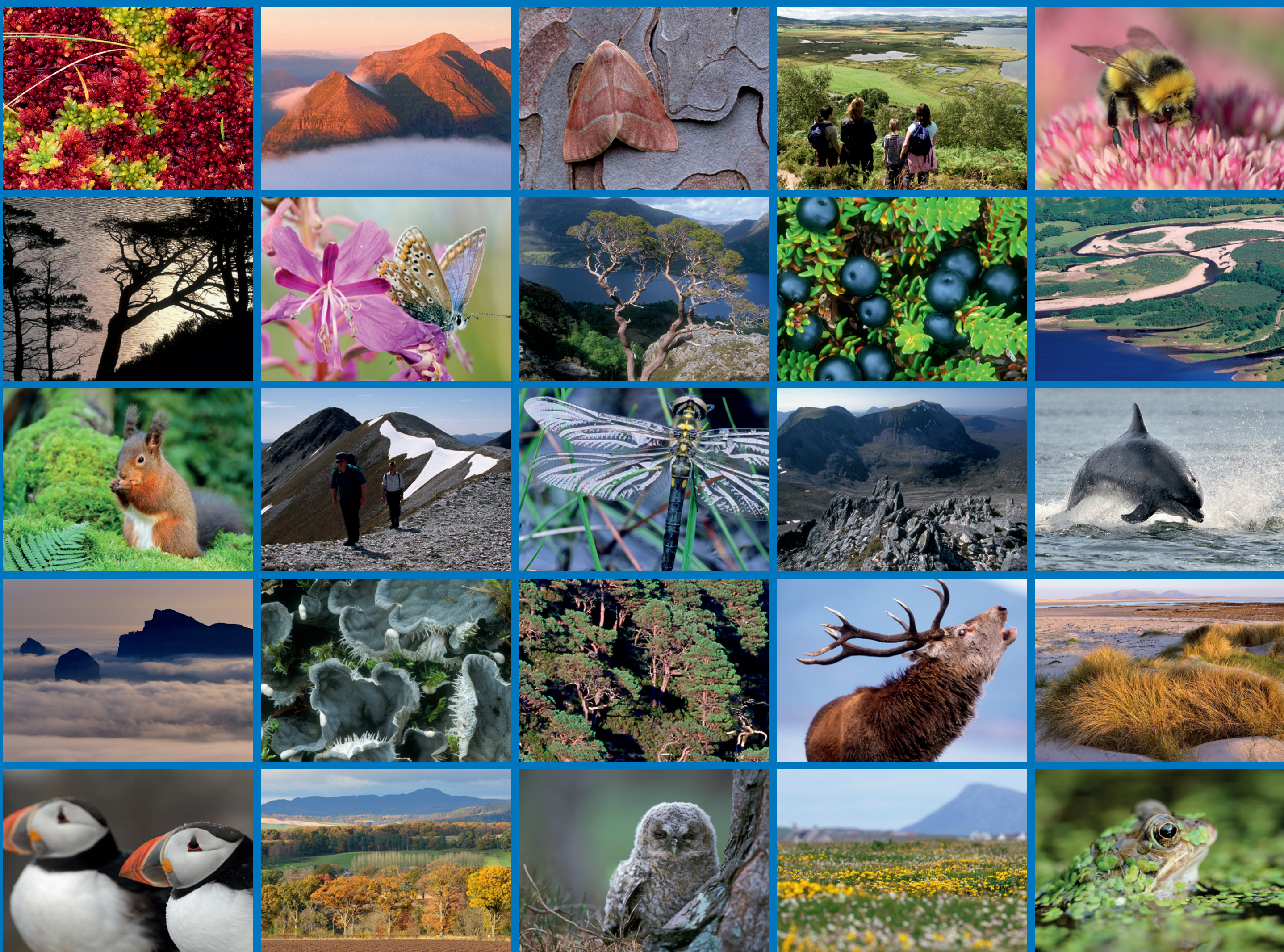
Scottish Natural Heritage
Research Report No. 887

Developing a habitat connectivity indicator for Scotland



RESEARCH REPORT

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RESEARCH REPORT

Summary

Developing a habitat connectivity indicator for Scotland

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Keywords

indicator; connectivity; habitat network; Equivalent Connected Area (Probability of Connectivity); ECA(PC); dispersal; functional

Background

This work reports on a method to:

a) quantitatively assess the level of functional habitat connectivity at a regional and national scale (*i.e. measuring* habitat connectivity); and

b) apply the method to produce an indicator of landscape change for Scotland (*i.e. developing an indicator* of habitat connectivity).

There is an international obligation to develop a suite of indicators to detect changes in biodiversity. SNH has developed an indicator for habitat connectivity using existing software and current landcover data, and which can measure connectivity at a national and regional scale.

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1. INTRODUCTION

1.1 Habitat connectivity – what is it?

Habitat connectivity has been described as 'the degree to which the landscape facilitates or impedes movement among resource patches' (Taylor *et al,* 1993). In essence, it's how well species can move between habitats within a particular area. There are two main elements to habitat connectivity – structural connectivity and functional connectivity.

- *Structural connectivity* concerns how habitat patches are distributed across a landscape and whether the patches are physically connected to each other by the same or similar habitat;

- *Functional connectivity* refers to the ability of species to move from one habitat patch to another based upon their dispersal abilities, and the nature of the intervening land cover - often referred to as the landscape matrix. The *permeability* of the landscape matrix to species movement is a key element in considering connectivity.

This work reports on a method to:

a) quantitatively assess the level of functional habitat connectivity at a regional and national scale (*i.e. measuring* habitat connectivity); and

b) apply the method to produce an indicator of landscape change for Scotland (*i.e. developing an indicator* of habitat connectivity).

1.2 Why is habitat connectivity important?

There has been a trend of increasing habitat loss and fragmentation over time. This process has several impacts on wildlife (Fahrig, 2003; Andrén, 1994), including:

- loss of available habitat area;
- increased distance between habitat patches;
- individual habitat patches becoming too small to support some species;
- small areas of habitat and their species being more vulnerable to catastrophic events;
- smaller habitat patches having an increased proportion of edge to core habitat, so reducing the amount of suitable habitat for some species.

Identifying fragmentation, with the view to improving an area's habitat connectivity through wider land management, would seem, on the surface, a simple way to counter these effects (Briers, 2010a & 2010b; Rudnick *et al,* 2012). However, several factors need to be taken into account when attempting to identify any effects of fragmentation on both structural and functional habitat connectivity.

The *quality* of a habitat patch or patches is an important consideration in habitat function across a landscape (Visconti & Elkin, 2009), as are habitat *size*, *shape* and *spatial configuration* (Watts *et al,* 2008 & 2010).

Additionally, functional connectivity can decrease or increase with no change in habitat fragmentation if the *permeability* of the surrounding landscape matrix alters (Baum *et al,* 2004; Baranyi, 2011; Zeller *et al,* 2012). Therefore analysing habitat connectivity can yield more information on the impacts of landscape changes on species than simply looking at fragmentation (Watts & Handley, 2010; Watts *et al,* 2008 & 2010; Saura & Rubio, 2010).

Measuring habitat connectivity quantitatively (Watts & Handley, 2010), together with *habitat network mapping,* allows connectivity to be represented visually. Maps can be used for a number of purposes (Latham *et al*,2013; Rudnick *et al*, 2012; Smith *et al*, 2008), such as helping to identify key areas of habitat fragmentation, pinchpoints essential for species movement, and species population extent according to available and accessible habitat, as well as:

- ecosystem restoration and monitoring;
- species conservation;
- design of protected area networks;
- urban development and land use planning;
- transport infrastructure design and barrier effect mitigation;
- habitat management and planning (*e.g.* reforestation);
- pests and disease transmission pathways;
- yield and catch analyses in marine and freshwater systems;
- public communication, interpretation and awareness raising.

Connectivity assessments are also seen as important in relation to the impacts of climate change (see, for example, Hodgson *et al.,* 2009). Habitat networks may provide an adaptation mechanism for species, allowing them to shift range to a new geographical area (Laita *et al*, 2010).

1.3 How can connectivity be measured?

Metrics to identify habitat connectivity involve calculating the strength of a connection or connections between pairs of habitat patches. Most connectivity metrics are based on graph theory (Saura & Torné, 2009; Urban *et al*, 2009) where a network is constructed from source habitat patches (termed 'nodes') and their connections (or 'links'). Metrics vary, but the most sophisticated take into account the size of habitat patches (within or *intra-patch* connectivity) as well as the connections between them (between or *inter-patch* connectivity).

The connections can be simply considered as a straightforward geographical (or Euclidean) distance measurement, or as a gradient of permeability according to the different land use types between the patches (the 'least-cost' or 'cost' distance). In habitat connectivity analyses, least-cost approaches use information on landscape permeability to determine the ecological 'cost' to a species travelling along a given pathway. Higher cost land uses (*i.e.* having a lower permeability) reduce the overall distance that can be travelled (Briers, 2010a; Cadotte, 2006; Zeller *et al,* 2012).

For example, for a native woodland species, native woodland itself as source habitat has no ecological cost to species movement. Heathy scrub, however, is likely to be less permeable to species movement than native woodland, though is more permeable than grassland. Consequently, a native woodland species can disperse a greater distance through heathy scrub than grassland. The ecological cost of dispersal through different habitats can be calculated accordingly (see section 2.5).

2. MEASURING CONNECTIVITY

2.1 Background to the method

The work presented here demonstrates how habitat connectivity can be measured at regional and national scales using the example of native woodland habitat. It is a summary based on a method developed by Saura *et al.* (2011) for assessing connectivity trends in European forests, and it uses the Conefor software developed by Saura & Torné (2009). A full methodology is in Appendix 2.

The data needed are:

- a landcover layer, combined with a source habitat layer (see sections 2.3 and 2.4.1);
- ecological cost tables (section 2.4.2, and Appendix 1);
- a dispersal distance (section 2.5).

In this study, two sets of connectivity values were produced: an overall national connectivity value for the whole of Scotland, and 10 regional values based on the SEPA advisory areas (referred to as 'catchments'). The latter areas were chosen for ecological and administrative reasons, as they generally follow watersheds and reflect the spatial scale at which much environmental planning takes place.[1]

2.2 The habitat connectivity metric

The metric described here is the **Equivalent Connected Area (Probability of Connectivity)** or **ECA(PC)**. It is defined as:

- 'the size that a single habitat patch would need to be, to produce the same probability of connectivity as the actual habitat pattern in the landscape under consideration.'(Saura & Rubio, 2010)

Section 2.3 gives examples of this measurement in practice.

There are several advantages of this metric:

- the higher the value, the greater the connectivity;
- the connectivity value is greater than the area of the largest patch in the landscape, and smaller than the sum of all patch areas;
- the reporting unit is a measure of area (usually hectares) making it potentially more understandable in how the results are presented,
- it does not require the overall area of the landscape to be defined (choosing the boundary of an area can be a somewhat arbitrary and potentially misleading decision);
- changes in this metric's values can be compared directly with changes in overall habitat area (*i.e.* hectare to hectare), allowing a greater understanding of a habitat's relationship to the landscape it occupies and the changes in the habitat's connectivity.

2.3 What does the ECA(PC) value tell us?

The ECA(PC) value encompasses habitat area, the size and numbers of patches, how the habitat patches are arranged in the area under consideration, and the effect the intervening landscape matrix exerts on species movement between habitat patches.

[1] See www.sepa.org.uk/environment/water/river-basin-management-planning/who-is-involved-with-rbmp/area-advisory-groups/

This can be illustrated using sample landscapes as examples. Figures 1-4 show four ECA(PC) analyses in landscapes each with roughly the same habitat area. The examples show the range of connectivity factors which influence their ECA(PC). These are:

- the amount of habitat in the area under consideration;
- the degree of fragmentation (i.e. the number of patches, and their size);
- the spatial configuration of the patches (i.e. how distant they are from one another);
- the permeability of the intervening land cover types (i.e. the cost distance); and
- the maximum dispersal distance of the species under consideration in favourable habitat.

2.4 Creating the native woodland source habitat layer

All woodland classified as 'native' within the Native Woodland Survey of Scotland (NWSS)[2] was selected as source habitat. In some connectivity studies (see Watts & Handley, 2010; Saura *et al,* 2011), a minimum patch size is used to avoid including very small fragments which would be unable to support the species being studied (and which would also unnecessarily increase the computational time and equipment needed for analyses). In this study, we used 0.5ha (which corresponds with the NWSS which uses a 0.5 ha minimum mappable unit).

See Appendix 2 for a detailed methodology.

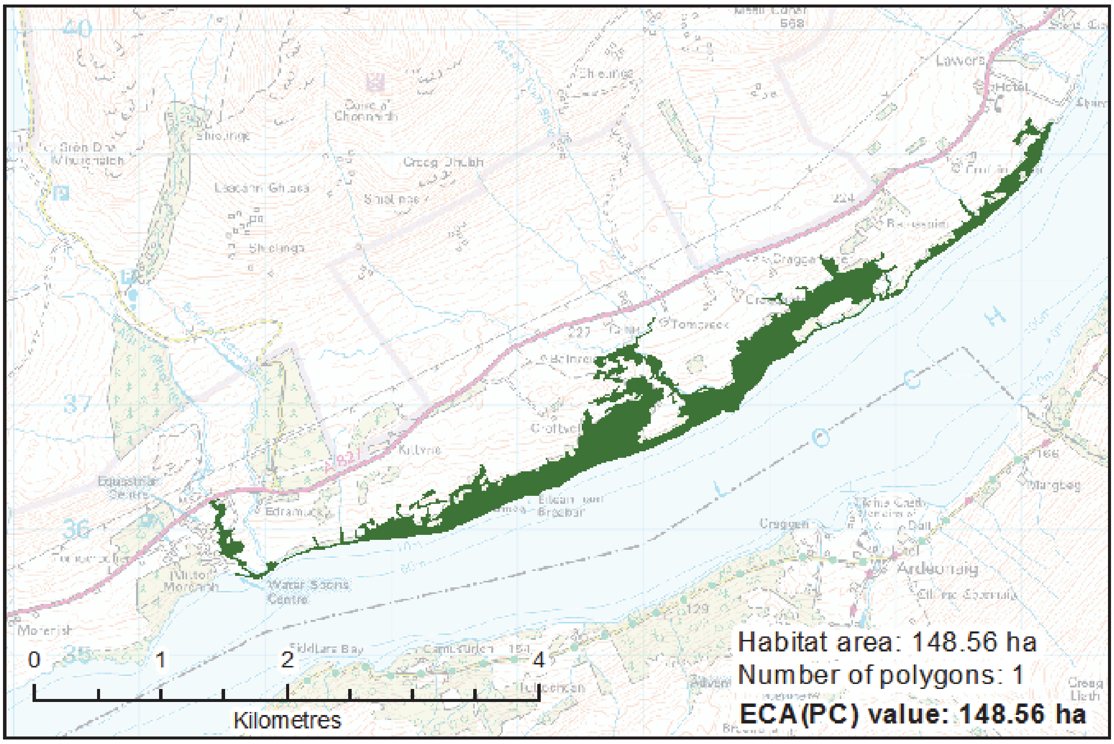

Figure 1. Showing a single habitat patch (ie one polygon) analysis, where the ECA(PC) value equals the size of the habitat area – ie habitat area = ECA(PC).

[2] See http://scotland.forestry.gov.uk/supporting/strategy-policy-guidance/native-woodland-survey-of-scotland-nwss

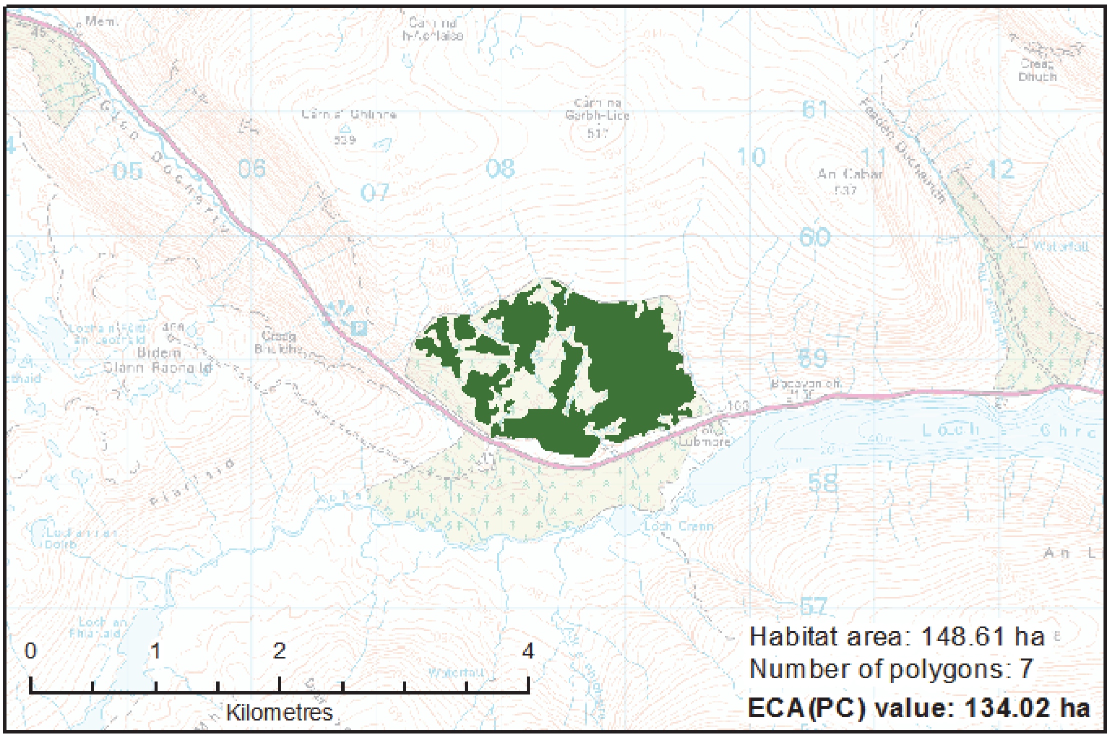

Figure 2. Showing 7 native woodland patches which are close together, and separated by non-native woodland. The ECA(PC) value is reasonably high indicating that the habitat patches are well connected, with the intervening landscape matrix (in this case, non-native woodland) being highly permeable to native woodland species movement.

