Analysing habitat patch size and connectivity at a national level for Scotland - data assessment part 2: HabMoS

Alison J. Hester, Sara Aguado and Andrea Britton

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Summary

1. In Scotland, plans for a National Ecological Network 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 2016-21, 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 is the second of two Hutton web papers examining 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 major knowledge-gap.
4. The first paper (Hester & Scholtens 2019) examined different national land cover datasets to explore their potential for use for this purpose. In addition to addressing the challenge of availability of land cover data at appropriate resolution, they also identified that one of the biggest data 'gaps' in the national land cover datasets was for alpine habitats, which had most commonly been amalgamated into a single 'montane' category making it impossible to assess spatial coverage of any individual alpine habitat type. This second paper assesses the potential for SNH's Habitat Map of Scotland (HabMoS) initiative to fill these gaps.
5. HabMoS is undoubtedly an excellent and much-needed national initiative, but we found that the inputted NVC survey data coverage at the time of our downloading (March 2019) covered only 15% of Scotland's land area, which of course is too little for any national level analysis at this stage.
6. Added to this coverage issue we found further challenges on closer interrogation of the data from individual NVC surveys, i.e. different surveys using different methodologies and some allocating NVC categories in very different ways – these challenges combined to make the collated NVC survey data limited in value for multi-site analyses.
7. Undoubtedly the inputting of these NVC survey data is hugely resource-hungry, and our findings suggest that, whilst there is great value in having a single central repository for access to all Scotland's habitat surveys (for a whole multitude of uses), for the purposes of creating a national level detailed habitat mapping resource it would be better to adopt a different approach.
8. In this respect, we applaud the ongoing work by SNH in developing and testing an innovative technique to habitat mapping developed in Sweden, which they have demonstrated can give a more rapid and cost-effective approach to mapping Scotland's habitats. Whilst the level of habitat/species detail is much less than NVC ground-survey data, it is greater than that of the two National Land Cover datasets tested by Hester & Scholtens (2018), particularly for alpine habitats. Given appropriate resourcing, we see excellent potential for wider application.

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Front page photograph taken by Alison Hester

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. Jongman et al. 2011; Gimona et al. 2012, 2015; Chambers et al 2019). Managing for ecological resilience requires a robust, spatially explicit understanding of the many factors driving resilience of habitats and species, to underpin development of management strategies that target action where it is likely to have the greatest benefits.

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) gave focus to help put some of the principles of the Lawton report into action. A commitment in the 25-year Plan was to create a Nature Recovery Network (NRN) for England, intended to improve, expand and connect habitats to address wildlife decline and provide wider environmental benefits for people. However, as indicated by responses to this proposal (e.g. The Wildlife Trusts 2018; Confor 2019; Wildlife and Countryside LINK 2019), there is still much debate about how to implement a national level approach. This is 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). The latest statistics on the UK's habitats and species, the State of Nature report 2019 (Hayhow et al 2019) give hard-hitting information on the continuing net losses of species and habitats across the UK and the main pressures considered to be driving these losses. Landscape scale conservation actions to redress some of these losses are still limited to local-initiatives (even the UK network of Nature Improvement Areas (NIAs) – a great national initiative - only cover a total area of 190km^2 across England) - many of these initiatives are demonstrating excellent partnership working across sectors, but there is an increasingly urgent need to scale this up to bigger, national-level action, underpinned by robust scientific data. In Scotland, plans for a National Ecological Network (NEN) are embedded within the National Planning Framework – but to date actions to progress this aim have also been largely local and the 'form' of a national level strategic approach (just as in England) is still under debate (e.g. https://www.gov.scot/publications/analysis-report-responses-online-discussion-developing-environment-strategy-scotland/pages/9/; https://www.scotlink.org/publication/nature-connections-benefits-of-a-national-ecological-network-in-scotland-event-report/).

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 and 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.

One 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 types of data 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.

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). These datasets combined provide unparalleled information on long-term changes in plant species composition across Scotland (example papers: Britton et al. 2009, 2017).

There are several possible sources of national level spatial habitat data and this has been the focus of our **two James Hutton Institute web papers in this series**, i.e. to examine spatial habitat data availability and characteristics at a national (Scotland) level for use in assessing the importance of patch size and connectivity for multi-species resilience, thus directly addressing the knowledge gap highlighted by Isaac et al. (2018).

In the first paper of this series, Hester & Scholtens (2019) examined different national land cover datasets and identified that one of the biggest data 'gaps' was for alpine habitats. They also highlighted other limitations in accuracy and resolution of aerial photo/satellite-based national classifications when used to generate spatial habitat configuration information for use with quadrat-based data collected in the field. For more easily recognised habitats such as moorland these limitations were found to be less of an issue. The ideal data source for an analysis of spatial habitat configuration would be national coverage of habitat plant-compositional information based on ground survey, and for the first time for Scotland this is becoming a possibility through the Habitat Map of Scotland (HabMoS) initiative https://www.nature.scot/landscapes-and-habitats/habitat-map-scotland.

By way of introduction to this national habitat mapping initiative (HabMoS), 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 this Habitat Map of Scotland (HabMoS) based on collating detailed ground survey data from multiple locations. The Habitat Map of Scotland (HabMoS) is intended to become the national repository for habitat and land use data, with all available habitat data being published as it becomes available to ensure as accurate and up to date a picture as possible of Scotland’s habitats.

Analysis of the HabMoS initiative is the focus of this second paper in our series – we assess the potential of habitat composition data being collated as part of the Habitat Map of Scotland (HabMoS) to provide national level information on the spatial configuration of different habitat types.

Our specific aim was to assess whether there is sufficient NVC survey mapping areal coverage at our long-term vegetation data plot locations (https://www.hutton.ac.uk/research/birse-and-robertson-archive) 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 - examined in Hester & Scholtens (2019).

Data, Methods and Results

This section takes the reader through the steps that we took to examine the data and its potential, to give as much information as possible for others wanting to use the data for similar purposes and to give detailed feedback useful for SNH and partners in their ongoing work on HabMoS.

Specifically, we were interested to find out: (a) the proportional coverage of Scotland of the NVC survey data collated to date within HabMoS (these data give information at a comparable level of detail to our Birse and McVean long-term vegetation change data – see below); the degree of spatial concurrence between the collated HabMoS NVC survey data and our Birse and Mcvean resurvey plot locations, particularly for alpine habitats (this being a notable ‘gap’ in the national datasets examined by Hester & Scholtens 2018) and moorlands; and: (c) the level of detail and consistency between different dates of NVC survey held in the HabMoS dataset.

Habitat mapping data for Scotland

The Habitat Map of Scotland (HabMoS) is a composite mapping process bringing together data from different sources, all re-classified into the European Nature Information System (EUNIS): 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 - this is a Scotland raster based (10m) landcover made up of best available national data classified into 12 amalgamated habitat types according to the EUNIS (EUropean Nature Information System): https://www.environment.gov.scot/news/scotlands-environment-blog/exciting-new-biodiversity-analysis-tools-habitat-map-of-scotland-and-ecosystem-health-indicators/.

This map is also being updated with more detailed habitat and land use information, with particular priority being given to European Priority Habitats (EU Habitats Directive Annex 1). Individual site surveys and all existing national habitat surveys are being brought into use. The Identity of original surveys is retained, so it is always clear where data has come from. The web information states that c 800 individual National Vegetation Classification (NVC) surveys have been added to the mapping dataset thus far. We could not find any statement of the actual areal extent of available NVC mapping coverage; but, examining the coverage map online shows that there is still a long way to go before this dataset will give national or near-national level NVC coverage. We focused our work on the NVC survey data map layer and dataset: http://gateway.snh.gov.uk/natural-spaces/index.jsp, as this gives the level of species and habitat detail required to test against our long-term vegetation change data.

This dataset has two shapefiles:

- NVC_SURVEY_COVERAGE
  Containing the data for the NCV surveys (SURVEY_ID, SURVEYNAME, ABSTRACT…)
- NVC_SCOTLAND
  Containing the NVC coverage divided in NVC categories.

Both shapefiles were supposed to cover the same total area of Scotland, but they do not, so all the area calculations were made using the NVC_SCOTLAND shapefile. NVC_COVERAGE was only used to extract the dates of each survey.

Scotland's country boundary was defined using a shapefile created from merging the European regions from OS Open Boundary Line data (May 2010), downloaded from the data-share platform of the University of Edinburgh. It was used for the calculation of Scotland's land area and NVC coverage area, as well as a base map for illustrating the area of Scotland in all the maps included in this paper.

