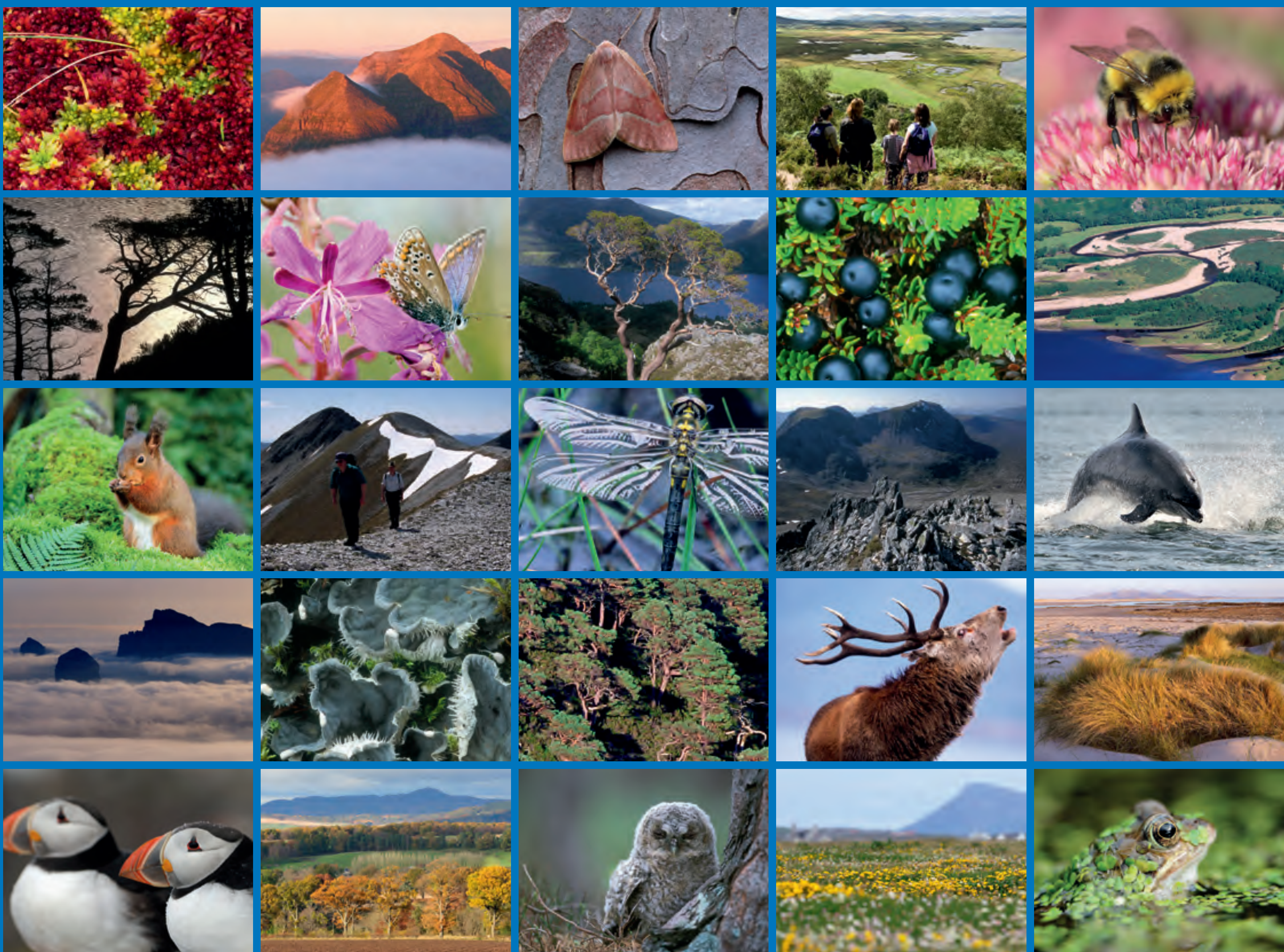
Scottish Natural Heritage
Research Report No. 983

Habitat Map of Scotland Upland Mapping Pilot: developing a method to map upland habitats using stereo colour near-infrared aerial imagery



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R E S E A R C H R E P O R T

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Habitat Map of Scotland Upland Mapping Pilot: developing a method to map upland habitats using stereo colour near-infrared aerial imagery

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RESEARCH REPORT

Summary

Habitat Map of Scotland Upland Mapping Pilot: developing a method to map upland habitats using stereo colour near-infrared aerial imagery

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Keywords

Habitat mapping; upland; colour near-infrared aerial imagery; stereo; manual interpretation; EUNIS; Annex I; HabMoS

Background

SNH is producing a Habitat Map of Scotland, a full coverage map of Scotland's terrestrial habitats classified according to EUNIS (European Nature Information System) and EC Habitats Directive Annex I classifications. A cost-effective method is required to map the existing upland survey gap, 2.7 million hectares of upland Scotland which lacks detailed habitat mapping. The Upland Mapping Pilot aimed to develop and test the 'stereo colour infrared (sCIR) aerial photo interpretation (API) technique' for mapping upland habitats, and establish if this method was suitable for wider roll-out across the upland survey gap along with the cost implications of delivering this.