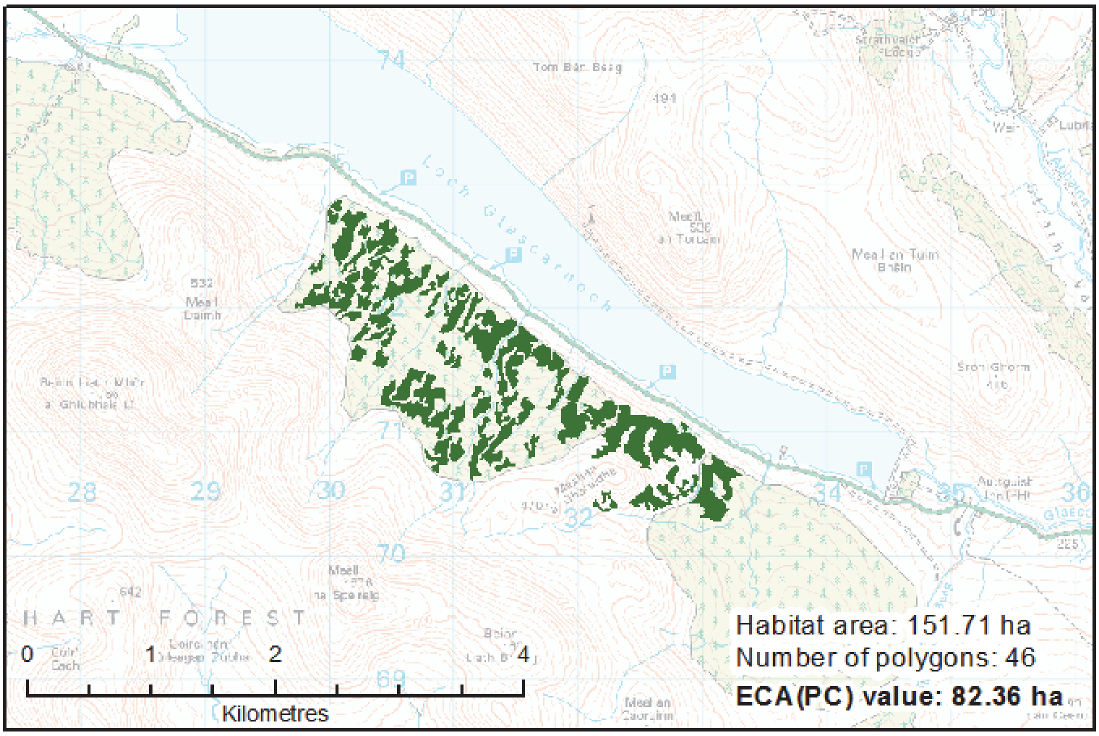

Figure 3. Showing 46 native woodland polygons quite close together, and separated by non-native woodland resulting in a moderate ECA(PC) value. Compared with figure 2, the ECA(PC) is lower – the patches being smaller and more numerous, despite the intervening landscape matrix (non-native woodland) and the total amount of native woodland habitat being roughly similar.

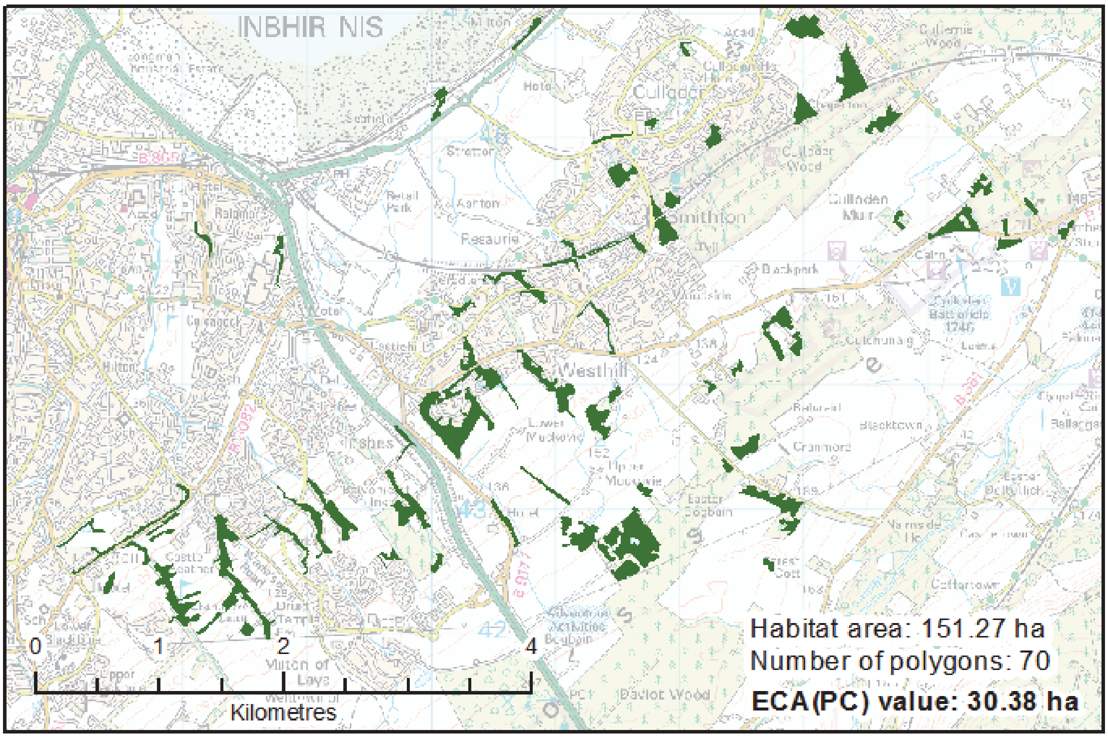

Figure 4. Here, 70 native woodland patches are small, dispersed and separated by high cost land cover types (mainly urban habitats and intensive agriculture), resulting in a low ECA(PC) value.

2.5 Calculating the cost distance between habitat patches

For connectivity studies containing less than several thousand patches, it is usual to calculate the least-cost distance between pairs of habitat patches which specifically measures the effect of the landscape matrix between them (Urban et al. 2009). However, for larger analyses this is computationally intensive. Saura & Rubio (2010) considered it infeasible to carry out least-cost path analysis between specific habitat patches across European regions in their study. They also questioned whether it was necessary to do so to calculate metrics over large regions.

Instead, they (in Saura *et al.*, 2011) calculated the average (i.e. mean) cost of moving a certain Euclidean cost distance through the landscape matrix of each region, which proved to be a suitable substitute for calculating numerous individual pathways (see section 2.7 for more detail).

To confirm these findings, the Ythan and Tweed catchments were tested here following Saura *et al*'s (2011) methodology, using both least-cost and average cost pathways (see table 1). The difference between the least-cost and average cost is not statistically significant (1.4ha (or 0.9%) for the Ythan; 3ha (or 0.8%) for the Tweed), supporting Saura *et al*'s conclusions.

Table 1. Comparison of methods for for calculating distances between habitat pairs for the Ythan and Tweed catchments. Option 1 is Euclidean distances, Option 2 involves using average (mean) costs per region, and Option 3 uses individually calculated least-cost paths. The study used LCM2007 broadleaved woodland data, a 25m grid size and a 500m maximum dispersal distance for 95% of dispersers.

	Ythan	**Tweed**
Number of patches	≈ 700	≈ 5,000
Total habitat area	1,645 ha	13,482 ha
ECA(PC) Option 1 [Euclidean]	204 ha	515 ha
ECA (PC) Option 2 [Mean cost]	153.8 ha	383 ha
ECA (PC) Option 3 [Individual least-cost]	152.4 ha	386 ha
Percentage difference between [Mean cost] and [Individual least-cost]	0.9%	0.8%

2.6 The landscape matrix

The recently developed EUNIS (European Nature Information System) Land Cover Scotland dataset3 (ELCS) was used to create the overall landscape matrix (Strachan, 2017) for this study. EUNIS is the classification standard the INSPIRE Directive, to enable open access and inter-operability of land cover data throughout Europe. It is a raster dataset at a 10m resolution that brings together the best available national land cover datasets within the hierarchical EUNIS classification.

2.7 Calculating permeability weightings for landscape regions

The permeability of the matrix (*i.e.* the ease with which a species can move through different land cover types) is defined by way of a *cost table* which gives the ecological cost for an individual species to move through each land cover type (see Appendix 1) – the ecological cost of which will vary between different species. As there is very little autecological information on species dispersal and patch size residency, the values used in this study were taken from Delphi analyses in previous work (Watts *et al,* 2008).

The Delphi method is widely used where empirical data are lacking (MacMillan & Marshall, 2006). It is a moderated process aiming to develop consensus between experts over several rounds of deliberation, on the assumption that combining the expertise of several individuals will provide more reliable results than consulting one or two individuals (MacMillan & Marshall, 2006). The cost table values derived from Watts *et al* (2008) were adapted to the EUNIS Land Cover of Scotland habitat classes by SNH habitat experts.

A value was calculated for each pixel (*i.e.* 10m square) in the landscape from the cost table, corresponding to each pixel's permeability weighting. For example, if an individual travelled from the pixel solely through a habitat type of cost 2 to reach the nearest source patch, the pixel's permeability weighting would be 2. In other words, each pixel's weighting indicates how much more costly is it to reach the nearest source habitat patch than the Euclidean distance alone.

These permeability weightings were then averaged (*i.e.* a mean was derived) across similar landscape areas of the country. For this, the Landscapes of Scotland[4] were chosen as they reflect areas with a similar composition of land cover types and are designed to be at a scale

[3] See https://www.nature.scot/landscapes-and-habitats/habitat-map-scotland
[4] See https://www.nature.scot/landscapes-and-habitats/about-scotlands-landscapes/landscape-variety-scotland

to help with regional planning. This dataset divides the country into 79 landscapes, according to similarity of habitat and landscape patterns.

SEPA advisory areas (‘catchments’) were not chosen in this case, as each covers a large diversity of land uses (*i.e.* upland and lowland environments of many kinds within a catchment), and therefore will contain a sizeable range of cost movement permeabilities. Consequently, averaging would produce an inadequate reflection of variation in the catchment’s permeability and therefore potentially lead to a less accurate measure of its connectivity.

For native woodland species, the permeability weighting for a pixel can range from 0 (as source habitat) and 1 (*e.g*. if a species only has to travel through broadleaved woodland or scrub to reach the nearest source habitat patch) through to 25 (if, for example, it has to pass through urban or water features to reach the nearest source patch). The averages across landscape regions range from 1.5 in Jura to 10.2 in Glasgow and Clydeside.

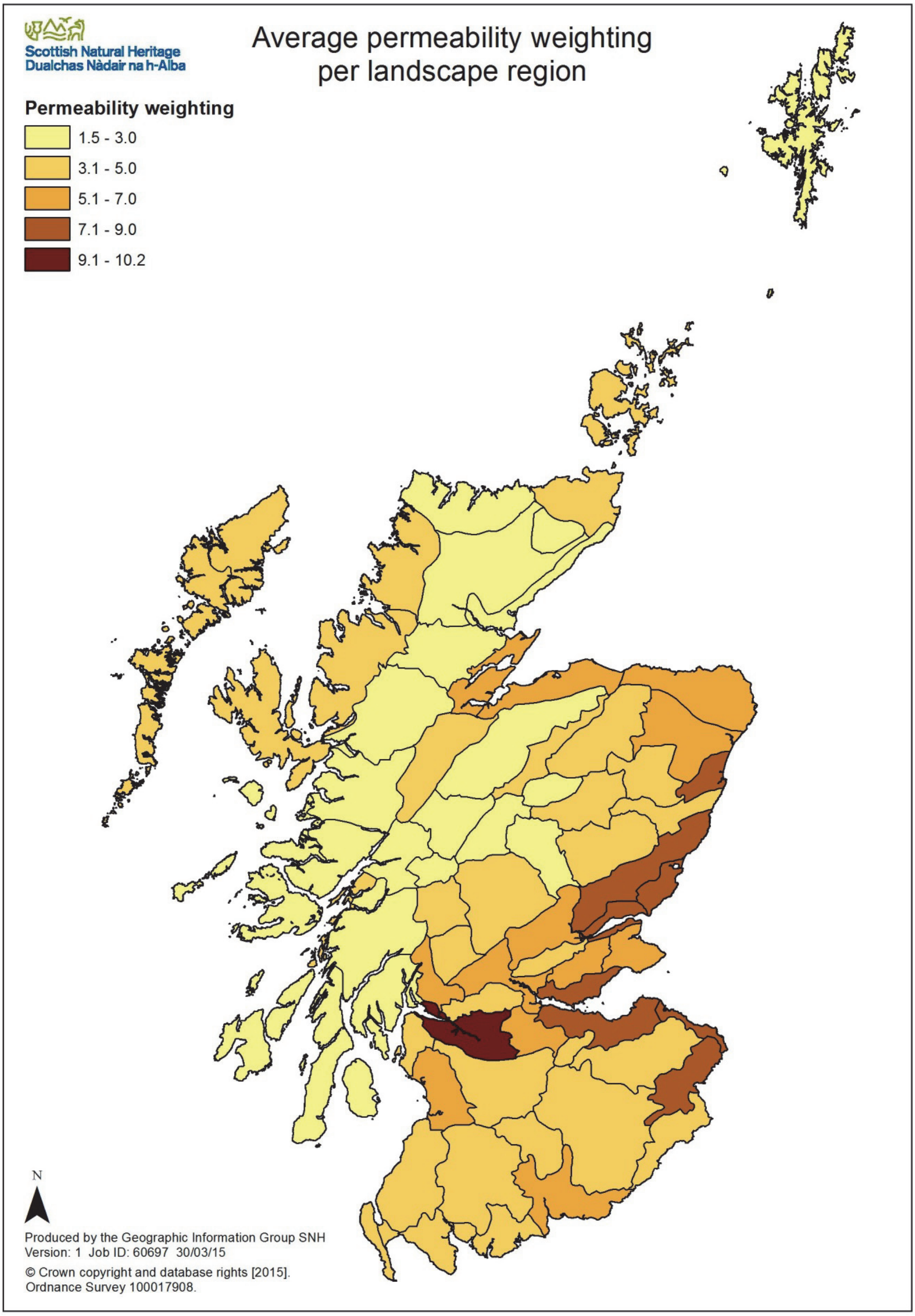

Figure 5. Average (mean) permeability weightings for each of Scotland's 79 landscape regions for a generic woodland species.

2.8 Calculating regional habitat connectivity values

The ECA(PC) metrics were generated with the freeware Conefor software (64 bit command line version) (Saura & Torné, 2009) for each SEPA catchment. Conefor automatically generates a node file containing the area of each habitat patch and a link file containing the Euclidean distance between each pair of habitat patches within a user defined distance threshold.

The maximum dispersal distance for generic woodland species (from Watts *et al,* 2008 & 2010) is 500m. However, the 500m value is the maximum distance for 95% of dispersers. Therefore 5% of species could disperse more than 500m and – ecologically - these could be important. Between 500m and 1000m, therefore, the probability of connectivity will be low but should not be disregarded. However, a cut-off needs to be applied, to make processing computationally feasible at a catchment scale. Consequently, we chose 1000m as it is more than twice the dispersal distance (as 1,000m is a Euclidean distance and 500m a cost distance) and is ecologically and computationally realistic.

The link file was then updated by multiplying the Euclidean distances by the average permeability weighting for the landscape region in which the habitat patches are situated (in cases where the two patches reside in different regions the two weightings were averaged).

The 10 SEPA catchment areas were run through Conefor as a batch file, completing within a couple of hours.

As per the above, a maximum dispersal distance of 500m was entered into the software with a probability value of 0.05 (as the Delphi study considered the 500m value to be for 95% of dispersers). By giving these two values, the software can derive a negative exponential dispersal curve (see fig. 2 in Saura & Rubio, 2010) which it uses to derive the probability of connectivity between two habitat patches. In other words, it indicates the likelihood of an individual dispersing from one patch to another.

2.9 Calculating a national habitat connectivity value

Ideally all source habitat patches (see 2.4) in Scotland for the species under consideration would be run through Conefor in the same analysis to generate a national connectivity value. That said, processing times (and computational power required) rise exponentially with an increase in the number of patches, and consequently computer RAM becomes a limiting factor. Previous testing with Land Cover Map 2007 data for broadleaved woodlands showed that combining the 10 regional values to give a national figure was only 1ha ECA(PC) different from running the whole of Scotland as one region. Therefore this combination approach was taken for generating a national figure for native woodlands.

However, simply adding together the 10 regional values gives an inaccurate ECA(PC) value for the whole of Scotland. This is because ECA(PC) is calculated in the following way:

$$ECA(PC) = \sqrt{PCnum} = \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i \cdot a_j \cdot p_{ij}^{*}}$$

Where a_i is area of patch I; a_j is area of patch j; and p_{ij}^{*} is the maximum product probability of connectivity between them (ranges between 0 when the patches are not connected and 1 where i = j).

For example, imagine a 100ha patch in one region and another 100ha patch in another. If these are treated as part of the same network and assuming they are not connected ($p_{ij}^* = 0$), the result would simply be the sum of their intra-patch connectivity ($p_{ii}^* = 1$ and $p_{jj}^* = 1$), *i.e.:*

$$\sqrt{(100 * 100 * 1) + (100 * 100 * 1)} = 141.4\ ha$$

However, if they are treated as two separate networks, each has a value of:

$$\sqrt{(100 * 100 * 1)} = 100\ ha$$

Adding them together would give 200 ha; so a very different result.

Therefore, to get an estimated national ECA(PC) figure from the regional values, each needs to be squared, the totals summed and then the square root taken.

This is likely to be a slight underestimate as connectivity will be lost at region boundaries where habitat patches are split or cross-border connections are broken. This is minimal for woodland but could be more significant for other habitats which are more likely to cross watersheds.

2.10 Results

Table 2 gives the total area of native woodland habitat, number of patches, size of the region and the ECA(PC) value for each of the 10 catchment areas and for Scotland as a whole. Figure 6 shows these results geographically.

Table 2. Native woodland connectivity results.

SEPA catchments	Area of native woodland (ha)	No. of patches	Size of region (ha)	ECA(PC) (ha)
Argyll	44,125	7,066	955,782	2,444.40
Clyde	30,588	7,759	789,327	1,356.00
Forth	19,060	4,732	486,696	1,283.20
North East Scotland	73,438	8,242	976,130	11,087.10
North Highland	70,178	8,973	1,410,872	5,818.80
Orkney & Shetland	37	28	248,216	8.4
Solway	17,857	5,678	703,268	725.6
Tay	32,386	6,338	877,453	2,109.40
Tweed	5,876	2,294	433,484	271.9
West Highland	17,550	3,349	998,000	1,315.60
Scotland	**311,154***	**54,337****	**7,631,012**	**13,153.8*****

* This is 59 ha more than the catchment areas added together as some woodland fragments extend below Mean High Water Springs which bounds the catchments.
** This is a lower number than the sum of the region totals as a few habitat patches are split at region boundaries.
*** See section 9.

