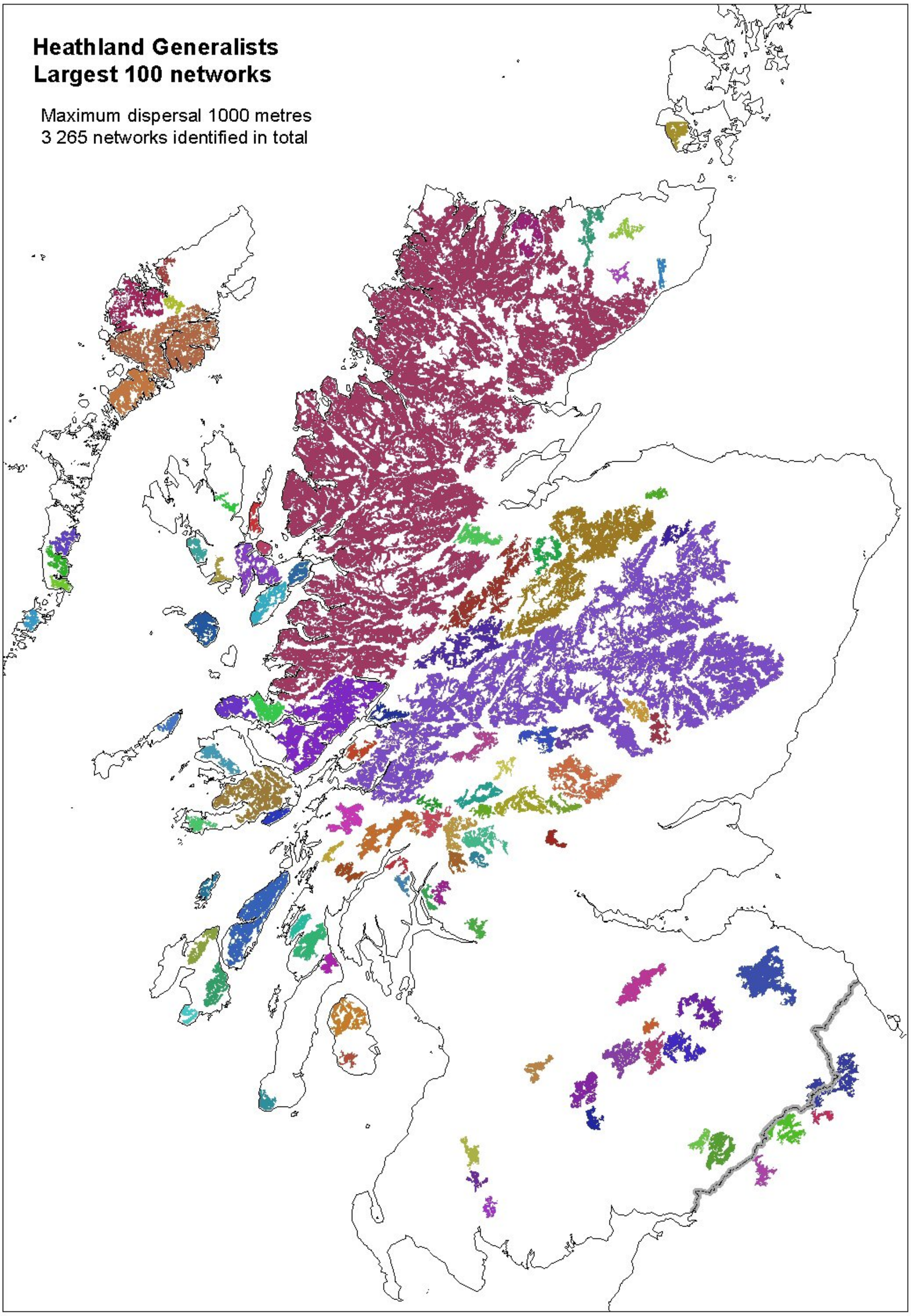


Figure 6. Heathland habitat network analyses at the national scale, indicating the largest 100 networks.

Regional scale

The regional analyses focused on the development of networks for habitats indicative and important in each area. Heathland generalists, woodland generalists, and broadleaved woodland specialists at dispersal distances of 250 m, 500 m, and 1000 m (representing very limited, limited, and moderate dispersal ability) are common to each of the regions. This section demonstrates the type and extent of the regional networks.

Highland

The analysis indicates that there are a number of large woodland generalist networks in Highland Region (Figure 7 and Table 5); many of these are concentrated around the extensive pinewoods located northwest of the Great Glen and in the Spey catchment, extending into the conifer plantations of Moray. There are large ancient pinewood networks, based on woodlands qualified by interview, situated in the Spey catchment and Glen Affric, with smaller networks within the unqualified pinewoods.

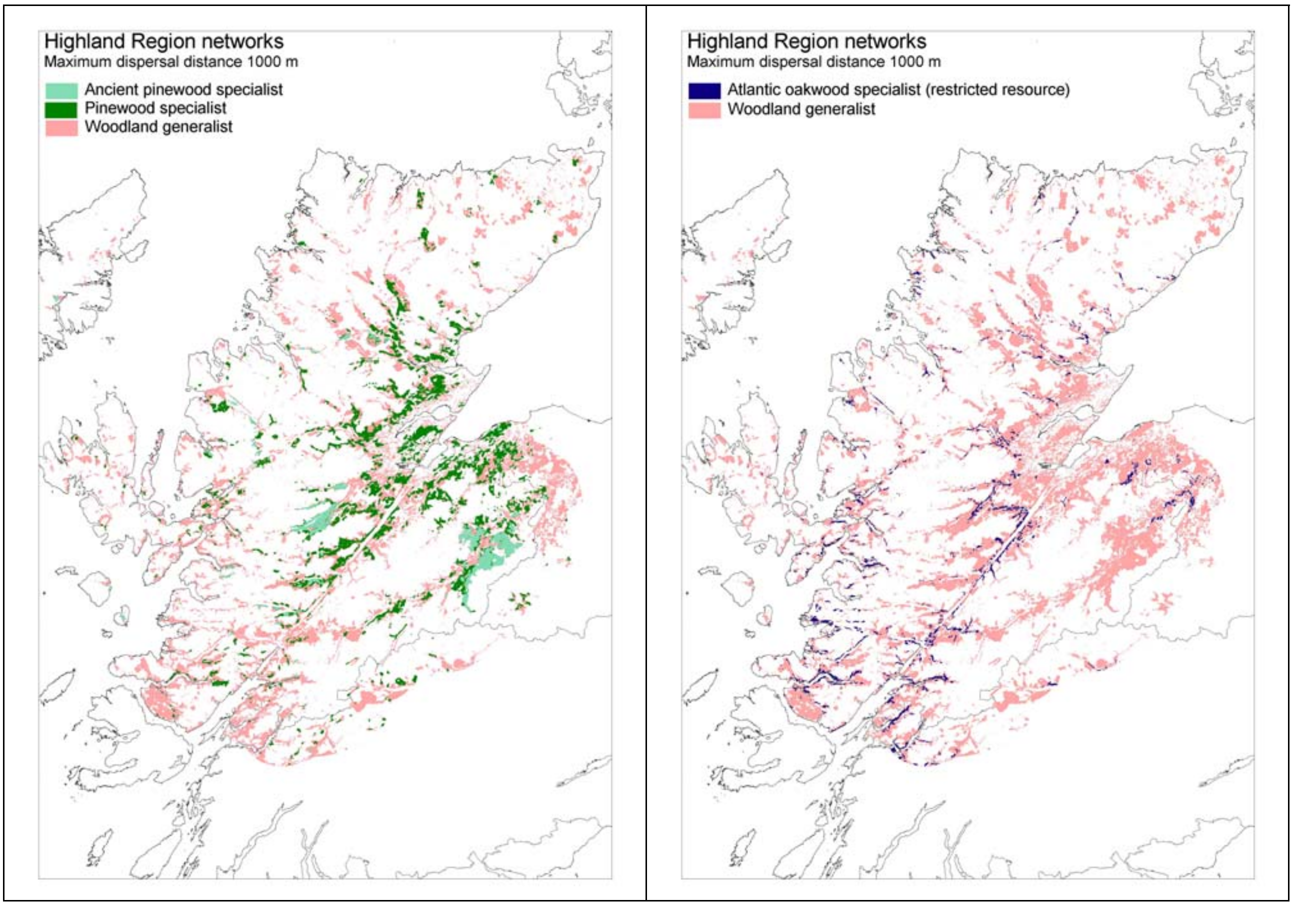
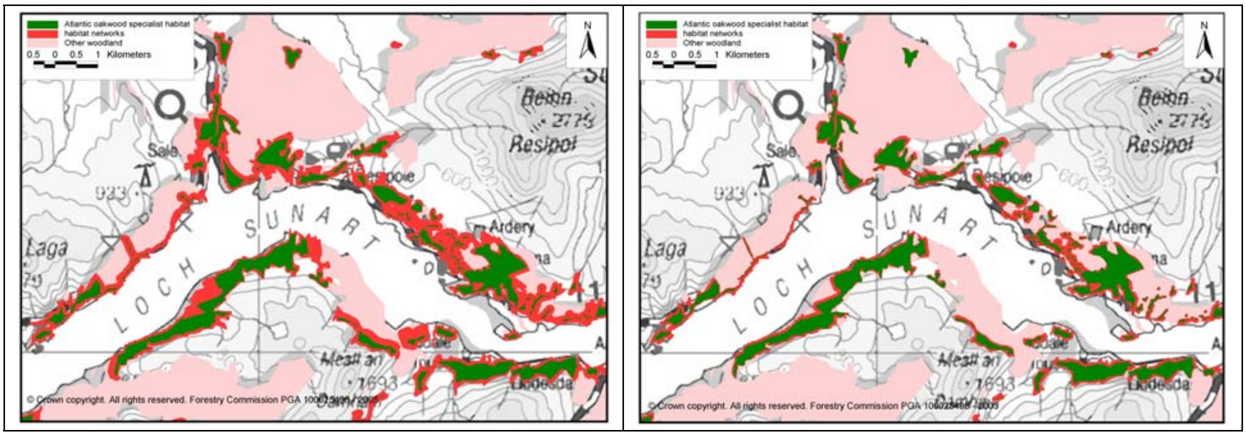


Figure 7. Woodland networks, assuming a maximum dispersal distance of 1km, for ancient pinewood specialists, pinewood specialists, Atlantic oakwood specialists, and woodland generalists in the Highland Region.

Atlantic oakwood networks, derived using a series of rules, appear somewhat limited in extent but indicate opportunities for their consolidation and expansion within the larger woodland generalist networks.

Many of the species associated with Atlantic oakwood networks are likely to be sedentary, suggesting that the smallest of the three maximum dispersal distances (250m) used in the analysis may be the most appropriate for habitat network strategies (Figure 8).

(a)



(b)

Figure 8. Habitat networks for Atlantic oakwood specialists with a maximum dispersal distance of (a) 1000 m and (b) 250 m, located around Loch Sunart.

Table 5. Summary statistics for: (a) woodland generalists; (b) Atlantic oakwood specialists; (c) ancient pinewood specialists; (d) pinewood specialists.

(a)

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)
250	10 978	564 163	51.4	70 384
500	9 022	574 209	63.6	77 347
1000	6 396	650 626	101.7	104 656

(b)

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)
250	1 625	29 493	18.1	502
500	1 312	38 625	29.4	597
1000	1 020	53 174	52.1	869

(c)

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)
250	298	28 863	96.9	5 731
500	229	33 425	146.0	6 398
1000	161	40 511	251.6	7 499

(d)

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)
250	1728	144 872	83.8	11 500
500	1265	169 486	134.0	12 288
1000	921	206 037	223.7	13 127

Borders and Lothians

The results show a large number of small woodland generalist networks, the largest being centred on the conifer plantations across the upland areas to the south of the Scottish Borders (Figure 9). It is also clear that woodland generalists have a larger proportion of habitat (comprised of conifer plantations) compared to specialists, but the degree of permeability over large parts of the landscape is poor, for both generalists and specialists. The woodland specialist networks are also largely fragmented with few networks over 118 ha. However, many of the larger networks are of high biodiversity quality, indicating a few core woodlands from which to initiate expansion.

Figure 9 shows the distribution of four types of network. These are specialists of high quality broadleaved woodland, high quality mixed woodland, other broadleaved woodland and woodland generalists. The map provides a spatially referenced index of a range of woodland networks of varying biodiversity value in Edinburgh, Lothians, and Scottish Borders. In particular, the map provides an estimate of the degree of linkage of high quality woodland with adjacent woodland of lower quality. It can be used as a reference for estimating where high quality woodlands should be protected and expanded, and how woodland expansion might seek to link existing structures, to form stepping stones between two or more networks.

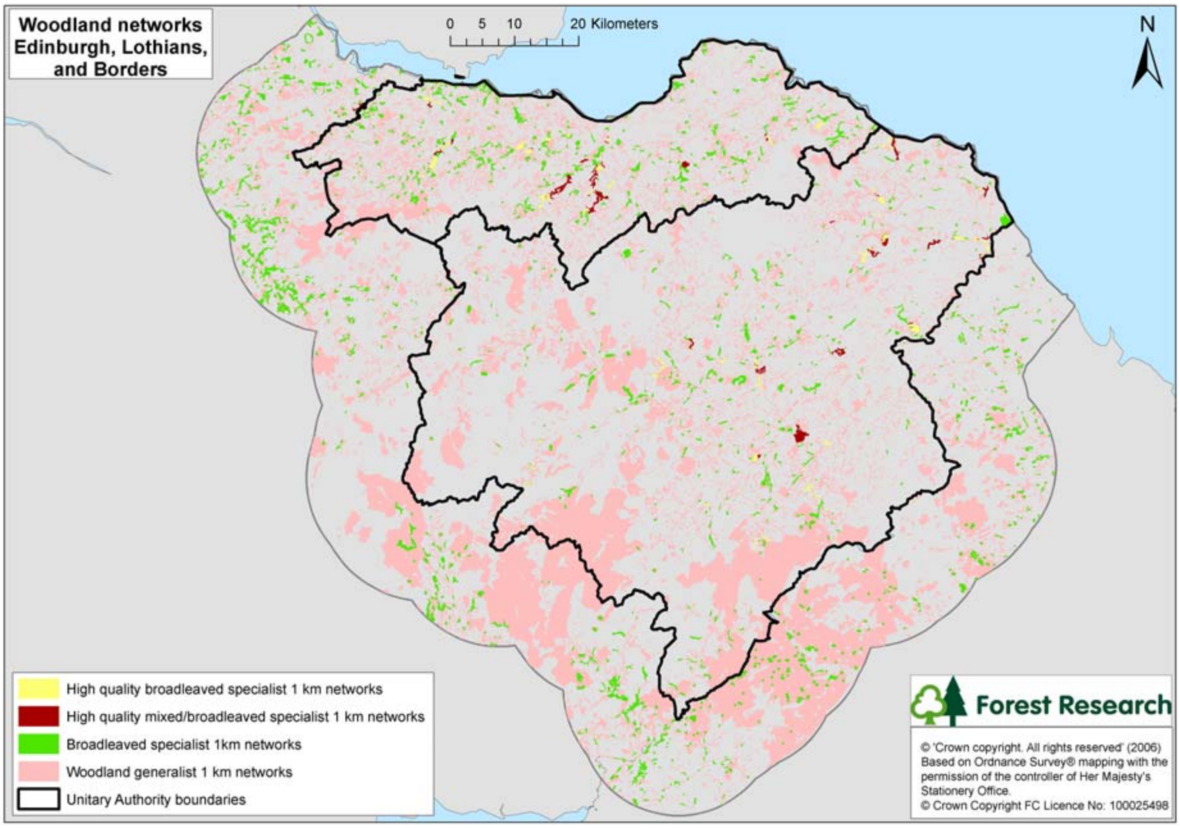


Figure 9. Woodland networks, assuming a maximum dispersal distance of 1km, for high quality specialists, broadleaved specialists, and woodland generalists in the regions of Edinburgh, Lothians, and Borders.