The sCIR API technique is a remote sensing approach which relies upon manual interpretation of high resolution aerial imagery facilitated by a small amount of fieldwork. Two novel aspects are employed to aid the discrimination of habitats: (i) use of colour near-infrared aerial imagery at 25 cm resolution; (ii) digital stereo (3D) visualisation of aerial imagery and vector graphics using a specialised computer workstation. In addition, image segmentation was used to provide automatic delineation of habitat boundaries.

Main findings

- Nine upland Annex I habitats and seven non-Annex I habitats were successfully mapped to EUNIS classification level three or lower (more detailed) at two 100 km^2 pilot sites in Scotland. As well as widespread/extensive habitats (e.g. *D1.2 blanket bog*), several rare/small-scale habitats (e.g. *D4.15€ alkaline fen*) were also successfully detected and mapped.
- The overall accuracy of mapping was 75-80%, as confirmed by an independent field survey which visited a random sample of mapped polygons at the two sites. Accuracy could have been improved further by undertaking field checks to resolve areas of uncertainty in the classification, a key step omitted due to time constraints.
- Projections were made about the potential application of the sCIR API technique to map the 32 upland (Annex I and equivalent EUNIS level) habitats that occur in Scotland along

with the relative intensity of fieldwork required to map them successfully. The following conclusions were reached:

(i) The sCIR API method can deliver accurate mapping of all seven widespread/extensive upland Annex I habitats and 10 non-Annex I habitats (which together comprise the vast bulk of the uplands) with only a small amount of fieldwork.

(ii) Significant examples of 11 rare/small-scale Annex I habitats could be mapped by utilising sCIR imagery and ancillary information to identify 'potential' occurrences and specific areas of search for targeted fieldwork. A higher intensity of fieldwork will be required to map these habitats, but this is localised to the small proportion of the uplands in which they occur.

(iii) The remaining four Annex I habitats are challenging to detect due to their small size and extreme rarity. However, much of their extent is already known via existing habitat maps and/or other datasets. The potential contribution of the sCIR API technique to further mapping of these habitats is limited to more accurate delineation of known locations and/or opportunistic detection during fieldwork.

(iv) The sCIR API method is suited to a bio-geographic approach for future roll-out. This would optimise the use of interpretation indicators and familiarity of the interpreter with the suite of habitats present within each region, and facilitate the most efficient use of resources required for fieldwork.

– Costings for a team, modelled on SNH staff cost rates, to apply the sCIR API technique to map the 2.7 million ha of upland survey gap were generated. The total cost was estimated to be in the region of £1.8 million, an average of £0.68 per hectare, less than half the cost for full field survey.
– The sCIR API technique presents a realistic and efficient means of achieving fit for purpose habitat mapping across the HabMoS upland survey gap. Wider application of this method is strongly recommended. Accuracy and efficiency will continue to improve following further iterative development of the mapping process.

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Table of Contents **Page**

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1. INTRODUCTION

1.1 Purpose of this study

Scottish Natural Heritage (SNH) is creating a Habitat Map of Scotland (HabMoS)[1], a full coverage map of Scotland's terrestrial habitats identified according to EUNIS (European Nature Information System)[2] and EC Habitats Directive Annex I[3] classifications. A combination of existing and new survey data are being used to create the map.

At present, a survey gap extending to approximately 2.7 million hectares exists across the Scottish uplands (Figure 1). This vast area, one third of Scotland, includes some of the most remote and challenging terrain in the country, and supports a complex array of upland habitats, both large and small scale. Mapping this area by full field survey would be both costly and protracted. SNH seeks an alternative, cost-effective, method to cover this gap.

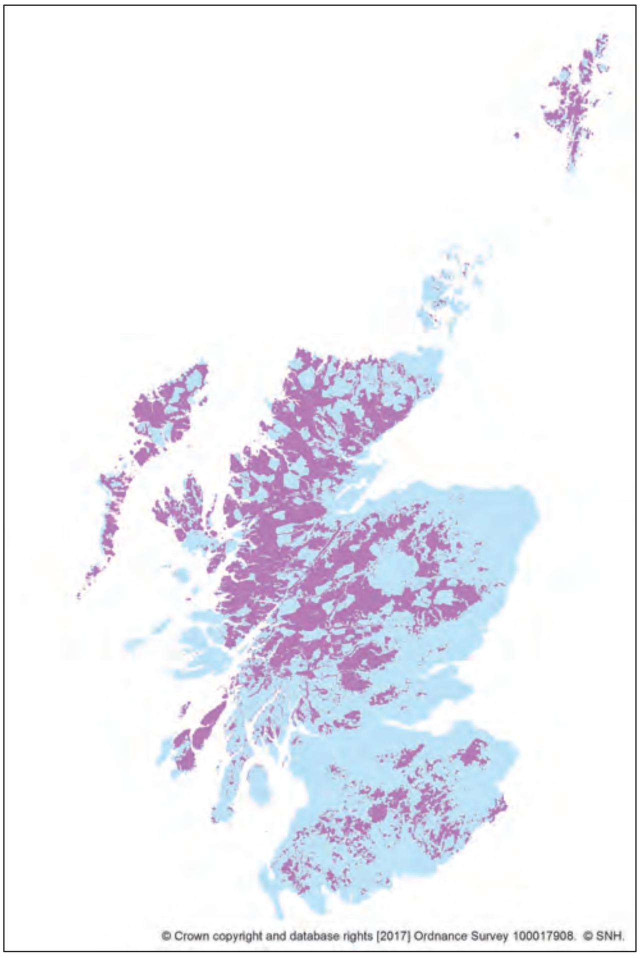


Figure 1. Habitat Map of Scotland (HabMoS) upland survey gap (purple) – upland area of Scotland currently lacking detailed mapping.

