A Forest Habitat Network for the Atlantic oakwoods in Highland Region, Scotland*

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Abstract

The need to conserve biological diversity and ensure the future viability and integrity of Atlantic oakwoods in a fragmented landscape has led to strategies that facilitate a more holistic view of biodiversity conservation across extensive areas. The Scottish Forestry Strategy contains a major aspiration to develop forest habitat networks through the restoration and improvement of existing woodland and the expansion of new woodland.

The Forest Research landscape ecology model BEETLE (Biological and Environmental Evaluation Tools for Landscape Ecology) uses a focal species approach to assess the functional connectivity of habitat within the wider landscape matrix. This model has been used to predict the current habitat network for Atlantic oakwood specialists in the Highland region of Scotland. The analysis outputs are presented with an approach to help practitioners and planners visualise the opportunities to target expansion, conversion or restoration of Atlantic oakwoods and their intrinsic biodiversity.

Keywords: *Forest habitat networks; BEETLE; Landscape ecology; Atlantic oakwoods.*

Introduction

The sessile oakwoods, commonly referred to as Atlantic oakwoods (Ratcliffe 1968), are an important component of the wooded landscape in the Highlands of Scotland (Tansley 1939; Rackham 1980; Peterken 1981; Rodwell 1991). However in the past many of the oakwoods have been neglected and heavily grazed by sheep and deer (*e.g.* UK Biodiversity Action Group 1995; Humphrey *et al.* 2004), and some oakwoods were underplanted. Additionally, the ancient semi-natural oakwoods remain largely fragmented because intensive management of the matrix (non-habitat) reduced the ability of species to disperse, habitat patch size has declined through edge erosion, and patches have been lost to other types of land use. The need to conserve biological diversity and ensure the future viability and integrity of woodland, such as Atlantic oakwoods, in a fragmented landscape has led to strategies that adopt a more holistic view of biodiversity conservation across extensive areas (Hawkins & Selman

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2002). The Scottish Forestry Strategy (Forestry Commission 2000) outlined a major aspiration to develop forest habitat networks through the restoration and improvement of existing woodland and the expansion of new woodland. It is now recognised that targeted woodland expansion using forest habitat networks, through the establishment of linkages and corridors, will conserve forest biodiversity by reversing the consequences of woodland fragmentation and habitat loss (Peterken *et al.* 1995; Bennett 2003). Strategies to achieve this include the retention of ancient woods, improvement of their condition, and buffered expansion to reduce edge effects. It is assumed that the development of forest habitat networks will help reverse native woodland fragmentation, and it is hoped that new patches will link sub-populations. Indeed it has been argued (*e.g.* Peterken *et al*. 1995) that this will maintain genetic contact both within and between meta-populations and, in turn, provide greater species resilience in times of external stress, such as climate change. The forest habitat network approach also seeks to improve 'matrix' quality, *i.e.* non-woodland, by restoring scrub and other semi-natural habitat and encouraging more extensive management, to take account of the habitat requirements of open ground species.

Methodology

Resource identification

The location and extent of woodlands which may be classified as Atlantic oakwoods is poorly understood, making the identification of relevant stands for analysis difficult. In Highland Conservancy, the Atlantic oakwoods are mainly composed of upland oak woodland, which is characterised by a predominance of oak (most frequently sessile, but pedunculate can be locally common) and birch in the canopy, with varying amounts of holly, rowan and hazel as the main understorey species (Hall & Kirby 1998). The proportion of birch increases towards the north-west, where upland oak woodland is usually replaced by northern birchwoods.

As a spatial inventory of the Atlantic oakwoods in the Highlands is lacking, a methodology (Bryce 2002), was employed (Figure 1) to suggest Atlantic oakwood habitat. This identified the sessile oakwood extent from its potential distribution predicted by the Scottish Natural Heritage (SNH) / Macaulay Institute Native Woodland Model (NWM) (Towers 2002) combined with the Scottish Semi-natural Woodland Inventory (SSNWI) dataset (Sessile oak forms the major component of Atlantic oakwoods in the Highlands (Hall & Kirby 1998)). The criteria were:

- SSNWI woodland that was semi-natural or 80 to 90% semi-natural broadleaved, with a minimum of 10% canopy cover (the categories 'fragmented and open' (1 to 9%) and 'open' (<1%) were excluded as it is unlikely that such areas would constitute Atlantic oakwoods).
- National Vegetation Classification (NVC) (Rodwell 1991) identifiers used in the Native Woodland Model most likely to form sessile oakwoods were chosen (70 to 75, 80 to 84, 122, 125, 126, *i.e.* the main types (Table 1)). The identifiers were further restricted to only those identifiers with W11 present either as a single type or in mosaics (NVC identifiers 70, 71, 72, 73, 75, 83). These were thought to be the categories most likely to correspond to old sessile oakwoods with oak present, rather than woods that may be purely birch.