The metrics (Table 6b-d) indicate 1 329 broadleaved networks covering 34 888 ha. Within these structures are 64 high quality mixed / broadleaved woodland networks covering 4 754 ha, and 62 high quality broadleaved networks covering 2 565 ha. The 250 m to 1000 m dispersal sensitivity analysis shows that the number of high quality mixed woodland specialist networks is reduced by 46% with a 1.7 times increase in network size (Table 6c). Networks of this type constitute small sections of the woodland generalist networks, they are slightly less fragmented than, for example high quality broadleaved specialist networks (reduction in networks - 31%, size increase 1.9 times), and can be more easily connected through existing woodland corridors. The woodland specialist sensitivity analysis indicates that with increases in network size, connectivity is likely to be affected by the relatively low cost of dispersal through other woodland types. This is apparent in the smaller increase in area of non-habitat in the specialist networks compared to the generalists, suggesting that the matrix is much less permeable to specialists than to generalists.

Table 6. Landscape metrics for the five generic focal species analyses covering the region of Edinburgh, the Lothians, and the Borders.

a) Woodland generalists

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat in network (ha)	Percentage less favoured habitat in network
250	12 768	231 453	18.1	33 492	42 640	18
500	11 005	256 683	23.3	36 834	67 870	26
1000	7 876	311 824	39.6	62 485	123 011	39

b) Broadleaved woodland specialists

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat in network (ha)	Percentage less favoured habitat in network
250	1 915	15 907	8.3	227	11 835	74
500	1 613	22 857	14.2	328	18 785	82
1000	1 329	34 888	26.3	433	30 816	88

c) High quality mixed woodland and broadleaved woodland specialists

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat in network (ha)	Percentage less favoured habitat in network
250	119	2 879	24.2	242	1 792	62
500	80	3 642	45.5	324	2 559	70
1000	64	4 754	74.3	398	3 672	77

d) High quality broadleaved woodland specialists

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat in network (ha)	Percentage less favoured habitat in network
250	90	1 336	14.8	104	950	71
500	71	1 798	25.3	119	1 405	78
1000	62	2 565	41.4	145	2 158	84

e) Heathland generalists

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat in network (ha)	Percentage less favoured habitat in network
250	4 706	1 456 981	309.6	430 571	163 398	11
500	2 953	1 587 773	537.7	522 174	294 190	19
1000	1 791	1 800 132	1 005.1	924 580	506 549	28

Grampian

The results show a large number of small woodland generalist networks, the largest being located through the Dee catchment, the Spey catchment, and Moray (Figure 10). The woodland specialist networks are largely fragmented and, with the exception of the pinewoods, few networks are greater than 100 ha. However, many of the larger riparian and wet (Carr) woodland networks support a large number of important species, suggesting that there are key areas of high biodiversity value from which to initiate expansion. Figure 10 shows three types of network: specialists of riparian woodland, other broadleaved woodland and woodland generalists. The map indicates the degree of linkage of riparian and wet (Carr) woodlands with adjacent woodlands of other types, which can be used to determine where networks might be enhanced.

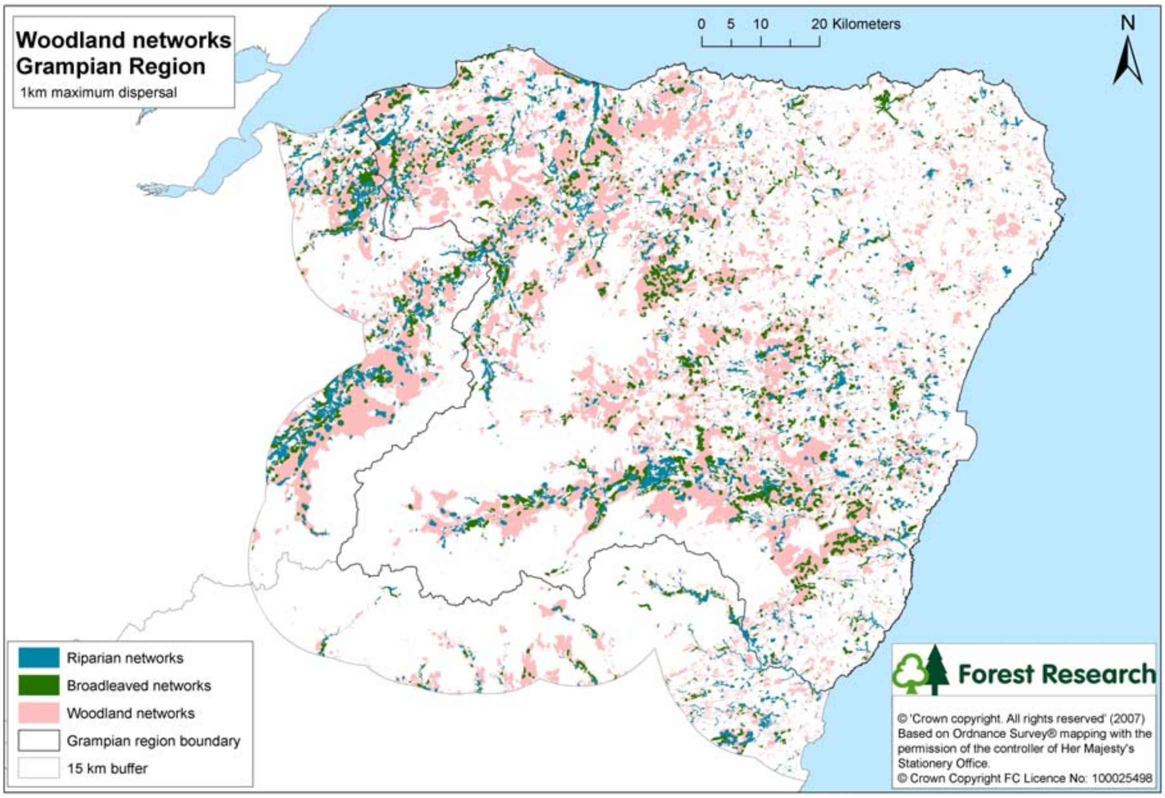


Figure 10. Woodland networks, assuming a maximum dispersal distance of 1km, for riparian woodland specialists, broadleaved specialists, and woodland generalists in the Grampian Region.

The metrics for woodland generalists (Table 7) illustrates the relative degree of habitat fragmentation for different GFS of woodland, and a comparison with the heathland GFS. We can test the sensitivity of woodland generalists in the modelled landscape by increasing the dispersal distance from 250 m to 1000 m. This has the effect of reducing the number of woodland generalist networks (Table 7a) by about 33%, indicating increased network connectivity, while increasing the network area 1.2 times. For this study we have settled on the 1000 m dispersal distance, reflecting moderately mobile woodland generalists: woodland birds, fox, badger, and wind dispersed woodland edge plants.

Table 7(b-d) shows 1 676 broadleaved networks covering 87 834 ha of land. Within these structures are 1 595 riparian woodland networks covering 52 214 ha, and 1 324 wet (Carr) woodland networks covering 45 071 ha. The 250 m to 1000 m dispersal sensitivity analysis shows that the number of riparian woodland networks is reduced by 37% with a 2.9 times increase in network size (Table 7c) and the number of wet (Carr) woodland networks is reduced by 40% with a 2.8 times increase in network size. Networks of this type constitute small parts of the wider woodland generalist network. However they are more fragmented than broadleaved woodland networks (reduction in networks - 46%, size increase 2.2 times), but could be connected through targeted land-use change. The woodland specialist sensitivity analysis indicates that increases in both network size and connectivity are likely to be affected by the relatively low cost of dispersal through other woodland types. This is apparent in the smaller proportional increase in area of less favoured habitat in the specialist networks compared to the generalists, suggesting that the matrix is much less permeable to specialists than to generalists. The riparian and wet (Carr) woodland networks are likely to contain a larger percentage of less favoured habitat than broadleaved networks due to the smaller buffer (20 m rather than 50 m) used for identifying the core riparian and wet (Carr) woodland habitat.

Table 7. Landscape metrics for the four of the generic focal species analyses in the study area (Grampian region and a 15 km external buffer).

a) Woodland generalists

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat in network (ha)	Percentage less favoured habitat in network
250	8 363	274 613	32.8	41 131	43 772	16%
500	7 334	296 359	40.4	46 815	65 518	22%
1000	5 567	340 091	61.1	75 127	109 250	32%

b) Broadleaved woodland specialists (50 m internal buffer applied)

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat in network (ha)	Percentage less favoured habitat in network
250	3 094	40 360	13.0	458	26 454	66%
500	2 308	57 253	24.8	1 217	43 347	76%
1000	1 676	87 834	52.4	3 266	73 928	84%

c) Riparian woodland specialists (20 m internal buffer applied)

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat in network (ha)	Percentage less favoured habitat in network
250	2 550	17 744	7.0	149	13 518	76%
500	2 016	29 469	14.6	429	25 243	86%
1000	1 595	52 214	32.7	1 128	47 988	92%

d) Wet (Carr) woodland specialists (20 m internal buffer applied)

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat network (ha)	Percentage less favoured habitat in network (ha)
250	2 185	15 863	7.3	145	11 794	74
500	1 552	26 023	16.8	482	21 954	84
1000	1 324	45 071	34.0	1 268	41 002	91

e) High biodiversity pinewood specialists (50 m internal buffer applied)

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat network (ha)	Percentage less favoured habitat in network (ha)
250	108	16 822	155.8	5 708	4 107	24
500	75	19 174	255.7	6 268	6 459	34
1000	62	22 894	369.3	7 390	10 179	44

f) Pinewood specialists (50 m internal buffer applied)

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat network (ha)	Percentage less favoured habitat in network (ha)
250	1 135	73 603	69.3	9 435	36 990	47
500	806	89 623	111.2	9 987	48 010	54
1000	566	113 263	200.1	11 320	7 1650	63

g) Heathland generalists

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat in network (ha)	Percentage less favoured habitat in network
250	1 058	274 265	259.2	84 318	30 384	11%
500	649	298 134	459.4	95 502	54 253	18%
1000	378	337 529	892.9	248 493	93 648	28%

SW Scotland

The SW Scotland study identified the quantity and location of the broadleaved woodland specialist networks (Figure 11) and further identified the high quality broadleaved woodland specialist networks. The total area of broadleaved woodland specialist habitat identified by the analysis is 25 000 ha. However, 20 000 ha (80%) was removed as core habitat as a result of imposing the 50 m edge effect buffer. This represents a greater proportion than the 74% removed in the national analysis. The reason for this is because broadleaved woodlands in SW Scotland are generally long and narrow, concentrated in the river valleys and in strips along the coast. As a result such habitat has a high edge:area ratio which is higher than the national average.

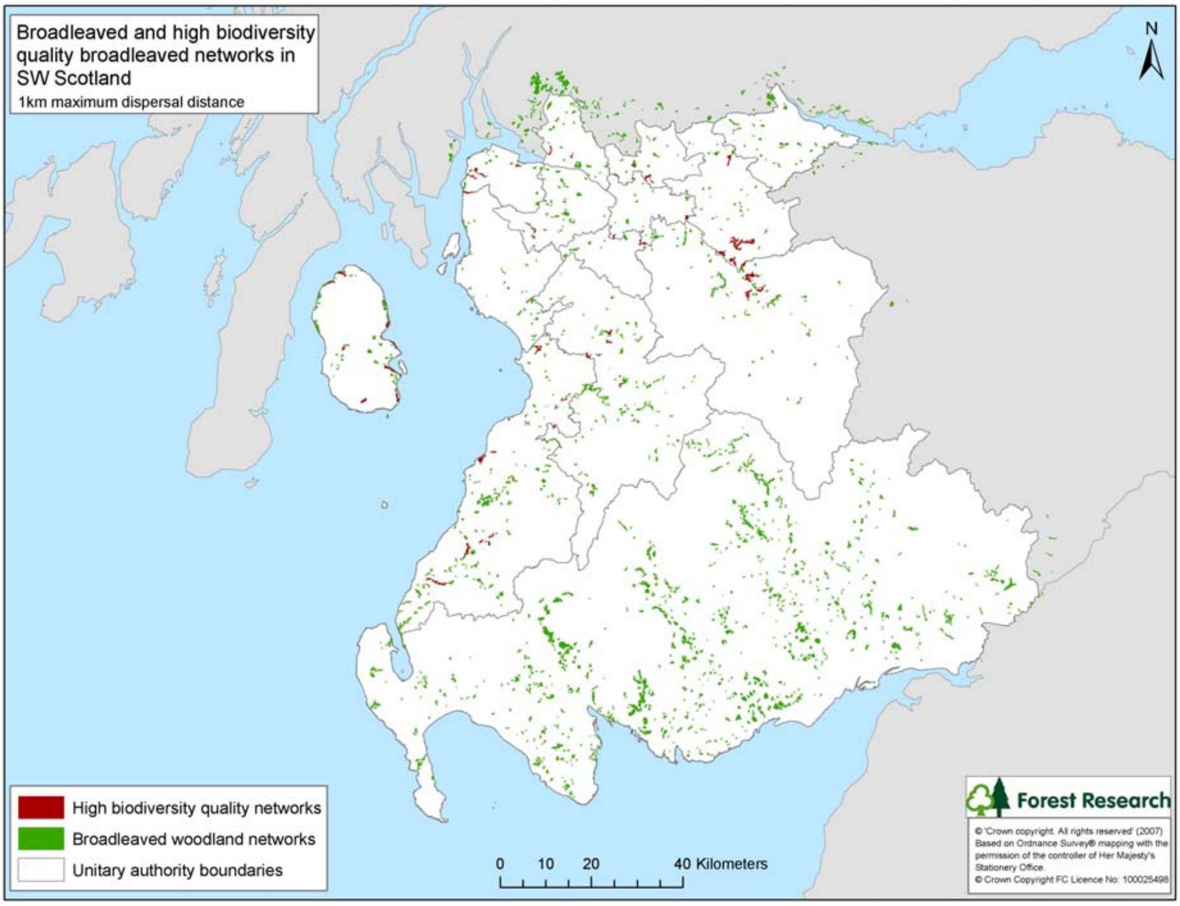


Figure 11. Woodland networks, assuming a maximum dispersal distance of 1km, for high quality specialists and broadleaved specialists in SW Scotland.

The total area of broadleaved woodland specialist habitat qualified as potentially having a high biodiversity value is 1,792 ha. This does not include 1,249 ha, representing 70% of the area of broadleaved woodlands, which was removed from the habitat layer as lying within 50 m of the woodland edge. The core woodland conditions were assumed only to apply 50 m or more from a woodland edge. The metrics for SW Scotland are summarised in Table 8.