ArcGIS software was used for all the spatial extractions and analyses. GenStat 18th Edition (https://www.vsni.co.uk/software/genstat) was used to make all the graphics and associated regression analyses.

Table 1. *Source information for the Country Boundary and NVC shapefiles at the time of downloading (March 2019)*

NAME	TYPE	DESCRIPTION	DATE OF LAST UPDATE WHEN DOWNLOADED	DATA SOURCE
Scotland Country Boundary	shapefile	Country boundary polygon for Scotland created from merging the European regions from OS Open Boundary Line data (May 2010). GIS vector data. This dataset was first accessioned in the EDINA ShareGeo Open repository on 2010-07-29 and migrated to Edinburgh DataShare on 2017-02-21.	21/02/2017	https://datashare.is.ed.ac.uk/handle/10283/2409
National Vegetation Classific-ation	shapefile	National Vegetation Classification (NVC) survey. Classifies British vegetation into a series of plant communities according to phytosociological groups using standard field methods and data analysis/classification techniques. The methodology is based on taking quadrats using a strict sampling system from stands of homogeneous vegetation.	15/03/2017	https://gateway.snh.gov.uk/natural-spaces/dataset.jsp?dsid=NVC

Long-term vegetation change data

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).

For this paper, we used: (a) *Birse & McVean resurvey alpine habitat data* (the main 'gap' identified by Hester & Scholtens 2019); and: (b) *Birse & McVean moorland data* (to allow direct comparison with the findings from the national datasets examined in Hester & Scholtens (2019). Two shapefiles (one for alpine plots and the other one for moorland plots) were created in ArcGIS using the X and Y coordinates of all the resurveyed plots.

Information on long-term compositional changes in these habitats can be found in Britton et al. (2009) for alpine plots, and Britton et al. (2017) for moorland plots.

STEP 1: assessing NVC coverage & ranges of survey dates

Once the datasets were compiled (as above), the first steps were to quantify the NVC layer coverage in Scotland; to find out how many different surveys there were in the NVC dataset; to identify the dates of these surveys and then to create a map showing the survey coverage by date ranges.

NVC coverage. For the first question the *NVC_SCOTLAND.shp* and *Scotland boundary.shp* files were examined in ArcGIS. First the total area of Scotland in km^2 was calculated adding a new attribute (AREA) in *Scotland boundary.shp* and using "calculate the geometry" tool of ArcGIS. After this, the geoprocessing tool called "Clip" was used to clip *Scotland boundary.shp* with *NVC_SCOTLAND.shp* and a new shapefile was created. In this new shapefile, the area (and %) of NVC coverage across Scotland were calculated adding two new attributes to the *NVC_SCOTLAND_AREA.shp* shapefile.

NVC survey data coverage was found to cover only 15% of the total land area of Scotland, as at time of downloading (March 2019).

Number of surveys and date ranges. First the geoprocessing tool called "Dissolve" was used to dissolve *NVC_SURVEY_COVERAGE* with its attribute SURVEY_ID. In this process, a new layer was created containing only one polygon for each survey instead of having many different polygons with the same SURVEY_ID.

This revealed that the total number of NVC surveys in this shapefile was 7788.

When trying to categorise these surveys into date ranges some problems were found. The first and most important one was that the layer does not have an attribute indicating the date of each survey, so it was impossible to do a quick categorisation. Instead of this, the following attributes were used to estimate the date of the survey:

- SURVEY_START
- SURVEY_END
- SURVEYNAME
- SRC_FILE
- ABSTRACT

Each survey was given a date according to the dates appearing in these attributes, the order of priority for choosing a date was SURVEY_START, SURVEY_END, SURVEYNAME, SRC_FILE and finally ABSTRACT. In some cases, none of these attributes had a date so instead of a specific year "ND" was written, meaning "No data".

Once each survey had its date, the surveys were divided into 4 date ranges of 10 years between 1980 and 2020, to summarise when most survey data had been carried out (Fig. 1). As shown in Fig. 1, 37% of the surveys in this dataset do not have date information. *More than 60% all surveys were carried out between 1990 and 2010.*

Figs 1 and 2 were created using the *NVC_SURVEY_COVERAGE* shapefile, because it is the only one containing details of the surveys such as survey name or survey date.

Figure 1. *Number of NVC surveys per date range – as at date of downloading (March 2019)*

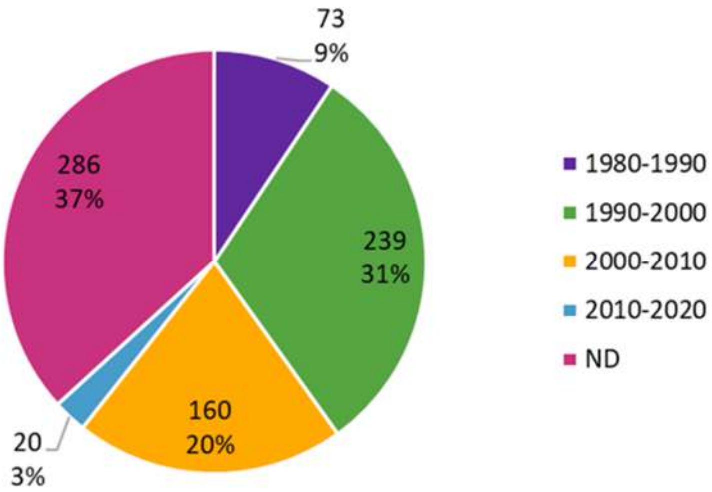
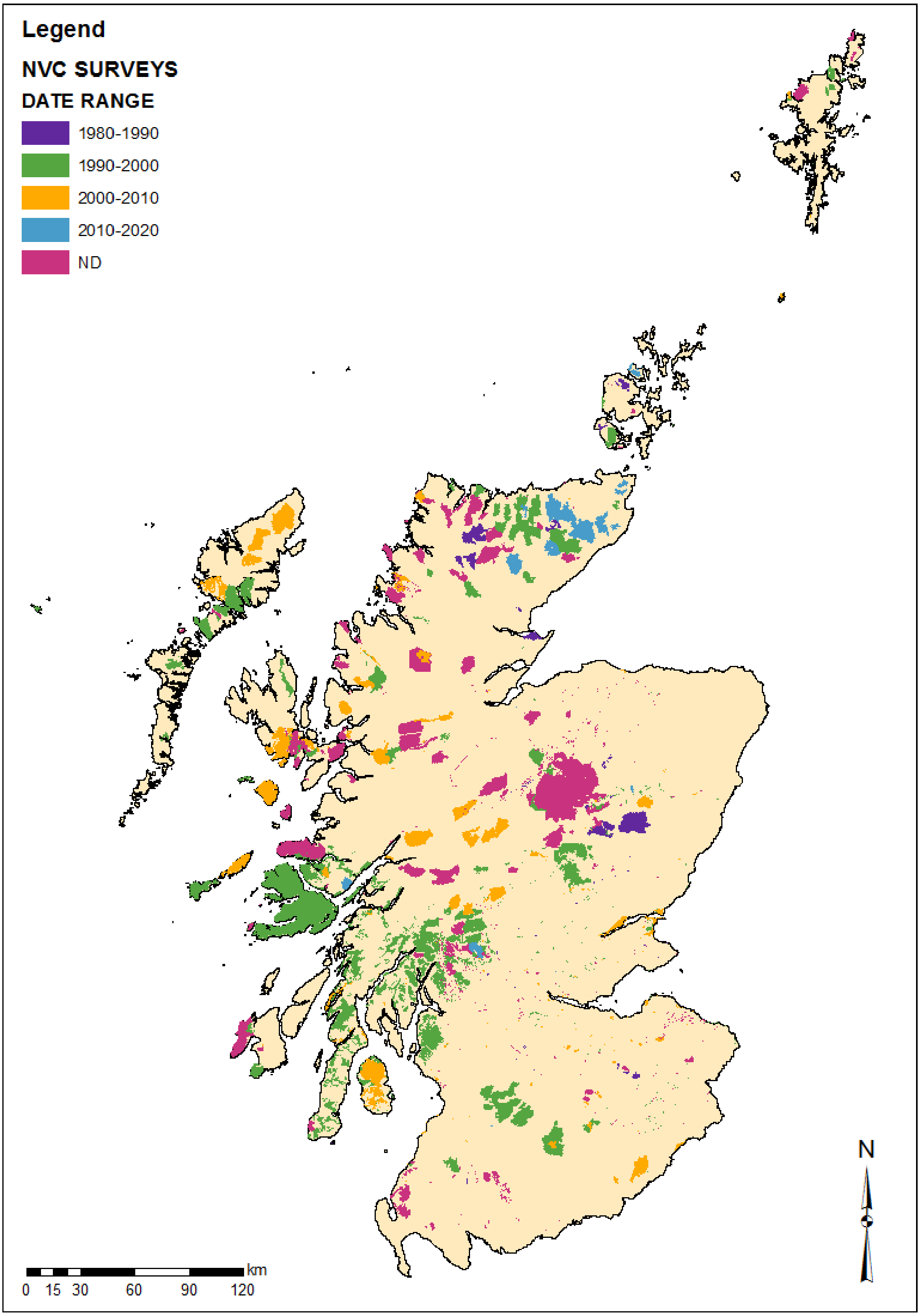