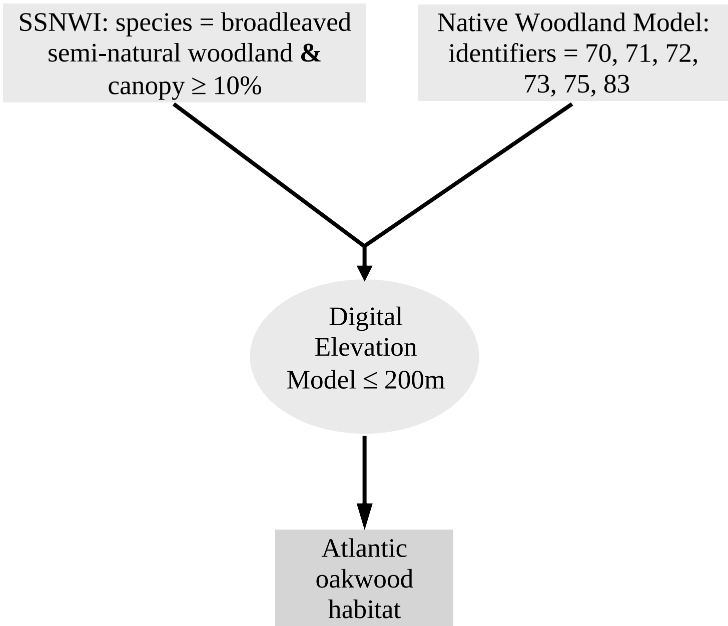


Figure 1. The methodology used to predict Atlantic oakwood habitat in Highland Conservancy using the Native Woodland Model (NWM) and Scottish Semi-natural Woodland Inventory (SSNWI) data.

Site altitude was used to distinguish areas likely to conform to the CORINE (Commission of the European Communities 1991) oakwood definitions (41.532 British sessile oakwood) rather than the associated birchwood types (41.B12 Medio-European dry acidophilous birch woods and 41.B2 Sub-boreal birch woods), as sites at higher elevation are more likely to tend towards birchwood types. Examination of the existing selection of oakwood candidate Special Areas of Conservation (cSACs) (European Commission 1992) provided a guide to the maximum likely altitude of these oakwood types, with a 200 m filter being adopted.

Table 1. National Vegetation Classification (NVC) identifiers and corresponding NVC types used in the Native Woodland Model.

NVC Identifier	**NVC type**
70	W11 (Upland oakwood)
71	W11/W4 (Upland oakwood or downy birch wet woodland)
72	W11/W17 (Upland oakwood or Northern birchwood)
73	W11 & W7 mosaic (Upland oakwood and alder-ash wet woodland mosaic)
74	W11/W9 (Upland oakwood or ashwood)
75	W11/W7 (Upland oakwood or alder-ash wet woodland)
80	W17 (Northern birchwood)
81	W17 & W4 mosaic (Northern birchwood & downy birch wet woodland mosaic)
82	W17/W18 (Northern birchwood or native pinewood)
83	W17/W11 (Northern birchwood or Upland oakwood)
84	W17/W18 & W4 (Northern birchwood or native pinewood & downy birch wet woodland with open ground)
122	W4 & W17 mosaic (Downy birch wet woodland & Upland oakwood mosaic)

125	W4/Sc5/W17/W18 (Downy birch wet woodland with open ground & peatland with scattered trees/scrub & Northern birchwood or native pinewood mosaic)
126	W4/W17/W18 (Downy birch wet woodland with open ground & northern birchwood or native pinewood mosaic)

It was assumed that Atlantic oakwood specialists would require oakwood habitat and would also be sensitive to the woodland edge. This was represented within the GIS by the internal buffering of a distance of 2 tree heights (50 m), which is considered to be the normal extent of any edge effects (Murica 1995).