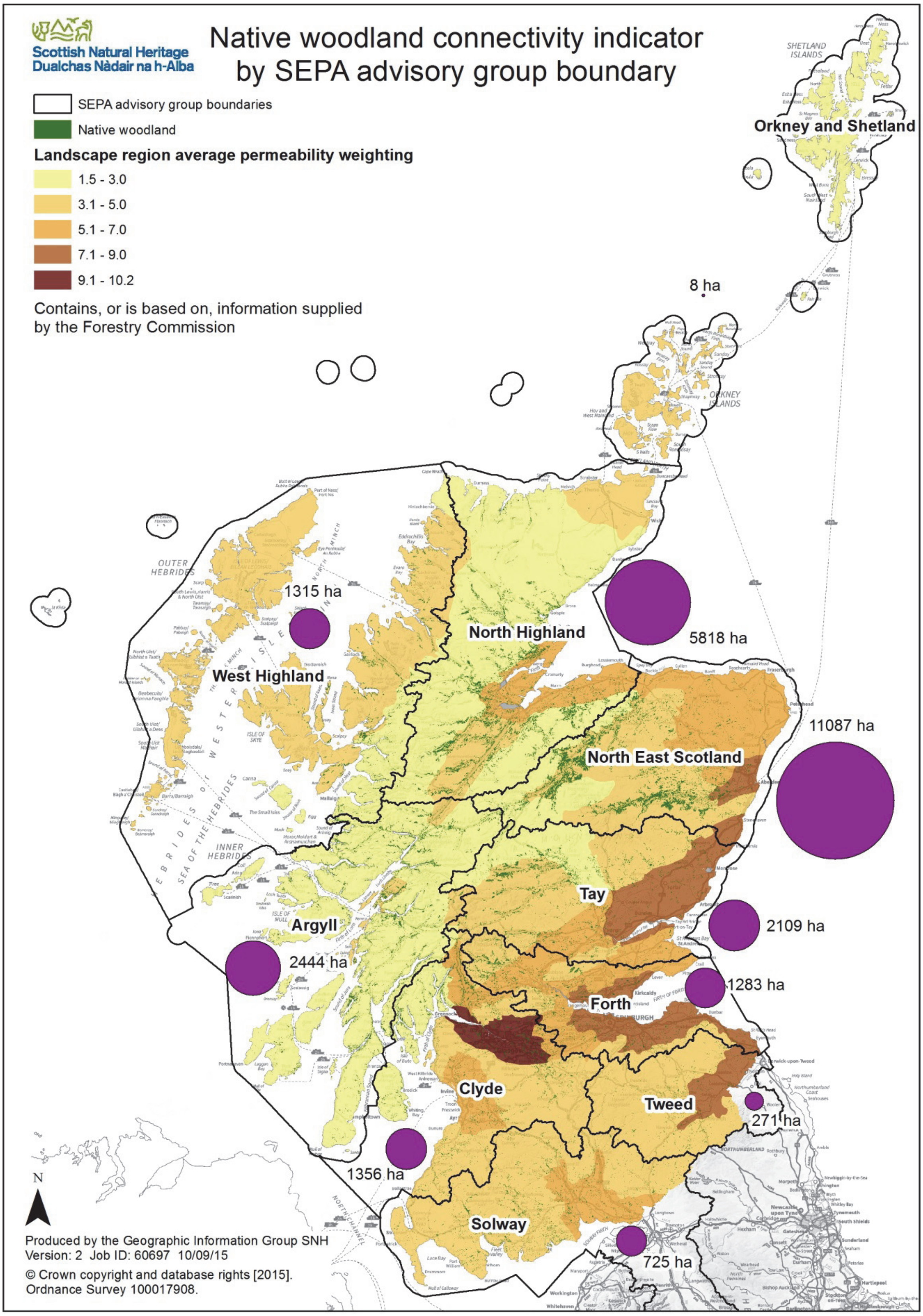

Figure 6. ECA(PC) values shown graphically for each of the 10 catchment areas.

3. INTERPRETING THE REGIONAL ECA(PC) VALUES

Table 2 and Figure 6 show that native woodland connectivity varies considerably across Scotland and between each catchment area. There are likely to be many causes for this, as the ECA(PC) value incorporates several landscape ecology measures.

As in section 2.3, we can start to interpret the results by comparing catchments with similar amounts of native woodland but very different ECA(PC) values.

For example, table 2 shows that Solway and West Highland both have similar total areas of native woodland (around 17,500 ha) yet the ECA(PC) for Solway is about half that for West Highland (*i.e.* 725.6 and 1,315.6 respectively). This indicates that native woodland habitat in West Highland is much better connected. This may be due to a number of factors such as:

- West Highland having fewer (and hence larger) woodland patches (*i.e*. 3,349 compared with 5,678) which increases intra-patch connectivity;
- in addition to being fewer and larger, the patches in West Highland may be also be comparatively much closer to each other, which would increase the inter-patch connectivity, whereas the Solway woodlands are more evenly spread across the lowland landscape;
- the permeability of the intervening landscape matrix being higher within West Highland than Solway (*i.e.* ranging 1.5 to 5, and 3.1 to 7 respectively) meaning that woodland species can move more easily between habitat patches in West Highland than Solway. Solway comprises proportionally more agricultural land, and a relatively greater concentration of roads (Benítez-López, 2010) which may explain this.

Similarly North East Scotland and North Highland have very different ECA(PC) values (roughly 11,000 ha and 6,000 ha respectively) despite a similar habitat area (73,438 ha vs 70,178 ha) and a similar number of patches (8,242 vs 8,943). As mentioned above, the metric reflects more than the spatial configuration of habitat patches according to patch size, number and location alone: North East Scotland has slightly more habitat comprising fewer habitat patches than North Highland may account for some of the difference. However, it is likely that much of the variance is due to the high concentration of woodland habitat in the Spey and Dee river valleys (as can be seen in fig. 6). These concentrations are likely to outweigh the slightly lower permeability of the North East Scotland landscape matrix (1.5 to 9.0) as a whole than North Highland (1.5 to 7.0).

As highlighted in section 2, ECA(PC) reflects a number of landscape ecology features. As these factors vary within and between each catchment area, the main conclusion to note is that ECA(PC) values can give us an insight into multiple rather than single differences between areas that could then be investigated further to see what specific factors account for the differences in connectivity.

4. DEVELOPING A HABITAT CONNECTIVITY INDICATOR

4.1 Background

The work above shows how habitat connectivity can be quantitatively measured, which has potential in producing an indicator of habitat connectivity. The aim of a habitat connectivity indicator is to measure connectivity at a point in time and then again in the future in order to detect change. This can help in monitoring the progress, or otherwise, of land management interventions, identifying trends, and to influence future policy and management.

The UK is a signatory to the Convention on Biological Diversity (CBD) and is committed to the biodiversity goals and targets ('the Aichi Targets') agreed in 2010. A requirement is to produce a suite of biodiversity indicators. Indicator C2 requires habitat connectivity to be measured (JNCC, 2013). It is the primary indicator for Aichi Target 5 (CBD, 2010):

Target 5:
By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.

It is also a relevant indicator for Aichi Target 11:

Target 11:
By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascapes.

Since 2010, the UK has produced a suite of indicators, which were last updated in 2017 (JNCC, 2017). Within Scotland, a series of Ecosystem Health Indicators have been developed[5], covering habitat and species function, condition and resilience. Habitat connectivity is included within this series.

4.2 Previous habitat connectivity indicator work

Previous work by DEFRA carried out by Watts *et al.* (2008 and 2010) reported on the connectivity of broadleaved, mixed and yew woodland, and neutral grassland broad habitat types for review in 2011 and 2012, which contributed to the UK's 5th National Report to the CBD in 2014 (and also, unchanged, to the 2017 report). The connectivity analyses were based on a sample of 1km Countryside Survey squares, and used a metric called the Probability of Functional Connectivity (Watts & Handley, 2010).

They used the Countryside Survey 1km squares, as these form the only reliable time series of land cover data in the UK, but it is also limiting. Habitat networks are more usually viewed at landscape scales and, as a sampling approach could not be avoided in the DEFRA analyses, and that other data were lacking, it was subsequently decided that the information available was *'insufficient for an assessment of change to be made'* (JNCC, 2013). Different approaches to habitat connectivity at a UK-level are currently being discussed - such as looking at population synchrony, with butterflies as a proxy species (JNCC, 2017).

As the ECA(PC) approach taken in this study used a national land cover data layer, and it has produced results that are quantitative and meaningful, we have explored whether it be

[5] See https://www.environment.gov.scot/our-environment/state-of-the-environment/ecosystem-health-indicators/

developed into a national indicator, with the results presented in an appropriate format suitable for range of users and audiences.

4.3 Creating an indicator from ECA(PC)

As shown above, we generated ECA(PC) values for each of the 10 catchment group areas in Scotland, and combined these into a single connectivity value for native woodland habitat. We undertook further analyses to produce ECA(PC) values for:

- semi-natural woodland
- semi-natural grassland
- fen/marsh/swamp
- heathland

The landcover base map used in these analyses was as described in section 2 (and detailed in Appendix 1; sections 2 and 4.1), with each source habitat layer complied as per Appendix 1; sections 4.1.1 – 4.1.4. The cost tables are as shown in Appendix 1, and the dispersal distances and minimum habitat patch sizes in Table 3.

Note that 'semi-natural woodland' source habitat indicated here is derived from ELCS[6] (section 2.6), and is not the same as 'native woodland' described in section 2.4 (from the Native Woodland Survey of Scotland)

Table 3. Dispersal distances and minimum patch sizes used per habitat, from Watts et al. (2008 and 2010)

Habitat	Dispersal distance	Minimum habitat patch size
Semi-natural woodland	500m	0.5ha
Semi-natural grassland	300m	0.5ha
Fen/marsh/Swamp	150m	0.02ha
Heathland	500m	0.5ha

4.4 Results

The analyses for semi-natural woodland, semi-natural grassland, heathland, and fen/marsh/swamp are shown in Table 4.

[6] See https://www.nature.scot/landscapes-and-habitats/habitat-map-scotland

Table 4. Showing the ECA(PC) values per catchment area for each of the four habitats, with corresponding data on area of habitat and number of patches Note that 'semi-natural woodland' source habitat used here is derived from ELCS, and is not 'native woodland' as derived from NWSS in section 2.

	Fen / Marsh / Swamp			Semi-Natural Grassland			Heathland			Semi-Natural Woodland		
Catchment	**Area of habitat (ha)**	**No. of patches**	**ECA(PC) (ha)**	**Area of habitat (ha)**	**No. of patches**	**ECA(PC) (ha)**	**Area of habitat (ha)**	**No. of patches**	**ECA(PC) (ha)**	**Area of habitat (ha)**	**No. of patches**	**ECA(PC) (ha)**
Argyll	1,232	884	135.2	83,985	4,248	5,110.9	439,609	3,821	70,701.7	96,068	10,429	5,552.1
Clyde	292	256	54.1	117,476	8,955	8,639.4	136,377	3,112	19,741.2	91,665	16,356	3,420.9
Forth	393	169	99.5	60,359	6,035	9,285.4	46,452	1,547	10,356.9	50,498	10,887	2,259.4
Orkney & Shetland	972	664	112.7	53,470	5,167	2,506.4	117,259	1,645	24,380.7	255	67	109.9
North East Scotland	540	146	152.6	57,491	11,788	1,342.1	292,611	3,670	124,813.0	71,851	13,475	2,454.6
North Highland	2,393	630	530.7	59,281	7,379	2,391.0	799,628	4,152	190,200.0	93,187	12,618	4,163.8
Solway	2,932	348	1010.0	132,514	9,035	11,898.7	74,238	2,824	10,586.5	90,922	12,327	4,769.9
Tay	586	162	160.5	77,574	6,384	6,549.1	275,735	2,307	105,796.0	58,861	11,181	2,341.3
Tweed	35	24	11.8	94,870	5,612	10,113.0	73,446	1,495	20,779.3	33,450	6,393	2,836.4
West Highland	2,018	1,283	200.2	47,344	4,711	2,886.4	702,291	3,861	150,880.0	33,786	4,462	3,199.5

4.5 Presenting the results

Our challenge was to present an ECA(PC) value in relation to its habitat's wider context, in a format that was suitable for inclusion in the Scottish Ecosystem Health Indicators and UK Biodiversity Indicators suite *i.e.* as a visual graphic, chart or graph, with a minimum of accompanying data.

ECA(PC) gives a hectare value which, as seen in section 2, has advantages - for example, as a useful metric for comparing a single habitat between regions. However, as discussed earlier, a single figure is difficult to interpret on its own - without the accompanying contextual data tables showing the number of patches and the total habitat amount, and maps of the habitat configuration.

After some experimentation, we found the simplest and most meaningful way was to show the ECA(PC) value(s) as percentages of the total amount of the habitat in the area in question, on a map (Table 5). Figures 6-9 illustrates this as a percentage segment within a pie-chart, the size of which circle indicated the total amount of habitat. These pie-charts are further presented on a map of Scotland arranged according to their catchment areas, and showing the habitat in question.

This allows a rapid visual comparison of:

- the degree of connectivity relative to the amount of habitat present (segment within pie-chart);
- the relative amount of habitat present (size of pie-chart);
- the broad spatial configuration and amount of habitat in total across Scotland (map).

These maps are also published within the Scotland Ecosystem Health Indicators suite under indicator 8: connectivity.[7]

[7] See https://www.environment.gov.scot/our-environment/state-of-the-environment/ecosystem-health-indicators/function-indicators/indicator-8-connectivity

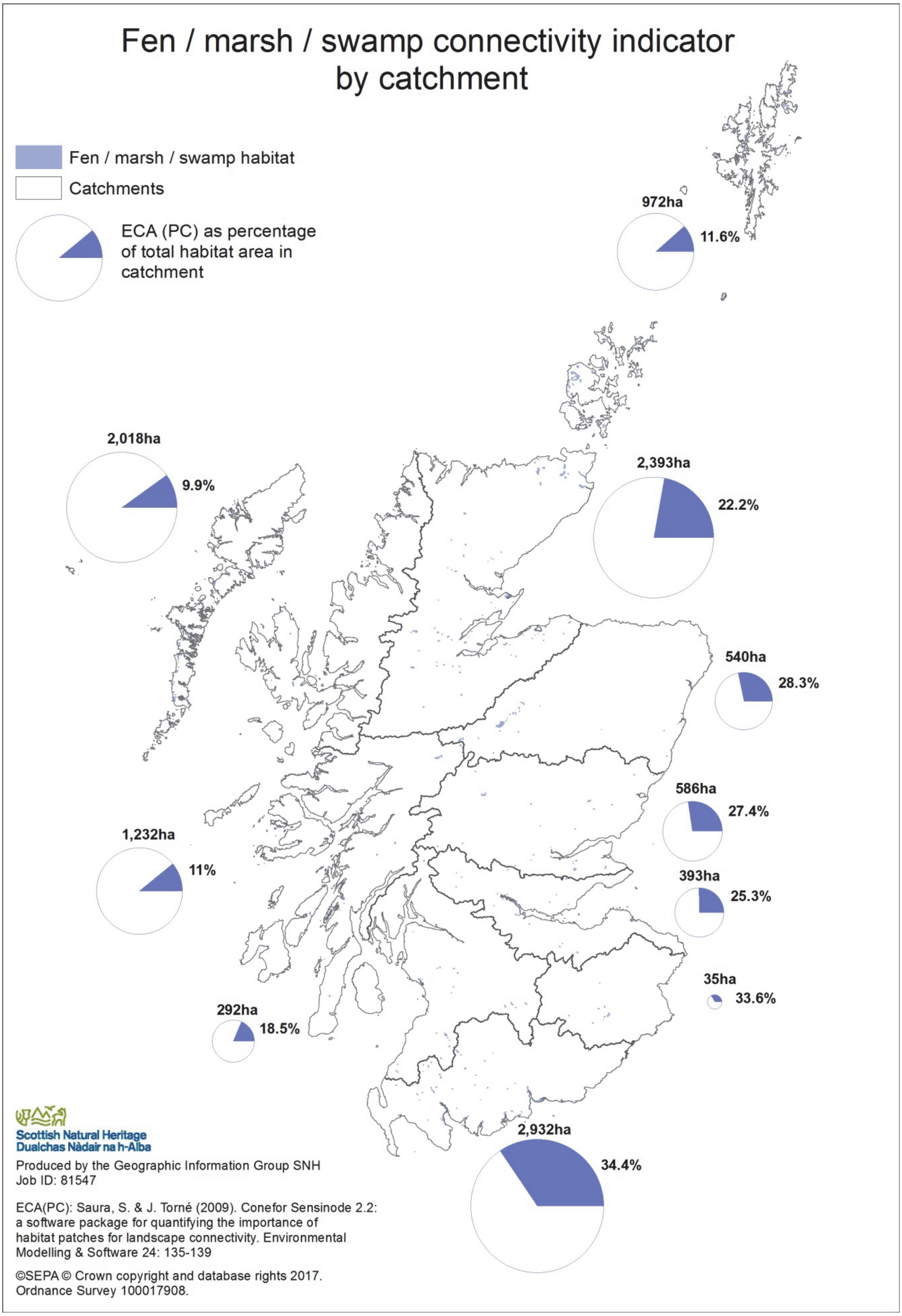

Figure 6. Showing each catchment area's ECA(PC) as a percentage of the area's total habitat for fen/marsh/swamp.

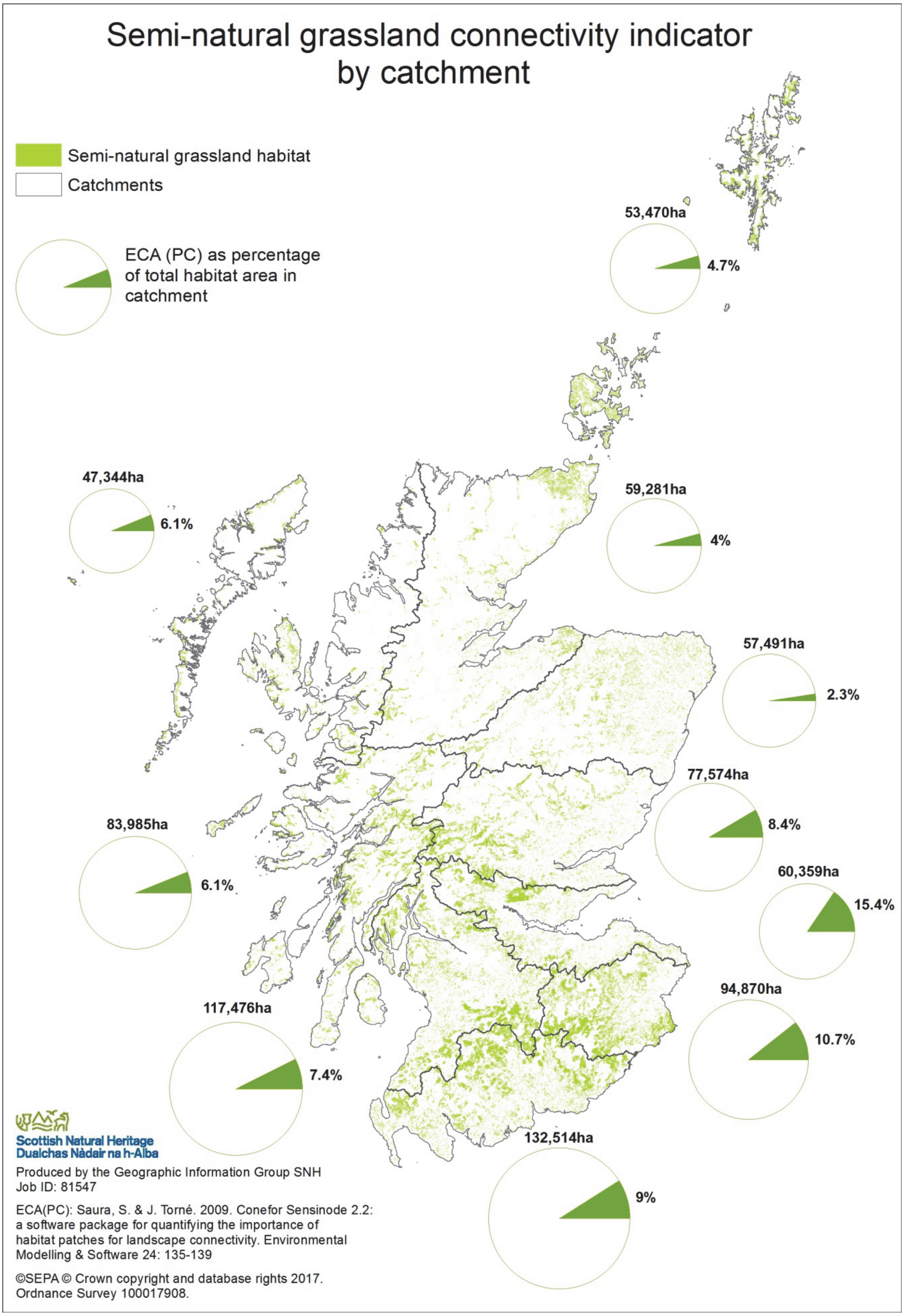

Figure 7. Showing each catchment area's ECA(PC) as a percentage of the area's total habitat for semi-natural grassland.

