Analysing habitat patch size and connectivity at a national level for Scotland - data assessment

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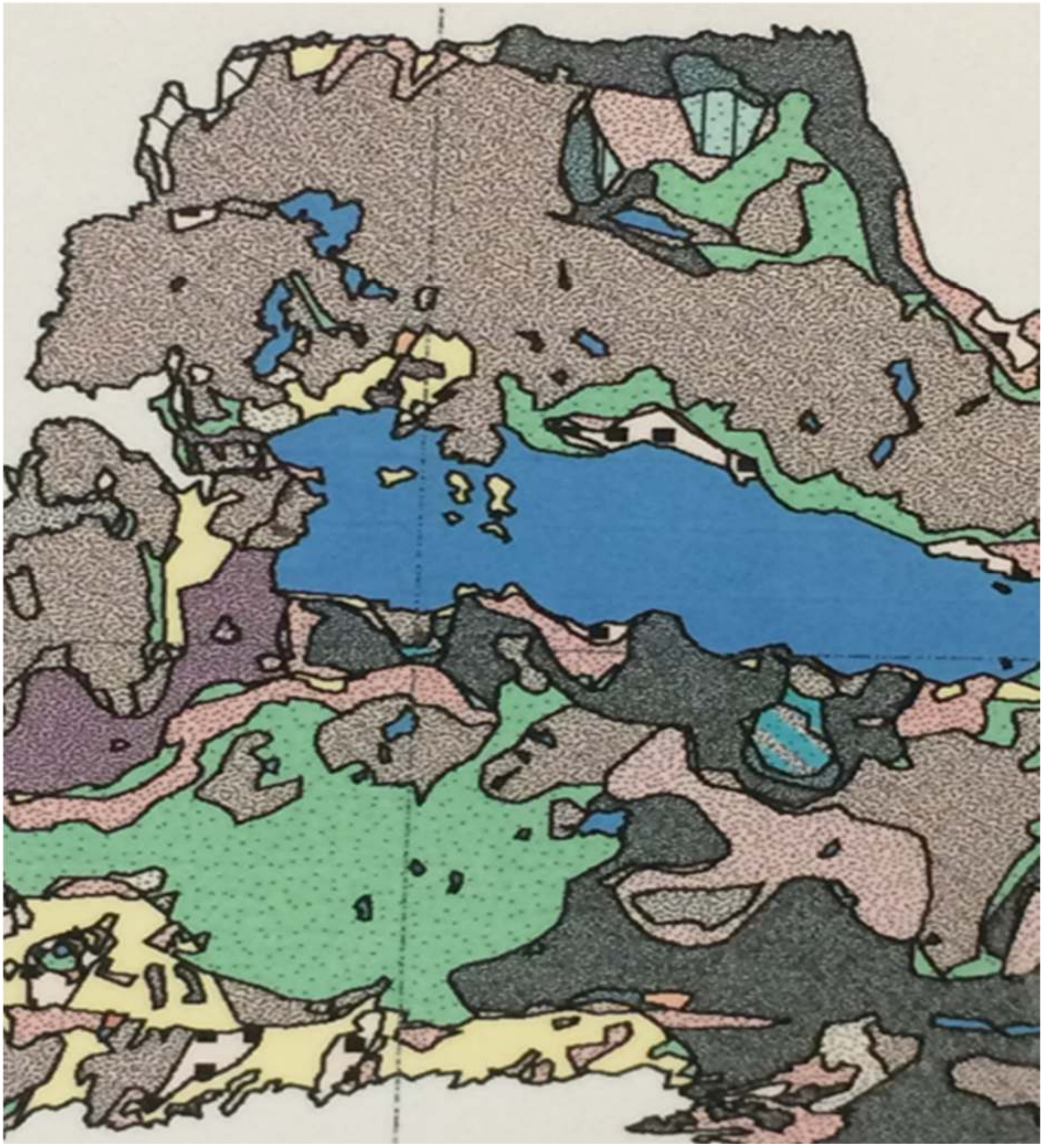


Summary

1. In Scotland, plans for a National Ecological Network (NEN) are embedded within the National Planning Framework, representing an ambitious, practical, positive and long-term vision for enhancing Scotland's natural environment in both rural and urban landscapes.

2. As part of our research funded by the Rural & Environment Science & Analytical Services Division of the Scottish Government, we are focusing on some key knowledge gaps to provide new information that can underpin ongoing work towards defining and implementing a National Ecological Network for Scotland.