Modelling approach

The Forest Research landscape ecology model BEETLE (Biological and Environmental Evaluation Tools for Landscape Ecology) uses a focal species approach to assess the functional connectivity of habitat within the wider landscape matrix (Watts *et al.* 2005). Focal species are considered as surrogates, representing a group of species in terms of their utilisation of the landscape (Lambeck 1997). The use of generic focal species concentrates attention on the landscape scale processes, allowing allocation of real species within the generic focal species groupings, such as those described in Table 2, to be undertaken as the process develops (Ray *et al.* 2003; Ray *et al.* 2004). BEETLE tests the landscape pattern against specific generic focal species profiles (Van Rooij *et al.* 2001).

Table 2. Some suggested indicator species occurring in Atlantic oakwoods in the Highland region of Scotland.

Species	Common name	Habitat requirements	Dispersal ability	Area requirement	Atlantic oakwood Specialist or Generalist
Adelanthus decipiens	A liverwort	Semi-natural oakwoods	low	small	S
Bazzania trilobata	A liverwort	Western acid oak woodlands	low	small	G
Ficedula hypoleuca	Pied Flycatcher	Mature open deciduous woodland, especially oak	high	small / medium	G
Hyacinthoides non-scriptus	Bluebell	Broadleaf woodland	low	small	G
Hydnellum spongiosipes	Velvet tooth fungus	Broadleaf woodland, particularly oak	low	small	G
Hymenophyllum wilsonii	Wilson’s Filmy fern	Shaded rock faces & tree trunks in humid woods	low	small	G
Lobaria pulmonaria	Tree lungwort	Established broadleaf woodland, particularly oak	low	small	G
Lobaria virens	A lichen	Established broadleaf woodland, particularly oak	low	small	G
Plagiochila atlantica	A liverwort	Upland Sessile oakwoods	low	small	S
Plagiochila killarniensis	Killarney featherwort	Western acid oak woodlands	low	small	G
Phoenicurus phoenicurus	Redstart	Mature woodland, especially sessile oakwoods	high	small / medium	G
Phylloscopus sibilatrix	Wood warbler	Beech woods and mature upland oakwoods	high	small / medium	G
Martes martes	Pine martin	Broadleaf or conifer woodland	high	large	G

A BEETLE analysis was undertaken across the Highland region of Scotland using an Atlantic oakwood specialist generic focal species, assuming three maximum dispersal abilities of 250, 500, and 1000 m. The model BEETLE identifies forest habitat networks within a Geographic Information System (GIS) framework, using an accumulated cost distance buffer (ACDB) analysis (Adriaensen *et al.* 2003). An ACDB surrounding each habitat patch was calculated up to the dispersal distance limit for the generic focal species (250, 500, or 1000 m in this case). Weighting factors (permeability costs) were applied to represent the ease of dispersal of the generic focal species through the landcover types (Table 3). Local knowledge was used to account for differences between those Atlantic oakwoods providing typical habitat and those that are degraded by designating Atlantic oakwood stands as ‘good’, ‘medium’, or ‘poor’ quality. ‘Good’ quality (habitat) was defined by stands with good structural components (old trees, multi-layer canopy with gaps), a quantity of deadwood (*e.g.* standing deadwood – snags, fallen deadwood), and a well developed ground flora. ‘Medium’ quality stands would have some of these features, whilst ‘poor’ quality stands would have few. A weighting factor of 0 (no permeability cost) was allocated to actual habitat, small costs, *e.g.* 1 to 5, for the most suitable landcover types, and higher costs (10 to 50) for less suitable types. For example, a generic focal species with a dispersal distance of 1000 m, traversing a landcover type with an assigned weighting factor of 10, would be allocated an effective dispersal distance of 100 m. The ACDB was used to link habitat patches within the dispersal distance limit. At the dispersal limit a barrier was assumed to exist. All of the habitat patches and intervening matrix, connected by virtue of falling within the ACDB, were classified as a single habitat network.

Table 3. A selection of some of the permeability costs applied to the landcover types used in the Atlantic oakwood specialist BEETLE analysis.