Opportunities and constraints for reducing woodland habitat fragmentation were explored (Figure 12). The major land cover types in lowland SW Scotland are improved grassland, urban areas, and woodlands. There may be opportunities for the reduction in management intensity of improved grasslands or conversion to woodland through Land Management Contracts. In the proximity of urban areas, woodland expansion through the Woodlands In and Around Towns initiative (WIAT (Anon., 2005)) may be appropriate. Woodlands that are not broadleaved woodland specialist habitat were classed as other woodland in the analysis, and will include mixed broadleaved/conifer and pure conifer woodlands which could be converted to broadleaf. Priority open ground habitats, such as unimproved grassland and wetlands should be protected and care needs to be taken the any woodland expansion strategies do not adversely affect the integrity of these habitats.

Table 8. Summary statistics for unqualified and qualified broadleaved woodland specialist networks

Specialist network type	Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)
Unqualified broadleaved	1000	1273	46084	36	598
Unqualified broadleaved	2000	990	80495	81	1636
Qualified broadleaved	1000	61	3886	64	461
Qualified broadleaved	2000	56	6444	115	654

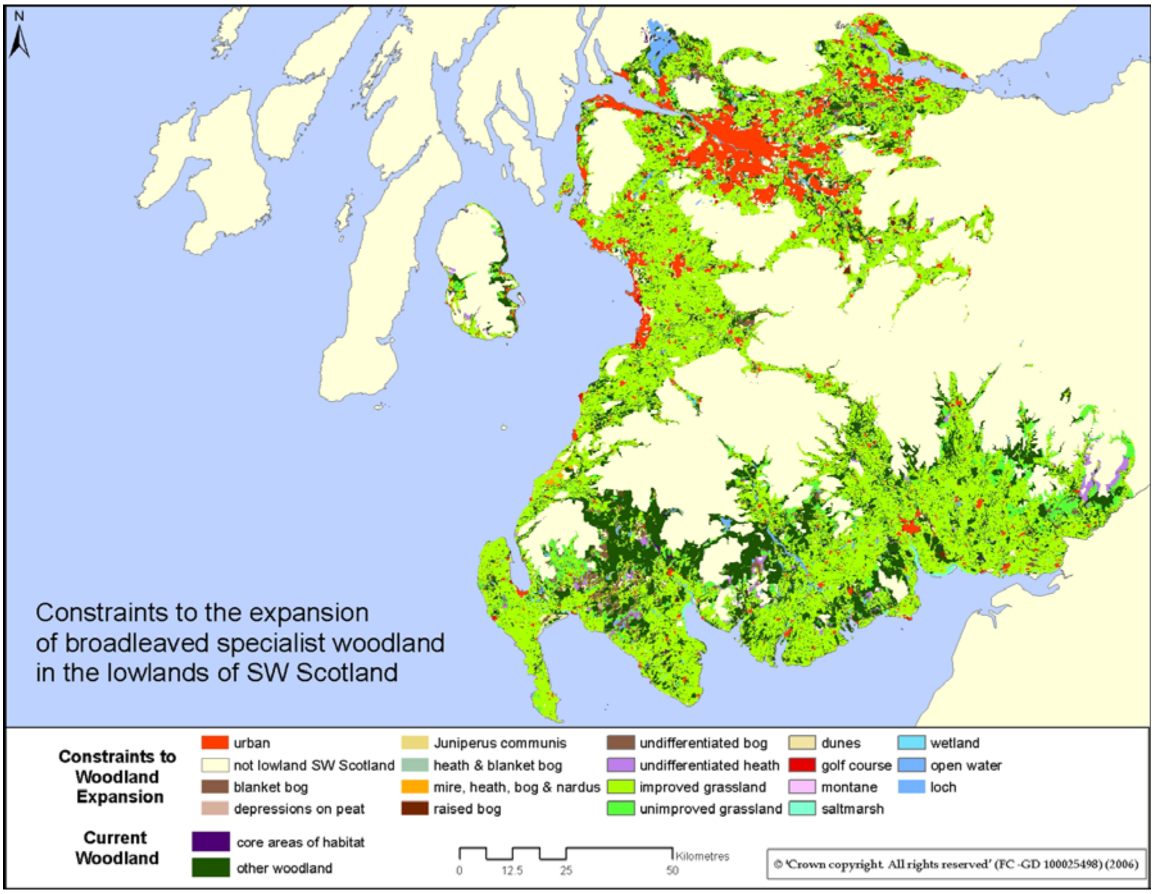


Figure 12. Constraints to the expansion of broadleaved woodland specialists in the lowlands.

Perth, Argyll & Fife

The analysis for this region identified the extent of the networks for: broadleaved woodland specialists, pinewood specialists, woodland generalists and heathland generalists (Figure 13). The woodland generalist networks are more extensive in the west of the region, due to the large coniferous plantations, whilst the broadleaved woodlands occur in valleys, and are associated with rivers, streams, and lochs across a wide geographical area. The pinewood networks occur mostly to the north and east of the region, with other pinewoods occurring to the east of Loch Lomond.

The map (Figure 13) indicates the degree of linkage between the woodland specialist networks and, in particular, shows how they can be used as a reference for estimating where opportunities exist for protecting, improving, and expanding specialist networks within the larger woodland generalist network.

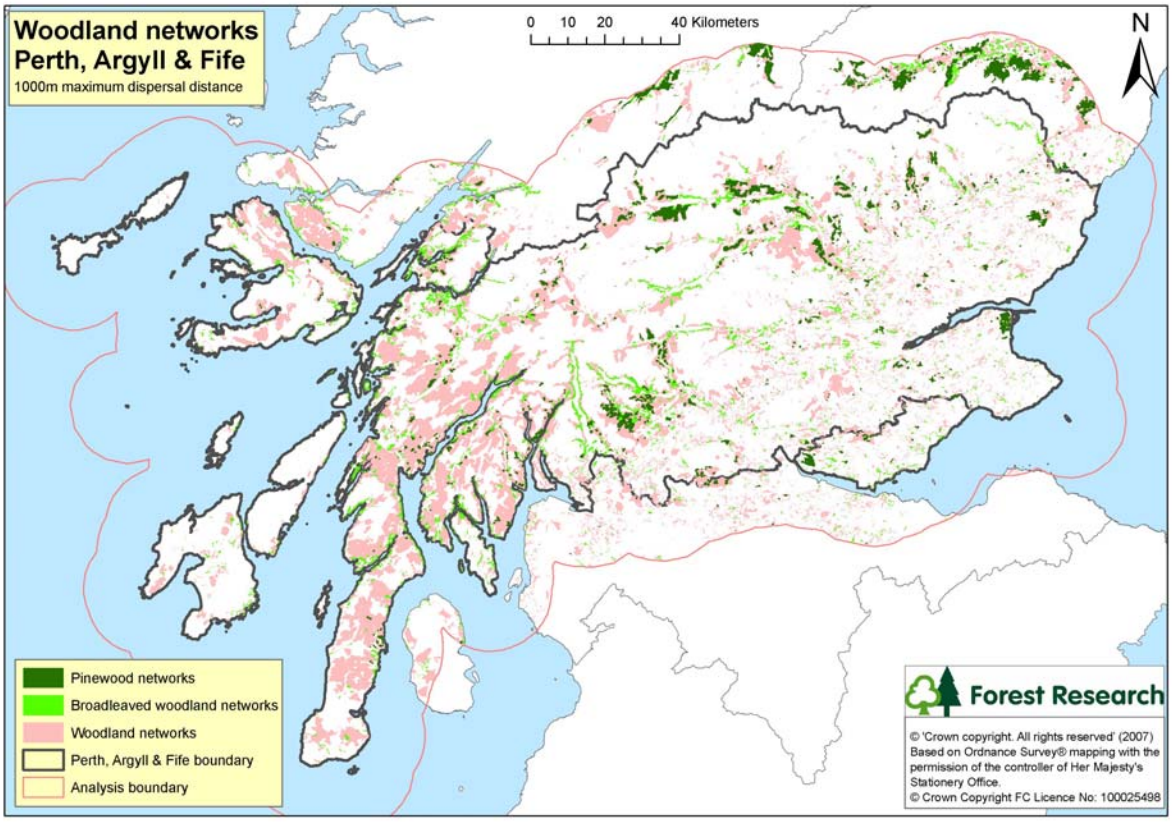


Figure 13. Woodland networks, assuming a maximum dispersal distance of 1km, for pinewood and broadleaved specialists, and woodland generalists, in Perth, Argyll & Fife.

Table 9 shows that 8 756 woodland generalist networks occur in the region, covering 544 505 ha. Within these structures are 1 996 broadleaved networks covering 71 285 ha and 767 pinewood networks covering 69 171 ha.

The 250 m to 1000 m dispersal sensitivity analysis showed a 36% reduction in the number of broadleaved woodland specialist networks with a 1.7 times increase in network size (Table 9b). Networks of this type constitute small sections of the woodland generalist network, they are slightly less fragmented than, for example pinewood specialist networks (reduction in networks - 45%, size increase 1.9 times), and can be more easily connected through existing woodland corridors. The woodland specialist sensitivity analysis indicated that increases in network size and connectivity are likely to be affected by the relatively low cost of dispersal through other woodland types. This is apparent in the smaller increase in area of non-habitat in the specialist networks compared to the generalists, suggesting that the matrix is much less permeable to specialists than to generalists.

Table 9. Landscape metrics for the four of the generic focal species analyses in the study area (Perth, Argyll & Fife and a 15 km external buffer).

a) Woodland generalists

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat in network (ha)	Percentage less favoured habitat in network
250	11767	464059	39.4	14029	22069	5%
500	10410	499394	48.0	22647	57404	11%
1000	8756	544505	62.2	26901	102515	19%

b) Broadleaved woodland specialists (50 m internal buffer applied)

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat in network (ha)	Percentage less favoured habitat in network
250	2719	41106	15.1	480	27757	68%
500	2272	51181	22.5	551	37832	74%
1000	1996	71285	35.7	998	57936	81%

c) Pinewood specialists (50 m internal buffer applied)

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat in network (ha)	Percentage less favoured habitat in network
250	1389	37249	26.8	2173	18572	50%
500	1046	48746	46.6	2401	30069	62%
1000	767	69171	90.2	2768	50494	73%

d) Heathland generalists

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)	Area of less favoured habitat in network (ha)	Percentage less favoured habitat in network
250	1683	694280	412.5	83373	67915	10%
500	1241	751144	605.3	96845	124779	17%
1000	865	847267	979.5	344018	220902	26%

Sensitivity analyses

Sensitivity analyses undertaken for the Highland region, by increasing and decreasing the dispersal cost values by ± 20%, indicate relatively small changes in the number, total area and mean area of networks for Atlantic oakwoods and high biodiversity pinewoods (Table 10). The standard errors generated suggest that the mean area of networks may be slightly more sensitive to changes than the number of networks and total area of networks are individually.

Table 10. Sensitivity analyses, including standard errors for Atlantic oakwood and high biodiversity specialist networks in Highland Conservancy.

		Atlantic oakwoods			High biodiversity pinewoods		
Costs	**Dispersal distance**	**Number of networks identified**	**Total area of networks (ha)**	**Mean area of networks (ha)**	**Number of networks identified**	**Total area of networks (ha)**	**Mean area of networks (ha)**
Original	250	284	5 679	20.0	113	18 795	166.3
Increased	250	297	5 445	18.3	120	18 395	153.3
Reduced	250	268	5 985	22.3	104	19 315	185.7
	Standard Error	8.386	156.346	1.159	4.631	266.333	9.414
Original	500	238	6 850	28.8	91	20 639	226.8
Increased	500	247	6 506	26.3	96	20 042	208.8
Reduced	500	230	7 339	31.9	87	21 433	246.4
	Standard Error	4.910	241.678	1.620	2.603	402.887	10.857
Original	1000	197	8 694	44.1	72	23 299	323.6
Increased	1000	204	8 125	39.8	78	22 514	288.6
Reduced	1000	185	9 485	51.3	66	24 349	368.9
	Standard Error	5.548	394.338	3.355	3.464	531.557	23.244

The sensitivity analysis undertaken for sample areas of Grampian Conservancy region and Perth, Argyll & Fife, with dispersal cost values increased and decreased by ± 20% (Table 11 and Table 12), also indicate relatively small changes in the number, total areas and mean areas of networks for broadleaved specialist and woodland generalist networks. Broadleaved specialist networks are slightly more sensitive to changes than woodland generalist networks, which is likely to be due to the larger amount of less favoured habitat in the broadleaved networks than those in woodland generalist networks.

Table 11. Sensitivity analyses, including Standard Errors for woodland generalist networks in sample areas of Grampian Conservancy and Perth, Argyll & Fife.

Woodland generalist		Grampian			Perth, Argyll & Fife		
Costs	**Dispersal distance**	**Number of networks identified**	**Total area of networks (ha)**	**Mean area of networks (ha)**	**Number of networks identified**	**Total area of networks (ha)**	**Mean area of networks (ha)**
Original	250	377	11 673	31.0	123	4 867	39.6
Increased	250	401	11 206	27.9	129	4 673	36.2
Reduced	250	371	11 865	32.0	123	4 883	39.7
	Standard Error	9.165	195.905	1.213	2.000	67.365	1.136
Original	500	341	12 817	37.6	108	5 170	47.9
Increased	500	362	12 157	33.6	113	5 043	44.6
Reduced	500	322	13 279	41.2	104	5 213	50.1
	Standard Error	11.552	325.592	2.212	2.603	50.948	1.593
Original	1000	272	14 884	54.7	91	5 659	62.2
Increased	1000	292	14 149	48.5	95	5 454	57.4
Reduced	1000	248	15 661	63.2	85	5 838	68.7
	Standard Error	12.719	436.497	4.256	2.906	110.940	3.266

Table 12. Sensitivity analyses, including Standard Errors for broadleaved specialist networks in sample areas of Grampian Conservancy and Perth, Argyll & Fife.

Broadleaved specialist		Grampian			Perth, Argyll & Fife		
Costs	**Dispersal distance**	**Number of networks identified**	**Total area of networks (ha)**	**Mean area of networks (ha)**	**Number of networks identified**	**Total area of networks (ha)**	**Mean area of networks (ha)**
Original	250	97	1 727	17.8	53	806	15.2
Increased	250	105	1 626	15.5	59	760	12.9
Reduced	250	92	1 825	19.8	51	857	16.8
	Standard Error	3.786	57.487	1.257	2.404	28.009	1.138
Original	500	82	2 283	27.8	44	1 023	23.3
Increased	500	85	2 077	24.4	48	946	19.7
Reduced	500	80	2 469	30.9	40	1 119	28.0
	Standard Error	1.453	113.069	1.854	2.309	49.875	2.389
Original	1000	74	3 254	44.0	37	1 422	38.4
Increased	1000	78	2 856	36.6	37	1 281	34.6
Reduced	1000	71	3 628	51.1	35	1 546	44.8
	Standard Error	2.028	222.975	4.183	0.667	76.497	2.960

5. Use of the networks (Recommendations)

The national and regional habitat networks provide a decision support tool within the forest planning process. Specifically, the networks can help to identify opportunities for addressing habitat fragmentation at a range of scales:

- National – for strategic level planning, e.g. expansion of woodland resource where appropriate in conjunction with helping to inform how policy may direct grant aid. Climate change proofing – identifying where potential 'pinch points' are within networks to enable targeting of measures to facilitate how species may move in response to climate change.
- Regional – to meet regional targets and priorities, *e.g.* conversion of conifer plantations to broadleaved woodlands, where to target within region. Determination of how forest plans can be developed to minimise disruption to existing FHNs. Examination of the broadleaved woodland specialist networks to identify potential threats posed by grey squirrel movement into red squirrel strongholds.
- Local / Catchment – targeted improvement of habitat networks of local importance, particularly for designated sites and restoration of ancient woodland.
- All scales – link into land management contracts to prioritise habitat network improvements, incorporating other decision-support systems such as Ecological Site Classification (ESC). HAP targets for expansion and restoration of woodland to determine how to extend networks to reach targets, whilst avoiding priority open ground. Identification of open ground areas where forest expansion is not appropriate, e.g. priority open-ground habitat

Strategic applications of the habitat networks to reduce woodland fragmentation and isolation are detailed below, followed by examples of how planning should take account of open ground habitats. Guidance on the use of the networks at regional and local scales has been incorporated into separate document, downloadable from http://www.forestresearch.gov.uk/habitatnetworks .