[1] Habitat Map of Scotland, Scottish Natural Heritage: https://www.nature.scot/landscapes-habitats-and-ecosystems/habitat-map-scotland [Accessed: 24 April 2018]
[2] European Nature Information System, developed by the European Environment Agency: http://eunis.eea.europa.eu/ [Accessed: 20 July 2017]
[3] European Commission Habitats Directive: http://jncc.defra.gov.uk/page-1374 [Accessed: 20 July 2017]

A potential remote sensing solution to this problem was proposed by Mattisson & Sullivan (2016) who, after undertaking a small-scale trial at Glenfeshie in 2014, concluded that manual interpretation of stereo colour near-infrared aerial imagery and a small amount of complementary fieldwork had considerable potential to deliver rapid mapping of upland habitats, and recommended further development of this approach.

The Upland Mapping Pilot commenced in June 2015 to further develop and test the 'stereo colour infrared (sCIR) aerial photo interpretation (API) technique' for mapping upland habitats. The primary objective was to establish if this technique was suitable for wider roll-out across the HabMoS upland survey gap, and could this provide a viable alternative to full field survey. This pilot aimed to build upon the Glenfeshie trial by applying the sCIR API technique over larger areas, sampling a greater number of habitats from several different biogeographic zones, and undertaking an accuracy assessment to provide a measure of the reliability of the technique.

Specifically the pilot aimed to:

- (i) Apply and further develop the sCIR API technique to map extensive areas of upland habitat in two or more different biogeographic zones;
- (ii) Produce a set of mapping rules to create a standardised approach for mapping upland habitats using this technique;
- (iii) Develop interpretation indicators to aid the identification of habitats using sCIR imagery;
- (iv) Trial the use of segmentation as a potential means of auto-delineation of habitat boundaries;
- (v) Undertake an accuracy assessment to provide a measure of the reliability of this technique;
- (vi) Establish how the sCIR API technique could be deployed to map the full suite of habitats that occurs in the Scottish uplands;
- (vii) Provide an estimate of time and resource requirement for this technique to be scaled up for roll-out across the full HabMoS upland survey gap.

1.2 Background to the sCIR API technique

Two novel aspects of the sCIR API technique contribute vital layers of information to facilitate discrimination of habitats via the manual interpretation process:

- (i) Use of (false) colour near-infrared (CIR) aerial imagery, as well as true colour red, green, blue (RGB), at 25 cm resolution;
- (ii) Digital stereo (3D) visualisation of aerial imagery and vector graphics using a computer workstation with specialised hardware and software.

Aerial photography, specifically ortho-rectified aerial images (orthophotos), has long been used as an aid for vegetation mapping in Great Britain and further afield, providing a means of delineating habitat boundaries based on the appearance (spectral signal) of vegetation in the imagery. Originally, black and white images were used, including imagery captured by the RAF around the time of the Second World War, replaced by true colour (red, green, blue = RGB) imagery (Figure 2 A) as it became more widely available from the 1980s.

In addition, the use of false colour near-infrared (CIR) aerial imagery (Figure 2 B) and its application for vegetation mapping has been pioneered in Sweden over the last three decades (e.g. Ihse, 2007). CIR imagery has greater potential for discriminating among vegetation types than black and white or true colour imagery as the spectral signal of vegetation shows a greater range of variation in the near-infrared part of the spectrum than the visible (Ihse, 2007).

Infrared light is reflected by the lower surface of a leaf. The strength of the signal is therefore influenced by leaf structure, size, shape and density, and can be interpreted to derive information on the identity of individual plant species or groups of species which together comprise vegetation. The spectral signal of plant species which exhibit marked seasonal phenologies can show a striking contrast between images captured at different times of year.

Viewing aerial imagery using manual and, more recently, digital stereoscopes adds a further layer of information to the process enabling visualisation of imagery in relation to topography (Ihse, 2007). This 3D model of the landscape allows the spectral signal of vegetation to be considered in the context of slope, aspect and altitude – key factors in determining vegetation and habitat types.

This is enhanced further still when using high resolution aerial imagery (e.g. 25 cm pixel size or smaller) which, when viewed in 3D, can provide an insight into the physical structure of vegetation, including height, texture and layering of individual plant species. Multi-temporal imagery, where available, can provide an additional facet to this, highlighting seasonal variation among plant species and vegetation.

Combined, these elements provide a powerful tool for discrimination of vegetation at a fine level of spatial detail. Further still, this can be achieved with only a small amount of fieldwork to train the development of habitat interpretation indicators. While this methodology had been widely applied in Sweden (Ihse, 2007), it had not been tested in Scotland until the 2014 trial at Glenfeshie (Mattisson & Sullivan, 2016) when the potential application of this method for mapping the Scottish uplands was first realised.