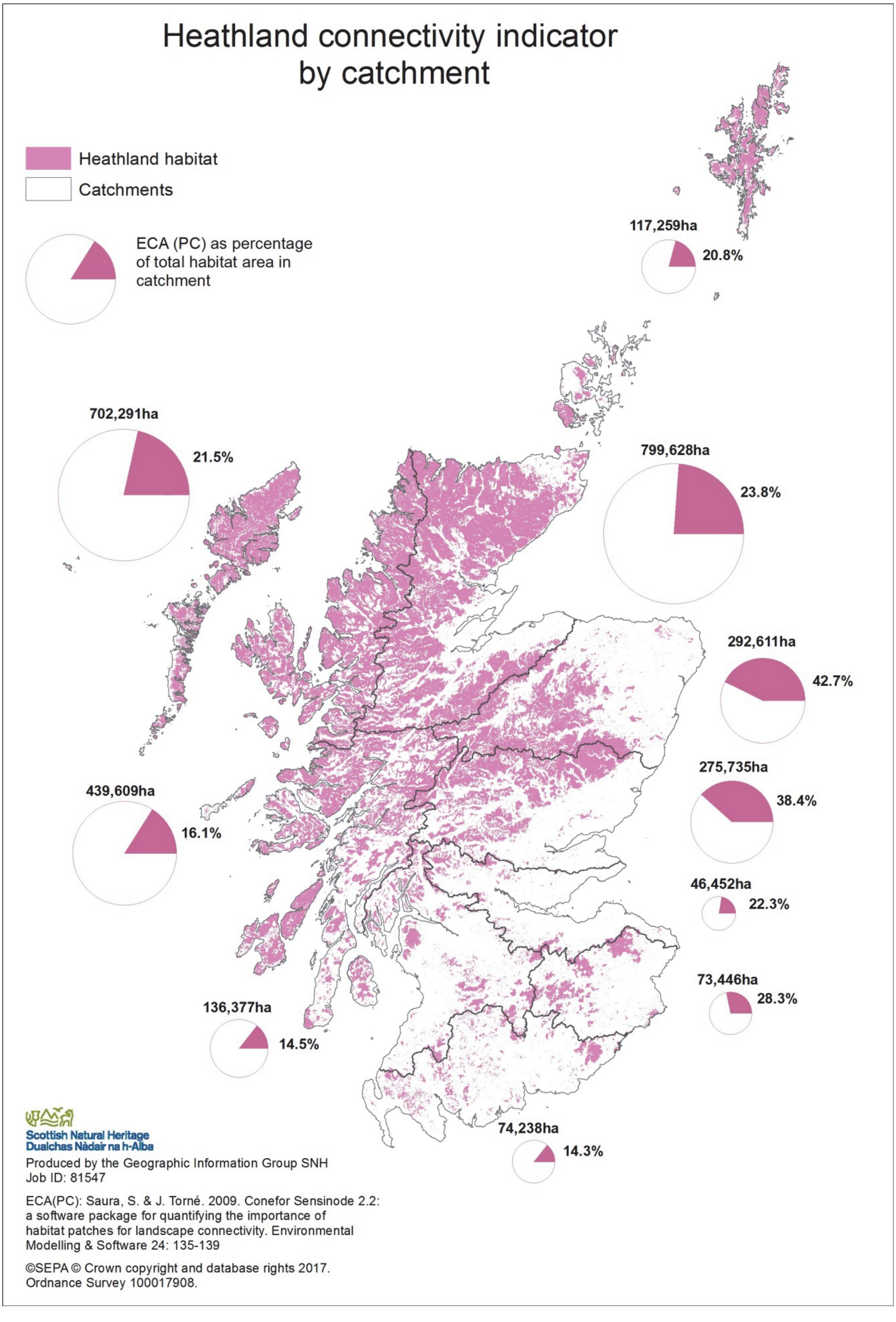

Figure 8. Showing each catchment area's ECA(PC) as a percentage of the area's total habitat for heathland.

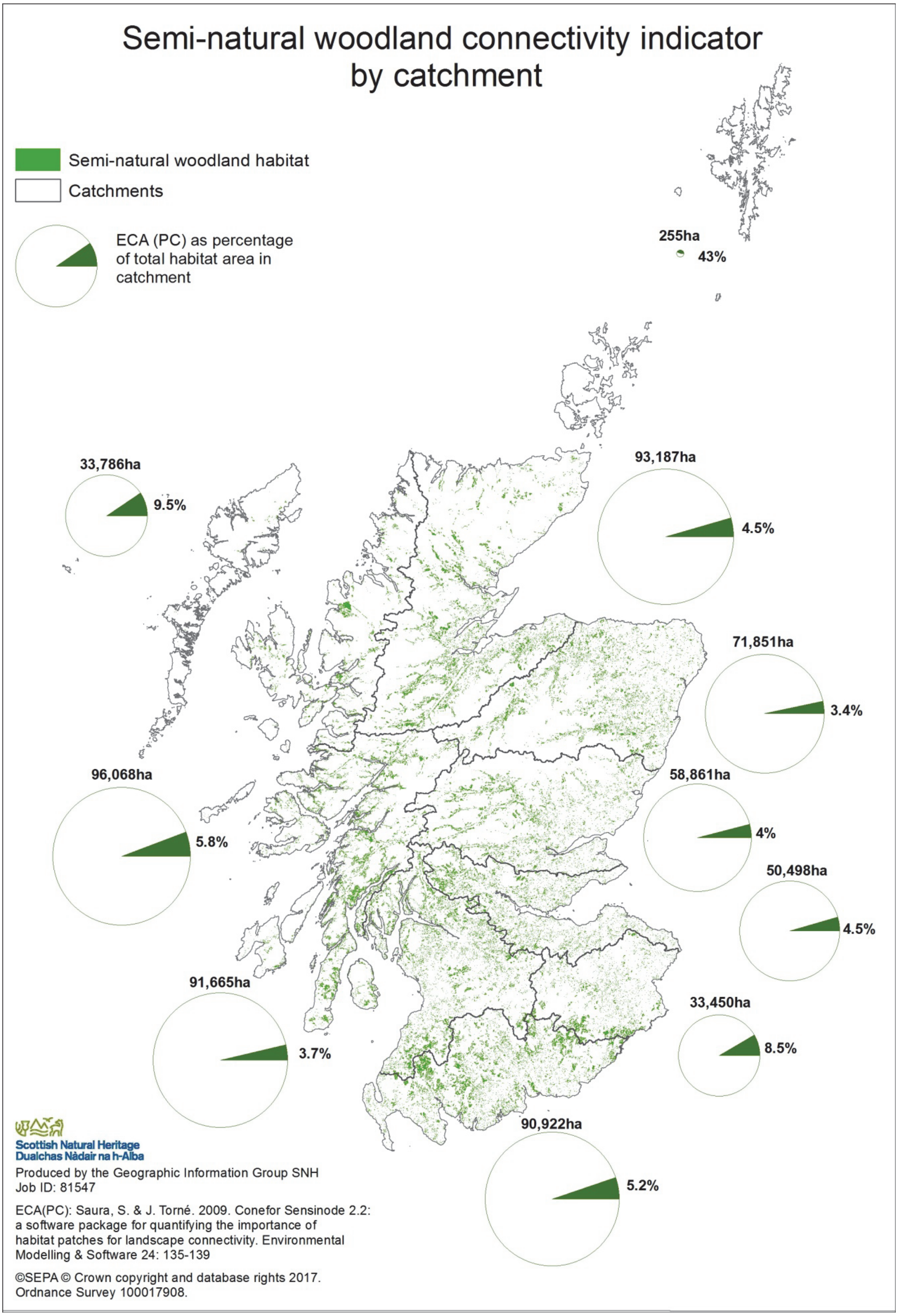

Figure 9. Showing each catchment area's ECA(PC) as a percentage of the area's total habitat for native woodland.

5. DISCUSSION

This work has shown that the ECA(PC) methodology is suitable for current Scottish landcover data, and the results can provide useful and meaningful metrics for measuring habitat connectivity. ECA(PC) considers a range of landscape ecology features (patch size, number, shape, spatial configuration, and the landscape matrix), all of which are key considerations in assessing functional connectivity, and a single value is created which can be compared and interpreted between different areas.

The work described used four habitats, each of which have very different spatial distributions and quantities, and it was found possible to produce ECA(PC) values for each. 'Semi-natural woodland', 'heathland', 'fen/marsh/swamp' and 'semi-natural grassland' are the main broad terrestrial habitats in Scotland, and were chosen because of their likely use and applicability, and that they each have national level datasets. There is scope potentially to use other habitats (such as 'salt marsh' and 'reedbed') – depending on the quality and availability of source habitat datasets at a national level. There is also scope potentially to split the currently used broad habitats into more specific habitats (*e.g.* sub-dividing 'semi-natural grassland' into 'calcareous grassland' or 'acid grassland' or 'machair'), again depending on the source habitat inputs, and the likely scale of analyses needed. This study hasn't investigated or undertaken any regional or local level analyses (incorporating non-national datasets such as NVC or phase 1 habitat surveys) though work elsewhere shows the methodology is suitable and generates meaningful results (SNH, in press).

The ECA(PC) methodology generates a single figure which we've presented as a percentage, to allow a simple visual between-catchment and between-habitat comparison. To give interpretive context, we've selected the number of habitat patches (in a catchment), its area, and its spatial distribution as a map, as the minimum associated data needed. Additional accompanying data may also be included, and could include information on, for example, a habitat's average patch size (mean and/or mode and/or median). Data such as these may give more context, without unnecessarily adding too much of a data deluge for the lay reader. This may be particularly useful according the size and scale of a particular analysis, and is explored further below.

The methodology relies completely on a good quality land cover layer; inconsistent data will give poor (at best) or meaningless (at worst) analyses. The EUNIS Land Cover Scotland used in this study is compiled from best available national datasets. The ELSC's data range from land cover surveys from 1988 (in, for example, in parts of the uplands) to the present. Some elements are updated regularly (such as the National Forest Inventory) others, such as the uplands are not. ELCS, being a national data set, does not include more detailed local habitat surveys or any other local/regional-only data (such as phase I or NVC). The ECA(PC) results presented above must be interpreted in this context.

Issues of scale also affect interpretation of results. In this work, we undertook analyses at a catchment scale, each of which comprise a range of land use types (according to land form, management, geology *etc*; see section 2.7) which potentially affect the interpretation of results. For example, some catchments contain a significant amount of heathland in their uplands, with very little in their lower ground (see figure 8). To assess this, we undertook a further analysis and sub-divided the Tay catchment into 'upland' and 'lowland'. ECA(PC) results showed some striking differences. The catchment ECA(PC) percentage for heathland is 38.4 (table 4 and fig. 8) whereas the percentage ECA(PC) values are 39.0% and 13.4% for 'upland' and 'lowland' respectively. Land use patterns are therefore important considerations and further analyses according to the Landscapes of Scotland (section 2.7) may prove useful. However, the Landscapes of Scotland series comprises 79 individual areas, which may be an unwieldly number of analyses for a national scale analysis.

Scale of analysis, therefore, is a key consideration in generating meaningful results for a particular habitat, as are the level and comprehensiveness of accompanying data and maps which are to aid the interpretative context. This is explored in more detail (in SNH, in press).

Whilst the ECA(PC) methodology has proved to work with large datasets, there are computational limitations; as noted in section 2.9, the time needed to perform analyses is exponential to the number of patches under consideration. Ideally the ECA(PC) value for all of Scotland would be calculated as one process but a test of 41,500 patches took 50 hours to run. Running the methodology as described here is reasonably quick; calculating the ECA(PC) value for the 10 regions takes about an hour. Hence, it was necessary to amalgamate each catchment's ECA(PC) as described above, which, whilst producing a minimal and non-significant discrepancy in the overall results, is not ideal. As mentioned above, 79 individual analyses according the Landscapes of Scotland may improve absolute accuracy but may take considerable time to generate and amalgamate, without actually producing much additional value.

As noted above, it is not currently possible to detect changes in connectivity over time, on a national scale at least, due to inconsistent national landcover data over time. The update schedule and data capture methodology to various components of the landcover (such as in the Land Cover Map series) is highly variable. Consequently, changes in the landcover may affect ECA(PC) values more than actual changes in habitat connectivity itself. On a local level, however, bespoke landcover data may be put together allowing directly comparable land cover between two or more time periods, as in other current work (SNH, in press).

This bespoke and applied use of the methodology is promising, as it allows a measurement of the effectiveness of land management within an area (SNH, in press). Within the EcoCoLIFE project[8], ECA(PC) has been used to measure the connectivity of a habitat at the beginning of the project ('before'), with a further analysis following habitat creation ('after'). Preliminary analyses are encouraging and suggests that even small changes in land management can be detected (SNH, in press), allowing connectivity assessment and monitoring of habitat management impacts.

This and related work on the ECA(PC) methodology and analyses have thus shown considerable potential. It can measure habitat connectivity at a variety of scales, and it has the capability to measure changes in habitat connectivity over time at a local level. The applications are considerable – from targeting and assessing land management changes, spatially representing habitats and their connectivity, and potentially helping to deliver policy requirements such as the National Ecological Network[9], and the Land Use Strategy[10].

[8] EcoCoLIFE is a £2.3 million (or 3.1 million euro) project funded by the Life+ financial instrument of the European Community for habitat restoration and creation to improve ***eco***logical ***co***herence within the Central Scotland Green Network area. More information on https://www.ecocolife.scot/

[9] See Priority Project 10 in the Scottish Biodiversity Strategy's Route Map to 2020 http://www.gov.scot/Publications/2015/06/8630/0

[10] See http://www.gov.scot/Topics/Environment/Countryside/Landusestrategy

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APPENDIX 1: A SUMMARISED COST TABLE FOR EACH OF THE HABITATS USED IN THIS STUDY

A summarised cost table for each of the habitats used in this study (from SNH, 2016).

EUNIS code	**EUNIS description**	**Semi-natural wood-land**	**Semi-natural grass-land**	**fen/ marsh/ swamp**	**Heath-land**
A	Marine habitats	25	25	25	25
A1	Littoral rock and other hard substrata	25	25	25	25
A2	Littoral sediments	25	25	25	25
A2.5	Coastal saltmarshes and saline reedbeds	20	25	0	5
B	Coastal habitats	20	25	25	25
B1	Coastal dunes and sandy shores	20	5	25	25
B2	Coastal shingle	25	25	25	25
B3	Rock cliffs, ledges and shores, including supralittoral	25	20	25	20
C	Inland surface waters	25	25	1	25
D1	Raised and blanket bogs	3.3	7	2	0
D2/D4/D5	Fens, mires, sedge- and reedbeds	3.3	7	0	2
E	Grasslands and lands dominated by forbs, mosses or lichens	5	0	3	5
E1.2	Perennial calcareous grassland and basic steppes	5	0	3	5
E2.6	Agriculturally-improved, re-seeded and heavily fertilised grassland, including sports fields and grass lawns	5	5	3	25
E4	Alpine, subalpine and extensive grasslands	5	0	1	5
E4.3	Acid alpine, subalpine and extensive grassland	5	0	1	5
E4.4	Calcareous alpine, subalpine and extensive grassland	5	0	1	5
E5	Woodland fringes and clearings and tall forb stands	2	5	1	5
E5.3	*Pteridium aquilinum* fields	2.5	5	6	5
E7.1	Atlantic parkland	0	2	3	5
F2	Arctic, alpine, subalpine and extensive scrub	1	10	3	5
F3.1	Temperate thickets and scrub	1	10	3	5
F4	Temperate shrub heathland	1	10	3	0
F4.1	Wet heaths	5	5	1	0
F4.2	Dry heaths	5	5	3	0
F9.2	*Salix* carr and fen scrub	1	10	1	0
FA	Hedgerows	1	10	2	20
G	Woodland, forest and other wooded land	0	10	3	25
G1	Broadleaved deciduous woodland	0	10	3	25
G1.4/G1.5	Broadleaved swamp woodland	0	10	1	25
G1.8	Acidophilous *Quercus*-dominated woodland	0	10	3	25
G1.9	Non-riverine woodland with *Betula, Populus tremula* or *Sorbus aucuparia*	0	10	3	25

G1.A	Meso- and eutrophic *Quercus, Carpinus, Fraxinus, Acer, Tilia, Ulmus* and related woodland	0	10	3	25
G3	Coniferous woodland	2	10	15	25
G3.4	*Pinus sylvestris* woodland south of the taiga	2	10	3	25
G3.E	Nemoral bog conifer woodland	2	10	3	2
G3.F	Highly artificial coniferous plantations	2	10	15	25
G4	Mixed deciduous and coniferous woodland	0	10	3	10
G5.6	Early-stage natural and semi-natural woodlands and regrowth	0	10	3	10
G5.7	Coppice and early-stage plantations	0	10	3	10
G5.8	Recently felled areas	0	10	3	10
G6	Exotic woodland and scrub	2	10	3	25
H2/H3	Screes, inland cliffs, rock pavements and outcrops	25	25	15	25
I1	Arable land and market gardens	12.5	7	15	7
I1.2	Mixed crops of market gardens and horticulture	12.5	7	15	7
I2	Cultivated areas of gardens and parks	12.5	7	15	7
J	Constructed, industrial and other artificial habitats	25	13	25	13
J1/J2	Buildings of cities, towns and villages / Low density buildings	25	13	25	13
J3	Extractive industrial sites	25	13	25	13
J3/J6	Extractive industrial sites / Waste deposits	25	13	25	13
J4	Transport networks and other constructed hard-surfaced areas	20	13	25	13
J4.2	Road networks roadside	20	13	25	13
J4.2	Road networks motorway	30	13	25	13
J4.2	Road networks A road	25	13	25	13
J4.2	Road networks B or minor road	20	13	25	13
J4.2	Road networks private road	15	13	25	13
J4.3	Rail networks	25	13	25	13
J4.5	Hard-surfaced areas of ports	25	13	25	13
J4.7	Constructed parts of cemeteries	25	13	25	13
J5	Highly artificial man-made waters and associated structures	25	13	25	13
K	Montane habitats	7	8	8	2
K1	Montane vegetation	7	8	8	2
X28	Blanket bog complexes	3.3	7	3	0

APPENDIX 2: A STEP-BY-STEP ACCOUNT OF THE ECA(PC) GIS METHODOLOGY USED

The following is the step-by-step account of the ECA(PC) GIS methodology used in this work (SNH, 2017).

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1. BACKGROUND

The aim of this document is to describe the semi-automated method followed to calculate a nationwide connectivity indicator for four habitats, semi-natural woodland, semi-natural grassland, fen/marsh/swamp and heathland. It follows the methodology used to calculate the habitat connectivity indicator for native woodland produced on 2015 and described in the non-technical version document (SNH ref: A1579650).