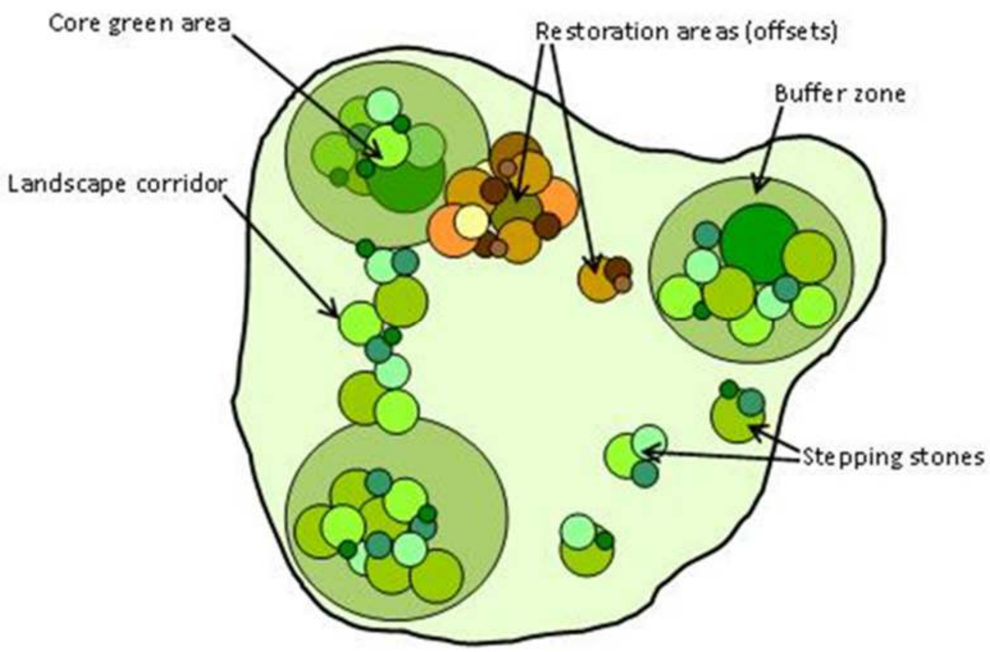
3. This paper examines data availability and characteristics at a national (Scotland) level for assessing the importance of patch size and connectivity for multi-species resilience, which is an area that has been identified as a knowledge-gap.

4. We identify the potential as well as limitations of existing national datasets and point towards new developments in spatial data collection and collation that should greatly improve the possibilities for national-level analysis of the importance of habitat spatial configuration in affecting multi-species changes across different habitat types.

Introduction

The spatial extent and connectivity of habitats has long been considered important for ecological resilience. It has received increasing attention in recent years with the concerns about resilience of species and habitats to climate change across the globe (e.g. Bennett & Mulongoy 2006; Jongman et al. 2011; Gimona et al. 2012, 2015). In the UK, the publication of the highly influential Lawton report in 2010 (Lawton et al. 2010) followed by publication of Defra's 25-year Environment Plan for England in 2018 (Defra 2018) has given a focus to help put some of the principles of the Lawton report into action, with a goal to create a resilient Nature Recovery Network. In Scotland, plans for a National Ecological Network (NEN) are embedded within the National Planning Framework, representing an ambitious, practical, positive and long-term vision for enhancing Scotland's natural environment in both rural and urban landscapes. Good progress is being made particularly in and around urban areas, with initiatives such as the Central Scotland Green Network providing innovative and exciting new ideas for green infrastructure development and integration. There are also several other progressive initiatives in more rural areas of Scotland (e.g. see examples in Hester et al. 2017: https://www.hutton.ac.uk/sites/default/files/files/Connectivity%20workshop%20150317%20-%20Report.pdf). However, there is still much debate about how to implement a national level approach, partly due to a lack of supporting information and understanding about how to address some of the key concepts - in particular, what the most important elements of a resilient ecological network should be (Isaacs et al. 2018).

Figure 1. Components of an ecological network (redrawn from Lawton et al. 2010).



Box 1: extract from the Scottish Biodiversity Strategy "2020 Challenge for Scotland's Biodiversity", page 16, outlining the importance of a National Ecological Network for Scotland.

Towards a national ecological network

The second *National Planning Framework (2009)*[18] proposed the recognition and enhancement of a national ecological network. This idea of a 'network' is grounded in a well-understood feature of nature that species depend on each other in complex relationships; that movement of species across or through the environment requires proximity or connectivity of habitat; and that some species require different habitats for different aspects or stages of their lives. It also recognises the fact that energy and information are carried through natural systems, and that water, nutrients and elements such as carbon are cycled, stored and recycled in complex ways. The term 'network', then, encompasses this idea of functional connectivity, interdependence and the channels of energy, material and information flow that life requires.

Hence, a 'national ecological network' is a way of characterising the nature of Scotland, laying importance on how its different parts relate to each other in ways that best support biodiversity and provide the many benefits (or ecosystem services) to people. This network in the array of woodlands, grasslands, moorlands, wetlands, rivers and lochs across great swathes of countryside, and also the smaller mosaics of hedgerows, marshlands and bogs, woodlands, pastures and arable land on individual farms. This can work well in sustaining diversity and providing multiple benefits of wildlife as well as food, fibre and fuel.