Landcover type	**Cost**
Broadleaf woodland	1.5
Coniferous woodland	5
Mixed woodland	3
Atlantic oakwood of good quality	0
Atlantic oakwood of medium quality	1
Atlantic oakwood of poor quality	1.5
Rough unimproved grassland with trees	5
Dry heather moor with trees	10
Wet heather moor with trees	15
Wet heather moor with no trees	20
Bracken with trees	5
Bracken with no trees	10
Wetlands with trees	15
Wetlands	30
Montane	40

Analyses were undertaken across the Highland Conservancy area to identify the extent and functional linkage of the Atlantic oakwood resource, and at a local scale to illustrate the scope of the methodology in identifying and planning the conservation management strategy.

Results and Discussion

Highland analysis

The number of habitat networks identified for Atlantic oakwood specialists in Highland Conservancy ranged from 1 289 when assuming a maximum dispersal distance of 1000 m, to 1 945 for a dispersal distance of 250 m (Table 4).

Table 4. Summary statistics of the networks for Atlantic oakwood specialists within Highland Conservancy

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)
250	1 945	31 288	16.1	514
500	1 607	38 740	24.1	623
1000	1 289	51 396	39.9	755

Total area, mean area, and the area of the largest individual network increased with increasing dispersal distance indicating that the habitat networks for dispersal-limited species are much smaller than those for species with high dispersal ability. The differences reflect how, with larger dispersal ability, more neighbouring networks merge as they become functionally connected, *i.e.* resulting in a smaller number of networks each covering a larger area. At the regional scale, assuming a maximum dispersal distance of 1000 m, the Atlantic oakwood specialist habitat networks are prominent along the lochs and glens (Figure 2).