Figure 2. *Map showing the NVC coverage for Scotland categorized by survey date ranges – as at date of downloading (March 2019)*



STEP 2: number of Birse & Robertson and McVean & Ratciffe resurvey alpine and moorland plots located within HabMoS NVC mapping coverage

To assess the possibilities for using the HabMoS NVC mapping data with our Birse & Robertson and McVean & Ratcliffe (hereafter shortened to B-R and McV-R) long-term vegetation change data, we examined how many B-R and McV-R plot locations coincided with the 15% Scotland's of Scotland's land area covered by the HabMoS NVC mapping data, for: (a) alpine and (b) moorland habitats. Using the "select by location" tool in ArcGIS, the plots of each habitat that were totally within *NVC_SCOTLAND.shp* were selected and two new layers were created (one for alpine plots, one for moorland plots) containing only the plots of the B-R and McV-R dataset that were within the HabMoS NVC coverage.

Alpine plots. There are 560 B-R and McV-R alpine vegetation resurvey plots across Scotland - 265 (47%) of these were located within NVC mapping coverage (Fig 3). Plot locations (with NVC coverage in background) are shown in Fig. 4.

Figure 1. *Pie chart showing the number of Birse & Robertson and McVean & Ratciffe alpine resurvey plots within and outside of the NVC mapping coverage – as at date of downloading the NVC mapping datafiles (March 2019)*

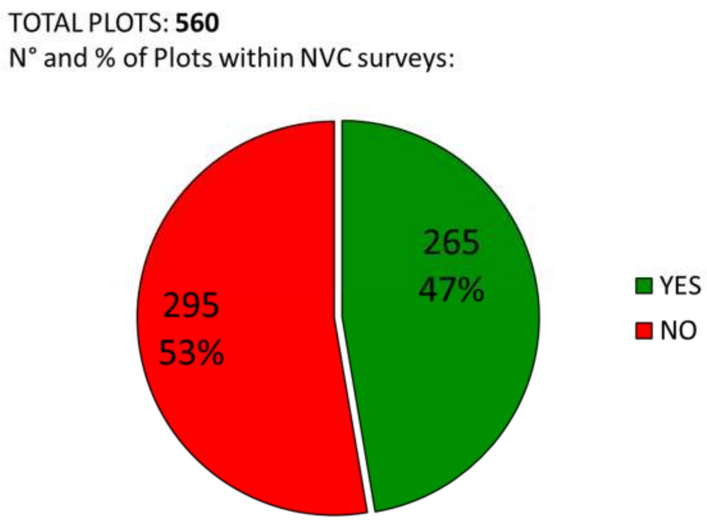
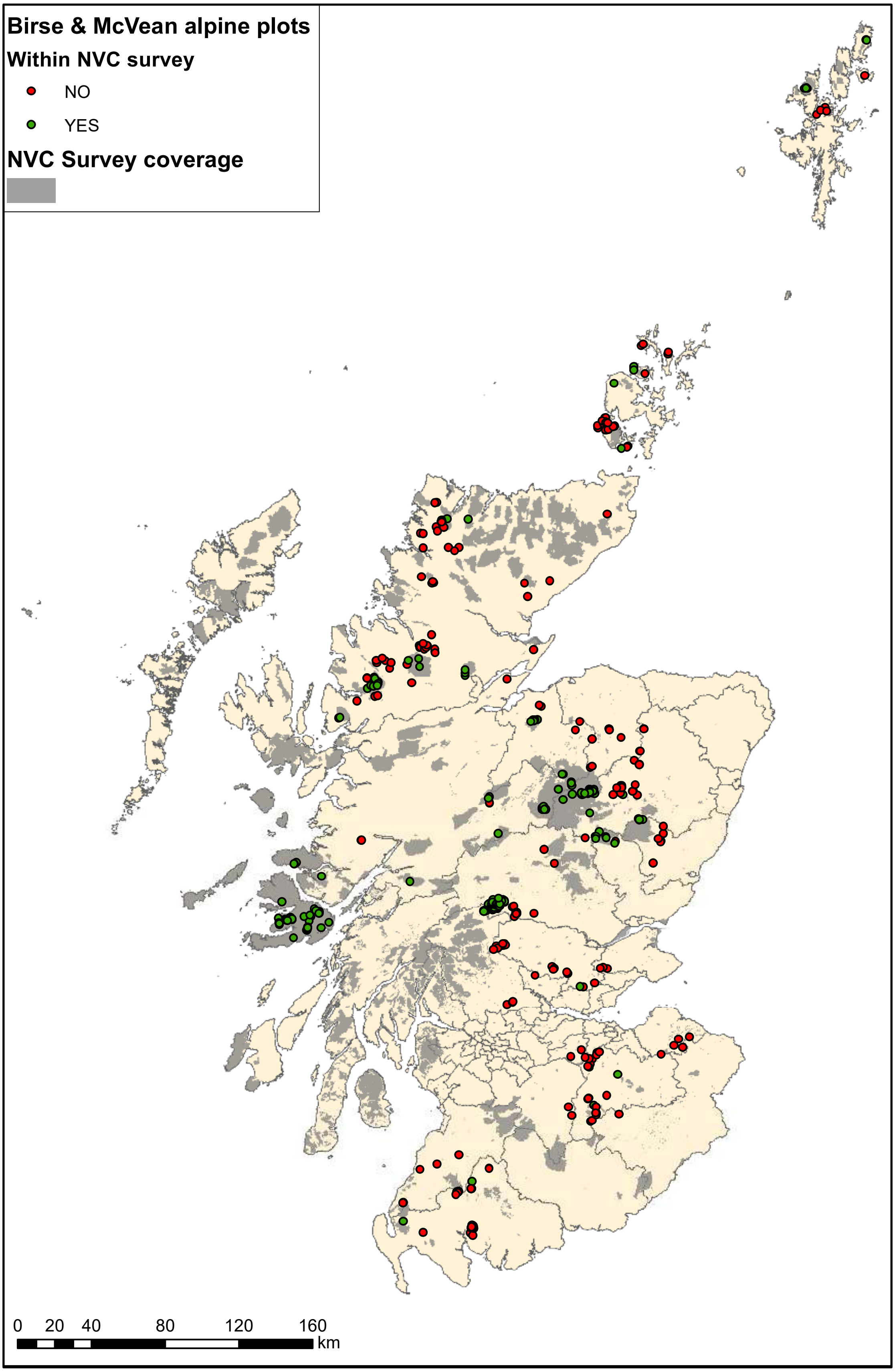