But, as we have seen from the *UKNEA (2011)*[11], some ecosystem services are deteriorating. Work on a national ecological network should endeavour to redress and restore these services. Development of green infrastructure in and around our towns and cities will help, as should enhancement of ecosystem health across river catchments.

Aims of this work

As part of our research funded by the Rural & Environment Science & Analytical Services Division of the Scottish Government, we are focusing on some of the key knowledge gaps, to provide new research information that can underpin ongoing work towards defining and implementing a National Ecological Network for Scotland.

One such knowledge gap is as follows: The importance of habitat networks for individual species is considered relatively well-established, but their importance for multi-species resilience is still poorly understood (e.g. Albert et al. 2017; Isaac et al. 2018).

The Lawton report 'motto' of bigger, better, more joined up is well supported by ecological theory, supports the assertions that bigger patches of specific habitats should buffer species assemblages against perturbations; greater numbers of patches should increase resilience through a greater probability of survival of at least some patches surviving perturbations; and connectivity between patches should further increase resilience through facilitating species movements through the landscape, for example in response to changes in climate. But empirical data availability is still very limited, particularly because the testing of network resilience requires long-term monitoring.

For Scotland, we are examining possible routes for empirical data collation and analysis at a national level to address this important issue. One such route to analysing change over long timescales is to examine long-term historical changes in multi-species assemblages and assess how changes over time might have been affected by the connectivity and extent of different habitats. There are two main requirements for such analysis: first, data on long-term changes in species composition across different vegetation types; second, spatial data on the distribution and extent of those different vegetation types – combination of these two allows analysis of how spatial distribution and extent of different vegetation types has affected the directions or magnitudes of species compositional changes; and exploration of how spatial configuration might buffer, accelerate or redirect some impacts of major drivers such as climate change, pollution and land use. Key questions include: Have species compositional changes differed depending on size of patch and/or proportion of the same habitat within different distances from sample plots? Is there evidence for buffering of species compositional changes associated with specific drivers, such as climate? Are there measurable associations between habitat extent and distribution and the losses or gains of, for example: (a) species of conservation importance; and/or: (b) invasive species? This in turn will help inform predictions about likely impacts of changes in areal extent and connectivity of some of Scotland's habitats into the future.

National datasets for Scotland on long-term changes in vegetation composition

The increasing availability of empirical data quantifying long-term multi-species compositional changes across national and multi-national scales (e.g. Bernhardt-Romermann et al. 2015; Britton et al. 2017; Steinbauer et al. 2018) gives an exciting opportunity to investigate empirical evidence for how ecological resilience of different habitats might be affected by their spatial extent and connectivity. Scotland holds an extensive national dataset on long term plant species compositional changes across a range of different habitats, based on the Birse and Robertson Archive (https://www.hutton.ac.uk/research/birse-and-robertson-archive). It also holds a smaller, spatially complementary, dataset based on the McVean and Ratcliffe archive (Ross & Flagmeier 2015).

The Birse and Robertson archive is a unique collection of historical information on the status of Scottish plant communities, built up over the last 70 years. Eric Birse and Jim Robertson surveyed and studied Scottish vegetation between 1945 and 1985, collecting almost 7000 records of vegetation composition throughout Scotland, covering all major Scottish vegetation types. Between 2004 and 2014 approximately 1500 of the original survey locations were re-visited and re-surveyed as part of Scottish Government funded projects to investigate long-term change in Scottish vegetation. Resurveyed habitats include alpine, moorland, woodland, wetland and grasslands, and a number of publications have been produced describing vegetation change in Scotland over the last 30-50 years and relating this to changes in climate, pollution and land-use (some also including selected data from the McVean and Ratcliffe archive – details below).

The McVean and Ratcliffe archive covered a similar period to the Birse and Robertson archive and focused primarily on the Scottish Highlands - both sets of surveyors cooperated to ensure that their survey locations were spatially complementary rather than overlapping. A report by Ross & Flagmeier (2015) details the methodology and data collected. It does not state the number of plots originally surveyed, nor the numbers resurveyed, but references are given for each individual resurvey and the full data can apparently be downloaded as an excel spreadsheet from the SNH website (although we could not find any link to this).

These datasets combined provide unparalleled information on long-term changes in plant species composition across Scotland.