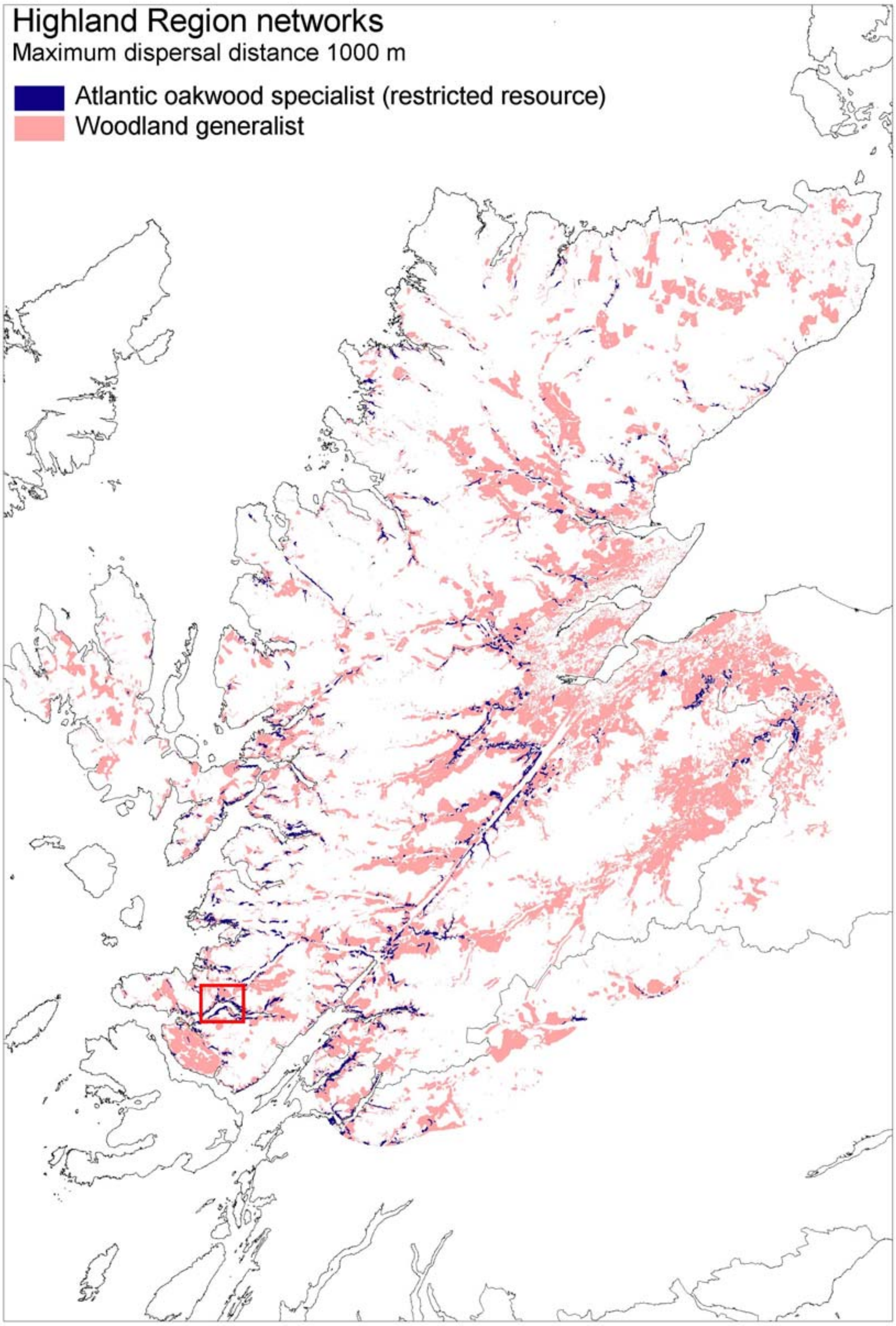


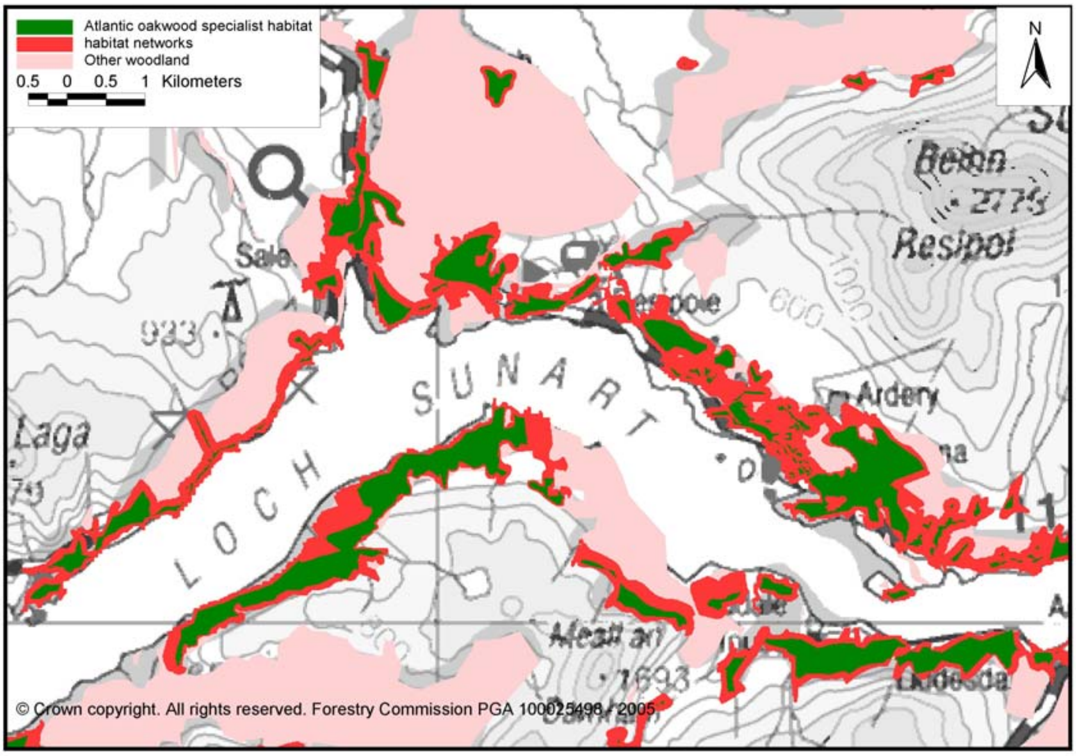
Figure 2. The distribution of forest habitat networks in Highland Conservancy for Atlantic oakwood specialists and woodland generalists. The red box highlights the Atlantic oakwoods around Loch Sunart.

Loch Sunart Analysis

The consolidation of networks can be clearly seen at a local scale around the shores of Loch Sunart area (Table 5 & Figure 3) when comparing the maximum dispersal distances of (Figure 3a) 1000 m and (Figure 3b) 250 m. The obvious difference between the two networks is greater connectivity of woodland for the 1000 m dispersal distance, indicating that, in this location, those species with high dispersal ability should be able to move freely through the woodland which separates the fragmented patches of Atlantic oakwood. For those species with low dispersal ability (Figure 3b) movement between habitat patches may be restricted, with some of the functional networks unlikely to be large enough to support species with a high area requirement. Figure 3c demonstrates how the restoration and management of relatively small areas of oakwood can be targeted to reduce habitat fragmentation of the existing Atlantic oakwood habitat, allowing dispersal across a much larger geographic area. In addition, the analysis identifies oakwood patches that may be too small to support characteristic sedentary species that require substantial habitat to maintain viability, enabling directed management to be undertaken.