2. DATASETS USED

Eunis Land Cover Scotland: GIS_SNH_OWNER.HABMOS_EUNIS_BASE
Landscape region boundaries: GIS_SNH_OWNER.LANDSCAPE_MAP
SEPA advisory group boundaries:
GIS_EXTERNAL_OWNER.SEPA_Advisory_Group_Boundaries
Cost tables: GIG analysis methodology - 81547 - ELCS costs - 63 classes - December 2016 (SNH ref: A2171825)

3. DISPERSAL DISTANCES AND PATCH SIZES

Habitat	Dispersal distance	Minimum habitat patch
Semi-natural woodland	500m	0.5ha
Semi-natural grassland	300m	0.5ha
Fen/marsh/Swamp	150m	0.02ha
Heathland	500m	0.5ha

4. METHODOLOGY

4.1 Creating source habitat layer

- GIS_SNH_OWNER.HABMOS_EUNIS_BASE – Habitat source extracted from this dataset. From the cost table provided we know that the source habitats are those with "0" cost assigned to them:
    - Heathland – D1, F4, F4.1, F4.2, F9.2, X28 (Heath_source)
    - Fen/marsh/swamp – A2.5, D2/D4/D5 (Fen_source)
    - Semi-natural grassland – E, E1.2, E4, E4.3, E4.4 (Grass_source)
    - Semi-natural Woodland – E7.1, G, G1, G1.4/G1.5, G1.8, G1,9, G1.A, G4, G5.6, G5.7, G5.8
- Source datasets were dissolved and minimum patch sizes excluded. See sections 4.1.1 to 4.1.4. A simple dissolve did not dissolve adjacent patches with one common vertex. Outputs for overall habitat: Heath_source_all, Fen_source_all and Grass_source_all. Outputs excluding minimum patch size: H_source, F_source, G_source, W_source
- Minimum patch sizes, as per previous section: heathland 0.5 ha, fen/marsh/swamp 0.02 ha, semi-natural grassland 0.5 ha, semi-natural woodland 0.5 ha.
- A long integer field called 'NodeID' was created in this dataset and the OBJECTID copied across. This was done once the min area had been decided and polygons below the min patch size excluded

4.1.1 Fen/marsh/swamp

- Reclassify the values of GIS_SNH_OWNER.HABMOS_EUNIS_BASE, whatever EUNIS code is fen to 1 and the rest to 0 (*fen*)
- Region group of the result, neighbors to eight and Add link field checked (*fen_reg*)
- Add field to the result call it Fen, calculate field [Value] * [LINK]
- Raster to polygon, use Fen as field, it will be the GRID_CODE in the result. Whatever is different to 0 will be fen (fen_*ras*)
- Query for records <> 0 and then dissolve by grid_code (*Fen_source_all*)
- Export polygons with area >= *0.02ha (200m^2 = min patch size)* and call it ***F_source***
- Repair geometry, it helps not to have errors in the following steps

4.1.2 Heathland

- Reclassify the values of GIS_SNH_OWNER.HABMOS_EUNIS_BASE, whatever EUNIS code is heathland to 1 and the rest to 0 (*heath*)
- Region group of the result, neighbors to eight and Add link field checked (*heath_reg*)
- Add field to the result call it Heath, calculate field [Value] * [LINK]
- Raster to polygon, use Heath as field, it will be the GRID_CODE in the result. Whatever is different to 0 will be heath (*heath_ras*)
- Query for records <> 0 and then dissolve by grid_code (*Heath_source_all*)
- Export polygons with area >= *0.5ha (5000m^2 = min patch size)* and call it ***H_source***
- Repair geometry, it helps not to have errors in the following steps

4.1.3 Semi-natural grassland

- Reclassify the values of GIS_SNH_OWNER.HABMOS_EUNIS_BASE, whatever EUNIS code is grassland to 1 and the rest to 0 (*grass_rclss*)
- Region group of the result, neighbors to eight and Add link field checked (*grass_reg*)
- Add field to the result call it Grass, calculate field [Value] * [LINK]
- Raster to polygon, use Heath as field, it will be the GRID_CODE in the result. Whatever is different to 0 will be grass (*grass_ras)*
- Query for records <> 0 and then dissolve by grid_code (*Grass_source_all*)
- Export polygons with area >= *0.5ha (5000m^2 = min patch size)* and call it ***G_source***
- Repair geometry, it helps not to have errors in the following steps

4.1.4 Semi-natural woodland

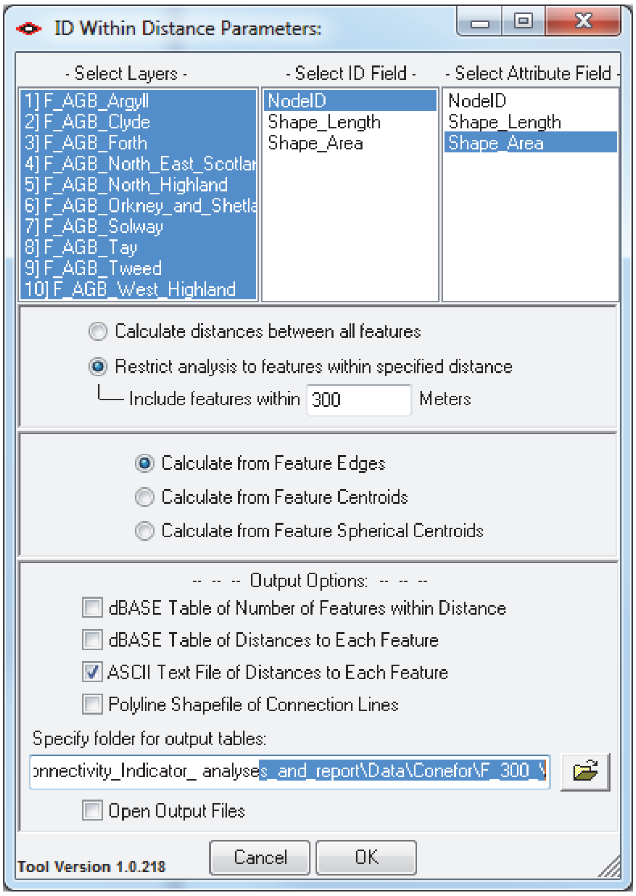
- Reclassify the values of GIS_SNH_OWNER.HABMOS_EUNIS_BASE, whatever EUNIS code is grassland to 1 and the rest to 0 (*wood_rclss*)
- Region group of the result, neighbors to eight and Add link field checked (*wood_reg*)
- Add field to the result call it Wood, calculate field [Value] * [LINK]
- Raster to polygon, use Wood as field, it will be the GRID_CODE in the result. Whatever is different to 0 will be grass (*wood_ras)*
- Query for records <> 0 and then dissolve by grid_code (*Wood_source_all*)
- Export polygons with area >= *0.5ha (5000m^2 = min patch size)* and call it ***W_source***
- Repair geometry, it helps not to have errors in the following steps

4.2 Creating Conefor node and distance files

- As in previous analysis, the analysis with be run regionally and then the results will be combined to give an estimated national figure.
- The dataset SEPA_Advisory_Group_Boundaries was used to split the country into 10 areas for reporting on results. First the dataset was intersected with the MasterMap MHWS polygon dataset from 2012 and then dissolved to remove tile boundaries. The

same dataset from the previous analysis has been used **SEPA_AGB_MHWS_intersect_dissolve**

- Then the 'Split' tool was used to split the habitat patches (G_Source, F_source and H_source, W_source) by the advisory group boundaries – SEPA_AGB_MHWS_intersect_dissolve (By the field AG_NAME)
- Use SEPA_AGB_MLWS_intersect_dissolve for fen habitat
- Note that the SEPA boundaries do not totally match the Scottish Border so there could be a minor discrepancy in habitat totals when they are summed.
- The Conefor extension could be run on all 10 at once. Note that twice the dispersal distance values have been used. This is done for each habitat:



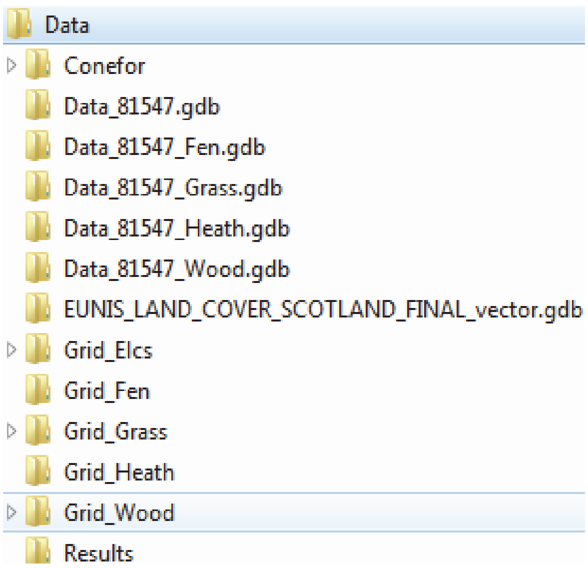
4.3 Calculating permeability weightings

- The raster dataset HABMOS_EUNIS_BASE was exported to the job folder as **elcs**
- A cost table **Costs.txt**, a tab delimited text file was derived from document listed in section 2. Source habitat codes should have a value of 1 in the cost table so that the cost distance is not less than the Euclidean distance through small habitat patches less than the minimum patch size. Nevertheless, change the "0" to "1" in a copy of the cost table. This table is called **Costs_conefor.txt** and simplified to each habitat as **Costs_F, Costs_G, Costs_H, Costs_W**; and exported to the geodatabase as info table as they made the model crash.
- A model was then built in ArcMap called '**Calculate distance weightings'** to carry out the steps required producing a distance weighting for each pixel in the cost raster. Model properties were set that the extent and snap raster for processing are equal to the landcover raster being used. The steps are:
    - Reclass by table to create the cost raster from the datasets above. Note that the woodland costs values that were not integer (2.5, 3.3 and 12.5) were truncated

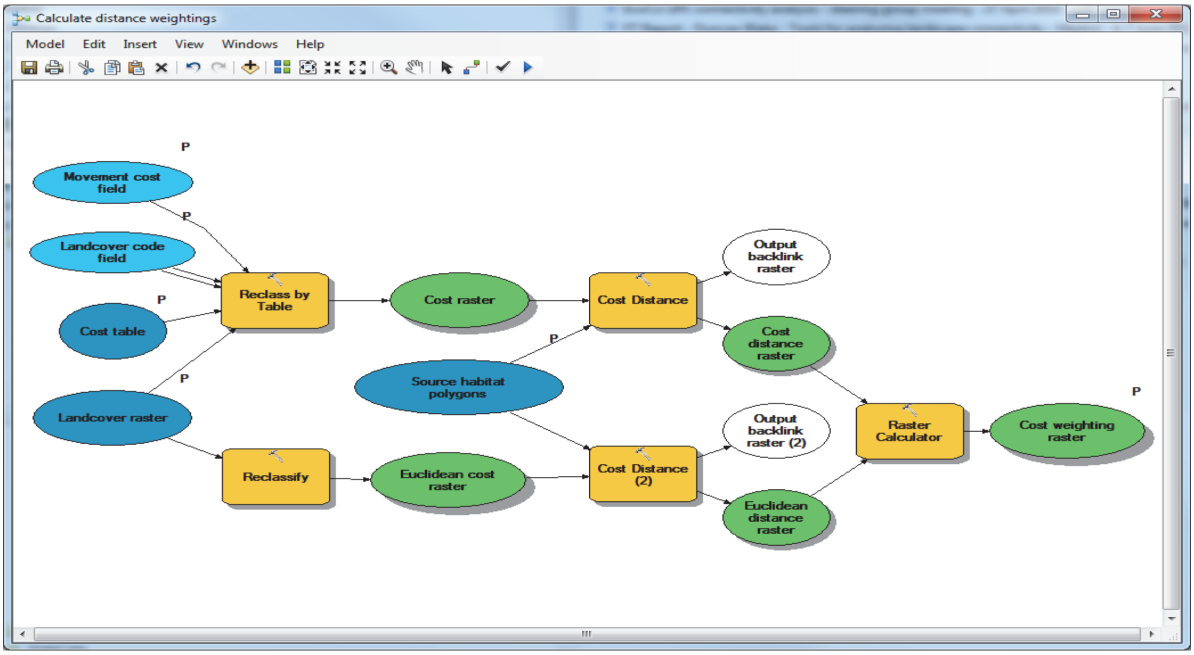
as being integer was a requirement of the “assignment values in the output field” in this tool. Output: **elcs_fn_cost (elcs_gr_cost, elcs_he_cost, elcs_wo_cost)**

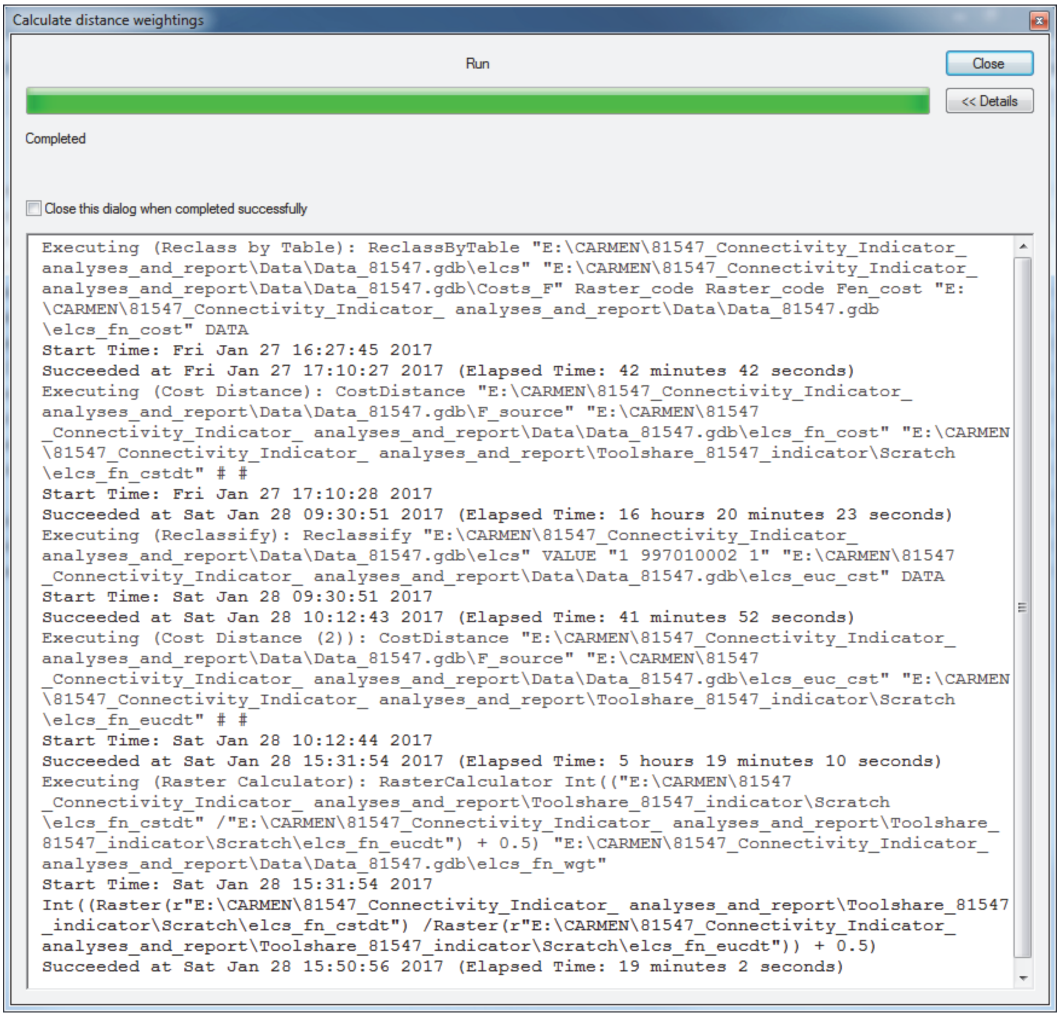
- The cost distance tool was run using F_source as the input data and elcs_fn_cost as the cost raster. Output (scratch): **elcs_fn_cstdt (elcs_gr_cstdt, elcs_he_cstdt, elcs_wo_cstdt)**
- The tool Reclassify (previous analysis used the tool ‘Test’ but there were issues using the value field, as it didn’t recognise some of the values) was run to reclassify all values in the elcs raster to 1. Output**: elcs_euc_cost**
- The second cost distance tool was run using F_source (G_source, H_source, W_source) as the input data and elcs_euc_cost as the cost raster. Output (scratch): **elcs_fn_eucdt (elcs_gr_eucdt, elcs_he_eucdt, elcs_wo_eucdt)**
- **NB these two processes were run instead of a straightforward Euclidean distance to account for the fact that estuaries and other areas below MLWS are deemed to be a barrier to woodland species (and fen, heath, grass – checked on cost table for cost of these habitat in marine habitat) movement and this enables both the cost distance and Euclidean distance to be compared in an equitable way.**
- The Raster Calculator tool was used to divide the two datasets and to add on 0.5 and converted to integer with the expression int(("%Cost distance raster%" / "%Euclidean distance raster%") + 0.5). Note 1: +0.5 compensates for the truncation done by the ‘int’ function (i.e. 8.9 would be truncated to 8 but if adding 0.5 it would be truncated to 9 that is a closer value to 8.9). Note 2: by dividing the costs, when the division would be 1 then the cost distance is equal to the Euclidean distance). Output: **eun_fn_wgt (eun_gr_wgt, eun_he_wgt, eun_wo_wgt)**

- The two intermediate cost rasters are large float files so they are written to the Scratch folder to enable easy deletion. The rest of the outputs are being saved in a folder for each habitat.



Updated model





4.4 Applying average permeability weightings to landscape regions

- The python tool developed in job 60697 (connectivity indicator), 'Calculating average permeability per polygon', was used to assign average permeability weightings to each landscape region (or any other polygon dataset if required instead). The python script was slightly modified, a couple of lines to assign the environments were marked out, and this was compensated by setting the environments manually in the environment tab before running the tool.