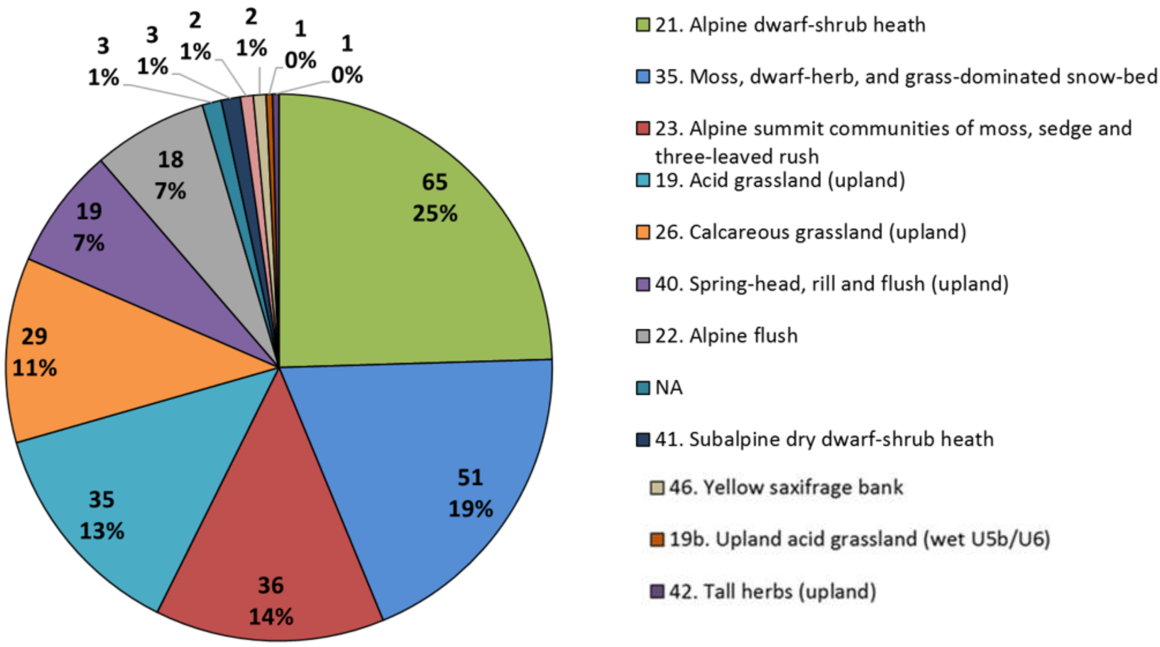
Figure 2. Map showing the location of the Birse and McVean resurvey alpine plots within and outside of NVC mapping coverage – at the time of downloading the NVC mapping datafiles (March 2019)



We split those 265 alpine plots that were located within NVC coverage into broad habitat types (Fig. 5) to assess which had sufficient NVC coverage for spatial configuration analysis with long-term vegetation change data. We grouped the samples using the same habitat names as in the JNCC Common Standards Monitoring Guidance for Upland Habitats ('upland feature types': JNCC 2009) – the guidance contains detailed information on correspondence between these broad habitat types and NVC codes (which is what we used to classify our B-R and McV-R resurvey plots).

Only 5 broad habitat types were considered to have sufficient sample sizes for analysis (total 216 alpine plots) these were: Alpine dwarf-shrub heath; Moss, dwarf-herb and grass-dominated snow-bed; Alpine summit communities of moss, sedge and three-leaved rush; Acid grassland (upland) and Calcareous grassland (upland).

Figure 5. *Pie chart showing the number and % of B-R and McV-R alpine resurvey plots with NVC mapping coverage, split into broad habitat types (JNCC 2009; numbers refer to codes in dataset used).*



Non-alpine moorlands. For the B-R and McV-R moorland resurvey plots not classified as alpine (total number 392), there was much lower proportional coverage in the NVC mapping dataset – only 110 (28%) were located within NVC mapping coverage (Fig. 6). Plot locations (with NVC coverage in background) are shown in Fig. 7.

Figure 6. *Pie chart showing the number and % of B-R and McV-R non-alpine moorland resurvey plots within and outside of the NVC mapping coverage – as at date of downloading the NVC mapping datafiles (March 2019)*

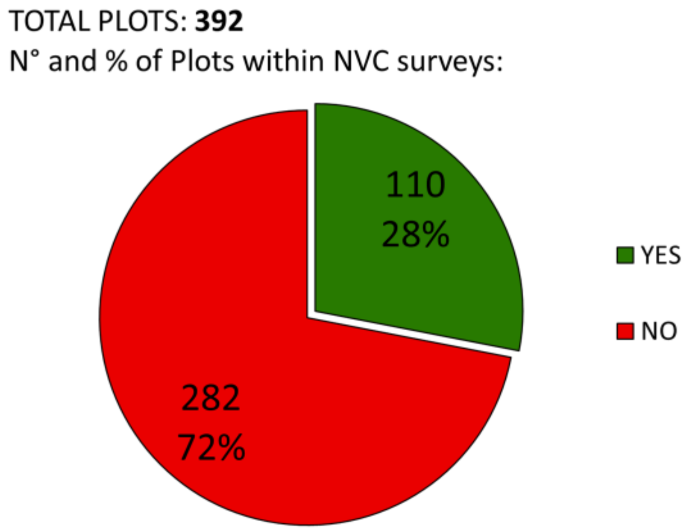
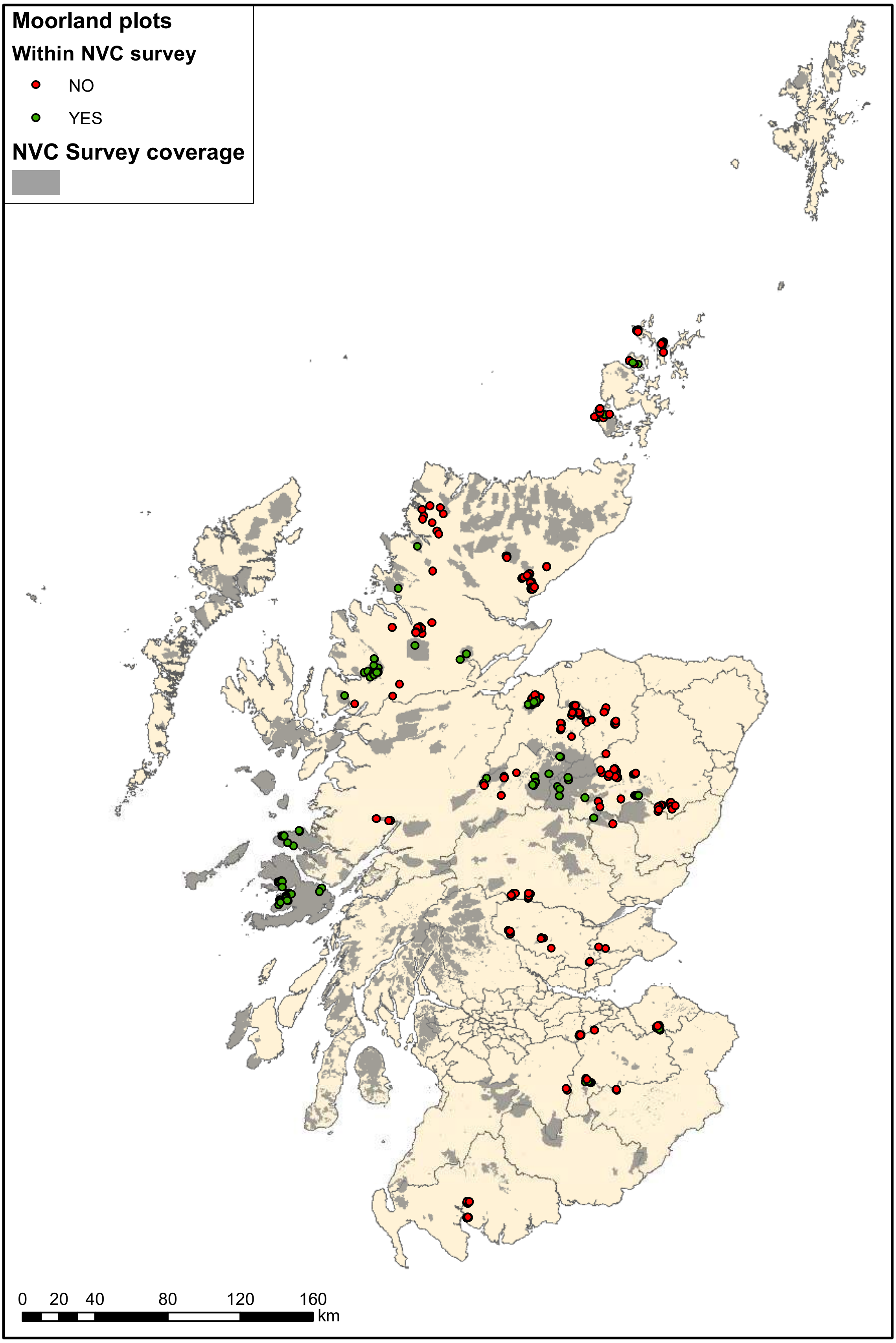
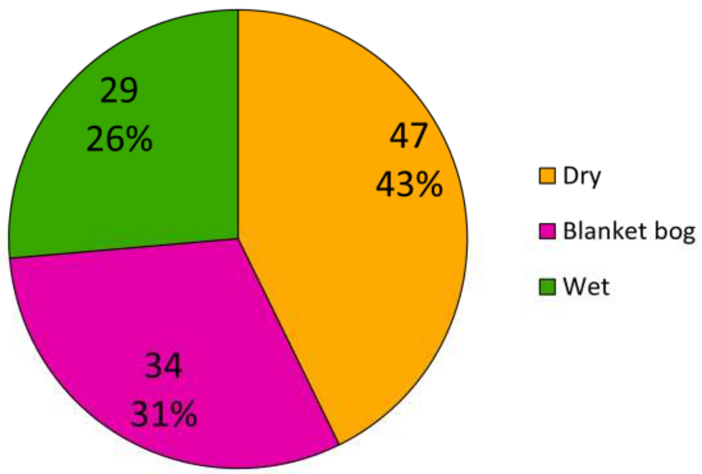


Figure 7. *Map showing the location of the B-R and McV-R resurvey non-alpine moorland plots within and outside of NVC mapping coverage – at the time of downloading the NVC mapping datafiles (March 2019)*



Dividing these plots with coverage into three broad habitat categories – dry heath, wet heath, blanket bog – all three were considered to have sufficient sample numbers for spatial configuration analysis with long-term vegetation change data (Fig. 8).