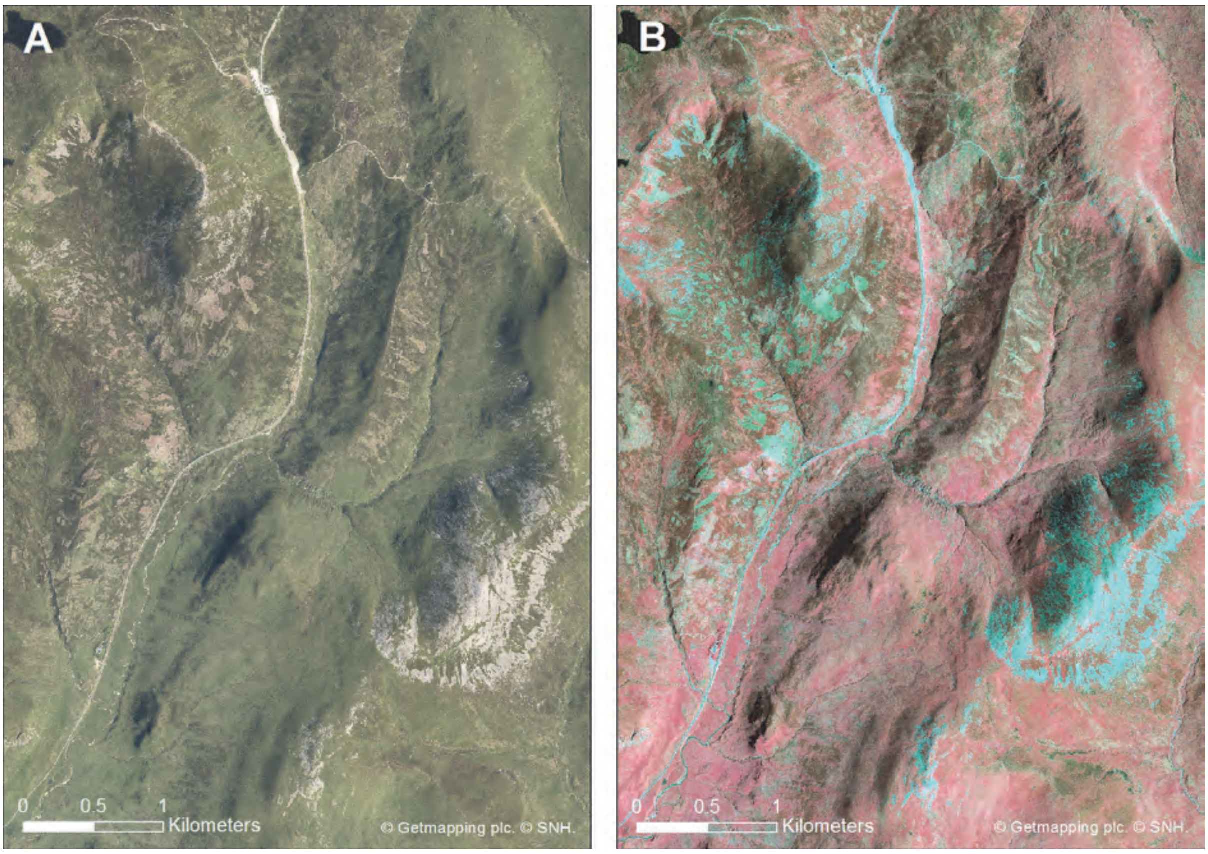


Figure 2. A: true colour red, green, blue (RGB) image; and B: false colour near-infrared (CIR) image, showing upland area to south of Glenshee Ski Centre in the Cairngorms.

1.3 Concept of the sCIR API technique

The sCIR API mapping technique is a remote sensing approach which utilises a small amount of initial reconnaissance fieldwork, plus any existing habitat surveys from the vicinity of the target area, to identify and sample the range of habitats present on the ground and relate them to spectral signals in the aerial imagery. This 'training data' allows the 'interpreter' to establish the appearance of different habitats in the imagery and identify key factors (e.g. colour, texture, shape, extent, slope, altitude, seasonal variation) that can be used to distinguish between them.

These factors are called 'interpretation indicators' and, once developed for the habitats of interest, they are applied to undertake full classification and mapping of the target area. Development of indicators and subsequent interpretation of habitats is an iterative process, and field validation is undertaken of an initial (first draft) map to resolve specific areas of uncertainty and identify weaknesses in the interpretation. This information is used to improve the indicators and modify the map accordingly. Several iterations of this process may take place to fine tune the indicators and final map output.

Some habitats may be relatively distinct in the imagery and, with experience, could be identified with a high degree of confidence by the interpreter. Other habitats may prove more difficult to identify from the imagery alone. For example, those which are characteristically small in size may be difficult to see in the imagery. Others may require knowledge of the presence of indicator species to distinguish them from other superficially similar habitats. In these instances, supplementary field visits to likely areas of search identified in the imagery may be required to map them successfully.

Where it is desirable to obtain a measure of accuracy of the final map, an accuracy assessment is undertaken. This involves an independent field survey team who visit a random sample of polygons from each mapped class and identify habitats present on the ground. This acts as 'reference data' against which to compare the 'classified data' from the map.