National land cover datasets

Quantifying connectivity or areal extent of habitats at a national or multi-national scale requires appropriate land cover map data and, as exemplified by Jongman et al. (2011), this brings particular challenges relating to mapping scale and the diversity of land use classification choices. At a European level, the Corine programme was initiated in 1985 to gather, coordinate and ensure the consistency of information on the state of the environment and natural resources in the European Community - Corine means 'coordination of information on the environment'. The European Environment Agency holds the Corine inventory of land cover (created through analysis of satellite images by national teams), which has 44 classes, a map scale of 1:1000,000 and a smallest mapping area of 25 ha (https://www.eea.europa.eu/publications/COR0-landcover). The Corine Land Cover database for the UK has been updated for the reference year 2012, with a mapping scale of 5 ha (Cole et al. 2015). This scale is considered too coarse for the purposes of our analyses so has not been considered further. Other UK- and Scotland-level mapping exercises have produced land cover maps at finer-scales and these are the ones we discuss here.

To date we have used two selected broad habitat types - native woodlands and moorlands – as case-studies to explore the availability and potential of more detailed land cover datasets for Scotland. These habitats were selected for two reasons: (a) both broad habitat types contain specific species and habitats of national and European conservation importance; (b) they are also considered relatively straightforward to identify remotely (i.e. on aerial photographs or remotely-sensed images) as well as through ground-survey, increasing the likelihood of successful national level spatial data acquisition (compared to some other, more visually-cryptic habitats that are much harder to identify remotely). To date, we have examined the following land cover datasets that give full national coverage.

The Native Woodland Survey of Scotland

Woodlands are one of the easiest habitat types to classify remotely, as trees are relatively straightforward to distinguish on aerial photographs or remotely sensed images (identifying species composition remotely is more challenging, however, beyond distinguishing coniferous versus deciduous tree species). The Native Woodland Survey of Scotland (NWSS) represents a major national achievement: an exciting and ambitious ground-survey carried out between 2006-2013 to produce the first authoritative picture of Scotland's native woodlands (Forestry Commission Scotland 2014). This survey aimed to identify, classify and record the condition of all Scotland's native woodlands greater than 0.5 ha in area (https://scotland.forestry.gov.uk/supporting/strategy-policy-guidance/native-woodland-survey-of-scotland-nwss). It provides a high quality, comprehensive source of detailed, spatially-referenced information not just on distribution and extent of different woodland types, but also their species composition, condition, and a range of other factors.

Summary assessment: Interrogation of the NWSS dataset at the individual plot level for the Birse and Robertson woodland plots gives robust data on the spatial extent of different woodland types at and around the survey plot locations, allowing us to examine the relationships between areal extent, spatial distribution and long-term changes in plant community composition for different woodland habitat types.

Land Cover maps

There are two major national land cover maps available for Scotland, both of which classify a range of habitat types that can be identified remotely with some degree of confidence (i.e. from aerial photographs/satellite imagery with limited ground truthing):

- the **Land Cover of Scotland 1988 (LCS88)** map (Macaulay Land Use Research Institute 1993; https://www.hutton.ac.uk/learning/exploringscotland/landcover-scotland-1988)
- the **CEH Countryside Survey Land Cover Maps (LCM)** (1990, 2000, 2007, 2015 now available: https://countrysidesurvey.org.uk/content/land-cover-map).

The LCS88 was based on a whole-Scotland aerial photographic coverage flown in 1988, interpreted manually by experienced surveyors and validated by ground survey (Macaulay Land Use Research Institute 1983). It used a hierarchical system of land cover classification, with 126 single land-cover features (habitat type plus additional information, for example whether recently burnt or not in the case of moorland) and mosaics where individual types could not be separated at the selected interpretation scale, giving a total of 1323 different land cover categories (354 of which cover 99% of the land area of Scotland) that can be amalgamated at different levels. The LCS88 minimum mapping area was 0.25 ha.

The LCMs were interpreted using satellite imagery, with some ground truthing (Morton et al. 2011). At the time of the research reported here, the most recent available LCM dataset was LCM2007, so we assessed LCM2007 and LCS88 for the work reported here. The LCM2015 is now available under license and the Dataset documentation lists several updates to the methods used for LCM2007 (NERC (CEH) 2017). The LCM maps defined 25 target land cover classes, based upon UK Biodiversity Action Plan broad habitat types, with a minimum mappable unit of 0.5 ha. A notable change in the LCS2015 mapping is the method of classification for montane areas, which should greatly improve its value for mapping of high altitude habitats (we plan to check this with the Birse and Robertson 'alpine' habitats plots to update our assessments detailed below). All the previous LCMs included a 'Montane' class that was mapped purely as a function of a variable altitude threshold (Morton et al. 2011), and not from the spectral data. For the LCM2015, these areas are mapped based on the spectral data and are classified as 'inland rock' or one of the other upland habitats.