Figure 8. *Pie chart showing number and % of B-R and McV-R resurvey non-alpine moorland plots with NVC mapping coverage, split into three main habitat types*



STEP 3: Calculating proportional coverage of NVC mapping data at increasing distances around each B-R and McV-R resurvey plot.

A key element of spatial data that we want to be able to extract for analysis relates to the aerial extent and coverage of individual habitat 'patches' within which we have long-term vegetation change resurvey plots, to allow us to analyse how this might have influenced long-term vegetation changes in different locations. The national land cover datasets analysed in Hester and Scholtens (2019) have 100% coverage and it is therefore possible to assess the extent of specific habitat patches associated with our B-R and McV-R resample plots. Given the fact that the NVC mapping coverage is only 15% of Scotland's land area (at time of downloading), we anticipated that for many of our resurvey plots located within areas of NVC mapping coverage, we would be increasingly unlikely to have full NVC coverage with increasing distance from our sample points. To test this, we assessed the degree of coverage of NVC mapping data using increasing sizes of buffer around each B-R and McV-R resurvey plot. We did this for the 5 alpine habitat types selected as having sufficient sample sizes (total 216 alpine plots) and for all three non-alpine moorland habitat types defined above (total 110 plots).

For each B-R and McV-R resurvey plot we calculated the proportional NVC mapping coverage in increasing sizes of circle around the plots - 2km, 5km, 10km and 20km radius (= max. distance from plot location). We assessed how many plots of each habitat had >95% NVC coverage in each size of buffer, as this was considered sufficiently close to full coverage for us to use the data for analysis.

The ArcGIS "Buffer" tool was used to create 4 shapefiles of 2km, 5km, 10km and 20km buffer-distances for each habitat dataset (alpine, moorland). A new attribute called AREA was then created for each shapefile and the geometry of each 2km, 5km, 10km and 20km buffer dataset was calculated in km^2. Each of those 8 shapefiles was then clipped with the *NVC_SCOTLAND.shp* using the "Clip" tool in ArcGIS to create 8 new shapefiles with the NVC coverage area of each plot for each of the different buffer distances.

In each of those new shapefiles two new attributes were calculated: (1) the total area of NVC coverage (km^2) in the buffer around each plot; (2) the proportional area of NVC coverage in the buffer around each plot, for each of the different sized circles, using the "field calculator". Figures 9 and 10 show the % coverage of NVC data in the different sized buffers around each B-R and McV-R resurvey plot for alpine and non-alpine moorland, respectively.

Out of the 5 alpine habitat types tested, only three had 30 or more B-R and McV-R resurvey plots with >95% NVC coverage within 2km, the smallest buffer: Alpine dwarf-shrub heath; Alpine summit communities of moss, sedge and three-leaved rush; and Moss, dwarf-shrub and grass-dominated snow-bed (Fig. 9). Within the 5km buffer, the Moss, dwarf-shrub and grass-dominated snow-bed had 20 plots with >95% NVC coverage; all other habitat types had less than 15 plots. For the two larger buffer distances, no plots had sufficient samples for robust statistical analysis against vegetation change data.

NVC coverage for the non-alpine moorland plots (Fig. 10) was much poorer, with no habitat types having more than 19 plots where there was >95% NVC coverage, even within the smallest buffer distance of 2km.

In order to further analyse the NVC data coverage and detail (next step), we selected the three alpine habitats that had >30 samples with > 95% coverage within the 2km buffer zone – i.e. Alpine dwarf-shrub heath; Alpine summit communities of moss, sedge and three-leaved rush; and Moss, dwarf-shrub and grass-dominated snow-bed.

Figure 3. Histograms showing the number of alpine plots in each broad habitat, sorted by NVC area proportion ranges (1-25%; 26-50%; 51-75%; 76-85%; 86-95%; 96-100%) in 2km, 5km, 10km and 20km buffer distances. Sample sizes given above each bar.