The key stages in the sCIR API mapping process are represented by the diagram in Figure 3, and an explanation is provided in the accompanying text.

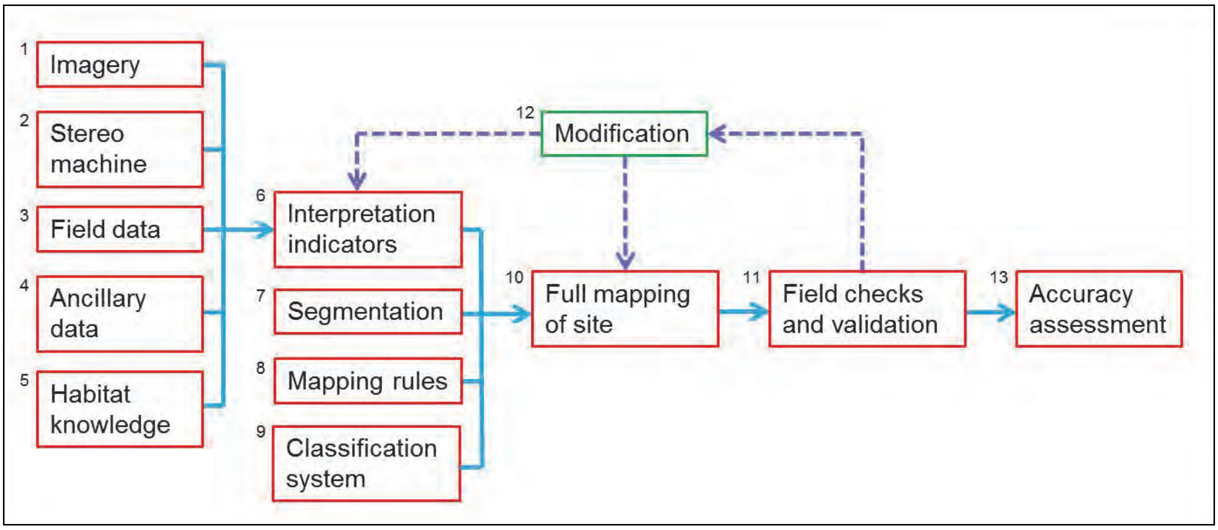


Figure 3. Flow diagram representing key steps in the stereo colour infrared (sCIR) aerial photo interpretation (API) mapping technique.

1. Imagery – false colour near-infrared (CIR) and true colour red, green, blue (RGB) aerial imagery (25 cm resolution) from Getmapping plc. National coverage available for Scotland. Capture dates vary for each area.

2. Stereo machine – computer workstation with specialist hardware and software (Summit Evolution LITE © DAT/EM Systems International) for viewing imagery and vector graphics in 3D. Summit uses stereo frames and blockfiles (containing aerial triangulation data) to create stereo models.

3. Field data – visits are made to a small proportion of the target area to identify and record the location/extent of habitats on the ground. These 'reconnaissance areas' should aim to sample the range of variation present at the site. Data from existing habitat surveys can be used in a similar way.

4. Ancillary data – additional sources of data, e.g. soil or geology maps, which can be used to identify areas of search for specific habitats.

5. Habitat knowledge – individual(s) doing the mapping work must have experience of upland habitat field survey which they will draw upon throughout the process. Published work such as British Plant Communities, Volumes 1-5 (Rodwell, 1991-2000) provides important additional information.

6. Interpretation indicators – field data is used to relate habitats observed on the ground with the aerial imagery and identify key factors which can be used to discriminate between them.

7. Segmentation – automatically delineated polygons, derived from image analysis using eCognition Developer (© Trimble Geospatial) software, provide initial habitat boundaries, either used unchanged, or merged and edited where required.

8. Mapping rules – framework for the mapping process to promote a consistent approach. Rules for each habitat include minimum mappable units (MMUs).

9. Classification system – habitats classified according to EUNIS (European Nature Information System) and EC Habitats Directive Annex I codes.

10. Full mapping of site – using interpretation indicators and segmentation, and according to the mapping rules, full mapping and classification of site is undertaken. In essence, the mapper uses indicators developed from studying a few small areas in detail and extrapolates over wider landscape.

11. Field checks and validation – targeted fieldwork aimed at resolving areas of uncertainty encountered during the mapping process, and also a general check for correspondence between classified data and habitats on the ground. Includes visits to specific 'areas of search' for rare/small-scale habitats identified by the mapping which need fieldwork to confirm.

12. Modification – update interpretation indicators and classification/delineation of the map to reflect outcome of field checks and validation.

13. Accuracy assessment – independent field surveyors sent out to collect field data from a random sample of the mapped area against which to assess the accuracy of the classified data.

2. METHODS – MAPPING

2.1 Pilot sites

The pilot focused on two 100 km^2 pilot sites in Scotland, one in the northwest, Beinn Eighe and Flowerdale Forest, the other at Caenlochan in the Cairngorms area (Figure 4; Annex 1, Map 1A & Map 2A). These sites were selected in order to sample a range of variation in upland habitats in these two distinct biogeographic regions. This included widespread/extensive habitats, potentially easier to identify in the imagery, and rare/small-scale habitats, potentially more challenging to detect and map using aerial imagery alone.