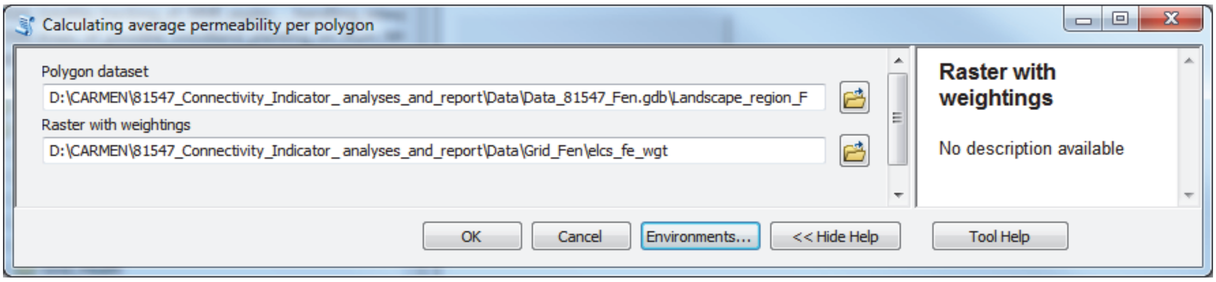
average_weightings

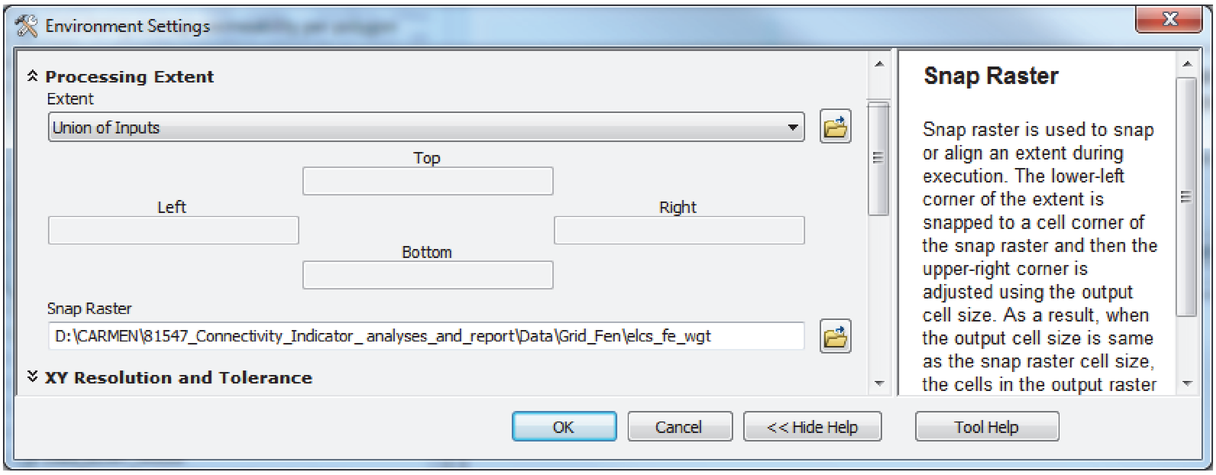
```
# --------------------------------------------------------------------------
# average_weightings.py
# Created on:Tues Oct 10 2013
# Duncan Blake
# Usage: regionDataset <polygon dataset to give average weightings>, weightGrid <raster with integer weight values>
# --------------------------------------------------------------------------

# Import system modules
import arcpy, sys, string, os
from arcpy import env
from arcpy.sa import *

env.OverwriteOutput = True

try:

    arcpy.AddMessage ("Average weighting for region number ")

    # Script arguments...

    # polygon region dataset for which average weightings need to be calculated
    regionDataset = sys.argv[1]

    # weighting raster - this is produced by the ArcGIS model in the previous stage of the job.
    # this needs to be set as a Raster Layer parameter in the toolbox if adding the raster from ArcMap
    weightGrid = sys.argv[2]

    # set extent to that of the vector file and snap raster outputs to the weight raster

    #arcpy.env.extent = regionDataset

    #arcpy.env.snapRaster = weightGrid


    # Check out the ArcGIS Spatial Analyst extension license
    arcpy.CheckOutExtension("Spatial")

    # Find the path for the scratch directory by finding the path of the script
    scriptPath = sys.path[0]
    arcpy.AddMessage("Script folder: " + scriptPath)

    # Get the pathname to the ToolShare folder
    toolSharePath = os.path.dirname(scriptPath)
    arcpy.AddMessage("ToolShare folder: " + toolSharePath)

    # Now construct pathname to the Scratch folder
    scratchPath = os.path.join(toolSharePath, "Scratch")
```

- The tool does the following:
  - Adds a float field called 'WEIGHTING' to the polygon dataset if it doesn't already exist.
  - Gets the number of features in the polygon dataset.
  - Loops through each feature by selecting each one by incremental OBJECTID.
  - For each feature extracts the relevant part of the integer costs weighting raster (produced as output from the model in the previous process).
  - Saves the raster as extract_i grid file in the scratch folder.
  - Creates a field called 'PRODUCT' within a table view.
  - Multiplies the' VALUE' and 'COUNT' fields into the 'PRODUCT' field.
  - Calculates the total of the 'COUNT' field and the 'PRODUCT' field.
  - Divides the total product by the total count to get a <u>mean</u> average weighting.
  - Updates the polygon with this value in the 'WEIGHTING' field

- This took 7 hours to run for a 10m resolution raster (this was the longest time, times varied for the different habitats).
- Note the landscape region dataset is to MHWS so will not take into account areas down to MLWS (which are considered within the land cover dataset).

Fen



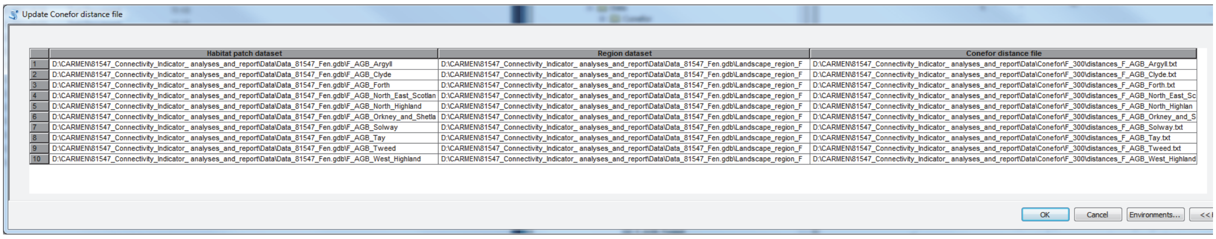


4.5 Updating Conefor distance file with permeability weightings

- A second python tool was developed (Update Conefor distance file) to do this. It does the following:
  - Takes as input a polygon file containing habitat patches, a polygon dataset containing the regions with their weightings (output from previous tool) and a Conefor distance file created at step 4.2.
  - Creates a centroid for each habitat patch and stores them in a shapefile in the Scratch directory with the same name as the polygon file but with a suffix '_centroids.shp'
  - Spatially joins these points to the regions.
  - Will raise an error message if not all the points are joined.
  - Reads each node id and it's weighting into a python dictionary.
  - Reads in the Conefor distance file line by line. For each line:
    - Looks up node 1 in the dictionary for its weighting.
    - Looks up node 2 in the dictionary for its weighting.
    - If these are the same it multiplies the Euclidean distance by the weighting to get the effective distance.
    - If they are different (i.e. habitat patches fall in different regions) an average is calculated and then the effective distance calculated.
    - Writes out the new line to a new Conefor distance file (filename_effective_distances.txt).

- The 10 AGB distance files were converted to effective distances by running this tool in batch mode:
  - Right click on tool 'Update Conefor distance file' and select Batch.
  - Populate the batch grid
  - Run

Fen



Update Conefor distance file

	Habitat patch dataset	Region dataset	Conefor distance file
1	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\F_AGB_Argyll	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\Landscape_region_F	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300\distances_F_AGB_Argyll.txt
2	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\F_AGB_Clyde	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\Landscape_region_F	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300\distances_F_AGB_Clyde.txt
3	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\F_AGB_Forth	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\Landscape_region_F	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300\distances_F_AGB_Forth.txt
4	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\F_AGB_North_East_Scotlan	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\Landscape_region_F	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300\distances_F_AGB_North_East_Sc
5	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\F_AGB_North_Highland	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\Landscape_region_F	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300\distances_F_AGB_North_Highlan
6	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\F_AGB_Orkney_and_Shetla	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\Landscape_region_F	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300\distances_F_AGB_Orkney_and_S
7	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\F_AGB_Solway	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\Landscape_region_F	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300\distances_F_AGB_Solway.txt
8	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\F_AGB_Tay	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\Landscape_region_F	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300\distances_F_AGB_Tay.txt
9	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\F_AGB_Tweed	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\Landscape_region_F	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300\distances_F_AGB_Tweed.txt
10	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\F_AGB_West_Highland	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Data_81547_Fen.gdb\Landscape_region_F	D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300\distances_F_AGB_West_Highland

OK Cancel Environments... <<

4.6 Running Conefor

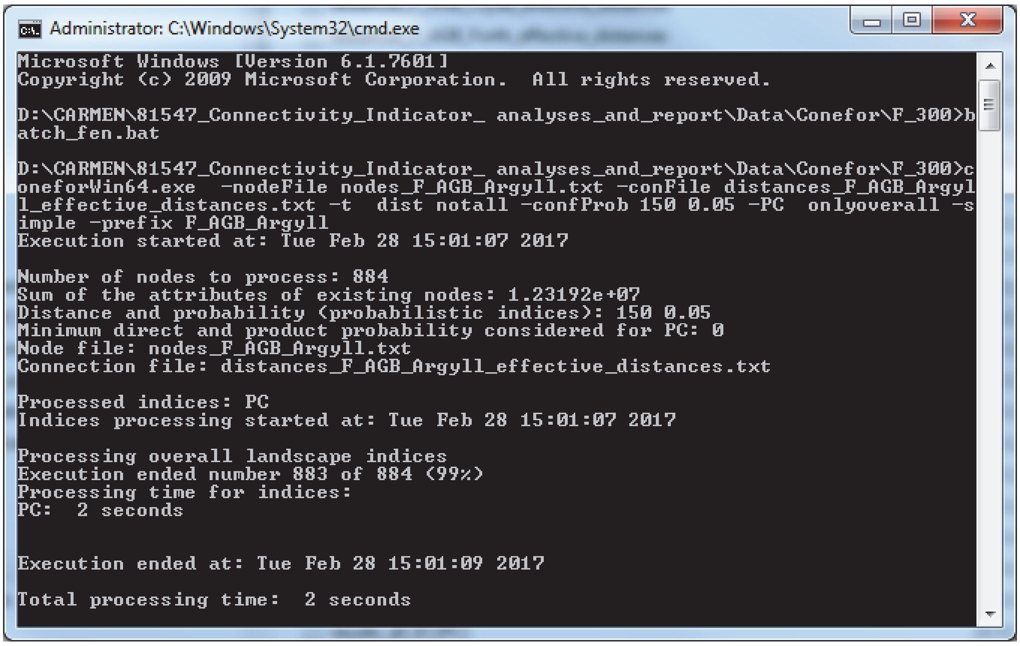
- To run Conefor a batch file was created to run all 10 files called batch_fen.bat (NB be careful this is not saved as a text file).

```
coneforWin64.exe  -nodeFile nodes_F_AGB_Argyll.txt -conFile
distances_F_AGB_Argyll_effective_distances.txt -t  dist notall -confProb 150 0.05 -PC  onlyoverall -simple -
prefix F_AGB_Argyll

coneforWin64.exe  -nodeFile nodes_F_AGB_Clyde.txt -conFile
distances_F_AGB_Clyde_effective_distances.txt -t  dist notall -confProb 150 0.05 -PC  onlyoverall -simple -
prefix F_AGB_Clyde

coneforWin64.exe  -nodeFile nodes_F_AGB_Forth.txt -conFile
distances_F_AGB_Forth_effective_distances.txt -t  dist notall -confProb 150 0.05 -PC  onlyoverall -simple -
prefix F_AGB_Forth

coneforWin64.exe  -nodeFile nodes_F_AGB_Orkney_and_Shetland.txt -conFile
distances_F_AGB_Orkney_and_Shetland_effective_distances.txt -t  dist notall -confProb 150 0.05 -PC
onlyoverall -simple -prefix F_AGB_Orkney_and_Shetland

coneforWin64.exe  -nodeFile nodes_F_AGB_North_East_Scotland.txt -conFile
distances_F_AGB_North_East_Scotland_effective_distances.txt -t  dist notall -confProb 150 0.05 -PC
onlyoverall -simple -prefix F_AGB_North_East_Scotland

coneforWin64.exe  -nodeFile nodes_F_AGB_North_Highland.txt -conFile
distances_F_AGB_North_Highland_effective_distances.txt -t  dist notall -confProb 150 0.05 -PC  onlyoverall
-simple -prefix F_AGB_North_Highland

coneforWin64.exe  -nodeFile nodes_F_AGB_Solway.txt -conFile
distances_F_AGB_Solway_effective_distances.txt -t  dist notall -confProb 150 0.05 -PC  onlyoverall -simple -
prefix F_AGB_Solway

coneforWin64.exe  -nodeFile nodes_F_AGB_Tay.txt -conFile distances_F_AGB_Tay_effective_distances.txt
-t  dist notall -confProb 150 0.05 -PC  onlyoverall -simple -prefix F_AGB_Tay

coneforWin64.exe  -nodeFile nodes_F_AGB_Tweed.txt -conFile
distances_F_AGB_Tweed_effective_distances.txt -t  dist notall -confProb 150 0.05 -PC  onlyoverall -simple -
prefix F_AGB_Tweed

coneforWin64.exe  -nodeFile nodes_F_AGB_West_Highland.txt -conFile
distances_F_AGB_West_Highland_effective_distances.txt -t  dist notall -confProb 150 0.05 -PC  onlyoverall -
simple -prefix F_AGB_West_Highland
```

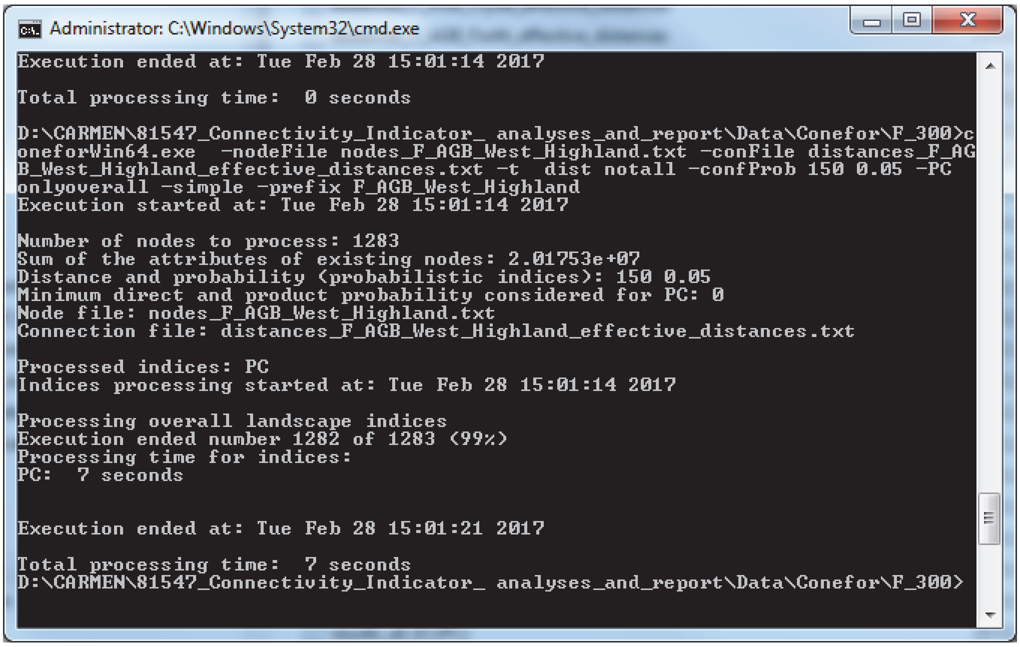
- The command line version of coneforWin64.exe was used to take advantage of the 64Bit machine.
- The executable was copied into the same folder as the node and distance files.
- In Windows Explorer the folder was navigated to and then cmd typed in the address bar to open a command prompt window with the pathname already there.
- **Batch_fen.bat** was then typed in to run the batch file.
- For the 10 areas Conefor took a maximum of 13 hours to run, but depended on the habitat, heathland took 18 minutes to run.
- Conefor writes output files to the same folder:
    - Results_all_overall_indices.txt

- Results_all_EC(PC).txt

Fen



```
Administrator: C:\Windows\System32\cmd.exe
Microsoft Windows [Version 6.1.7601]
Copyright (c) 2009 Microsoft Corporation.  All rights reserved.

D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300>b
atch_fen.bat

D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300>c
oneforWin64.exe  -nodeFile nodes_F_AGB_Argyll.txt -conFile distances_F_AGB_Argyl
l_effective_distances.txt -t  dist notall -confProb 150 0.05 -PC  onlyoverall -s
imple -prefix F_AGB_Argyll
Execution started at: Tue Feb 28 15:01:07 2017

Number of nodes to process: 884
Sum of the attributes of existing nodes: 1.23192e+07
Distance and probability (probabilistic indices): 150 0.05
Minimum direct and product probability considered for PC: 0
Node file: nodes_F_AGB_Argyll.txt
Connection file: distances_F_AGB_Argyll_effective_distances.txt

Processed indices: PC
Indices processing started at: Tue Feb 28 15:01:07 2017

Processing overall landscape indices
Execution ended number 883 of 884 (99%)
Processing time for indices:
PC:  2 seconds


Execution ended at: Tue Feb 28 15:01:09 2017

Total processing time:  2 seconds
```



```
Administrator: C:\Windows\System32\cmd.exe
Execution ended at: Tue Feb 28 15:01:14 2017

Total processing time:  0 seconds

D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300>c
oneforWin64.exe  -nodeFile nodes_F_AGB_West_Highland.txt -conFile distances_F_AG
B_West_Highland_effective_distances.txt -t  dist notall -confProb 150 0.05 -PC
onlyoverall -simple -prefix F_AGB_West_Highland
Execution started at: Tue Feb 28 15:01:14 2017

Number of nodes to process: 1283
Sum of the attributes of existing nodes: 2.01753e+07
Distance and probability (probabilistic indices): 150 0.05
Minimum direct and product probability considered for PC: 0
Node file: nodes_F_AGB_West_Highland.txt
Connection file: distances_F_AGB_West_Highland_effective_distances.txt

Processed indices: PC
Indices processing started at: Tue Feb 28 15:01:14 2017

Processing overall landscape indices
Execution ended number 1282 of 1283 (99%)
Processing time for indices:
PC:  7 seconds


Execution ended at: Tue Feb 28 15:01:21 2017

Total processing time:  7 seconds
D:\CARMEN\81547_Connectivity_Indicator_ analyses_and_report\Data\Conefor\F_300>
```

4.7 Calculating a national habitat connectivity value

To get an estimated national figure from the regional values each needs to be squared, the totals summed and then the square root taken.