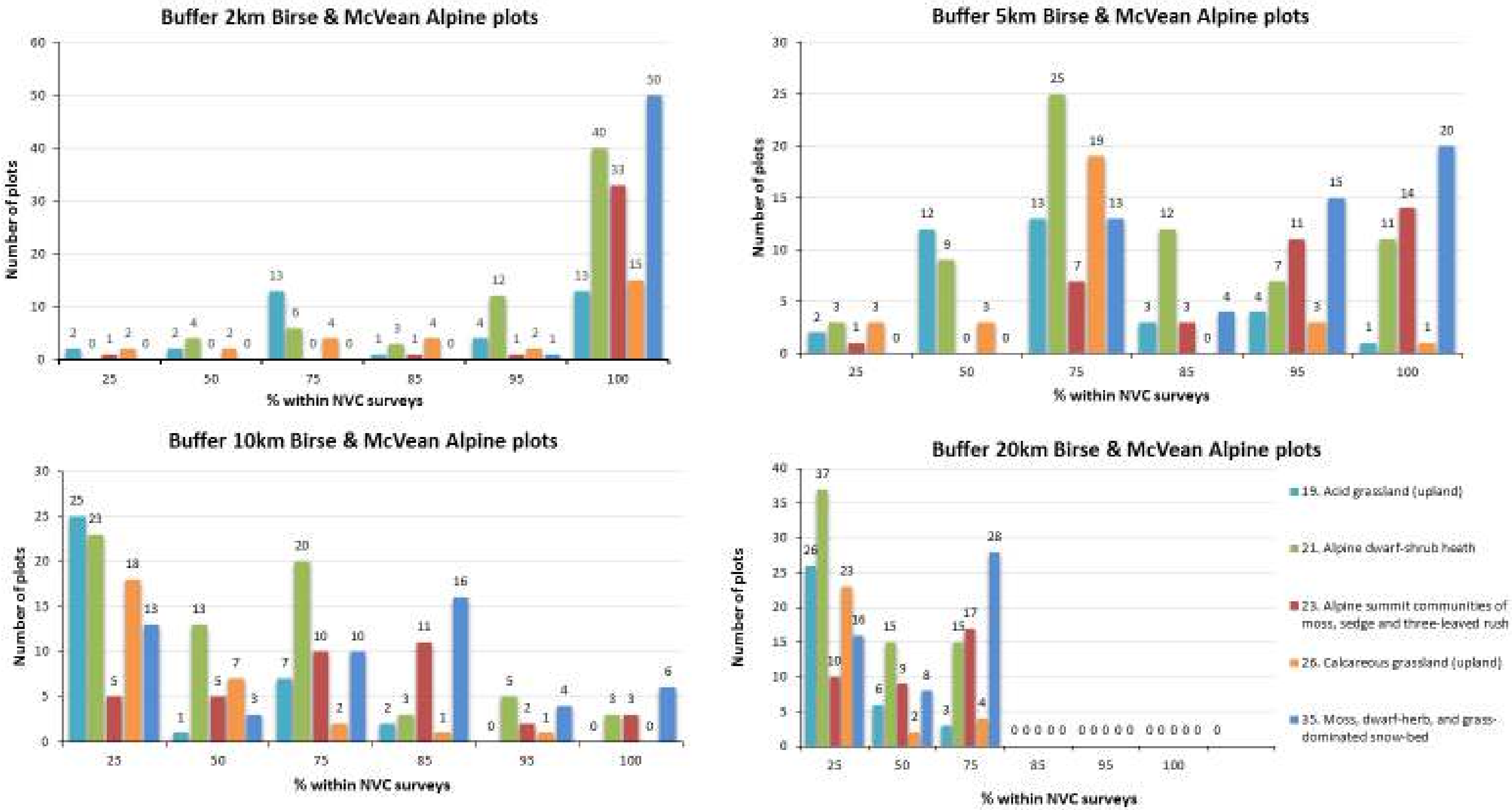
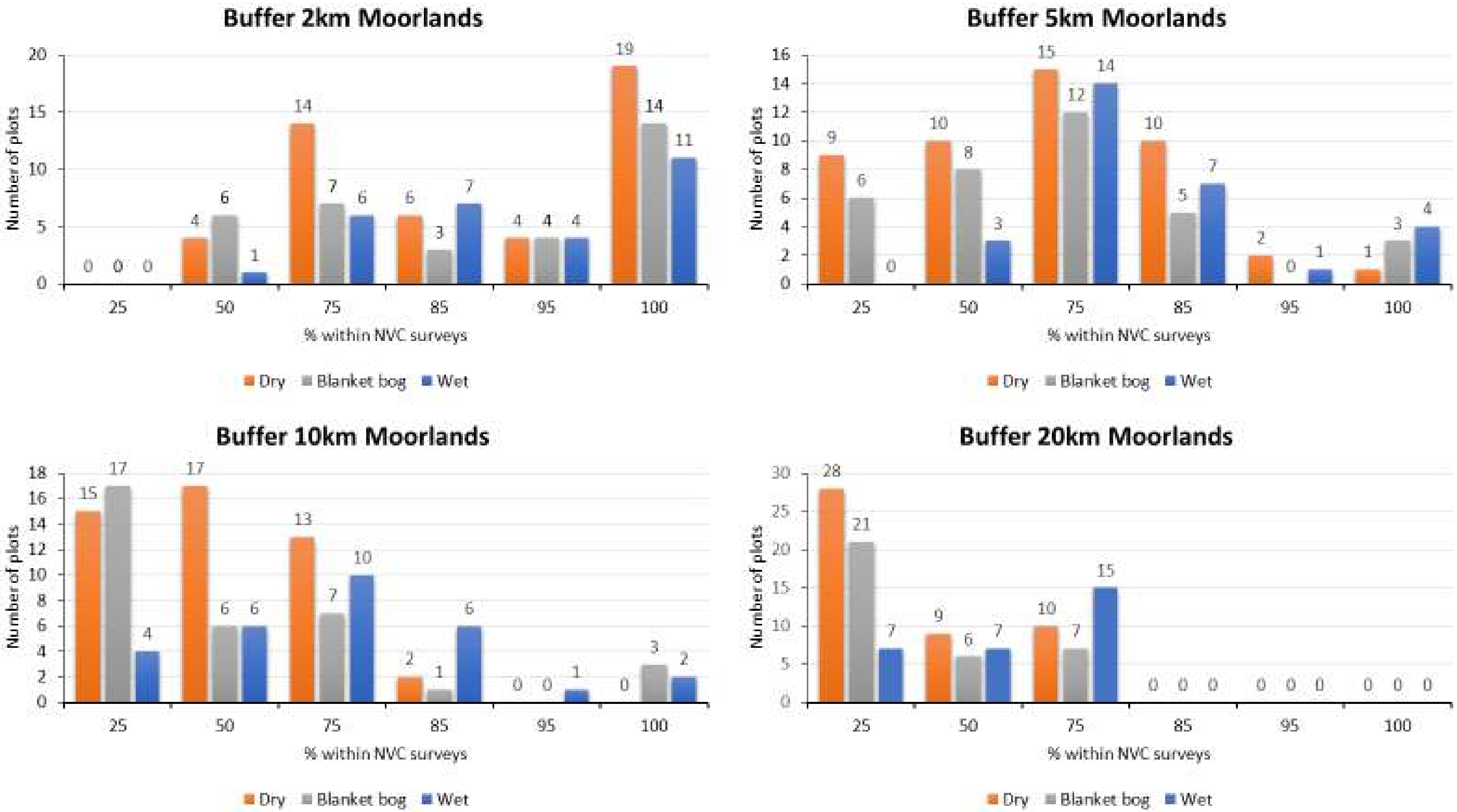


Figure 4. *Histograms showing the number of non-alpine moorland plots in each broad habitat, sorted by NVC area proportion ranges (1-25%; 26-50%; 51-75%; 76-85%; 86-95%; 96-100%) in 2km, 5km, 10km and 20km buffer distances. Sample sizes given above each bar.*



STEP 4: Interrogating NVC coverage data within 2km buffers to calculate total survey coverage and detail

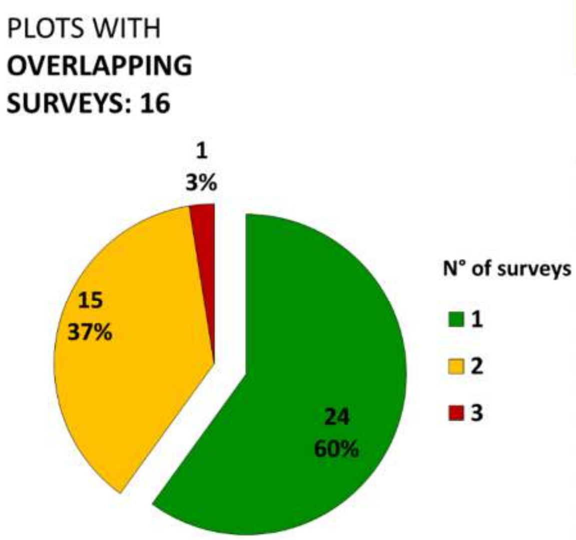
Here we found some major challenges with the dataset - the NVC layer contains amalgamated data from 778 different surveys - we found that:

(a) there is little consistency between surveys in NVC allocation - many surveys have different ways of naming the categories, including some that only allocate one NVC type to every locational polygon, and others that name several NVC types to individual polygons (many of which give no indication as to which NVC type might have highest coverage in that polygon);
(b) many areas have overlapping surveys done at different times, and in many cases the named NVC category(ies) for the same area does not match.

Assessing the level of survey overlap was our first step (challenge (b) above), to establish how much of an issue this would be for our habitat sample locations.

Within the GIS, we calculated the number of 2km buffer areas per habitat that had overlapping survey areas and the proportion of the buffer area that this overlap covered. For Alpine dwarf-shrub heath, out of the 40 plots with >95% of NVC coverage area in the 2km buffer, there were 16 plots with overlapping NVC surveys (Fig. 11) some of them with very small proportional overlap (0.2%) and others with almost all the 2km circle area with overlapping NVC surveys (89.9%). For all plots except one (3 overlapping surveys), there were two different overlapping surveys.

Figure 11. *Alpine dwarf-shrub heath – 2km buffer areas with overlapping NVC surveys. The table gives total area of overlap, proportional area and number of different surveys that overlap in area.*

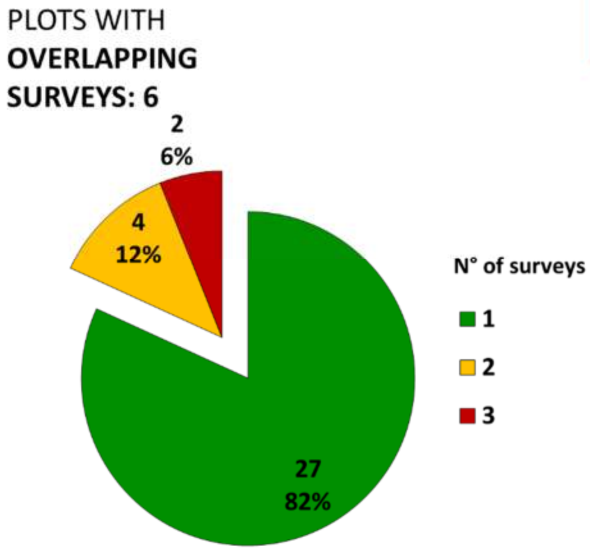


21. Alpine dwarf-shrub heath

	SERIAL	AREA OVERLAP (km^2)	PROP OVERLAP	Nº SURVEYS
1	1850	11.301	0.899	2
2	2740	2.973	0.237	2
3	1570	2.518	0.200	2
4	2730	2.171	0.173	2
5	74371	1.434	0.114	2
6	74370	1.329	0.106	2
7	74366	0.772	0.061	2
8	1550	0.228	0.018	2
9	74405	0.098	0.008	3
10	70514	0.095	0.008	2
11	2450	0.054	0.004	2
12	1340	0.053	0.004	2
13	1350	0.042	0.003	2
14	1360	0.035	0.003	2
15	2020	0.023	0.002	2
16	2220	0.001	0.001	2

For the Alpine summit communities of moss, sedge and three-leaved rush broad habitat type, out of 33 plots with >95% of NVC coverage area in the 2km buffer, only 6 plots had overlapping surveys (Fig. 12). For one of these, almost all the 2km circle area (99%) had 2 or more overlapping surveys, but for all the other plots there was relatively little survey overlap (0-39%).