Strategic applications to reduce woodland fragmentation and isolation

Analyses at the regional and national scales are important for testing scenarios of the impact of climate change and forest policy.

A) Addressing climate change at National & Regional scales

There is much interest in ensuring that forest managers and land managers in general are equipped with tools to assess the impact of climate change, in order to implement an appropriate adaptive management response. One of the potential implications of climate change is that the climatic selection pressure may cause ill-adapted species to shift in range to cooler localities (northwards and to higher ground) in response to increased warmth (Broadmeadow *et al.,* 2005). It is recognised that "ecosystem resilience needs to be enhanced and the connectivity of habitats improved to allow for necessary shifts in ranges and unhindered migration" (DEFRA, 2006). Woodland (and other semi-natural open ground) ecosystems can maintain resilience and continue to provide opportunities for species dispersal within a larger meta-population. To do this habitat networks need to be robust, and they should provide a range of microsite conditions for colonisation and dispersal processes to function. This will help ensure that a functional woodland ecosystem continues to support range changes as selection pressure is exerted by climate change. This largely entails a consideration of strategic networks to facilitate species dispersal south to north at the regional and national scale. However securing our current habitats, and creating new areas that may in the future provide suitable habitat for species dispersal, is largely based on a precautionary assumption. We assume that it is better to try and reduce fragmentation than do nothing – to support the wider woodland biodiversity in general - and hopefully some rare species in the process, as habitat conditions allow. It is very unlikely that new habitat creation will benefit sedentary woodland specialist species for a long time. Indeed it is more important to buffer good quality ancient and long established habitat to consolidate and support biodiversity. New habitat is likely to help generalists and less sedentary species sooner.

B) Targets for priority woodland

To secure long term viable habitat networks, it is necessary to evaluate the constituent woodland types within existing and potential networks. The Scottish Forestry Strategy has indicated a requirement to increase woodland cover over the coming half century from the current 17% to about 25%. The current forest policy aims to deliver a more targeted phase of woodland expansion than occurred last century. In addition there is an ambition to increase Priority woodland habitat as well as the area of productive woodland. The Priority woodland habitat will be targeted within woodland networks in situations where it is considered that there will be high biodiversity gain in the future decades. Priority woodland potential may be assessed using this approach to delineate the forest habitat network for woodland generalists as a pattern within which management, restoration, conversion and expansion might occur to achieve the expansion target. The Priority woodland targets could be set partly by assessing the potential woodland types within the generalist network. The potential Priority woodland has been assessed using a combined native woodland model (Macaulay Institute, SNH) and the Ecological Site Classification (Forestry Commission).

Determining where woodland network expansion may be inappropriate

In producing habitat networks, we have analysed land cover permeability, with the functional forest habitat networks comprising woodland components in an intimate mixture with elements of open habitat. Whilst the open habitat components are still physically separate from the woodland, it is important to emphasise their location so that they can be fully considered when forest habitat network development is being planned (Figure 14).

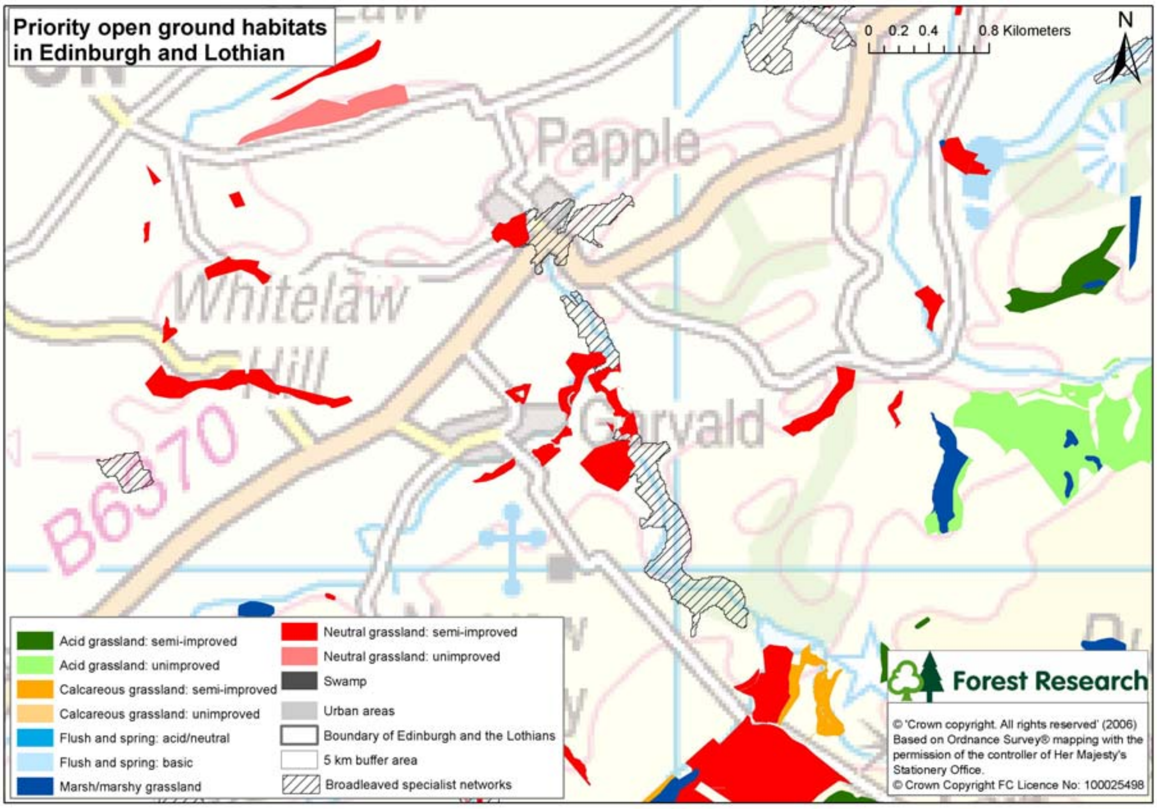


Figure 14. Priority open ground habitats close to a broadleaved habitat network. Woodland expansion across the semi-improved grassland may be inappropriate.

In this example, the broadleaved woodland specialist network in the centre of the map is fragmented, but may be improved by new woodland planting, perhaps as a 'stepping stone'. However, with the Priority open ground habitat layer visible we can see that there is an area of semi-improved grassland that it may be inappropriate to plant. Additional thought should be given to how the adjacent woodland may already affect the grassland habitat, *e.g.* through tree regeneration, so careful management of a range of habitats is required here.

Similarly, care needs to be taken in relation to designated sites such as SSSI, SCAs and SPAs, which may be categorised in terms of their suitability for woodland expansion. In Figure 15, sites on the Isle of Mull have been categorised as:

1. SSSIs primarily designated for a woodland interest and where woodland expansion is desirable.
2. SSSIs where there is some woodland interest in the designation and where some woodland expansion would be desirable, although other habitats are designated within the SSSI, implying that expansion would require a site survey to decide where woodland expansion would be appropriate.
3. SSSIs designated for non-woodland habitats where woodland would not be desirable. These are mostly wetland, geological or aquatic sites.

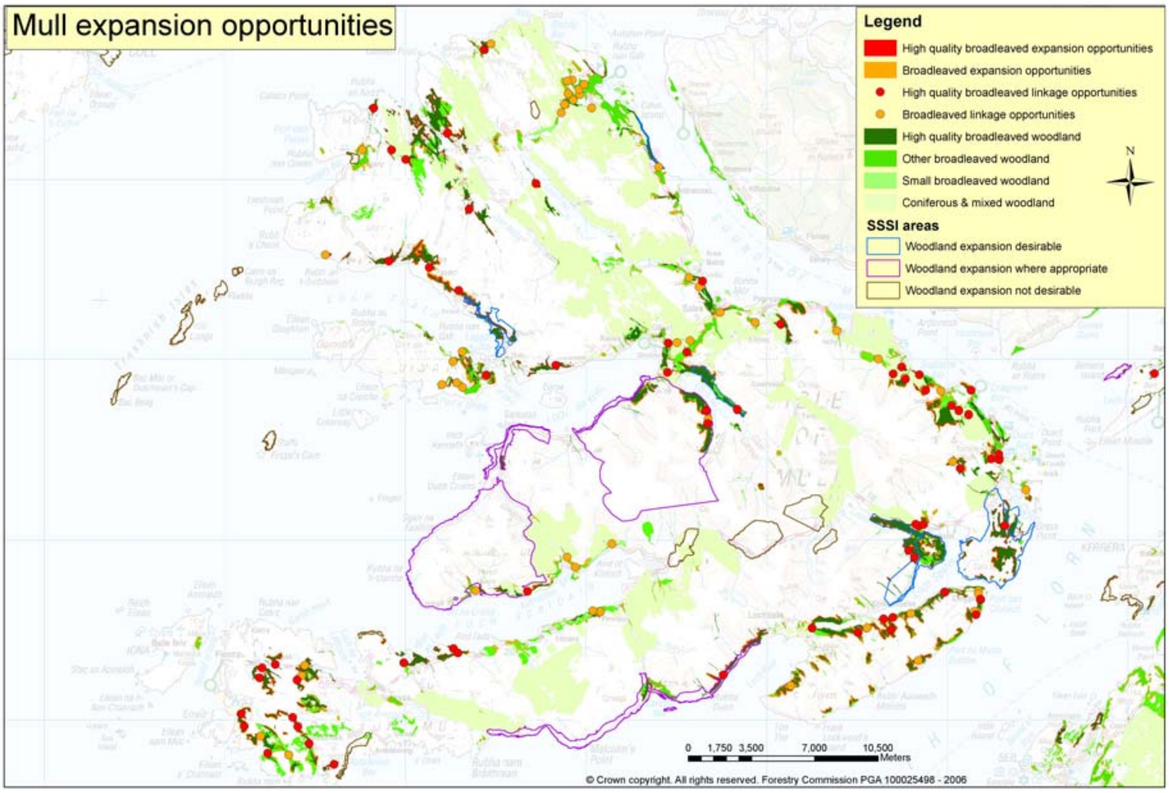


Figure 15. Woodland expansion desirability in terms of designated sites, categorised as desirable, where appropriate, and not desirable.

6. Discussion

Network approach

The approach adopted, using an accumulated cost-distance habitat network model, is simple to achieve with available spatial datasets. It provides an approximate analog to species dispersal, where this is limited by inadequate or poor autecological evidence. The use of GFS (Eycott *et al.*, 2007), rather than real species, takes the focus off the accuracy of the evidence-base for a specific range of species. Instead it provides an approximate classification into which it is possible to consider the range of a particular species from experience rather than evidence. This approach to define forest and open habitat networks is based on the principle of providing a strategic, spatially-explicit tool to aid the effective management of landscapes for biodiversity. It is designed to be an adaptive tool which aims to support and assist the targeting and the effective prioritisation of limited resources. It is based on the concept and assumption of improving the functional connectivity for woodland biodiversity in general, rather than a tool to predict the dispersal and viability of actual woodland species. The tool is also designed to avoid the use and implementation of approaches based on landscape structure.

There are inherent assumptions within this modelling approach, such as habitat preference, area requirements, dispersal distance and matrix permeability. These assumptions are based on sound ecological theories and principles. The GFS profiles have been discussed with expert open ground and forest ecologists to develop a set of relative profiles to classify forest generalists and specialists. Although this approach is not intended to model and predict actual species dispersal and viability, it could undoubtedly be validated and refined with species-specific studies, improved species profiles and data, and improved habitat and land cover data. The approach provides a practical analog to landscape ecology theory and can be used with caution to help design and prioritise woodland management and expansion within networks.

Data limitations

The use of GFS is an attempt to move the focus from the conservation of individual species to an approximate classification of groups of species and ecological processes. It arose from the recognition that there is very limited species data, particularly in terms of dispersal ability and use of the surrounding matrix. The inherent assumptions within the focal-species modelling approach; habitat preferences, area requirements, dispersal distance and matrix permeability undoubtedly have an impact on the model outputs and should be considered prior to use of the outputs. This particularly applies to the assumption regarding the extent to which individual species can act as umbrellas or surrogates for others. Additional species-specific studies will provide an opportunity to validate some of the assumptions within this network approach and further refine the focal species profiles. Some work is already underway in this area, *e.g.* a study of wood crickets on the Isle of Wight where the least-cost approach used in this project will be applied. Ideally, long-term monitoring of a range of habitat types is required to determine whether movement of species (including genetic diversity) occurs as the model predicts (see Sensitivity analysis below).

The data used to produce the networks are based on derived woodland and other land cover data sets that may have inaccuracies. For example, the data sets have limited value in assessing habitat quality and particular landscape features are omitted, such as hedgerows. The interviews and coincidence mapping used within the project has attempted to address this, but there are limitations relating to where such knowledge and information is available and the coincidence mapping is open to false negative results, since ‘no records’ cannot be assumed to mean ‘not present’, only ‘not recorded’. Improved spatial data sets at a range of scales could start to capture the dynamics of landscapes and provide useful information on habitat quality.

The networks should be used appropriately and reasonably with an awareness of their limitations. Attempting to link pinewood specialist networks with broadleaved specialist networks will not provide sensible outputs as they represent the way in which species use different types of habitat.

Sensitivity analysis

A set of sensitivity analyses were undertaken to determine whether the dispersal 'costs' (permeability score) applied to the generic focal species were sensitive to change. However, changing these by a relatively large amount, 20%, did not produce any spurious results. Indeed the standard errors generated were relatively small for each of the generic focal species, with only slightly higher values for specialist networks compared to generalist networks. These results indicate that the costs used for the habitat network analyses are within reasonable limits. However, actual testing of the assumptions on how species disperse through different land cover types, and the distances covered, can only be verified through survey. Current work (2007) is examining wood cricket habitat preferences and dispersal to help inform the assumptions and parameterisation of the model. Genetic markers within DNA are being assessed to examine the genetic similarity of populations. Populations which are functionally connected should show greater similarity than fragmented populations. The degree of similarity between populations will be examined with reference to the modelled network for the wood cricket.

The obvious approach to confirm that the model and its assumptions and parameters can predict real landscape processes is to undertake long-term monitoring studies. This will allow the occurrence and rate of dispersal events to be determined. However, such studies are expensive, but could be achieved by incorporating survey and monitoring studies into a larger research framework linked to other work. Another, perhaps quicker, pathway being considered is to determine whether similar genetic populations exist in separate habitat patches that have been identified as being functionally connected in the model (see below).