Figure 4. Location of pilot sites at Beinn Eighe and Flowerdale Forest, and Caenlochan in the Cairngorms area.

2.2 Imagery

The imagery used was obtained through the Scottish Public Sector aerial photography agreement supplied by Getmapping plc. This high resolution aerial imagery dataset offers full national coverage, is updated regularly and has multiple captures for a given area, extending back to 2008, but the capture date/year and the number of (re)captures for each location varies widely.

The following imagery was obtained from Getmapping:

(i) CIR and RGB stereo frames at 25 cm resolution, plus blockfiles (= processed aerial triangulation [AT] data required to build 3D models in Summit);

(ii) CIR and RGB orthomosaics, supplied as 1 km^2 tiles, at 25 cm resolution for RGB and 50 cm resolution for CIR (used for backdrop mapping and 2D digitisation);

Table 1 provides information on the capture dates of imagery used for each of the pilot sites. CIR and RGB imagery is captured by Getmapping on the same flight. Due to issues with AT data gathered during image capture by Getmapping, and subsequent impact on blockfiles required to build 3D models in Summit, stereo imagery for Beinn Eighe and Flowerdale was only available for the 2014 capture date, and for 2013 and 2008 capture dates at Caenlochan.

Table 1. Getmapping aerial imagery capture dates for upland mapping pilot sites.

Site	Capture date	Coverage/extent	Season
Beinn Eighe and Flowerdale	26 August 2014	Full site	Summer
	13 May 2009	Full site	Spring
Caenlochan	11 July 2014	N half	Summer
	25 May 2013	S half	Spring
	28 September 2008	Full site	Late Summer

2.3 Software and hardware for 3D visualisation and mapping

A dedicated computer workstation was configured for mapping work, running Summit LITE v7.3 (© DAT/EM Systems International, 2016) photogrammetric software for digital stereo (3D) visualisation of imagery and vector graphics, and ArcGIS 10 (© ESRI, 2010) for 2D visualisation and data capture. The set up included a 27” ASUS 3D monitor, plus NVIDA 3D vision glasses and emitter, for 3D viewing, paired with a standard 27” monitor for 2D work (Figure 5).

Figure 5. Stereo workstation with dual monitors enabling simultaneous visualisation of imagery and vector graphics in 3D and 2D environments.

‘DAT/EM capture’ system is used by Summit LITE to connect with and configure ArcGIS so that vector layers can be loaded in ArcGIS and projected in 3D using Summit LITE. This allows dual viewing of imagery and vector layers in both 3D and 2D environments. All editing and attribution of polygons was done in 2D using ArcGIS.

2.4 Pre-study and reconnaissance fieldwork

At the outset, a pre-study of each pilot site was undertaken. This included a general study of the location, landscape, and aerial imagery. Existing vegetation surveys were also examined (Averis & Averis, 1998; Barclay & Jones, 1985; Loizou, 1998; Loizou, 2004; O’Hanrahan & Headley, 2008) to establish which habitats had been recorded from the wider area, their appearance in the imagery, and the situations in which they were likely to be found.

Two reconnaissance areas, defined by a 2 x 4 km rectangle (to provide an approximate target for the field visit), were identified in each pilot site (Annex 1, Map 1B & Map 2B). These areas were selected, where possible, to sample the range of variation present across each site, informed by spectral signals in the imagery, and variation in altitude, aspect, slope and context.

Fieldwork visits were undertaken to each of the reconnaissance areas and a pre-planned route followed to visit particular signals or areas of interest identified in the imagery. A printed copy of the CIR and RGB imagery was taken in the field and relationships between signals in the imagery and habitats on the ground were studied. A GPS unit was used to gather habitat reference points (grid references), including key habitats present in the area, examples of marked variation within the same habitat, boundaries between adjacent habitats, and locations of small-scale habitats such as flushes. Photographs were taken to illustrate main habitat features to aid the development of indicators back at the desk.

Tablets (Samsung Galaxy Tab S2 9.7”) running ‘Collector for ArcGIS’ app (© ESRI, 2016) were later adopted as a means of achieving all of the above listed functions using one device.

2.5 Ancillary data

Other sources of data available for the pilot sites that could help with interpretation of habitats were collated, including: OS 10 m contour lines; digital terrain model (DTM); areas that were not to be classified as upland habitat (roads, buildings, waterbodies – derived from OS Vector Map District); areas identified as woodland – derived from the Native Woodland Survey of Scotland (Forestry Commission Scotland, 2014) and/or National Forest Inventory (Forestry Commission, 2012) datasets; lowland areas defined by the SNH Upland HAP Context Mask.

Geology and soil data would be a significant addition to this list, providing layers of information that could potentially be used to pinpoint areas of search for habitats associated with calcareous geology. However, it was not possible to obtain digital geology and soil data at a sufficient resolution to aid this mapping exercise. Further still, discussions with SNH geology and soil specialists highlighted a current limited understanding of associations between habitats and specific rock and soil types.

2.6 Interpretation indicators

Habitat reference data (GPS points and associated notes) gathered during field reconnaissance visits were converted to a point feature class in ArcGIS. The reference points were then viewed against the imagery, in both 2D and 3D environments, including different seasonal captures where available. Initial polygons were then hand digitised to define the extent of known habitats across each of the reconnaissance areas based upon their spectral signal in the imagery.