Table 5. Summary statistics of networks surrounding Loch Sunart for Atlantic oakwood specialists

Max. dispersal distance (m)	Number of networks identified	Total area of networks (ha)	Mean area of networks (ha)	Area of largest network (ha)
250	42	1 088	25.9	231
500	28	1 298	46.4	259
1000	17	1 607	94.5	469



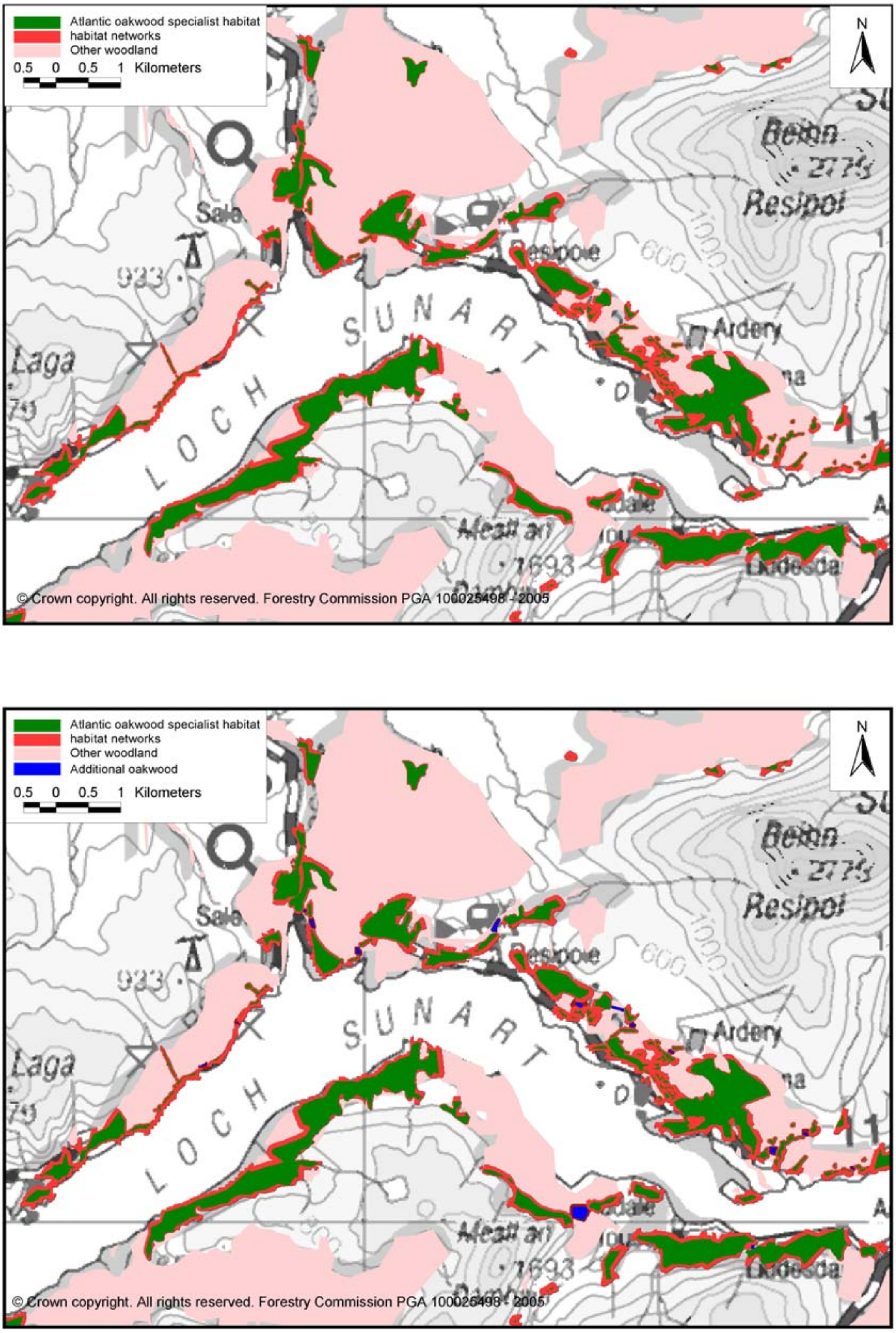


Figure 3. Habitat networks for Atlantic oakwood specialists with a maximum dispersal distance of (a) 1000 m and (b) 250 m, located around Loch Sunart. The area in green represents Atlantic oakwood habitat, as defined in the methodology, with a 50 m woodland edge, whilst the area in red represents the functional habitat network. Figure 3 (c) demonstrates how networks for specialists with a small dispersal ability, in this case 250 m, can be joined by the strategic planting of additional habitat, represented by the blue colour.

Comparing Forest Habitat Network theory with the BEETLE approach

In Scotland, forest habitat networks will form a key conservation initiative to reverse deforestation, which has been regarded by Peterken *et al.* (1995) as the greatest loss of Scotland's natural heritage in historic times. The concept of forest habitat networks was first discussed (Foreman & Godron 1986) in the context of a landscape ecology paradigm of patch, matrix, and corridor. The idea of greenways found favour with landscape architects and ecologists (Smith & Hellmund 1993) keen to demonstrate the social, aesthetic and ecological benefits of green space (including woodland) in the landscape. In Scotland, several authors have discussed modifications to these landscape ecology concepts, mindful of the expansion and restoration needs of Scotland's woodland in the form of forest habitat networks (Peterken *et al.* 1995, Hampson & Peterken 1998, Ratcliffe *et al.* 1998, Towers *et al.* 1999, Worrell *et al*. 2003). Most have described general and theoretical models for forest habitat networks, but Ratcliffe *et al.* (1998) for example, recognised the importance of focal species as surrogates for measuring the impact of landuse change on biodiversity.

The BEETLE approach is a practical tool which models landscape function; the interaction between landscape structure and ecological processes in the form of movement of particular species through the landscape, and the habitat size-species viability relationships of the landscape. The approach allows the specification of relatively broad classes in the form of generic focal species to represent woodland biodiversity. In the absence of detailed spatial data and autecological knowledge, this permits a focus on the wider biodiversity value of woodland and other habitat types, rather than on the conservation of single species (Watts *et al.