Figure 12. *Alpine summit communities of moss, sedge and three-leaved rush broad habitat – 2km buffer areas with overlapping NVC surveys. The table gives total area of overlap, proportional area and number of different surveys that overlap in area.*

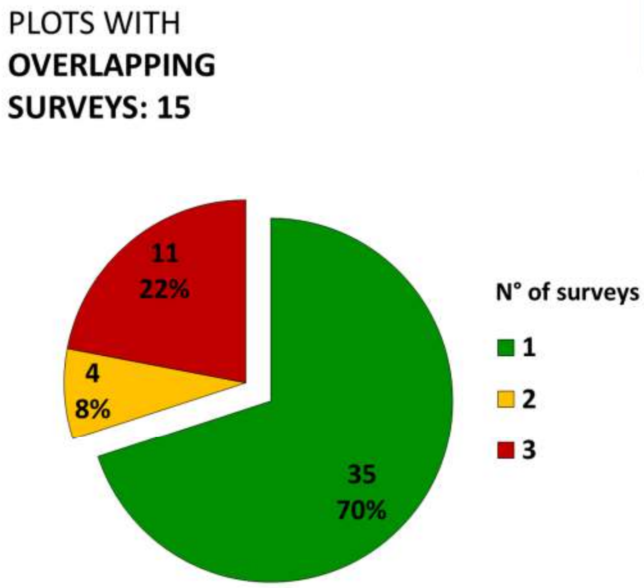


23. Alpine summit communities of moss, sedge and three-leaved rush

	SERIAL	AREA OVERLAP (km^2)	PROP OVERLAP	Nº SURVEYS
1	5330	12.437	0.990	3
2	5290	4.955	0.394	2
3	6280	2.361	0.188	2
4	5210	2.321	0.185	2
5	6220	0.772	0.061	3
6	70513	0.052	0.004	2

For the Moss, dwarf-herb, and grass-dominated snow-bed broad habitat, out of 50 plots with >95% of NVC coverage area in the 2km buffer, there were 15 plots with overlapping surveys (Fig. 13), with most of these overlaps covering more than 80% of the 2km circle. Most of these plots also had 3 overlapping surveys.

Figure 13. *Moss, dwarf-herb and grass-dominated snow bed– 2km buffer areas with overlapping NVC surveys. The table gives total area of overlap, proportional area and number of different surveys that overlap in area.*



35. Moss, dwarf-herb, and grass-dominated snow-bed

	SERIAL	AREA OVERLAP (km^2)	PROP OVERLAP	Nº SURVEYS
1	4970	12.534	0.998	3
2	4770	12.353	0.983	3
3	4810	12.311	0.980	3
4	6870	11.812	0.940	3
5	4800	11.727	0.933	3
6	6860	11.718	0.933	3
7	4780	11.604	0.924	3
8	6840	11.601	0.923	3
9	4990	10.449	0.843	3
10	5000	10.385	0.840	3
11	4980	10.176	0.827	3
12	4580	4.757	0.379	2
13	4700	4.582	0.365	2
14	4620	1.700	0.135	2
15	74372	1.529	0.122	2

STEP 5: Resolving the differences between overlapping surveys in NVC category naming

There is no simple solution to address the problem of the differences in NVC category naming between different surveys (and the multiple-NVC naming within some individual surveys). Options that we discussed included:

(a) Devising a prioritisation system for all surveys, such that whenever there is overlap, the prioritising system is used to select only one survey. We decided against this approach as it would favour some years of survey in some plots and others in other plots, depending on which ones overlapped, so it would introduce unhelpful date bias in the resulting data;

(b) Doing some sort of averaging across overlapping surveys for areas that had been classified as different NVC types. The biggest challenge here was the lack of consistency between surveys in terms of whether just one NVC category was used per polygon; whether many NVC categories were listed for the same polygon (with or without an indication of relative abundance); and for both the above, whether there was any match between surveys in the NVC categories allocated. So regardless of approach taken to averaging, at best the information would indicate the total area *containing* some of the target habitat but not necessarily the total area *occupied* by that habitat.

We decided to loosely follow option (b) and take the following approach. For each habitat type in turn, within each 2km buffer we first summed all the survey areas containing any NVC category corresponding to that specific habitat, using the tables contained in the Common Standards Monitoring Guidance (JNCC 2009) (Table 2). This gave information on what proportion of the total area in each 2km buffer 'contained' the same broad habitat as the B-R and McV-R resurvey plot. The word 'contained' is used, because in the surveys that listed multiple NVC types for any one polygon, it was impossible to assess exactly how much of that polygon was occupied by a specific habitat.

This was done separately for the parts of each 2km buffer that had overlapping surveys and the parts that had no overlaps (i.e. only one survey), as follows.

Table 2.*NVC types included in each of the three alpine broad habitat types that we tested, according to the JNCC Common Standards Monitoring Guidance. From top to bottom table: (a) Alpine dwarf-shrub heath; (b) Alpine summit communities of moss, sedge and three-leaved rush; (c) Moss, dwarf-herb, and grass-dominated snow-bed.*

(a) Alpine dwarf-shrub heath

Annex I types included*	**NVC types included**	**Birks & Ratcliffe types included**
Alpine and boreal heaths (H4060)	H13 *Calluna vulgaris - Cladonia arbuscula* heath H14 *Calluna vulgaris - Racomitrium lanuginosum* heath H15 *Calluna vulgaris - Juniperus communis* ssp. *nana* heath H17 *Calluna vulgaris - Arctostaphylos alpinus* heath H19 *Vaccinium myrtillus - Cladonia arbuscula* heath H20 *Vaccinium myrtillus - Racomitrium lanuginosum* heath H22 *Vaccinium myrtillus - Rubus chamaemorus* heath (in part) H22 crosses the boundary between alpine (montane) and subalpine (submontane) habitats. It may be assessed as either this feature type or as the subalpine dry dwarf-shrub (see section 2.23) heath depending upon the surrounding vegetation and topographic situation. H10b - Also include *H10b Calluna vulgaris - Erica cinerea, Racomitrium lanuginosum* sub-community, when its location is closely associated with the previous NVC types and it is strongly wind-clipped in appearance, but not otherwise.	B2 (all subtypes) B3b B3e B3f E1d

*This generic guidance type also covers other non-Natura feature types.

(b) Alpine summit communities of moss, sedge and three-leaved rush

Annex I types included*	NVC types included	Birks & Ratcliffe types included
Siliceous alpine and boreal grassland (H6150)	U7 *Nardus stricta-Carex bigelowii* grass-heath U8 *Carex bigelowii-Polytrichum alpinum* sedge-heath U9 *Juncus trifidus-Racomitrium lanuginosum* rush-heath U10 *Carex bigelowii-Racomitrium lanuginosum* moss-heath U11 *Polytrichum sexangulare - Kiaeria starkei* snow-bed U12 *Salix herbacea - Racomitrium heterostichum* snow-bed U14 *Alchemilla alpina - Sibbaldia procumbens* dwarf-herb community	C2b (in part) C6 C7 E3AS E1a E1b E1c E1e E3

*The definition matches that used for the Natura type but the guidance is also applicable to other non-Natura summit vegetation features (other than fellfield).