Information on the following key factors (adapted from Mattisson & Sullivan, 2016) was established for each habitat encountered – this was derived from the imagery, published information on upland vegetation communities in Rodwell (1991-2000) and Averis *et al* (2004), and habitat knowledge possessed by the interpreter:

- (i) Spectral signal (colour, tone, intensity);
- (ii) Physiognomy (vegetation height, structure, texture, density);
- (iii) Dominant species;
- (iv) Size, shape, pattern;
- (v) Site conditions (slope, aspect, altitude, exposure);
- (vi) Substrate (soil, moisture regime, nutrients, geology);
- (vii) Landscape context;
- (viii) Management and other anthropogenic impacts.

These factors formed the basis of interpretation indicators for each habitat of interest which not only describe how to recognise the habitat in the imagery, but also critical information on where in the landscape the habitat was likely to occur. Interpretation indicators developed for the Upland Mapping Pilot are presented in Annex 2.

An example of the indicators for EUNIS habitat *F2.25 boreo-alpine and arctic heaths* (Annex I code: H4060) is provided in Table 2 below.

Table 2. Example of interpretation indicators developed for F2.25 Boreo-alpine and arctic heaths (H4060).

F2.25 Boreo-alpine and arctic heaths (H4060)

NVC types: H10, H12, H13-15, H16, H17, H18, H19-20, H21, H22.

Descriptive indicators:

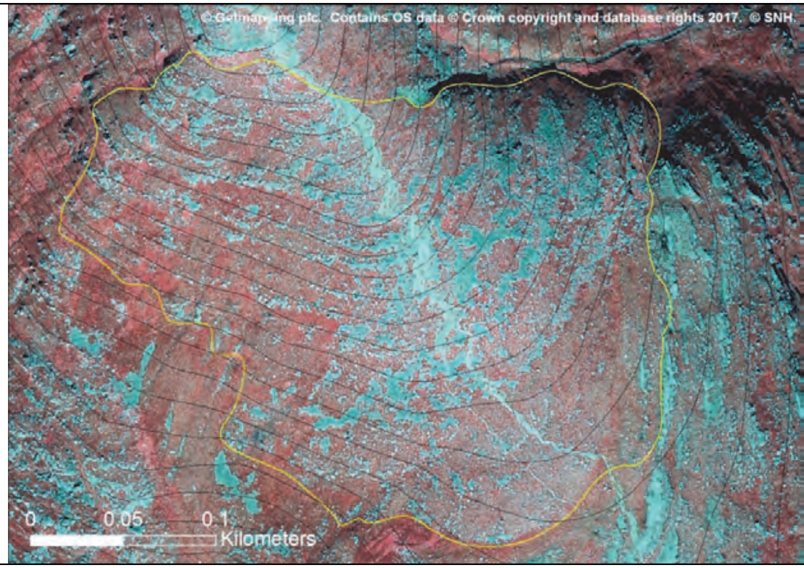
- Widespread habitat, principally occurring in extensive stands. Most frequent in the Scottish Highlands.
- Occurs on exposed ridges, upper slopes and summits of hills at moderate to high altitude on gentle and steep slopes.
- More common above 750 m altitude in the east, and above 400 m in the west, but there is no definitive line above which it occurs – exposure and/or snow-lie, which suppress the growth of dwarf-shrubs, are the critical factors rather than altitude.
- Substrate is shallow and acid, often damp but with a high frequency of gravel, rock and/or boulders.
- Vegetation comprises a sparse, open (often broken) cover of short, prostrate/wind-pruned dwarf-shrubs (<5 cm tall), including *Calluna vulgaris*, *Vaccinium myrtillus*, and *Empetrum nigrum*, and can have much exposed stone or bare gravel substrate, and/or lichen or *Racomitrium* moss among the dwarf-shrubs.
- Short/smooth/open appearance is critical in distinguishing this habitat from the tall/rough/closed dwarf-shrub canopy of F4.2.

Colour signal in aerial imagery:

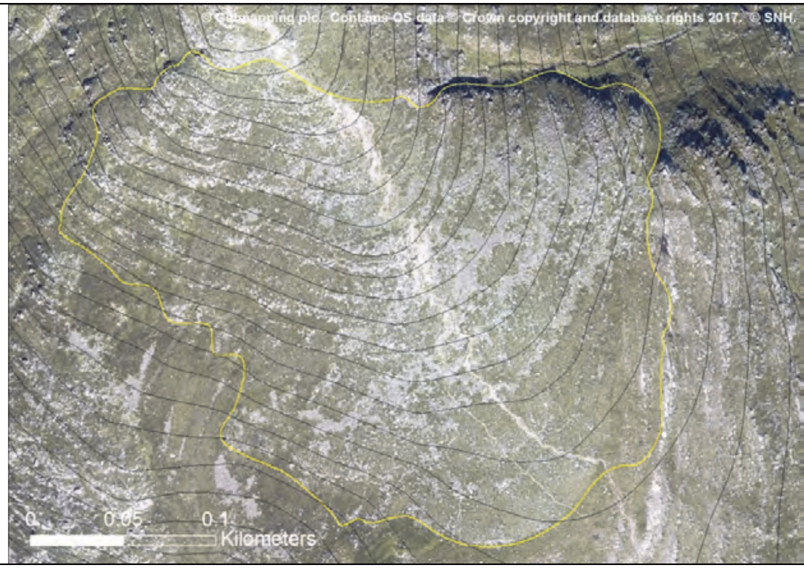
- CIR – bright red-pink signal of *V. myrtillus / E. nigrum,* and/or red-brown of *Calluna*, mixed/mottled with cool white-blue of gravel/rock and/or white-green of lichen/moss – with fine-scale clumped pattern/micro-roughness from prostrate mats or wind-pruned patches of dwarf-shrubs.
- RGB – mottled green or brown of dwarf-shrubs with white-grey of exposed stone or lichens/moss.