* 2005). The approach aims to supplement the theoretical issues regarded as important in planning forest habitat networks in Scotland. In particular the network concept (Peterken *et al*. 1995) of nodes (compact forest patches) and links (linear forest habitats) are represented within the focal species profiles as habitat patches (permeability cost 0) and the matrix (permeability cost 1 to 50). Scale considerations at the regional (core forest areas), landscape (forested sites) and forest scales (localities) are inherently represented in the BEETLE GIS analysis (which is independent of scale), and additionally within the specification of maximum dispersal distance within a particular generic focal species model (*e.g.* Atlantic oakwood specialist, woodland generalist).

Practical application of Atlantic oakwood networks

The analyses identify the functional networks connecting physically fragmented Atlantic oakwood in Highland Conservancy, and allow examination of the resource at the local scale. The value of the BEETLE forest habitat networks analysis is twofold: firstly it objectively identifies habitat networks, indicating the potential for dispersal across non-specialist habitat, and secondly it can be used to plan the consolidation and expansion of the specialist habitat to reduce fragmentation and support viable meta-populations at the landscape scale. This approach is suitable for adaptive management, enabling practitioners to test scenarios or the outcomes of woodland management. The generic focal species approach provides a useful tool for identifying Atlantic oakwood management and expansion priorities to reduce woodland fragmentation. The outputs from such analyses can be used in a number of ways:

1. Restoration of PAWS within networks. This should be a priority as PAWS within networks will theoretically have a better chance of colonisation by species associated with the network type.
2. Expansion and conversion within and at the boundaries of networks to maintain functional connectivity with the network.
3. Consolidation of ancient woodland fragments by buffered expansion.
4. Management grants to support structural, species, and deadwood diversity in woodlands within or close to the boundaries of specialist networks.
5. Identification of open ground specialist networks, which will prevent damaging the biodiversity of open habitats.

It is envisaged that the BEETLE approach will allow practitioners and planners to use these strategies in the conservation and expansion of the Atlantic oakwood resource in Highland Conservancy and in other regions of Scotland when further analyses are completed.

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