Interrogating LCS88 and LCM2007 land cover datasets using moorland as a test-case

Habitats dominated by the dwarf-shrub, heather (*Calluna vulgaris*) are considered relatively easy to identify remotely, but to date there has been no national level survey comparable to the Native Woodland Survey of Scotland. We investigated the accuracy of the LCS and LCM maps accuracy at six-figure grid referenced point-scales, to assess their potential value for use to classify the distribution and extent of heather-dominated vegetation on and around the Birse and Robertson resurveyed sample plots (hereafter called "Birse plots"). Two key elements for assessment of the usefulness of these datasets for our purposes are: (a) level of resolution; and (b) level of classification detail, i.e. the number and type of land cover categories used and how they relate to the habitat types surveyed on the ground, which are based on the amalgamated groups of National Vegetation Classification habitat types (Britton et al. 2017). All plots in our dataset had been classified as one of the NVC moorland types at the time of first survey and were also classified as moorland at the second survey 30-50 years later around 2005 (Britton et al. 2017), so it is likely that they remained heather-dominated between surveys. The LCM2007 map was closest in date to our resurvey year.

It is important to note at this point that neither of the national land cover datasets were designed for point-use and as far as we are aware this is the first time a detailed national-level assessment has been made of their potential value in this respect, so it has been a revealing and informative test of their potential in this respect.

All Birse moorland plots were classified based on vegetation into the following amalgamated broad habitats (aligned with Britton et al. 2017): Dry heath, Alpine heath, Wet heath, Blanket bog and Grassy heath. This level of amalgamation facilitated comparison with the broad classification categories of both the LCM and LCS maps. The 'R' package Raster was used to extract the cover classification of both maps at each six-figure locational grid reference for each Birse plot. This information was then compared to the actual broad habitat type defined from the Birse plot ground-survey (based on the NVC-classification of the species composition in each survey plot).

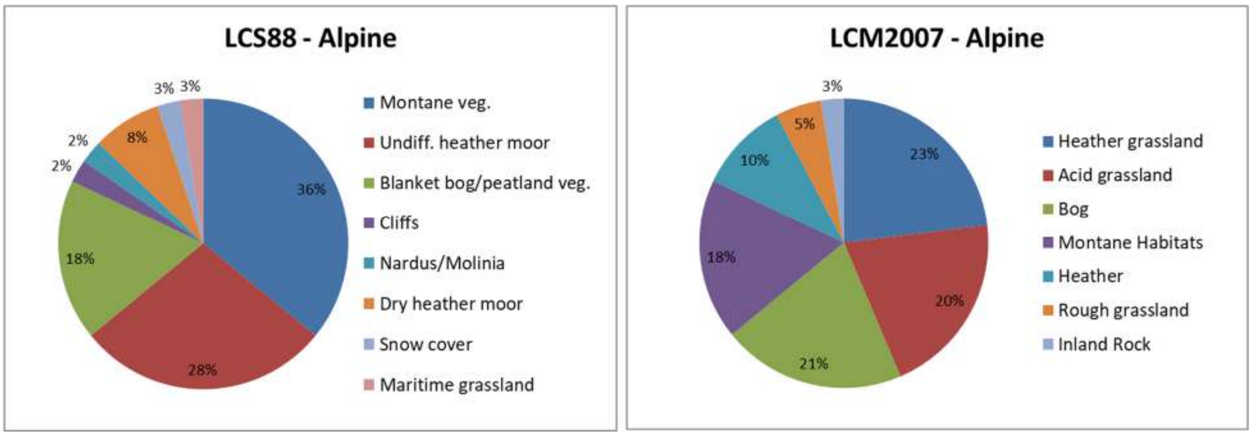
Comparisons of LCM and LCS classifications against the Birse habitat classifications were then used to assess which Land Cover dataset was most locally-accurate and useful for analysis with the Birse moorland plots; and how comparable these two datasets are in their classification of these broad moorland habitat types.

Our findings – which dataset was most locally-accurate and useful for analysis with the Birse & Robertson moorland plots

Point-level accuracy of habitat classification varied according to moorland habitat type as well as Land Cover Map (LCS v LCM). In addition to the different levels of classification detail, the two land cover maps also use different classifications that are not always directly comparable, even for moorlands, and some categories with the same name (e.g. 'montane') are mapped very differently. 'Montane' in the LCM2007 map is based on altitude and is bigger in areas than LCS88 'montane' habitat. This makes it hard to compare the maps one on one, and certainly removes the possibility of using the different maps to assess temporal changes in land cover between 1988 (LCS) and 2007 (LCM). The 'Montane' category gave us the most challenges for comparison with the Birse plot data, because it encompasses multiple habitat types (i.e. including, but not exclusively alpine heath).