(c) Moss, dwarf-herb, and grass-dominated snow-bed

Annex I types included*	NVC types included	Birks & Ratcliffe types included
None	Moss-dominated snow-beds: U8 *Carex bigelowii - Polytrichum alpinum* sedge-heath (when not part of Siliceous alpine and boreal grassland) U11 *Polytrichum sexangulare - Kiaeria starkei* snow-bed U12 *Salix herbacea - Racomitrium heterostichum* snow-bed Dwarf-herb dominated snow-bed: U14 *Alchemilla alpina - Sibbaldia procumbens* dwarf-herb community Grass-dominated snow-bed: U7 *Nardus stricta - Carex bigelowii* grass-heath U13 *Deschampsia cespitosa - Galium saxatile* grassland	C2b (in part) C5a E3AS E2 E3

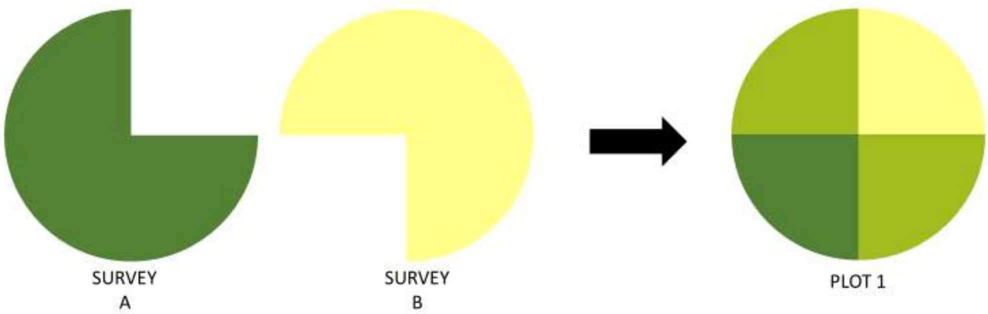
*Some snow-bed vegetation is included within the definition of Siliceous alpine and boreal grassland (H6150) (see section 2.5)

To calculate the areas of the different NVC categories for the parts of the plots *without overlapping surveys*, the overlapped area was deleted using the "Erase" tool in ArcGIS and a new layer was created. A new attribute was added to this new layer and using the "calculate geometry" tool of ArcGIS the area of each NVC category was calculated. These data were exported to an excel file and using a search string only the areas of the NVC categories matching the NVC types of each broad habitat were used to calculate the total area of each plot *covered by* (i.e. if the whole polygon had been assigned to just one NVC type) or *containing* (i.e. if the survey had listed more than one NVC type for that polygon) that broad habitat type.

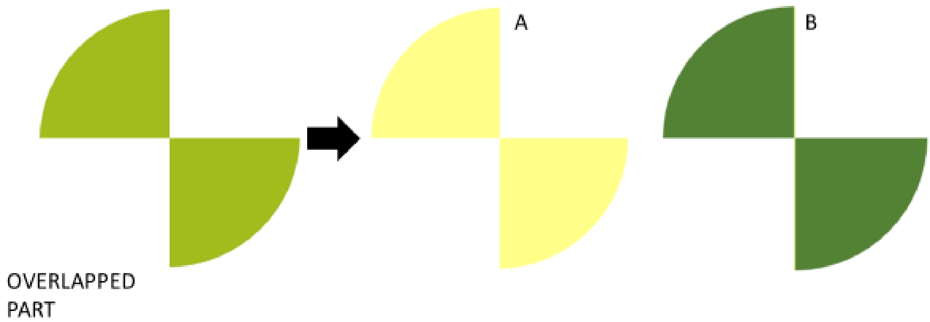
For the plots *with overlapping surveys*, non-overlapping areas were deleted (method as above) and a new layer was created. First, the area of each NVC category was calculated for each survey, and a new attribute was added to this new layer using the "calculate geometry" tool of ArcGIS. As above, these data were then exported to an excel file and using a search string only the areas of the NVC categories matching the NVC types of each broad habitat were used to calculate the total area of each plot covered by that broad habitat type. But in this case, as there was overlapping survey data, first the sum of all the areas containing NVC categories corresponding to each broad habitat type was calculated for each of the overlapping surveys in the same area, then the average of the total sums was calculated (averaging over the different NVC assignations from each survey). The resulting area was then summed with the total area of the part of the circle without overlap. This is challenging to describe so the process is also illustrated diagrammatically in Fig. 14.

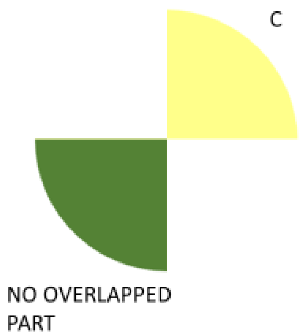
Figure 14. *Diagrammatic representation of how the total area per 2km buffer area containing at least some of each broad habitat type was calculated. Dark green = survey A; yellow = survey B; light green = overlap of surveys A and B.*

Survey A and B overlap to give composite coverage of the 2km buffer:



For overlapped parts, the average of survey A and B is taken. For non-overlapped parts just survey A or B is taken. Calculation of total area of target habitat within survey area is shown in box:





NVC area in 2km= $\frac{(A+B)}{2} + C$

Given the limitations described above, *at worst* this gave the total area of each 2km buffer that contained at least some of the broad habitat type being examined; *at best* (where only one NVC type had been allocated per polygon and there were no differences between surveys) this gave the total area of each 2km buffer that was covered by the broad habitat type being examined – most of the 2km buffer areas fell into the 'at worst' category.

Discussion

The aim of the work summarised in this paper was to examine the NVC survey habitat mapping data being collated as part of the Habitat Map of Scotland (HabMoS) initiative https://www.nature.scot/landscapes-and-habitats/habitat-map-scotland and assess whether there is sufficient areal coverage to explore the role of spatial configuration of different habitat types on their ecological resilience at much finer resolution than is possible with the National Land Cover maps examined in Hester & Scholtens (2019). HabMoS is undoubtedly an excellent and much-needed national initiative, but we found that the inputted NVC survey data coverage at the time of our downloading (March 2019) covered only 15% of Scotland's land area, which of course is too little for any national level analysis at this stage.

Our comparisons of the HabMoS NVC survey coverage with the B-R and McV-R resurvey plots revealed reasonable co-location of data for three specific alpine habitat types (c 50%), but very low co-location for the moorland plots.

If we consider this coverage issue together with the challenges that we found on closer interrogation of the data from individual NVC surveys - i.e. different surveys using different methodologies and some allocating NVC categories in very different ways – these challenges combine to make the collated NVC survey data of limited value for multi-site analyses. Undoubtedly the inputting of these survey data is hugely resource-hungry, and our findings suggest that, whilst there is great value in having a single central repository for access to all Scotland's habitat surveys (for a whole multitude of uses), for the purposes of creating a national level detailed habitat mapping resource it would be better to adopt a different approach.

In recognition of the poor coverage and other limitations of the available NVC survey data, and seeking new, more rapid and cost-effective approaches to mapping Scotland's habitats, SNH have also been testing (for HabMoS) an innovative technique developed in Sweden called 'stereo colour infrared (sCIR) aerial photo interpretation (API)' to map Scotland's habitats (https://www.snhpresscentre.com/news/mapping-breakthrough-with-benefits-for-people-and-nature). Two reports have been produced to date (Mattisson & Sullivan 2017; Scobie 2018), demonstrating good success for several Annex 1 habitats (detecting some small-scale habitats as well as more widespread, easier to map habitat types), with an overall accuracy of 75-80% compared to independent random-sample ground surveys. Whilst the level of habitat/species detail is much less than NVC ground-survey data, the level of habitat type detail is greater than that of the two National Land Cover datasets tested by Hester &

Scholtens 2018) - the Land Cover of Scotland 1988 (LCS88) map (Macaulay Land Use Research Institute 1993; https://www.hutton.ac.uk/learning/exploringscotland/landcover-scotland-1988); and the CEH Countryside Survey Land Cover Maps (LCM) (1990, 2000, 2007, 2015: NERC (CEH) 2017; https://countrysidesurvey.org.uk/content/land-cover-map) – particularly for alpine habitats.

Cost estimates for this new approach are less than half of the estimated costs for full field survey. SNH priority focus is on filling the upland survey 'data gap' (2.7 million ha of upland Scotland lacked detailed habitat mapping data at time of publication of Scobie 2018), but the approach shows good potential for wider application, given appropriate resourcing. The method is apparently continuing to be developed as part of the Collaborative Action for the Natura Network (CANN) project, an INTERREG-funded collaborative project between Scotland, Northern Ireland and Southern Ireland, working to ensure the future of internationally important habitats and species.

This is a good example of how HabMoS continues to be a collaborative effort between partners, as well as wider stakeholders (viz. Demonstration day Sept 2019 - https://storymaps.arcgis.com/stories/2dc7810ea85e4acbb2b245ba00737528) and the new method developments have good potential. As outlined in the Introduction to this paper, the Habitat Map of Scotland (HabMoS) is intended to become the national repository for habitat and land use data, with all available habitat data being published as it becomes available to ensure as accurate and up-to-date picture as possible of Scotland's habitats. We hope that this important work continues to attract funding to achieve this aim.

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