Further work

Long term monitoring

It is recommended that a long-term study is planned to determine whether the networks are operating in the way we think. An examination and comparison of biodiversity through the monitoring of new planting schemes approved in the Highland Locational Premium Scheme with traditional schemes may provide an evaluation in the shorter term. Genetic markers were suggested for examining gene flow within different woods that we think are 1) fragmented, and 2) connected. Work being undertaken at Aberdeen University on the genetic diversity of a fungus may provide a good case study.

Further sensitivity analysis is planned to support the expert knowledge-based cost approach applied in the model. These data, with further work to determine genetic groups with the population can be used to produce habitat networks for the wood cricket, allowing comparison of predicted and actual occurrence of genetic populations.

Climate change proofing

Work is currently underway to determine whether networks will provide the robust framework to withstand the effects of climate change. The work is investigating the impact of increased temperatures and moisture deficits on the suitability of potential priority woodlands and productive woodlands within habitat networks. It will also provide information on where weaknesses exist in networks, and ideas on how to adapt species choice and management to minimise the impact on woodlands and the habitat networks.

Workshops and technology transfer

Organisation of a series of workshops to demonstrate how the networks may be used to reduce habitat fragmentation is envisaged.

Application of the networks

The FHN Scotland analysis has produced a series of outputs in the form of reports and GIS shapefiles that can be used by woodland practitioners, planners, biodiversity officers, and others to help reduce woodland fragmentation at a range of scales. These outputs provide the tools required to identify existing networks; highlighting areas where the principles of reducing habitat fragmentation can be undertaken in a way that does not adversely affect other habitats. It is envisaged that use of the habitat networks will indicate opportunities for targeting grant schemes.

The project has been highly successful in driving initiatives to: reduce habitat fragmentation (Highland Region Locational Premium Scheme (Forestry commission, 2006)); indicate woodland and improvement and expansion opportunities (Argyll Islands habitat network study); apply habitat networks principles to the urban and peri-urban environment (Edinburgh and Lothians forest habitat network study); encourage the use of an integrated habitat network approach for woodland and open habitats (Glasgow & Clyde Valley integrated habitat network project) and also for people and biodiversity (Urban networks for biodiversity and people, form and function).

The principles for reducing habitat fragmentation not only consider priorities in terms of conserving and enhancing biodiversity, but are also pragmatic. Protection and management of areas with high biodiversity potential seems a sensible strategy for conserving our existing biodiversity, but the restoration, improvement and buffering of woodland adjacent to these areas are likely to achieve ‘quick wins’. Bailey (2007) considers that buffering existing woodlands and enhancing matrix quality is more important than increasing network connectivity as species dispersal and habitat maturation will be more rapid. This latter point is an important consideration in the light of the predicted impact of climate change on isolated species.

The analyses provide an indication of the opportunities for directed woodland consolidation and expansion to improve biodiversity over time, and not intended to be prescriptive. It is important to reiterate that the habitat networks estimate the dispersal of species from source habitat patches through a diverse land cover matrix. Connecting nearby FHNs does not require contiguous woodland planting. For some mobile species it may be achieved through planting small woodland ‘stepping stone’ patches or by a reduction in the intensity of open ground management. However, any plans to alter open ground habitat to facilitate dispersal should be checked by site survey so as not disadvantage open ground specialists.

The consolidation and expansion of woodlands, particularly those located on SSSIs and other notified sites, should first examine their often complex composition, which may comprise a mosaic of habitats, where the promotion of the woodland element might lead to an overall reduction in biodiversity.

Although the analyses here focus on woodland, we have also examined the interaction of woodland creation with heathland habitats/species. Woodland and heathland networks often overlap as the networks indicate *functional connectivity*, illustrating the permeability of non-woodland and heathland habitats for species that utilise woodland or heathland. Expansion of woodland networks should therefore consider how heathland networks may be affected, particularly in areas where heathland is fragmented. Detailed analysis of other open ground specialists was outside the scope of this work, but it is important that these types of issues should be considered when assessing the possibilities for improving the FHNs. Other open ground habitats are locally important, for example there is often a conflict of land use between afforestation and both wetland and unimproved grassland habitats, particularly along riparian corridors.

In conclusion, this document has described the principles that have been applied to the Forest Habitat Network Scotland project and provides a guide to how identified networks could be managed to reduce habitat fragmentation and improve biodiversity in Scotland. The map outputs should be used to focus attention, rather than be viewed as ‘the answer’ and should never be used without a site visit. It is hoped that land managers will use these data sets as a component of their management toolkits at national, regional, and local scales.

7 Frequently Asked Questions

Habitat networks

What is a habitat network? A habitat network is a configuration of habitat that allows species to move and disperse through a landscape. Networks can be produced for a particular type of habitat. For example, a forest habitat network focuses on how woodland species utilise woodland habitat and disperse through this and other habitat types in the wider landscape.

What is classed as habitat? Habitat is defined as the area of land cover where an organism or ecological community normally lives or occurs and is specific to each of the generic focal species being considered. For example, broadleaved woodland specialist habitat is derived from woodland data sets where the woodland type is broadleaved, within a minimum canopy cover. The woodland area classed as habitat may also be subject to a reduction in size due to the application of an internal buffer representing the edge effect.

What's the difference between a forest habitat network and a habitat network for open ground species? The principles for how forest species and open ground species use habitat networks are the same, but they are defined by the type of habitat. Hence an example of an open ground habitat network may be a heathland generalist for which the habitat is heathland, rather than woodland.

The woodland network covers priority open ground habitat. Does this mean that the open ground has been changed/lost? No, all networks represent the dispersal range of the generic focal species (GFS) being considered, rather than a physical change. Networks thus overlap a range of other habitats, and open ground networks are just as likely to overlap woodland habitat.

Why don't broadleaved networks link to pine networks? Broadleaved networks represent the functional connectivity of all types of broadleaved woodland and how species may move from one patch of broadleaved woodland to another. Although species specifically associated with broadleaved woodland may utilise some small elements of other land cover types, including pinewood, it is assumed they will find movement through these habitats more difficult. Consequently, broadleaved and pinewood networks are considered to operate independently and are not linked.

Why isn't there a network around all the woodlands? Woodlands that have little tree cover (less than 10% canopy cover), or are degraded or extensively managed (much farm and parkland woodland) are unlikely to possess the habitat attributes that many species require and were not considered as woodland habitat. Woodlands that are very narrow lack the 'core woodland' many species require, and this is represented in the modelling process by applying an internal buffer. Although these woodlands are not part of a network at present, they provide an excellent opportunity to improve the network through management and expansion.

Why hasn't a good quality woodland that I know about been included in a good quality network? The biodiversity quality of woodlands has been determined through interview (ancient pinewoods in Highland; mixed and broadleaved woodlands in the Borders, broadleaved woodlands in SW Scotland) or by using coincidence mapping (see Forest Habitat Networks Scotland - Borders and the Lothians report (PDF-2086K) for details). Both these approaches are reliant on knowledge or data being submitted, and it may be that information is missing. However, this does not mean an unqualified woodland is not good quality, we have highlighted those we know about. As more woodlands are qualified and the information is gathered, we can begin to improve our data sets and help to use this information to help benefit woodland biodiversity.

Generic focal species

What are generic focal species (GFS)? Conceptual or virtual species reflecting likely ecological requirements of a range of real species where species data are unavailable. This is similar to using an umbrella species except that the profile is not based on one actual species such as a slug, swallow or moth, but on a combination of most species needs. Further details on focal species (Eycott *et al.*, 2007).

What is a specialist / generalist generic focal species? Specialists refer to species associated with particular habitat types, *e.g.* a pinewood specialist GFS is associated with pinewood; generalist GFS refer to species associated with a range of habitat types, *e.g.* a woodland generalist is associated with all types of woodland.

Why have certain generic focal species been used in some areas but not in others? Regional variations have defined the important habitats that we have examined. Heathland generalists, woodland generalists, and broadleaved specialists have been used where the habitats are common across the regions, whilst pinewood specialists have been used in the extensive pinewoods of the highlands and western Grampian. There is little pinewood in the Borders, but broadleaved woodland is particularly important, so here we have focused on broadleaved and mixed woodland, particularly those of high biodiversity quality potential.

Why is an internal woodland buffer used? An internal woodland buffer is used for woodland specialist analyses to represent how the woodland edge is not used by many woodland species who prefer to use the internal woodland. This may be due to differences in climatic conditions, light/shade, noise, predators, *etc.* The buffer represents up to two trees lengths (50 m), although this may be less where tree height is less or by riparian areas where the edge effect is less.

Networks and change

What about climate change – do the networks take this into account? The networks demonstrate the current functional connectivity of the woodlands and heathland. Further analyses are being undertaken to determine how they may operate under future climate change scenarios and how they can be used to attempt to reduce the impact of climate change. A paper is currently being drafted to determine the robustness of the networks to deal with projected increases in temperature and the subsequent impact on site suitability for tree species.

How do the networks cope with land use change?
Changes in land use can affect the permeability of the habitat networks positively, through the addition of more semi-natural habitat, and negatively, if the change is to a more intensively managed land use. If the change in land use is not too extreme, e.g. if semi-natural land converted to buildings, then the networks are unlikely to change drastically. Larger area changes, such as intensification of farming practice on a large area of land within a habitat network is likely to reduce the permeability of the landcover matrix to many species. These larger changes in land use will require the datasets that represent the landcover to be updated periodically.

Who manages the data and how often is it updated? The data are managed by Forest Research and are updated annually using improved data obtained from users and new data sets.

Using the networks

How can the networks be used? The networks can be used to reduce the effects of habitat fragmentation and isolation using a number of approaches. For examples, refer to Evaluating Biodiversity in Fragmented Landscapes: Applications of Landscape Ecology Tools (PDF-1440K) - Forestry Commission Information Note 85.

Tools

What is BEETLE? BEETLE is an acronym for 'Biological and Evaluation Tools for Landscape Ecology', a suite of tools developed by Forest Research to model and analyse landscape fragmentation and connectivity using GIS (Geographic Information Systems).

How does the cost-distance model work? The model analyses the land cover layer in relation to the habitat preferences and dispersal abilities of each generic focal species. It then calculates how far the generic focal species can move outside of it's preferred habitat, through the wider landscape. This produces a buffer around each of the preferred habitat patches and where these buffers connect, they are designated as a functional network and the model joins them together. The model outputs are two GIS layers; one with the original preferred habitat, the other with the functional habitat networks.

Validation

Have the assumptions of how species move through the different land cover types been validated? There are inherent assumptions within the BEETLE approach, such as habitat preference, area requirements, dispersal distance and matrix permeability. These assumptions are based on sound ecological theories and principles which have been developed through consultation with the steering groups working with each habitat network project and are explicit within the modelling approach. Although this approach is not intended to model and predict actual species dispersal and viability, it could undoubtedly be validated and refined with species-specific studies, improved species profiles and data, and improved habitat and land cover data. A study is planned to test the theory for an individual focal species on the Isle of Wight. Future work may focus on the use of genetic markers to verify that fragmented woodlands belong to the same network. Until then, the networks should be treated as fuzzy boundaries, and anyone using the networks should bear in mind the assumptions made in the analyses, and treat the networks as another tool, rather than using them as a definitive answer, *e.g.* this particular lichen will disperse 10 km. Differences in habitats, topography, and management practices will all add local variation and some dispersal may be site specific, but the general assumptions made will hold true.

8 Glossary

Accumulated cost-distance	The accumulated 'cost' of dispersing through the land cover, calculated for each grid square within a GIS
ALTERRA	A research institute in the Netherlands who work on, amongst other things, landscape and spatial planning
ASNW	Ancient semi-natural woodland
BEETLE	Biological and Environmental Evaluation Tools for Landscape Ecology – a suite of evaluation tools being developed by Forest Research
Biodiversity	The totality of genes, species, and ecosystems of a region
Broadleaved woodland specialist networks	Woodland networks for species specifically associated with broadleaved woodland but which may be found in mixed woodland to a lesser degree and occasionally in conifer. The species have a rather reduced dispersal and a more exacting habitat requirement than "generalists".
Buffer	A zone surrounding an area, *e.g.* habitat.
Connectedness	A physical attribute of the landscape based on physical distance
Connectivity	Being connected
Core area	The area that is not highly modified by surrounding land use.
Core habitat	Habitat that is not affected by the influence of adjacent land cover types.
Core Network	A limited habitat network for a species with high habitat area requirements and low dispersal ability (see Focal Network)
Corridor	Areas that link habitat patches together, serving as highways or conduits for organisms to transfer or move from patch to patch
DEM	Digital Elevation Model
Dispersal cost	A value applied to represent the permeability of the land cover to species dispersal.
Dispersal distance	The distance that species can disperse through the land cover; often modified by the different land cover permeabilities.
ESC	Ecological Site Classification, a PC-based system to help guide forest managers and planners to select ecologically suited species to sites, instead of selecting a species and trying to modify the site to suit.
Edge effect	In the context of the forest habitat network Scotland project, the edge effect refers to the area of woodland that borders other land cover types where influences of the adjacent patches can cause an environmental difference between the interior of the patch and its edge. Woodland specialists are assumed to prefer core woodland conditions and would not use the woodland edge as habitat. The modelling process represents this as a distance of 2 tree heights.
FHN	Forest Habitat Network
Focal Network	An extensive habitat network for a species with medium habitat area requirements and medium dispersal ability (see Core Network)
Functional connectivity	A functional attribute of the landscape related to ecological processes where habitat patches are connected in such a way that they allow species to move and disperse even though some patches may not be physically connected
Generalist	Species associated with all types of woodland.
GFS	Generic Focal Species - defined to be representative of a number of species groups, priority habitats and key ecological processes
GIS	Geographic Information System – computer system capable of integrating, storing, editing, analysing, sharing, and displaying geographically-referenced information

Habitat	The area of land cover where an organism or ecological community normally lives or occurs
Habitat area	The area of habitat within the land cover.
Habitat fragmentation	The separation of a once continuous habitat into smaller areas, frequently caused by humans when native vegetation is cleared for human activities such as agriculture, rural development or urbanisation.
Habitat network	Patches of habitat that are considered to be functionally connected.
High quality broadleaved woodland networks	A woodland network for species associated mainly with woodland of particularly high ecological quality and (usually) long site occupancy.
Isolated	Neither physically or functionally connected
Land cover	The habitat or land use of an area
Landscape ecology	The study of the interactions between the temporal and spatial aspects of a landscape and the organisms within it.
Landscape permeability	A measure of how easily species can disperse through the land cover matrix.
LARCH	Landscape ecological Analysis and Rules for the Configuration of Habitat – a landscape ecology model
LCS88	Land Cover Scotland (1988)
LCM2000	Land Cover Map 2000
LEPO	Long-established of plantation origin
Matrix	The predominant habitat or landcover
Network	A configuration of habitat which allows species to move and disperse through a landscape.
NIWT	National Inventory of Woodland and Trees
NLM	Neutral Landscape Model
NWM	Native Woodland Model
PAWS	Plantation on ancient woodland site
Phase 1	Phase 1 Survey
SAC	Special Area of Conservation
SFGS	Scottish forestry grant scheme
SPA	Special Protection Area
Specialist	Species closely associated with particular woodland types
SSNWI	Scottish Semi-natural Woodland inventory
SSSI	Site of Special Scientific Interest
WGS	Woodland grant scheme
Woodland generalist network	A woodland network for species associated with *all types* of woodland or which may require woodland for a part of their life cycle, or for which woodland forms part of their range

9 Quality assurance

All work undertaken within the Forest Habitat Network Scotland project has met with internal quality assurance standards, detailed in standard operating procedures.