	Prefix	Distance	Probability	ECA(PC) ha	$ECA(PC)^2$
FEN / MARSH / SWAMP	**F_AGB_Argyll**	150	0.05	135.2	18,276.61
	F_AGB_Clyde	150	0.05	54.1	2,923.88
	F_AGB_Forth	150	0.05	99.5	9,896.85
	F_AGB_Orkney_and_Shetland	150	0.05	112.7	12,690.25
	F_AGB_North_East_Scotland	150	0.05	152.6	23,282.79
	F_AGB_North_Highland	150	0.05	530.7	281,646.74
	F_AGB_Solway	150	0.05	1010.0	1,020,140.40
	F_AGB_Tay	150	0.05	160.5	25,767.31
	F_AGB_Tweed	150	0.05	11.8	140.35
	F_AGB_West_Highland	150	0.05	200.2	40,069.23
	Total				1,434,834.40
	ECA(PC) Scotland				**1,197.85**
	Number of patches	4,526.00			
	Largest patch area	778.22			
	ECA(PC) Scotland	**1,197.85**			
	Sum of all patch areas	11,442.8			

	Prefix	Distance	Probability	ECA(PC) ha	$ECA(PC)^2$
SEMI-NATURAL GRASSLAND	**G_AGB_Argyll**	300	0.05	5,110.9	26,121,605.5
	G_AGB_Clyde	300	0.05	8,639.4	74,638,886.8
	G_AGB_Forth	300	0.05	9,285.4	86,219,396.0
	G_AGB_Orkney_and_Shetland	300	0.05	2,506.4	6,282,041.0
	G_AGB_North_East_Scotland	300	0.05	1,342.1	1,801,286.1
	G_AGB_North_Highland	300	0.05	2,391.0	5,716,689.7
	G_AGB_Solway	300	0.05	11,898.7	141,579,061.7
	G_AGB_Tay	300	0.05	6,549.1	42,890,841.8
	G_AGB_Tweed	300	0.05	10,113.0	102,272,769.0
	G_AGB_West_Highland	300	0.05	2,886.4	8,331,074.0
	Total				495,853,651.6
	ECA(PC) Scotland				**22,267.8**
	Number of patches	68,939.0			
	Largest patch area	7,804.2			
	ECA(PC) Scotland	22,267.8			
	Sum of all patch areas	786,776.7			

	Prefix	Distance	Probability	ECA(PC) ha	$ECA(PC)^2$
HEATHLAND	**H_AGB_Argyll**	500	0.05	70,701.7	4,998,730,382.9
	H_AGB_Clyde	500	0.05	19,741.2	389,714,977.4
	H_AGB_Forth	500	0.05	10,356.9	107,265,377.6
	H_AGB_Orkney_and_Shetland	500	0.05	24,380.7	594,418,532.5
	H_AGB_North_East_Scotland	500	0.05	124,813.0	15,578,284,969.0
	H_AGB_North_Highland	500	0.05	190,200.0	36,176,040,000.0
	H_AGB_Solway	500	0.05	10,586.5	112,073,982.3
	H_AGB_Tay	500	0.05	**105,796.0**	11,192,793,616.0
	H_AGB_Tweed	500	0.05	20,779.3	431,779,308.5
	H_AGB_West_Highland	500	0.05	150,880.0	22,764,774,400.0
	Total				92,345,875,546.2
	ECA(PC) Scotland				**303,884.6**
	Number of patches	28,054.0			
	Largest patch area	107,046.7			
	ECA(PC) Scotland	303,884.6			
	Sum of all patch areas	2,961,668.0			

	Prefix	Distance	Probability	ECA(PC) ha	$ECA(PC)^2$
SEMI-NATURAL WOODLAND	**W_AGB_Argyll**	500	0.05	5,552.1	30,825,259.20
	W_AGB_Clyde	500	0.05	3,420.9	11,702,214.72
	W_AGB_Forth	500	0.05	2,259.4	5,105,069.11
	W_AGB_Orkney_and_Shetland	500	0.05	109.9	12,076.69
	W_AGB_North_East_Scotland	500	0.05	2,454.6	6,025,061.16
	W_AGB_North_Highland	500	0.05	4,163.8	17,337,563.55
	W_AGB_Solway	500	0.05	4,769.9	22,752,136.81
	W_AGB_Tay	500	0.05	2,341.3	5,481,826.17
	W_AGB_Tweed	500	0.05	2,836.4	8,045,335.14
	W_AGB_West_Highland	500	0.05	3,199.5	10,237,056.21
	Total				117,523,598.77
	ECA(PC) Scotland				**10,840.83**
	Number of patches	97,843.0			
	Largest patch area	2,254.4			
	ECA(PC) Scotland	10,840.83			
	Sum of all patch areas	621,396.8			

4.8 Maps

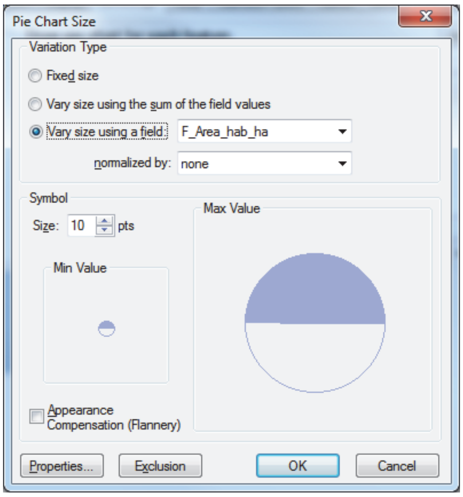
Create a map for each habitat. In the map display:

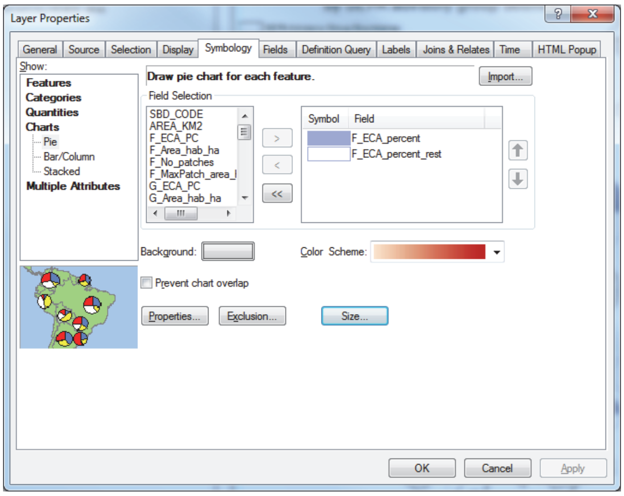
- Habitat source and SEPA regions. Colours for the habitats should be the ones created for EUNIS level 1 legend

  Symbology RGB values

Level 1 Class	Red	Green	Blue
D Mires, bogs and fens	158	170	215
E Grasslands and lands dominated by forbs, mosses or lichens	170	255	0
F Heathland, scrub and tundra	222	134	188
G Woodland, forest and other wooded land	56	168	0

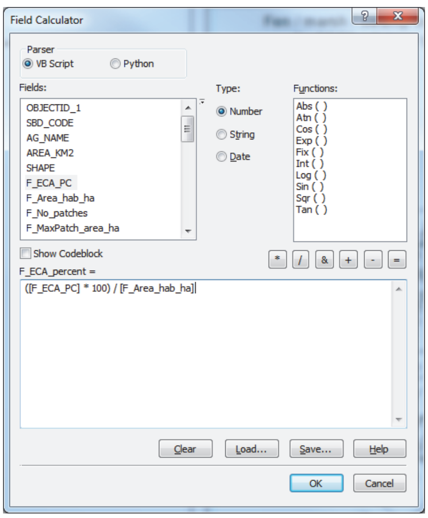
- Pie charts – the circle for each region should be proportional to the habitat size and within the pie chart indicates the proportion of the connectivity indicator value.





F_ECA_percent_rest is 100 minus F_ECA_percent

F_ECA_percent has been calculated as (note that both indicator and total area of habitat for the region are in hectares):



- Grahps – a bar graph, x-axis the patch size (6 ranges: <1, <10, <100, <1000, <10000, >=10000), y-axis the percent of patches in each category. Add over each graph the total number of patches in that region.

    - In F_AGB_all (sum of all the habitat regions) create a field with the hectares (**Patch_area_ha**) and calculate; and one called **range** with the values <1, <10, <100, <1000, <10000, >=10000. Use the queries below
      "Patch_area_ha" < 0.9999999999

      ("Patch_area_ha" > 0.9999999999) and ("Patch_area_ha"<10)

      ("Patch_area_ha" >=10) and ("Patch_area_ha"<100)

      ("Patch_area_ha" >=100) and ("Patch_area_ha"<1000)

      Calculate summary statistics and export the result table to Excel to create the graphs

Table

F_AGB_all_stats1

OBJECTID *	Region	Range	FREQUENCY	COUNT_Region	COUNT_Range
1	Argyll	<1	638	638	638
2	Argyll	<10	226	226	226
3	Argyll	<100	20	20	20
4	Clyde	<1	196	196	196
5	Clyde	<10	55	55	55
6	Clyde	<100	5	5	5
7	Forth	<1	123	123	123
8	Forth	<10	36	36	36
9	Forth	<100	10	10	10
10	North East Scotland	<1	65	65	65
11	North East Scotland	<10	65	65	65
12	North East Scotland	<100	16	16	16
13	North Highland	<1	412	412	412
14	North Highland	<10	168	168	168
15	North Highland	<100	48	48	48
16	North Highland	<1000	2	2	2
17	Orkney and Shetland	<1	469	469	469
18	Orkney and Shetland	<10	179	179	179
19	Orkney and Shetland	<100	16	16	16
20	Solway	<1	228	228	228
21	Solway	<10	87	87	87
22	Solway	<100	28	28	28
23	Solway	<1000	5	5	5
24	Tay	<1	110	110	110
25	Tay	<10	39	39	39
26	Tay	<100	13	13	13
27	Tweed	<1	14	14	14
28	Tweed	<10	10	10	10
29	West Highland	<1	959	959	959
30	West Highland	<10	282	282	282
31	West Highland	<100	42	42	42

7 (0 out of 31 Selected)

F_AGB_all_stats1

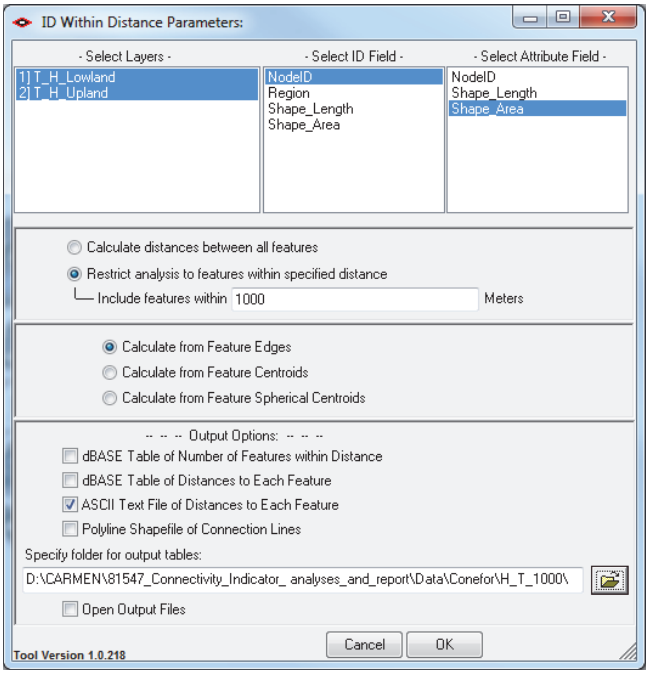
    - In H_AGB_all (sum of all the habitat regions) create a field with the hectares (**Patch_area_ha**) and calculate; and one called **range** with the values <1, <10, <100, <1000, <10000, >=10000.
    - In G_AGB_all (sum of all the habitat regions) create a field with the hectares (**Patch_area_ha**) and calculate; and one called **range** with the values <1, <10, <100, <1000, <10000, >=10000.
    - In W_AGB_all (sum of all the habitat regions) create a field with the hectares (**Patch_area_ha**) and calculate; and one called **range** with the values <1, <10, <100, <1000, <10000, >=10000.

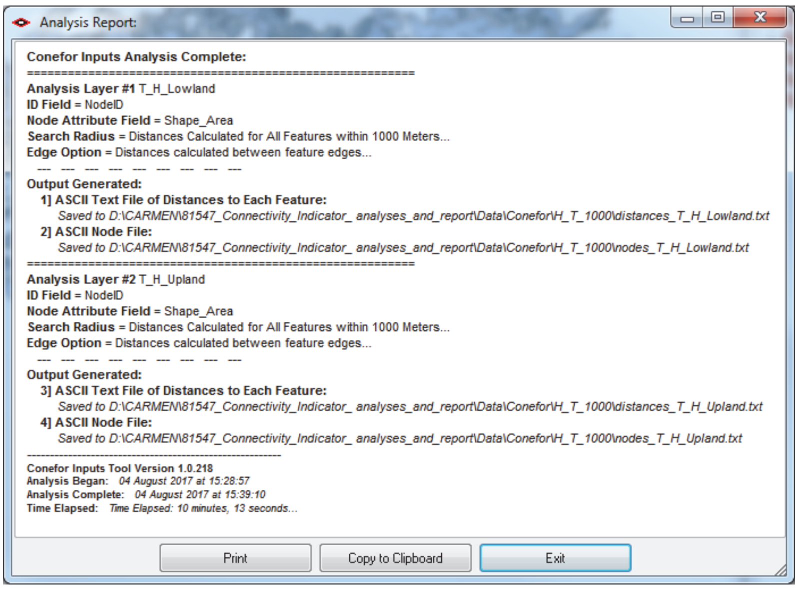
5. ADDITIONAL ANALYSIS – HEATHLAND UPLAND AND LOWLAND IN THE TAY CATCHMENT

- Create the boundary; that is, the Tay catchment and the upland and lowland within it (using the upland mask). Tay_up_low_mask
- Use as habitat source the one created in section 4.2 with the Split tool. H_AGB_Tay
- Update the NodeId field to the new Object id as the NodeId field has to have consecutive numbers
- Use the 'Split' tool to split the habitat patches (H_AGB_Tay) by our new boundary, upland and lowland (By the field Up_Low). The result is T_H_Upland and T_H_Lowland

5.1 Creating Conefor node and distance files

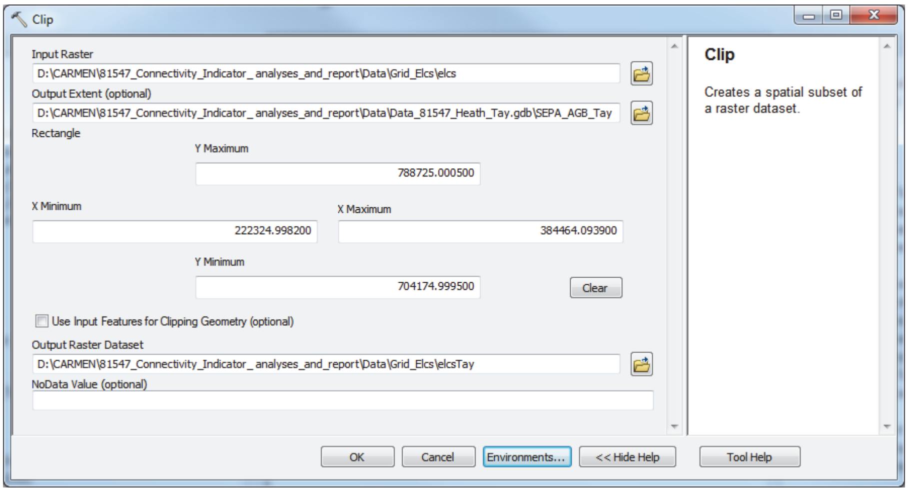
- Apply Conefor. As in previous analysis, twice the dispersal distance has been used (1000m)



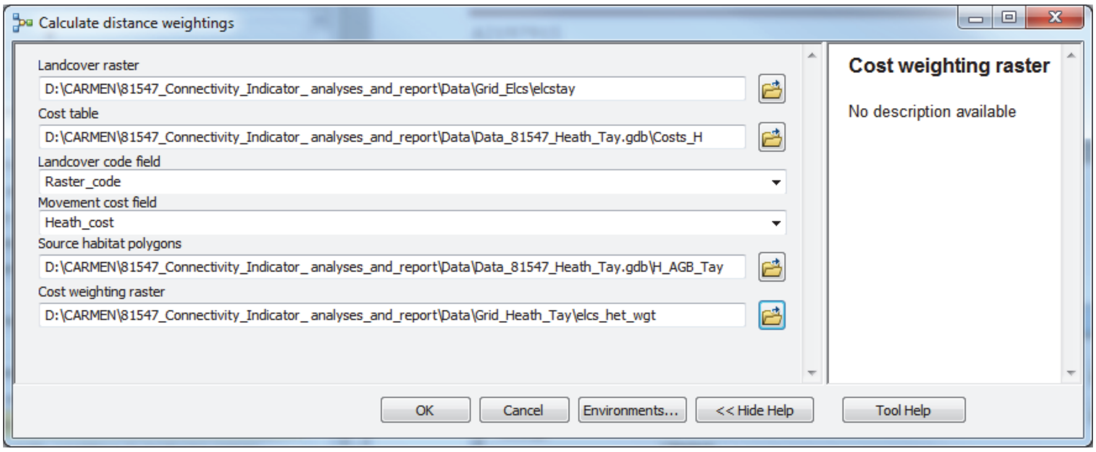


5.2 Calculating permeability weightings

- Use same raster dataset **elcs** but clip it to the Tay catchment extent



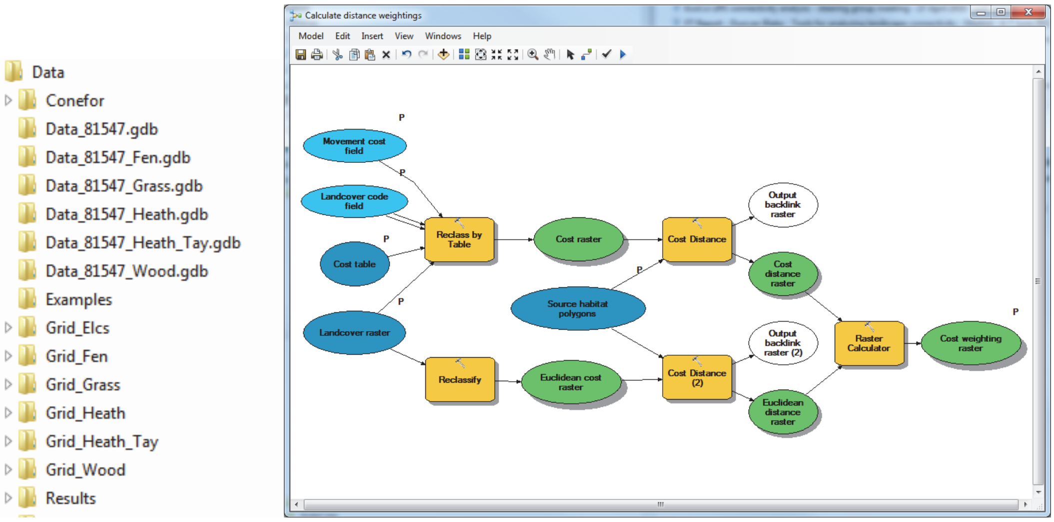
- Use the same cost table **Costs_H**

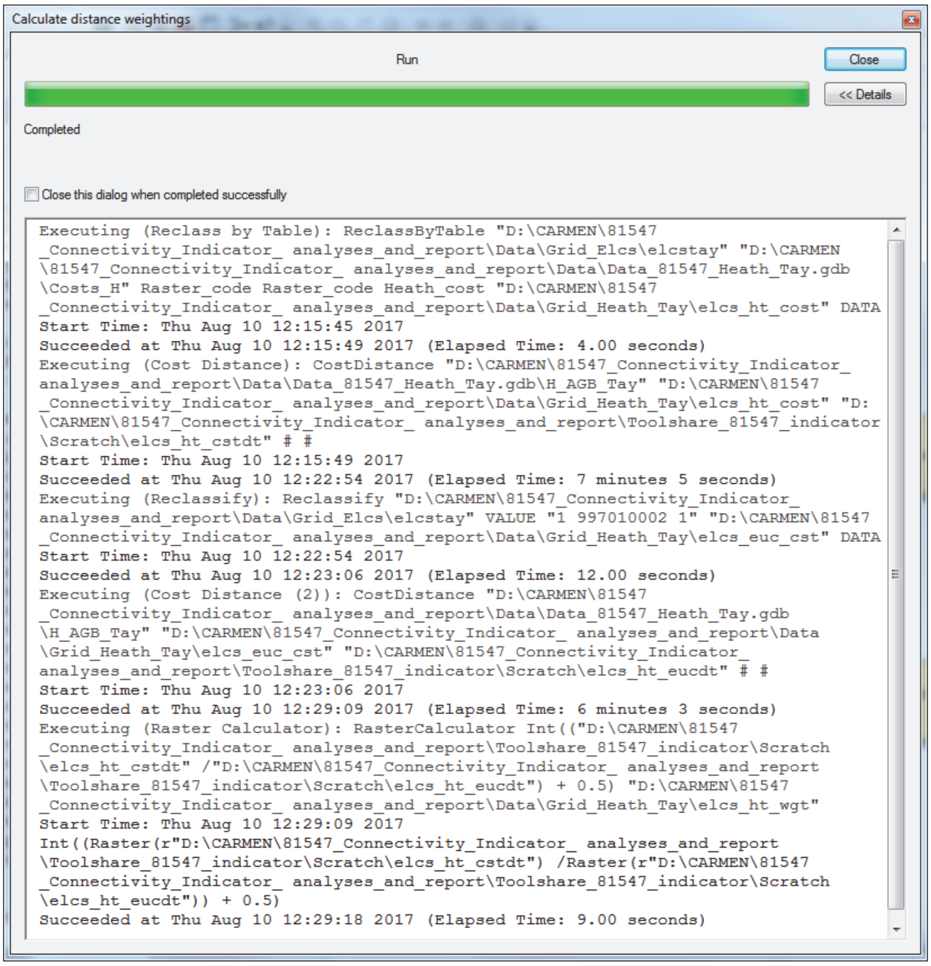


- Use the model to carry out the steps required producing a distance weighting for each pixel in the cost raster. The steps are:
  - Reclass by table to create the cost raster from the datasets above. Output: **elcs_ht_cost**
  - The cost distance tool was run using the habitat polygons (H_AGB_Tay) as the input data and elcs_ht_cost as the cost raster. Output (scratch): **elcs_ht_cstdt**
  - The tool Reclassify (previous analysis used the tool 'Test' but there were issues using the value field, as it didn't recognise some of the values) was run to reclassify all values in the elcstay raster to 1. Output**: elcs_euc_cost**
  - The second cost distance tool was run using the habitat polygons (H_AGB_Tay) as the input data and elcs_euc_cost as the cost raster. Output (scratch): **elcs_ht_eucdt**
  - The Raster Calculator tool was used to divide the two datasets and to add on 0.5 and converted to integer with the expression int(("%Cost distance raster%" / "%Euclidean distance raster%") + 0.5). Output: **eun_ht_wgt**