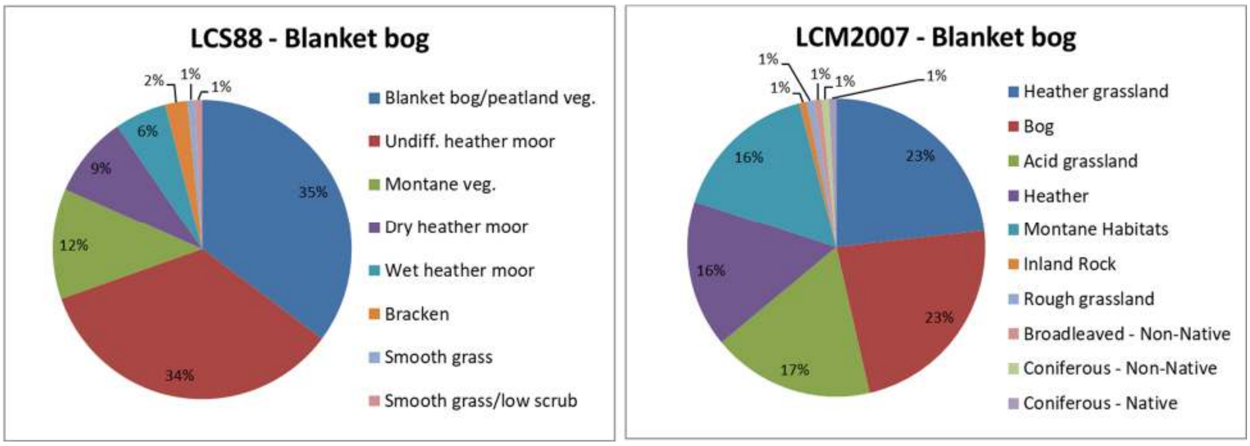
Figure 1. Pie charts showing proportions of Birse moorland plots that were classified under different land use categories in LCS88 and LCM2007. Pie charts are shown individually for each of the four main Birse moorland habitat types.

(a) alpine heath (n=39)



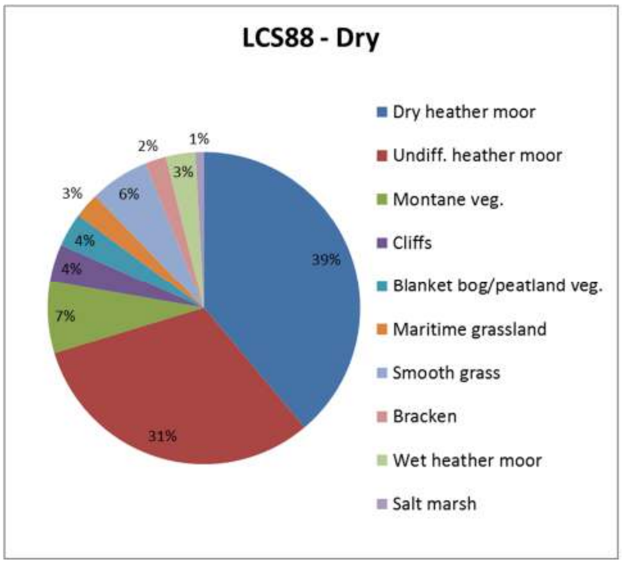
The Birse alpine heath plot locations challenged both land cover datasets because some of these plots were located in the undifferentiated 'montane' zone of each Land Cover map (36% for LCS88 and 18% for LCM2007). Overall, not including montane, both LCS88 and LCM2007 classified 54% correctly as a heather-dominated vegetation type – LCS88 classified only 10% of all plot locations as not heather-dominated (2% of these were classified as snow covered), whereas LCM2007 classified 28% as definitely not heather-dominated.

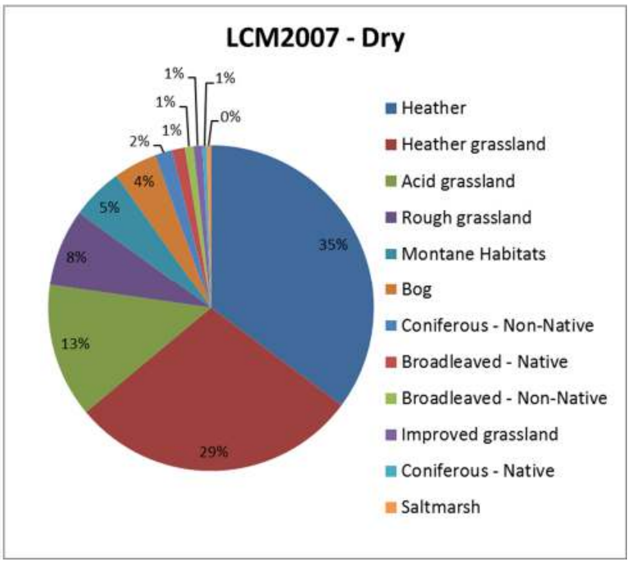
(b) blanket bog (n=125)



LCS88 classified 75% of Birse blanket bog locations as bog, wet heath or undifferentiated heather, with a further 9% classified as dry heath (= total 84% heather-dominated). A further 12% were located in the montane zone, and only 4% were definitely classified as non-heather vegetation types. LCM2007 classified 23% of locations as bog, a further 39% as heather or heather-grassland (= total 62% heather-dominated), 16% as montane and 22% as non-heather vegetation.