Standard Operating Procedures

A standard operating procedure (SOP) was derived for the methodology employed in the project, consisting of a series of flow diagrams to detail:

1. Management, responsibilities and timetable of work
2. Data sources & their categories (Figure 16)
3. Rules used to derive habitat for each of the generic focal species (Figure 17)
4. The procedure for assessing forest habitat networks, *i.e.* building the land cover matrix and using expert opinion to determine dispersal costs of the generic focal species through the different land cover types
5. The BEETLE accumulated cost distance buffer analysis procedure
6. The methodology for deriving lowland areas
7. Methodologies for assessing biodiversity quality

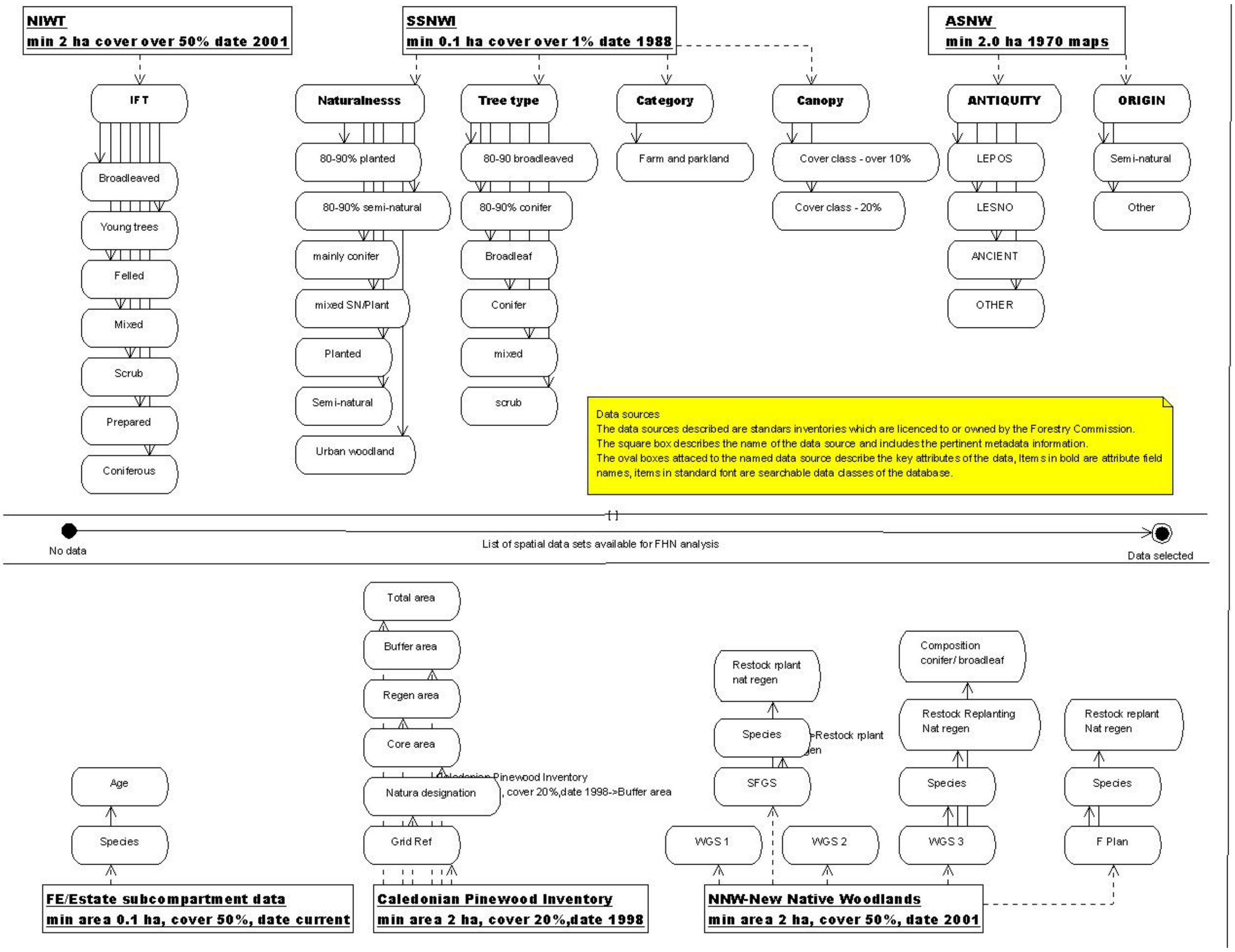


Figure 16. Flow diagram showing the data sources and main attributes used for defining woodland data.

Habitat and land cover costs were derived for each of the generic focal species from appropriate sources, using rules to reflect the ability of generic focal species to utilise habitat and disperse through different land cover types (Figure 17).

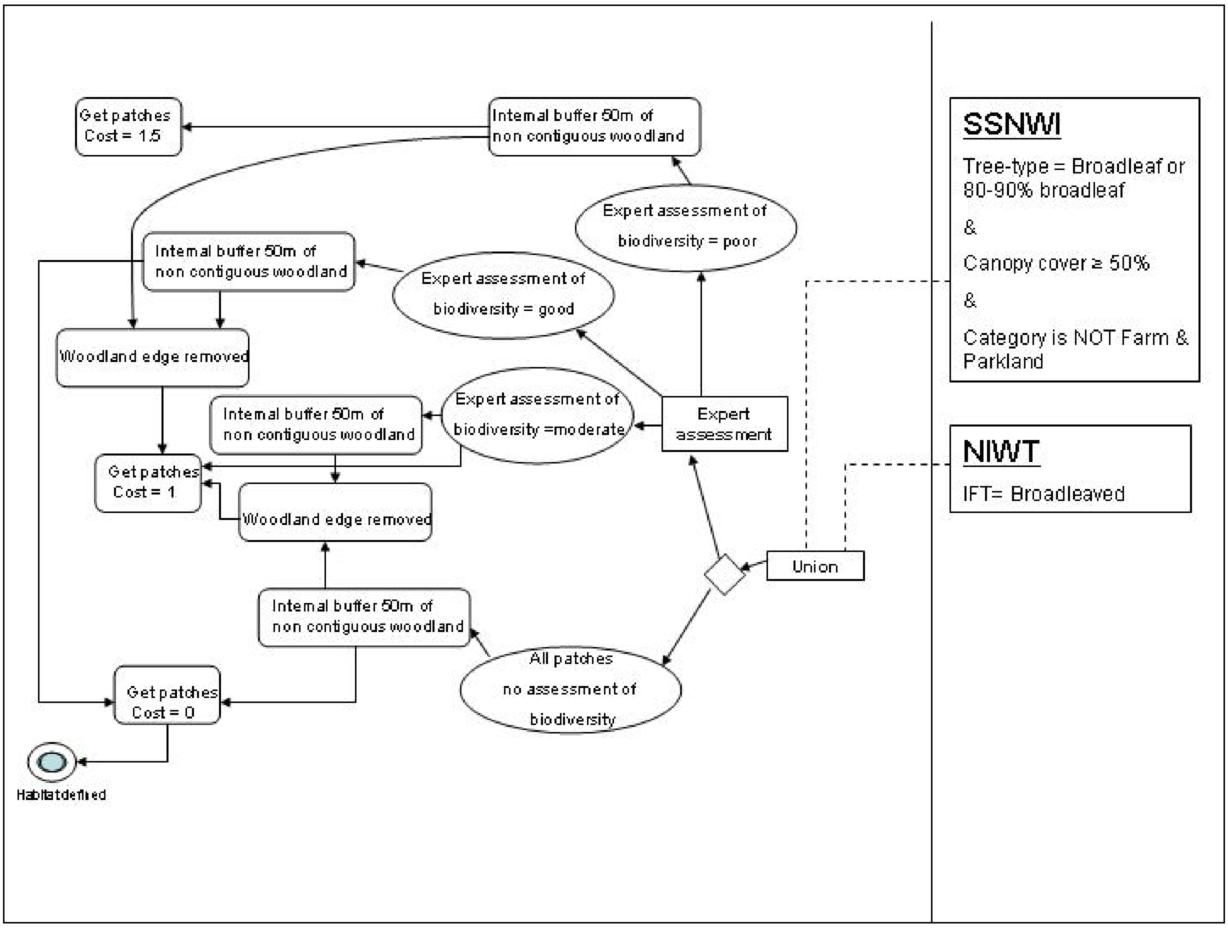


Figure 17. Example of a flow diagram showing sources and rules used to derive habitat from woodland data for generic focal species.

10 Contacts and support

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Sources of further information
The Forestry Commission has published an information note entitled "Evaluating Biodiversity in Fragmented Landscapes: Principles" (FC Information Note 073, Watts *et al.*, 2005b) which gives more background on fragmentation and its assessment. A further two information notes "Evaluating Biodiversity in Fragmented Landscapes: Applications of Landscape Ecology Tools" (FC Information Note 085, Watts *et al.*, 2007a) and "Evaluating Biodiversity in Fragmented Landscapes: The use of focal species" (in press) have been developed. The "Applications" note includes some of the examples used in this report, but also examines other ways of measuring fragmentation. The focal species note examines the development of focal species in more detail.

Forestry Commission publications
FC Bulletin 112 Creating New Native Woodlands
FC Bulletin 124 An Ecological Site Classification for Forestry in Great Britain
FC Practice Note 8 Using Local Stock for Planting Native Trees and Shrubs
FCS Guidance Note 9 Site Survey Requirements for New Native Woodland
FCS Guidance Note 20 Forest Habitat Networks
FC Handbook 5 Urban Forestry Practice
FC Community Woodland Design Guidelines
FC Forests and Water Guidelines

Joint/external publications
Scottish Native Woods publication Restoring and Managing Riparian Woodland
Woodland Networks for Wildlife and People – FC/SNH publication
Local Forest Habitat Network Plans published by FC/SNH
Water Framework Directive

Web page resources
Further information and regional reports regarding the habitat networks Scotland project and other habitat network analyses developed by Forest Research's Landscape Ecology group can be found on our web pages at www.forestresearch.gov.uk/habitatnetworks. For background information on landscape ecology, please see www.forestresearch.gov.uk/landscapeecology.

11 References

Anon (2000) Forests for Scotland: The Scottish Forestry Strategy. Forestry Commission, Scottish Executive, Edinburgh.

Anon (2002) Loch Lomond and The Trossachs Local Woodland and Forestry Framework - Prepared by Eamonn Wall & Co, Land Use Consultants. Loch Lomond & The Trossachs National Park Authority, Balloch, Scotland.

Anon (2003) Scottish Forestry Grants Scheme. Scottish Executive, Forestry Commission, Edinburgh.

Anon (2004) Scotland's Biodiversity - It's in Your Hands: A strategy for the conservation and enhancement of biodiversity in Scotland. Draft Research Strategy. Scottish Executive, Edinburgh.

Anon (2005) "WIAT: Woodlands in and Around Towns." Forestry Commission and Scottish Executive, Edinburgh, Scotland.

Anon (2006) Scottish Forestry Strategy. Forestry Commission, Scottish Executive, Edinburgh.

Bailey, S. (2007) Increasing connectivity in fragmented landscapes: An investigation of evidence for biodiversity gain in woodlands. Forest Ecology and Management, 238, 7–23.

Bennett, G. (Ed.) (1994) Conserving Europe's Natural Heritage: Towards a European Ecological Network. Graham and Trotman, Great Britain.

Bolck, M., de Togni, G., van der Sluis, T. and Jongman, R.H.G. (2004) From models to reality: design and implementation process, in Ecological Networks and Greenways: Concepts, Design, Implementation. Jongman, R. H. G. and Pungetti, G. (Eds.), Cambridge University Press, Cambridge, pp. 128-149.

Bouwma, I.M., Jongman, R.H.G. and Butovsky, R.O. (Eds.) (2002) The Indicative Map of the Pan-European Ecological Network - technical background document (ECNC Technical report series). European Centre for Nature Conservation, Tilburg, The Netherlands.

Broadmeadow, M., Ray, D. & Samuel, C. (2005) Climate change and the future for broadleaved tree species in Britain. Forestry, 78(2), 145-67.

Brooker, L. (2002) The application of focal species knowledge to landscape design in agricultural lands using the ecological neighbourhood as a template. Landscape and Urban Planning, 60, pp. 185-210.

DEFRA (2006) Migratory Species and Climate Change: Impacts of a Changing Environment on Wild Animals. UNEP / CMS Secretariat, Bonn, Germany. 68 pages.

European Commission (1992) Council Directive 92/43/EEC on the conservation of natural habitats and of wild flora and fauna. European Commission, Brussels.

Eycott, A.E., Watts, K., Moseley, D.G. and Ray, D. (2007) “Evaluating Biodiversity in Fragmented Landscapes: Use of Focal Species.” Information Note 089, Forestry Commission, Edinburgh.

Farina, A., (1998) Principles and Methods in Landscape Ecology. Chapman and Hall.

Fahrig, L. (2001) How much habitat is enough?, *Biological Conservation*, 100, pp. 65-74.

Foppen, R.P.B., Bouwma, I.M., Kalkhoven, J. T. R., Dirksen, J. and van Opstal, S. (Eds.) (2000) Corridors of the Pan-European Ecological Network: Concepts and examples for terrestrial and freshwater vertebrates (ECNC Technical report series). European Centre for Nature Conservation, Tilburg, The Netherlands.

Forestry Commission (2006) Scottish Forestry Grants Scheme Highland Locational Premium 2006 – 2008. FCCS263. Forestry Commission, Edinburgh.

Fowler, J. and Stiven, R. (2003) Habitat networks for wildlife and people: the creation of sustainable forest habitats. Forestry Commission Scotland, Scottish Natural Heritage, Edinburgh.

Freudenberger, D. and Brooker, L. (2004) Development of the Focal Species Approach for Biodiversity Conservation in the Temperate Agricultural Zones of Australia. Biodiversity and Conservation, 13, 253-274.

Grieve, Y., Sing, L., Ray, D., & Moseley, D. (2006) Forest Habitat Networks, Broadleaved Woodland Specialist Network for SW Scotland. Unpublished report to Forestry Commission Scotland and Scottish Natural Heritage. 25.pp

Hampson, A.M. and Peterken, G.F. (1998) Enhancing the biodiversity of Scotland's forest resource through the development of a network of forest habitats. Biodiversity and Conservation, 7, pp. 179-192.

Hawkins, V. and P. Selman (2002) Landscape scale planning: exploring alternative land use scenarios." Landscape and Urban Planning 60(4): 211-224.

Humphrey, J.W., Ferris, R. and Quine, C.P. (eds) (2003a) Biodiversity in Britain's planted forests: results from the Forestry Commission's biodiversity assessment project. Forestry Commission, Edinburgh.

Humphrey, J.W., Ray, D., Watts, K., Brown, C., Poulsom, E., Griffiths, M. and Broome, A.C. (2003b) Balancing upland and woodland strategic priorities. Forest Research. Roslin. Contract Report to Scottish Natural Heritage Contract No: AB(AA101)020398.