- Note 1. The model has been run from the editing window by 'run entire model'

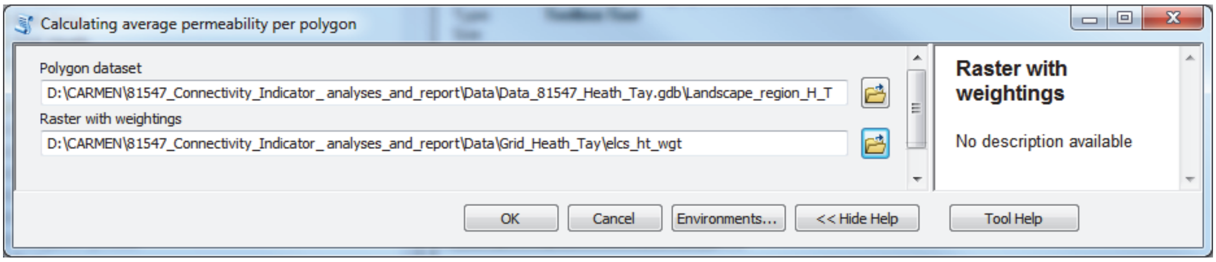
- Note 2. The two intermediate cost rasters are large float files so they are written to the Scratch folder to enable easy deletion. The rest of the outputs are being saved in a folder for each habitat.

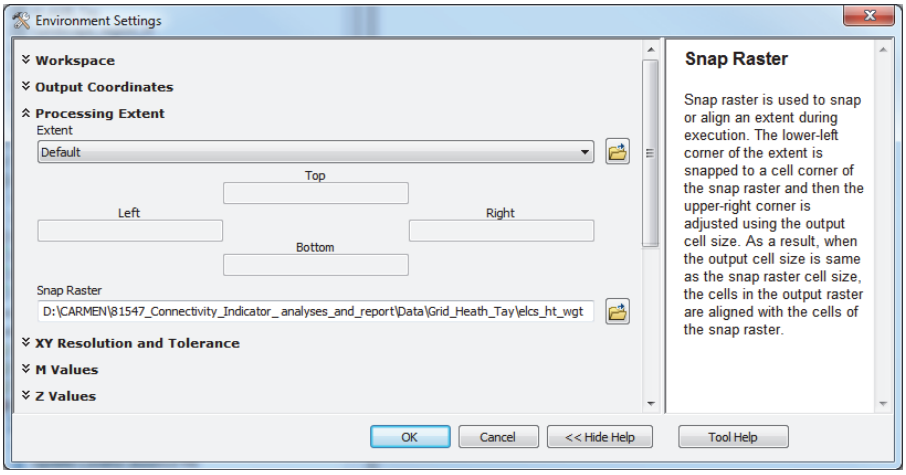




5.3 Applying average permeability weightings to landscape regions

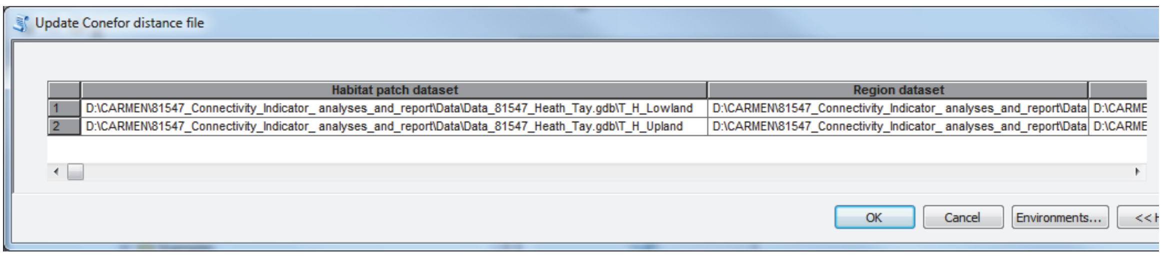
- As our permeability weightings are only for the Tay area, the landscape dataset has been clipped to the Tay area too. For this analysis I have used as polygons the **clip** of the landscape areas.
- Use the script ‘Calculating average permeability per polygon’ to assign average permeability weightings to each landscape region (or any other polygon dataset if required instead). Set the environments manually in the environment tab before running the tool.

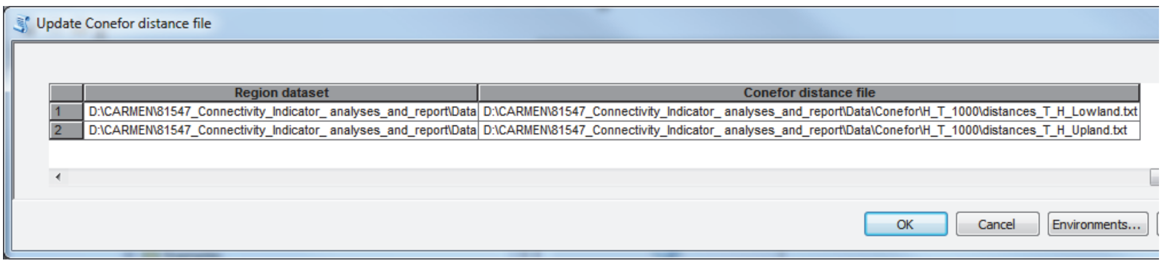




5.4 Updating Conefor distance file with permeability weightings

- Use the script “Update Conefor distance file” in batch mode to convert the two AGB distance files to effective distance files





5.5 Running Conefor

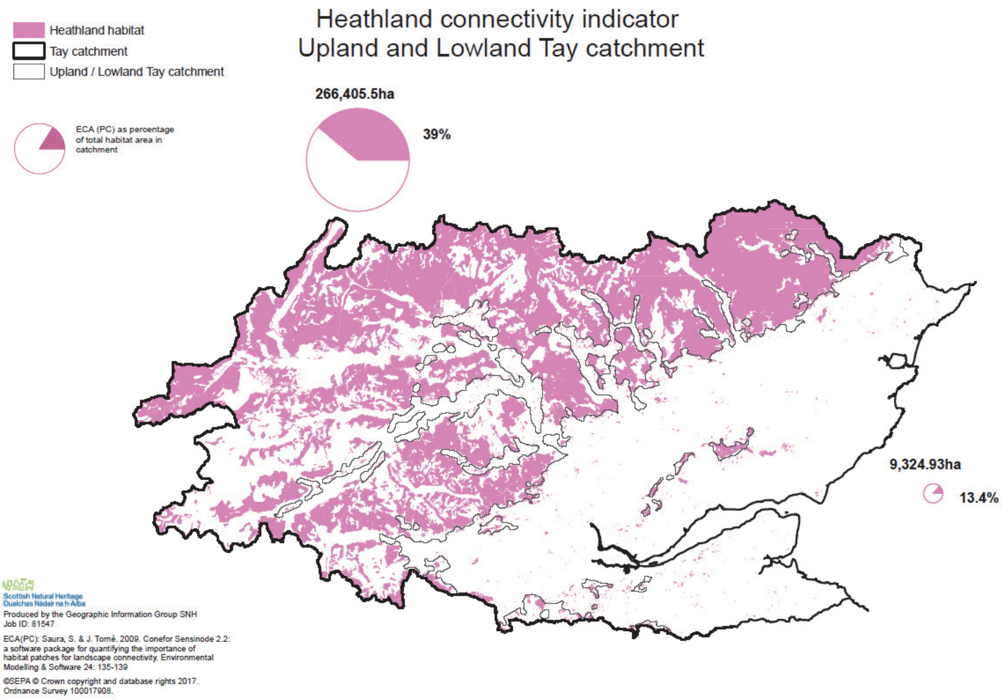
Heathland - Tay

```
coneforWin64.exe  -nodeFile nodes_T_H_Lowland.txt -conFile distances_T_H_Lowland_effective_distances.txt -t  dist notall -confProb 500 0.05 -PC  onlyoverall -simple -prefix T_H_Lowland

coneforWin64.exe  -nodeFile nodes_T_H_Upland.txt -conFile distances_T_H_Upland_effective_distances.txt -t  dist notall -confProb 500 0.05 -PC  onlyoverall -simple -prefix T_H_Upland
```

- To run Conefor a batch file was created to run the 2 files called batch_heath_tay.bat (NB be careful this is not saved as a text file).
- The command line version of coneforWin64.exe was used to take advantage of the 64Bit machine.
- The executable was copied into the same folder as the node and distance files.
- In Windows Explorer the folder was navigated to and then cmd typed in the address bar to open a command prompt window with the pathname already there.
- **batch_heath_tay.bat** was then typed in to run the batch file.
- Conefor writes output files to the same folder:
    - Results_all_overall_indices.txt
    - Results_all_EC(PC).txt

5.6 Calculating a national habitat connectivity value

Prefix	Distance	Probability	EC(PC)	ECA(PC) ha	$ECA(PC)^2$
T_H_Lowland	500	0.05	12,500,000.0	1,250.0	1,562,500.0
T_H_Upland	500	0.05	1,038,310,000.0	103,831.0	10,780,876,561.0
Total					10,782,439,061.0
ECA(PC) Tay				**103,838.5**	



6. ANNEX 1: PYTHON SCRIPTS

6.1 Calculating average permeability per polygon

```
# ---------------------------------------------------------------------------
# average_weightings.py
# Created on:Tues Oct 10 2013
# Duncan Blake
# Usage: regionDataset <polygon dataset to give average weightings>, weightGrid <raster with integer weight values>
# ---------------------------------------------------------------------------

# Import system modules
import arcpy, sys, string, os
from arcpy import env
from arcpy.sa import *

env.OverwriteOutput = True

try:

    # Script arguments...

    # polygon region dataset for which average weightings need to be calculated
    regionDataset = sys.argv[1]

    # weighting raster - this is produced by the ArcGIS model in the previous stage of the job.
    # this needs to be set as a Raster Layer parameter in the toolbox if adding the raster from ArcMap
    weightGrid = sys.argv[2]

    # set extent to that of the vector file and snap raster outputs to the weight raster
    env.extent = regionDataset
    env.snapRaster = weightGrid

    # Check out the ArcGIS Spatial Analyst extension license
    arcpy.CheckOutExtension("Spatial")

    # Find the path for the scratch directory by finding the path of the script
    scriptPath = sys.path[0]
    arcpy.AddMessage("Script folder: " + scriptPath)

    # Get the pathname to the ToolShare folder
    toolSharePath = os.path.dirname(scriptPath)
    arcpy.AddMessage("ToolShare folder: " + toolSharePath)

    # Now construct pathname to the Scratch folder
    scratchPath = os.path.join(toolSharePath, "Scratch")
    arcpy.AddMessage("Scratch folder: " + scratchPath)

    # Get number of regions to process
    NoFeatures = int(arcpy.GetCount_management(regionDataset).getOutput(0))
    arcpy.AddMessage ("Regions to process = "+ str(NoFeatures))

    # Add field to contain the average weighting if it does not exist already
    lstFields = arcpy.ListFields(regionDataset)
    x = False
    for field in lstFields:
        if field.name == "WEIGHTING":
            x = True

    if x <> True:
        arcpy.AddField_management(regionDataset, "WEIGHTING", "FLOAT", "", "", "","", "NULLABLE")

    # start looping through each region
    i = 1
    while i <= NoFeatures:
        arcpy.AddMessage ("Processing region number " + str(i))
```

```
        # Process: Make Feature Layer containing one region...
        arcpy.MakeFeatureLayer_management(regionDataset, "Region_Layer", "\"OBJECTID\" = "+str(i), "", "")

        # Execute ExtractByMask
        regionRaster = ExtractByMask(weightGrid, "Region_Layer")
        regionRaster.save(scratchPath + "\\extract_"+str(i))

        #Make table view of the raster attribute table to allow search cursor to work
        tableView = "Table_view_"+ str(i)
        arcpy.MakeTableView_management(scratchPath + "\\extract_"+str(i), tableView)
        arcpy.AddField_management(tableView, "PRODUCT", "LONG", "", "", "","", "NULLABLE")
        # multiply the value by the number of cells
        arcpy.CalculateField_management(tableView, "PRODUCT", "!VALUE! * !COUNT!","PYTHON")

        # get total number of cells and the total of all the products (cells * value)
        scur = arcpy.SearchCursor(tableView)
        totalCount = 0
        totalProduct = 0
        for row in scur:
            count = row.COUNT
            product = row.PRODUCT
            totalCount = totalCount + count
            totalProduct = totalProduct + product
        del row, scur

        # get the average cost weighting for region i - need the float to avoid the output rounding to the nearest integer
        averageWeighting = (totalProduct / float(totalCount))
        arcpy.AddMessage ("Average weighting for region number " + str(i) + " is "+str(averageWeighting))

        # use an update cursor to populate the weighting field of the region being processed
        ucur = arcpy.UpdateCursor("Region_Layer")

        for row in ucur:
            row.WEIGHTING = averageWeighting
            ucur.updateRow(row)

        del row,ucur,tableView,totalProduct,totalCount,count,product,averageWeighting

        i=i+1

    del scratchPath, toolSharePath, scriptPath, lstFields, field, NoFeatures

except arcpy.ExecuteError:
    arcpy.AddMessage (arcpy.GetMessages(2))
```

6.2 Update Conefor distance file

```
# ---------------------------------------------------------------------------
# update_conefor_distances.py
# Created on:Tues Oct 18 2013
# Duncan Blake
# ---------------------------------------------------------------------------
# define error trapping classes
class NoJoin(Exception):
    pass
# Import system modules
import arcpy, sys, string, os
from arcpy import env
from arcpy.sa import *

env.OverwriteOutput = True

try
    # Script arguments..
    # polygon dataset of habitat patches
    patchDataset = sys.argv[1]

    # polygon region dataset to determine in which each habitat patch lies
    regionDataset = sys.argv[2]

    # conefor distance file
    coneforDist = sys.argv[3]

    # Check out the ArcGIS Spatial Analyst extension license
    arcpy.CheckOutExtension("Spatial")

    # Find the path for the scratch directory by finding the path of the script
    scriptPath = sys.path[0]
    arcpy.AddMessage("Script folder: " + scriptPath)

    # Get the pathname to the ToolShare folder
    toolSharePath = os.path.dirname(scriptPath)
    arcpy.AddMessage("ToolShare folder: " + toolSharePath)

    # Now construct pathname to the Scratch folder
    scratchPath = os.path.join(toolSharePath, "Scratch")
    arcpy.AddMessage("Scratch folder: " + scratchPath)

    # Get habitat patch dataset filename
    patchDatasetList = patchDataset.rsplit("\\",1)
    patchDatasetFilename = patchDatasetList [-1]

    # Create a centre point for each habitat patch
    habitatCentroids =  scratchPath + "\\" + patchDatasetFilename + "_centroids.shp"
    arcpy.FeatureToPoint_management(patchDataset, habitatCentroids,"CENTROID")
    arcpy.AddMessage("Centroids created")

    # spatially join points to the region they fall within
    habitatJoin = scratchPath + "\\" + patchDatasetFilename + "_centroids_joined.shp"
    arcpy.SpatialJoin_analysis(habitatCentroids, regionDataset, habitatJoin, "JOIN_ONE_TO_ONE", "KEEP_COMMON","#",
"CLOSEST")

    # Check that all the features joined
    noCentroids = int(arcpy.GetCount_management(habitatCentroids).getOutput(0))
    noJoinedCentroids = int(arcpy.GetCount_management(habitatJoin).getOutput(0))
    if noCentroids == noJoinedCentroids:
        arcpy.AddMessage ("All "+str(noCentroids)+" centroids successfully joined")
    else:
        #raise custom exception
        raise NoJoin(result)
      # read weighting for each node into a dictionary
```

```
    weightDict = {}
    # set up search cursor to read through attribute table of joined centroids
    arcpy.MakeTableView_management(habitatJoin, "TableView")

    sCur = arcpy.SearchCursor("TableView")
    for row in sCur:
        nodeID = row.NodeID
        weighting = row.WEIGHTING
        weightDict [nodeID] = weighting
    del row, sCur
    arcpy.AddMessage ("Lookup dictionary populated")

    # get the path and filename of the input text file without the .txt

    coneforDistList = coneforDist.rsplit(".",1)
    textPath = coneforDistList [0]

    # read in conefor text file and for each line get Node ID 1 and lookup its weighting, then Node ID 2 and lookup its weighting
    # then get the euclidean distance and multiply by the weighting. Write new line out to a new text file.
    # had to use 'open' instead of 'file' command for the text files - not sure why.

    inFile = open(coneforDist, "r")
    outFile = open(textPath + "_effective_distances.txt", "w")

    x = 0
    for line in inFile.readlines():
        lineList = line.split("\t")
        node1 = lineList[0]
        node2 = lineList[1]
        eucDist = lineList[2]

        # get average weightings for each of the nodes from the dictionary - if they are the same multiply one of them by the
euclidean
        # distance .  If they are different get the average of the two and multiply by the euclidean distance.
        weight1 = weightDict[int(node1)]
        weight2 = weightDict[int(node2)]
        if weight1 == weight2:
            effDist = float(eucDist) * weight1
        else:
            avWeight = (weight1 + weight2)/2.0
            effDist = float(eucDist) * avWeight

        # \t needed to ensure tabs are written to output text file
        outFile.write(node1 + "\t" + node2 + "\t" + str(effDist) + "\n")

        x = x+1
        if x % 1000 ==0:
            arcpy.AddMessage("Number of rows processed = "+str(x))

    inFile.close()
    outFile.close()

    del coneforDistList, textPath, inFile, outFile, lineList, weightDict, weight1, weight2, eucDist, node1, node2

except NoJoin:
    arcpy.AddError ("Not all habitat patches have been spatially joined")

except arcpy.ExecuteError:
    arcpy.AddMessage (arcpy.GetMessages(2))
```

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