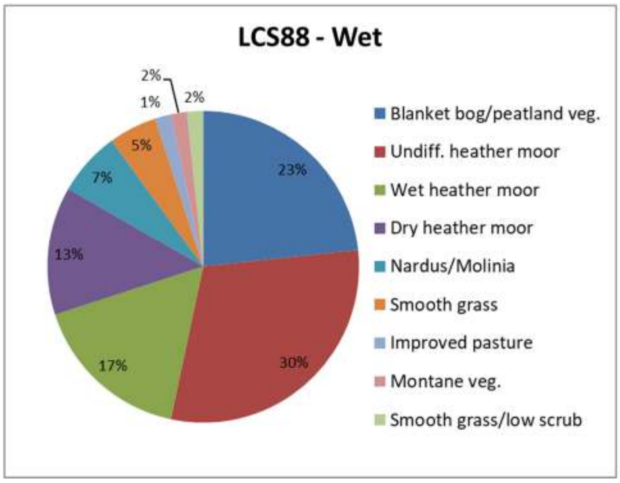
(c) dry heath (n=233)

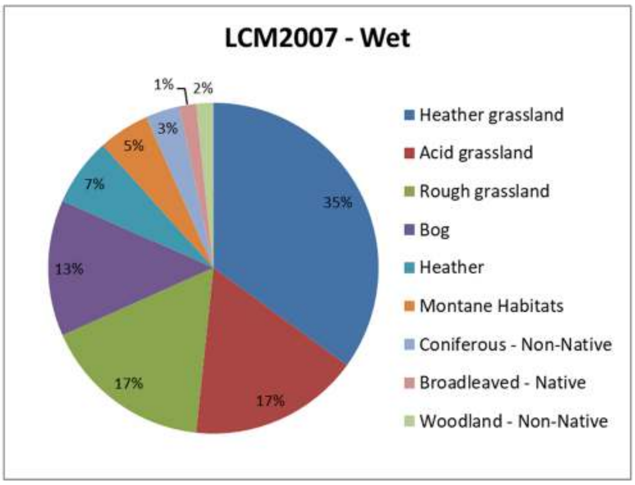




The Birse dry heath plot locations had 69% classified by LCS88 as dry or undifferentiated heather moor, and a further 7% as wet heath/bog (= total 76% heather-dominated), 7% were located in montane, and 16% were classified as non-heather vegetation. LCM2007 classified 64% as heather or heather grassland, 4% as bog (= total 68% heather-dominated), 5% as montane and 27% as non-heather vegetation.

(d) wet heath (n=60)





LCS88 classified 70% of plots as wet heath/bog or undifferentiated heather, and a further 13% as dry heath (= total 83% heather-dominated), 2% montane and 15% as non-heather vegetation. LCM2007 does not have a wet heath category but overall, 55% of locations were classified as some sort of heather, 5% montane, and 40% as non-heather.

Summary findings:

- Both datasets showed a better level of correspondence with the Birse habitat classifications than we expected, given that the Birse plots were smaller than the minimum mapping scales of both land Cover datasets. This is a really positive finding for our purposes (and is probably a reflection of one of the aims of the original surveyors which was to locate sample plots in patches of 'representative vegetation', so it is possible that many sampled habitat patches may have been larger than 0.25 or 0.5 ha).

- Overall, and for all except alpine heath, the LCS88 gave a better level of correspondence to the Birse plot point-scale habitat classifications than the LCM2007, with between 4-16% not classified as some sort of heather-dominated vegetation for any one Birse moorland type tested, whereas for LCS2015, between 22-40% of Birse plot locations were classified as non-heather. Given the greater resolution of LCS88 than LCM2007 (minimum mapping areas: 0.25 and 0.5 ha, respectively), as well as the much greater number of land cover categories in LCS88, this finding was expected.
- Precise classification of wet heath/bog versus dry heath was less successful than just classifying as 'any heather-dominated vegetation', so we note that assessments of the impacts of areal extent of heather-dominated habitat on species assemblages common to all or most heather-dominated Birse plots should be much more robust than species only found in wet or dry heather areas.
- For both land cover datasets, the undifferentiated montane category gave a problem for alpine heath ID, but even with this lack of definition, both land cover datasets classified just over 50% of Birse plots as some sort of heather-dominated vegetation. We look forward to assessing the LCM2015 with its new classification approach to this montane zone.
- Given the differences in land cover category definitions and detail (number of categories) between the LCS88 and LCM2007, as well as some methodological differences, we do not consider it feasible to compare differences in mapped cover of different land use types as proxies for temporal changes in local land cover around the Birse plots between 1988 (LCS survey date) and 2007 (LCM2007 survey date). Given that the LCS has now been repeat-mapped 4 times, broad changes in Land Cover can and have been assessed from these maps. But the LCS88 has only been carried out once.