Humphrey, J.W., Smith, M., Shepherd, N. and Handley, P. (2007) Developing Lowland Habitat Networks in Scotland: Phase 2 Contract report to Forestry Commission Scotland, Forestry Commision GB, Scottish Natural Heritage and Scottish Executive Environment and Rural Affairs Department. Forest Research. Roslin.

Lambeck, R. J. (1997) Focal species: a multi-species umbrella for nature conservation. Conservation Biology, 11, pp. 849-856.

Latham, J., Watts, K. and Thomas, C. (2004) Development of a Forest Habitat Network for Wales: linking research with policy, in Landscape Ecology of Trees and Forests - Proceedings of the 2004 IALE (UK) Conference, held at Cirencester Agricultural College, Gloucestershire, 21st-24th June 2004. Smithers, R. J. (Ed.), IALE(UK).

Lee, J.T., Woody, S.J. and Thompson, S. (2001) Targeting sites for conservation: Using a patch-based ranking scheme to assess conservation potential. Journal of Environmental Management, 61, 367-380.

Lee, J.T., Bailey, N. and Thompson, S. (2002) Using geographical information systems to identify and target sites for creation and restoration of native woodlands: a case study of the Chiltern Hills, UK. Journal of Environmental Management, 64, 25-34.

Lee, T.R., 2001. Perceptions, Attitudes and Preferences in Forests and Woodlands. Forestry Commission Technical Paper 18, Forestry Commission, Edinburgh, Scotland.

Lindenmayer, D.B., Cunningham, R.B., Donnelly, C.F. and Leslie, R. (2002) On the use of landscape surrogates as ecological indicators in fragmented forests. Forest Ecology and Management, 159, 203-216.

Melbourne, B.A., Davies, K.F., Margules, C.R., Lindenmayer, D.B., Saunders, D.A., Wissel, C. and Henle, K. (2004) Species survival in fragmented landscapes: where to from here? Biodiversity and Conservation, 13, 275-284.

Moseley, D.G., Sing, L. and Ray, D. (2005) Forest Habitat Networks Scotland - Highland Conservancy Report September 2005. Unpublished report to Forestry Commission Scotland and Scottish Natural Heritage. 46 pp.

Moseley, D.G. and Ray, D. (2006) Forest Habitat Networks Scotland - Borders and Lothians Report May 2006. Unpublished report to Forestry Commission Scotland and Scottish Natural Heritage. 57 pp.

Opdam, P. (2002) Assessing the conservation potential of habitat networks, in Applying Landscape Ecology in Biological Conservation. Gutzwiller, K. J. (Ed.), Springer-Verlag, New York, pp. 381-404.

Opdam, P. & Wascher, D. (2004) Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation, *Biological Conservation*, 117, pp. 285-297.

Peterken, G.F. (1999) Clyde Valley forest habitat network. Scottish Natural Heritage Commissioned Report. Contract BAT/L109/99/00/32. Scottish Natural Heritage, Edinburgh.

Peterken, G. F. (2000) Identifying ancient woodland using vascular plant indicators. British Wildlife, 11, 153-158.

Peterken, G.F. (2002) Reversing the Habitat Fragmentation of British Woodlands. WWF-UK, Godalming, Surrey.

Peterken, G.F. (2003) Developing forest habitat networks in Scotland, in The Restoration of Wooded Landscapes - Proceedings of a conference held at Heriot Watt University, Edinburgh, 14-15 September 2000. Humphrey, J., Newton, A., Latham, J., Gray, H., Kirby, K. H., Poulsom, E. and Quine, C. (Eds.), Forestry Commission, Edinburgh, pp. 85-91.

Peterken, G.F., Baldock, D. and Hampson, A. (1995) A forest habitat network for Scotland. Research, Survey and Monitoring Report, 44, Scotish Natural Heritage, Edinburgh.

Pyatt, D.G., Ray, D. and Fletcher, J., 2001. An Ecological Site Classification for Forestry in Great Britain: Bulletin 124. Forestry Commission, Edinburgh.

Ray, D., Hope, J.C.E. and Watts, K. (2004) Development of a forest habitat network strategy in West Lothian. Forest Research, Roslin. Contract report to Scottish Natural Heritage. Contract No: AB(LJ15)0304118.

Ray, D., Sing, L., Humphrey, J. and Watts, K. (2005) Forest Habitat Networks Scotland – Progress Report March 2005, 32 pp.

Rose, F. (1999) Indicators of ancient woodland: the use of vascular plants in evaluating ancient woods for nature conservation. British Wildlife, 10, 241-251.

Thompson, S., Larcom, A. and Lee, J.T. (1999) Restoring and enhancing rare and threatened habitat under agri-environment agreements: a case study of the Chiltern Hills Area of Outstanding Natural Beauty, UK. Land Use Policy, 16, 93-105.

Thompson, S., McElwee, K. and Lee, J.T. (2001) Using landscape characteristics for targeting habitat conservation and restoration: a case study of ancient semi-natural woodland in the Chiltern Hills Area of Outstanding Natural Beauty, UK. Landscape Research, 26, 203-223.

Towers, W., A. Malcolm, A. Hester, I. Ross, and E. Baird. (1999) Cairngorms Forest and Woodland Framework. Cairngorms Partnership.

Townshend, D., Stace, H. and Radley, D. (2004). State of nature: lowlands - future landscapes for wildlife. English Nature, Peterborough.

UK Government (1994) Biodiversity: The UK Action Plan (Cmnd 2428). HMSO, London.

UNCED (1992) United Nations Conference on Environment and Development - Agenda 21 - Action Plan for the Next Century. UNCED, Rio de Janiero.

van Rooij, S.A.M., Steingrover, E.G. and Opdam, P. F. M. (2001) Corridors for life: Scenario development of an ecological network in Cheshire County. Alterra, Wageningen.

Verboom, J. and Pouwels, R. (2004) Ecological functioning of ecological networks: a species perspective, in Ecological Networks and Greenways: Concepts, Design, Implementation. Jongman, R. H. G. and Pungetti, G. (Eds.), Cambridge University Press, Cambridge, pp. 56-70.

Watts, K. (2003) Landscape Ecology Project: Phase 4 Project Plan - Development of prototype landscape ecology evaluation tools to assist large-scale forest planning. Forest Research, Woodland Ecology Branch, Alice Holt, Farnham.

Watts, K., Griffiths, M., Quine, C., Ray, D. and Humphrey, J.W. (2005a) Towards a Woodland Habitat Network for Wales. In. Countryside Council for Wales, Bangor.

Watts, K., Humphrey, J., Griffiths, M., Quine, C., and Ray, D. (2005b). "Evaluating Biodiversity in Fragmented Landscapes: Principles." Information Note 73, Forestry Commission, Edinburgh.

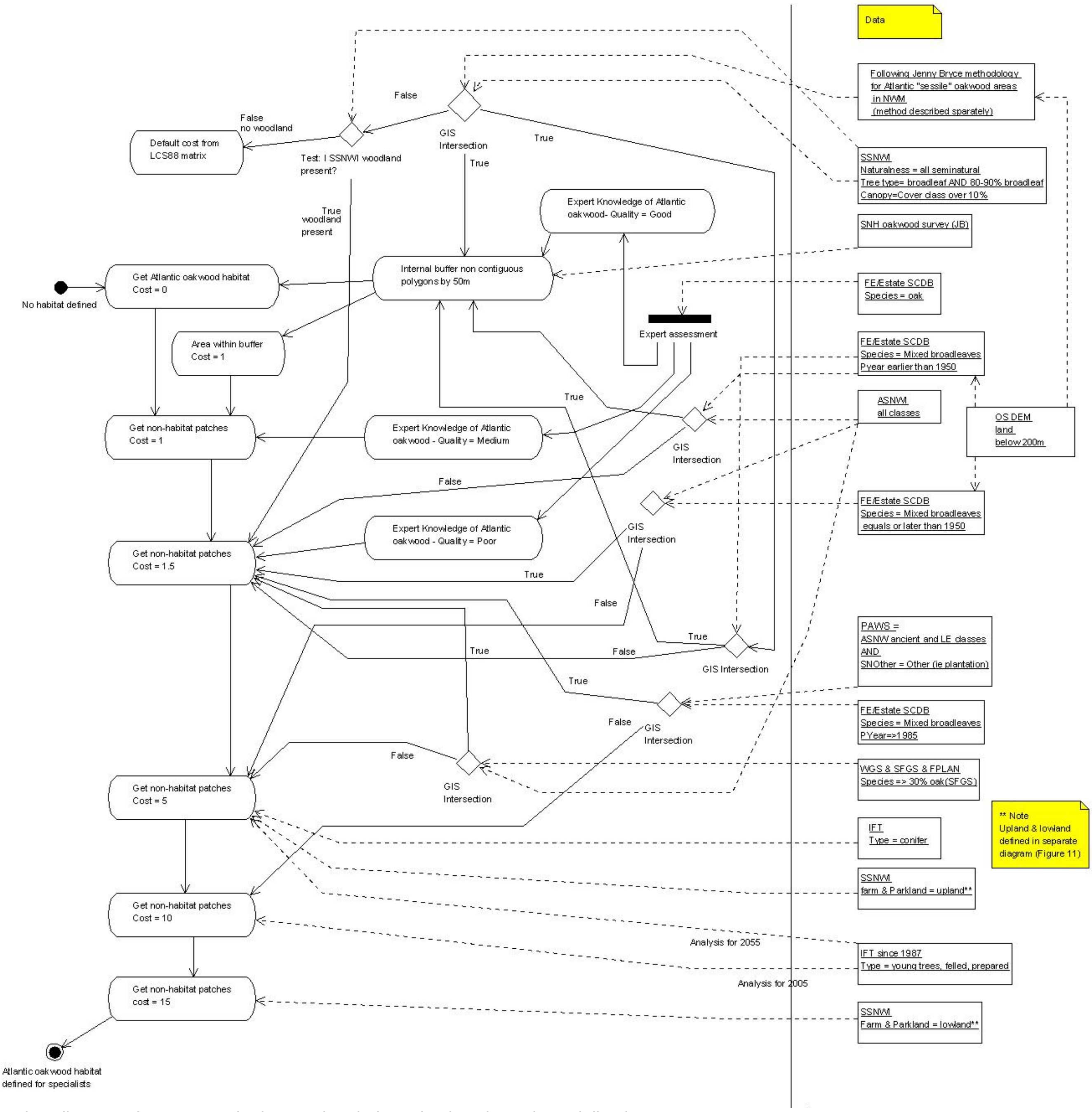
Watts. K., Ray, D., Quine, C., Humphrey, J.W. and Griffiths, M. (2007a) “Evaluating Biodiversity in Fragmented Landscapes: Applications of Landscape Ecology Tools.” Information Note 85, Forestry Commission, Edinburgh.

Watts, K., Eycott, A.E. and Griffiths, M. (2007b) Further Development of a Woodland Habitat Network Strategy for Wales. In. Unpublished report to Forestry Commission Wales and Countryside Council for Wales, Forest Research, Farnham.

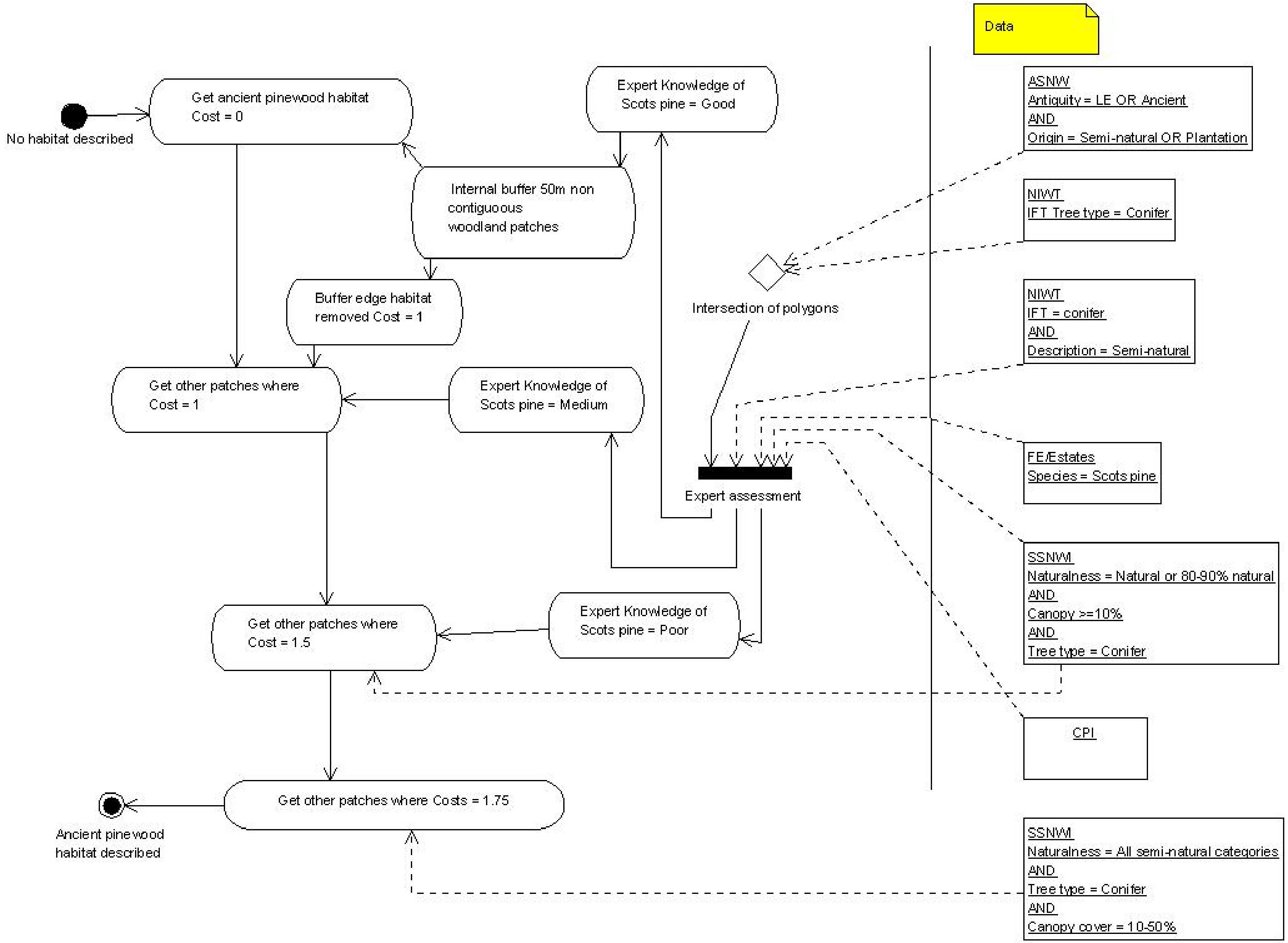
Watts, K. & Griffiths, M. (2004). Exploring structural connectivity in Welsh woodlands using neutral landscape models. In Landscape Ecology of Trees and Forests (ed R.J. Smithers). IALE(UK), Cirencester Agricultural College, Gloucestershire, 21st-24th June 2004.

Worrell, R., Taylor, C.M.A. and Spittal, J.J. (2003) Highland Perthshire Forest Habitat Network. Scottish Forestry, 57, 151-157.