Discussion and next steps

As stated earlier, Scotland holds a unique set of plot-based data on long-term changes in species composition for all the main habitat types. One of the biggest challenges addressed here is the availability of land cover data at appropriate resolution to be able to explore the influence of areal extent and connectivity of different habitats on their long-term ecological resilience (using the plot-based compositional data). Detailed species compositional data tends to be collected at plot scales of 10 x 10 m or less, whereas remotely-mapped (aerial photographs / satellite imagery) land cover maps currently available tend to have minimum mapping levels of 0.25-0.5 ha or greater.

At a multi-national level, the development of the pan-European ecological network (PEEN) plans faced similar challenges in addressing scaling issues between the different land cover datasets available in different parts of the planned network region (Jongman et al. 2011). The resulting pan-European networks maps were developed at a scale of 1:3,000,000, using a large number of different datasets and represent an impressive piece of work. The primary focus was on identification of non-fragmented areas of habitat considered large enough to sustain populations of large species and species of European importance requiring large areas. As the authors themselves discussed, a big shortcoming of this approach was the lack of ability to identify small-scale landscape features that might act as connectors below the minimum mapping size - this needed to be addressed separately at smaller scales.

Additionally, differences in land cover classifications make comparisons between different land cover maps challenging. In our assessments, the LCS88 offered a better fit to the Birse and Robertson moorland plot data, probably primarily due to the greater number of land cover categories mapped, as compared to the LCS2007, and smaller minimum mapping area. But the LCS88 was only created once (from 1988 aerial photographs), whereas the LCS has now been created at 4 different dates covering a timescale of 25 years. So the latter gives possibilities for analysing temporal changes in aerial extent and connectivity, but for our purposes the habitat categories are too generalised for detailed analysis even at the four broad habitat levels that we tested for moorland.

Towards a national habitat classification based on ground survey

The availability at a national level of a ground-based survey of Scotland's native woodlands (the Native Woodland Survey of Scotland) has opened up the possibility for detailed analyses of the role of areal extent and spatial distribution in driving or mitigating changes in woodland habitat composition. But we found no other ground-survey datasets that yet give full national coverage for any other habitat type. A commitment was made in the "2020 Challenge for Scotland's Biodiversity" (part of the Scottish Biodiversity Strategy) to produce a "comprehensive map of Scotland's main habitats". Scottish Natural Heritage and partners are coordinating the development of a Habitat Map of Scotland (HabMoS) based on collating detailed ground survey data from multiple locations: https://www.nature.scot/landscapes-and-habitats/habitat-map-scotland.

The Habitat Map of Scotland (HabMoS) development aims to publish all available habitat data as it becomes available to ensure as accurate as possible picture of Scotland's habitats. It is also stated on their website that SNH will also manage a programme to survey those areas for which new information is needed. The European Nature Information System (EUNIS) is being used to classify existing data: http://eunis.eea.europa.eu/habitats-code-browser.jsp. The first phase of work, completed in 2015, resulted in a new EUNIS Land Cover Scotland map, hosted on SE-Web website: https://www.environment.gov.scot/news/scotlands-environment-blog/exciting-new-biodiversity-analysis-tools-habitat-map-of-scotland-and-ecosystem-health-indicators/.

This is an excellent and much-needed initiative, opening up new potential for powerful analyses of the importance of habitat configuration on multi-species changes across different habitat types. Priority has initially been given by SNH to Annex 1 habitats, as these generally have the greatest conservation importance. Examination of the data collated to date indicates that more than 1500 individual NVC surveys have been added to the dataset to date, with good coverage of protected areas, coasts and peatlands. However, the total coverage of Scotland is still well under 50% (we could not find any statement of the actual areal extent of available NVC mapping coverage, so this is a visual estimate from the map).

Next steps in our research

We are currently assessing the proportional coverage of HabMoS for: (a) the Birse and Robertson survey plots for all alpine habitat types (not just alpine heath as discussed in this paper), given the limitations of the Land Cover datasets LCS88 and LCM in montane areas in particular; and: (b) all the different Birse and Robertson moorland habitat types, to assess whether there is sufficient areal coverage of plot locations to explore the role of spatial configuration of these habitat types on their ecological resilience at much greater resolution than is possible with the National Land Cover maps LCS and LCM.

Acknowledgements

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