Appendix A –Flow diagrams of data sources and rules used to derive Generic focal species data.



a. Flow diagram of sources and rules used to derive Atlantic oakwood specialist data



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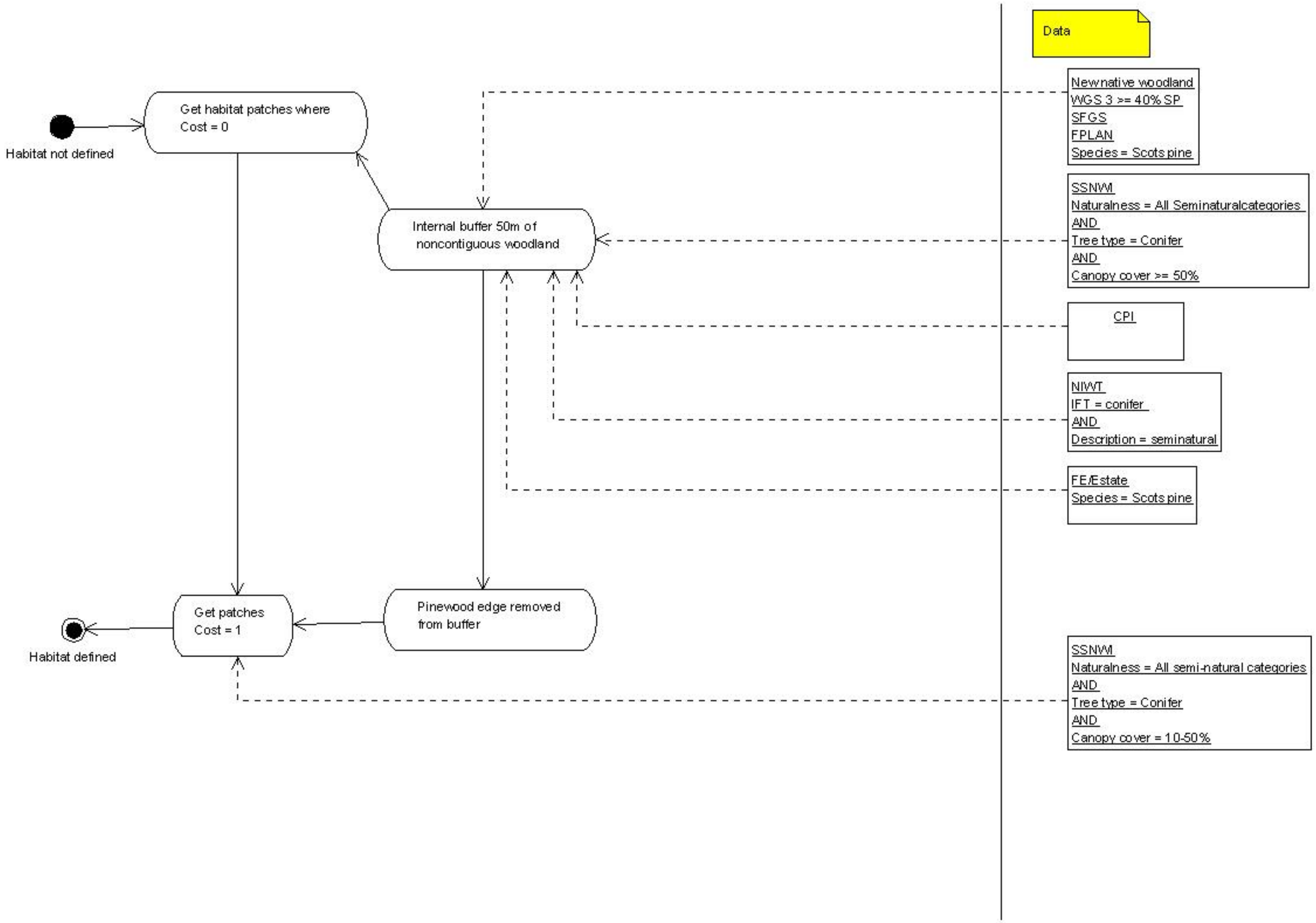
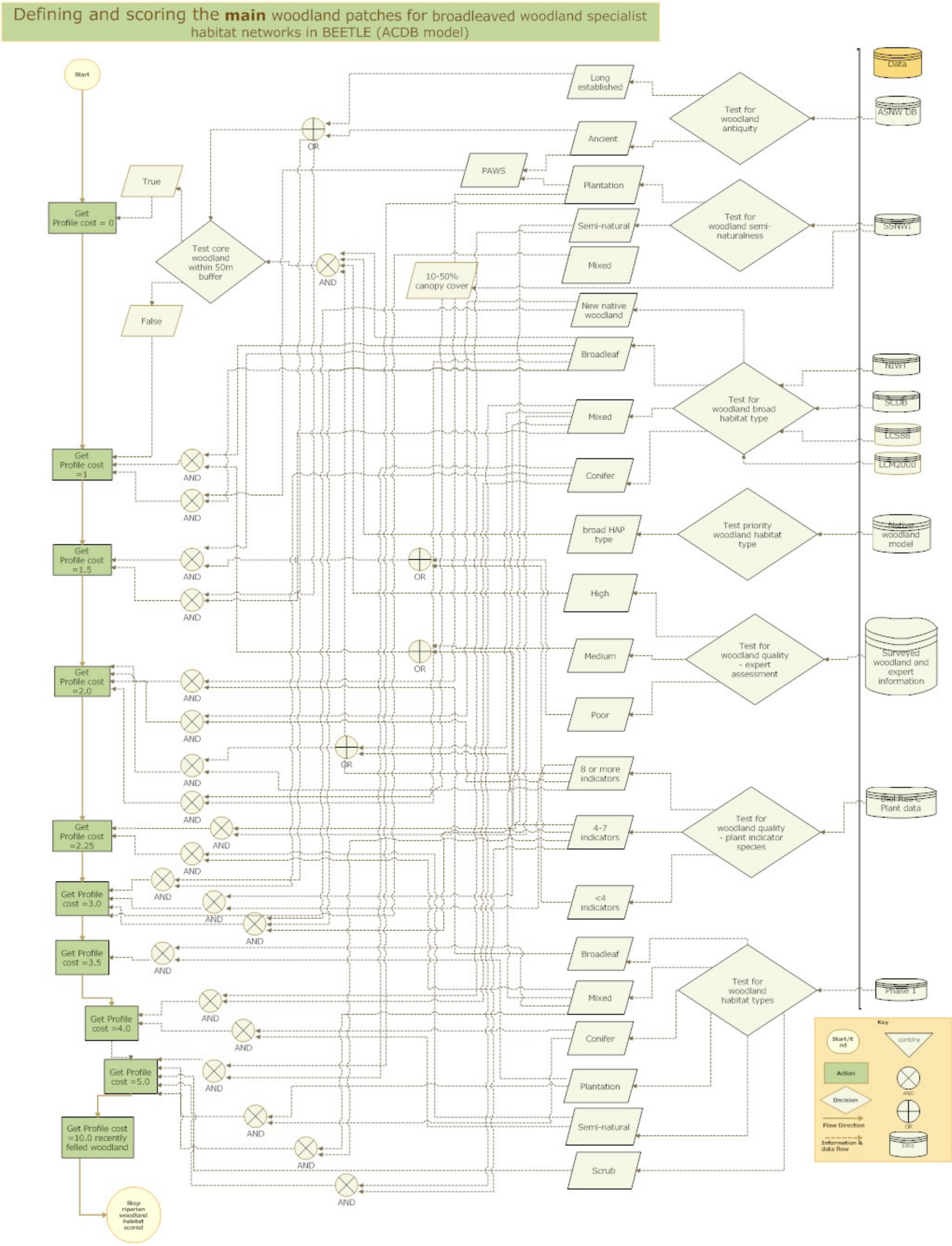
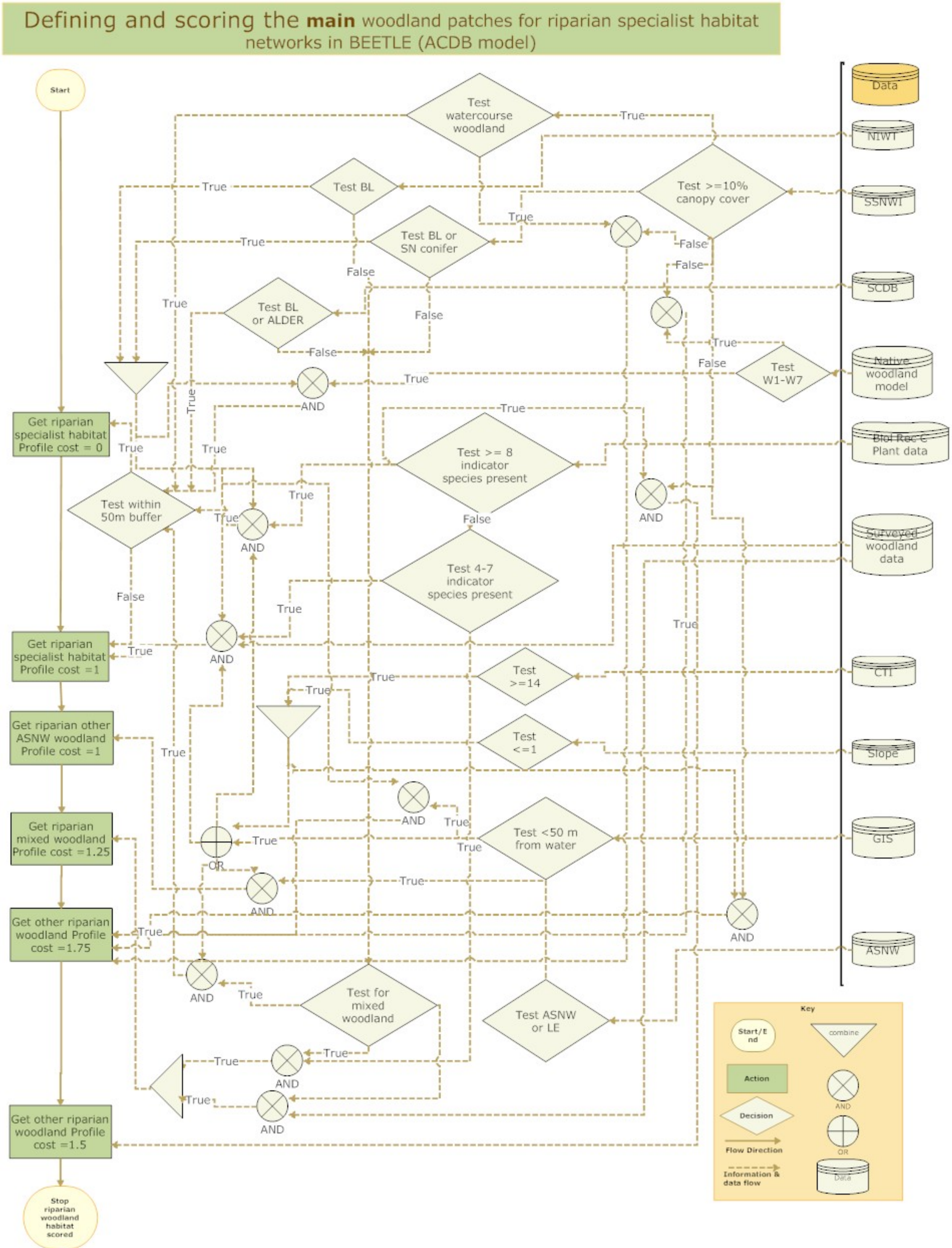


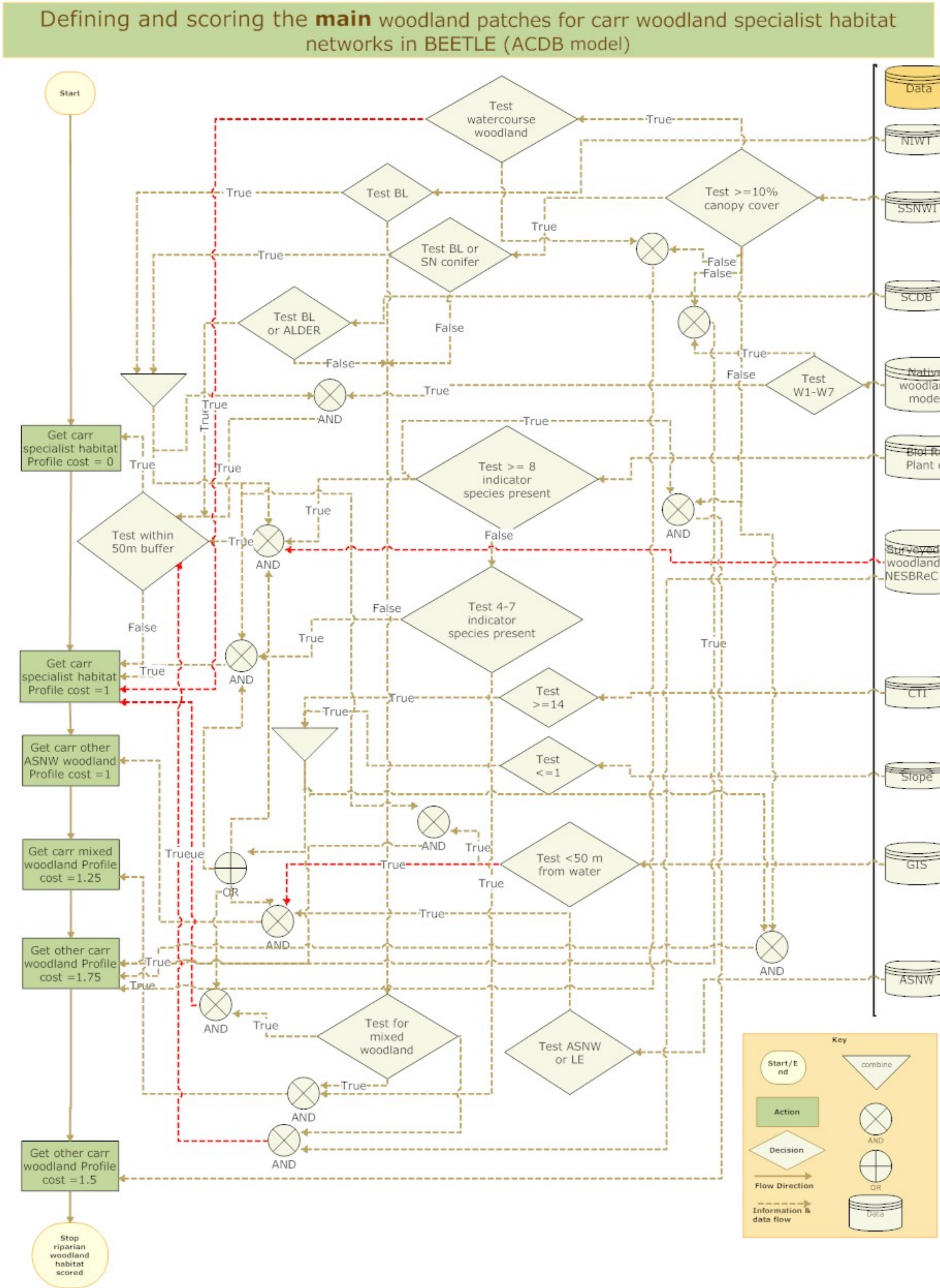
c. Flow diagram of sources and rules used to derive pinewood specialist data



d. Flow diagram of sources and rules used to derive broadleaved specialist data



e. Flow diagram of sources and rules used to derive riparian specialist data.



f. Flow diagram of sources and rules used to derive wet (Carr) woodland specialist data.