Mapping approach / constraints:

- Potential for confusion with F4.2, especially in the altitudinal transition zone where patchy occurrences of both habitats may occur. Similarly, confusion of the above and forms of F4.11 may occur in the northwest where all three can occur on the tops and sides of sparsely-vegetated stony knolls, and spectral signals are indistinct. A higher frequency of field checking will be required in these situations.
- Potential for some confusion with E4.32€, this generally has smoother or more consistent signal, compared to mottled/micro-roughness of F2.25.



CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – mottled red-brown and white-blue of stony F2.25, with patches of H2.31€, on exposed high slopes.



RGB – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – (as above) mottled brown and white-grey of stony F2.25.

2.7 Development of segmentation

Segmentation is a form of analysis which divides an image into homogeneous regions by grouping similar neighbouring pixels together, based on reflectance values. The objects (polygons) created by this process are defined by the spectral signal and shape of the features they describe. Segmentation was applied as a potentially time saving method over manual delineation to provide initial habitat boundaries used during the mapping process. These polygons could either be used unchanged, or merged and edited where required.

A segmentation was produced for each of the pilot sites by external contractors Environment Systems (Pike & Medcalf, 2016[a] & 2016[b]). The following provides a brief summary of the segmentation process undertaken for each of the two pilot sites.

Raw 25 cm resolution stereo frames (supplied by Getmapping) were orthomosaiced and merged to create a single image for the area covered by each capture date. The near-infrared band from the CIR was stacked with the red, green and blue bands from the RGB to create a new four-band image (red, green, blue, near-infrared). To prepare it for analysis, the four-band image was calibrated using the 'empirical line correction' method and ENVI software. During this process, a number of reference habitats (with known spectral profiles) were identified in the image and used to fit a regression line to transform the digital numbers assigned to each pixel across the image to values more representative of the normal range of vegetation reflectance.

Using the calibrated four-band image, a Normalized Difference Vegetation Index (NDVI) layer was calculated from the ratio of red and near-infrared bands. A 'multiresolution segmentation' was then run in eCognition on the calibrated four-band image plus the NDVI layer, resampled to a resolution of 1 m. The bands used in the segmentation and their relative weighting are shown in Table 3.

Existing spatial datasets were used to mask out areas from the segmentation which did not contain upland habitats. These included roads, water bodies and buildings, derived from OS Vector Map District, and areas mapped as woodland by the National Forest Inventory (Forestry Commission, 2012) and the Native Woodland Survey of Scotland (Forestry Commission Scotland, 2014).

Table 3. Image band/layer included in the segmentation and relative weighting.

Image band/layer	Weighting
Blue	0
Green	1
Red	2
Near-infrared (NIR)	2
Normalized Difference Vegetation Index (NDVI)	3

The following parameters can be altered to influence the segmentation output:

(i) Scale - influences the homogeneity of the objects. A low scale value creates smaller objects that differentiate fine-scale heterogeneity, and a high value creates larger more heterogeneous objects (range 0 to >1000). The value applied is influenced by the resolution of the imagery.

(ii) Shape - controls how much influence shape has on the objects compared to colour (spectral values). A low shape value favours spectral values contained within the individual pixels, and a high value would define objects based on the spectral values across the image as a whole (range 0 to 0.9).

(iii) Compactness - this alters how the shape homogeneity is defined to produce either smoother edges or a more compact form. A low value produces objects that spread out and follow natural features, whereas a high value minimises deviation from the ideal compact form (range 0 to 1).

Various iterations of the segmentation were produced on small trial areas within each pilot site to identify parameters that would result in meaningful habitat boundaries at an appropriate level of spatial detail for manual classification. The scale parameter was experimented with most widely. Examples of test segmentation outputs on trial areas at each pilot site are shown in Figure 6. The final segmentation parameters used for each site are presented in Table 4.

When deciding upon a fit for purpose output, there was an inevitable compromise between retaining a useful level of detail and delineation of small-scale habitats (avoiding having to manually draw boundaries of these habitats back in), and ending up with a large number of objects (polygons) which required merging together where they divided homogeneous areas of habitat. Judging the appropriate level of detail was not easy, but is likely to improve with experience.

Table 4. Final segmentation parameters used for Beinn Eighe and Flowerdale, and Caenlochan pilot sites.

Parameter	Beinn Eighe and Flowerdale	Caenlochan
Scale	425	1,000
Shape	0.9	0.9
Compactness	0.1	0.1

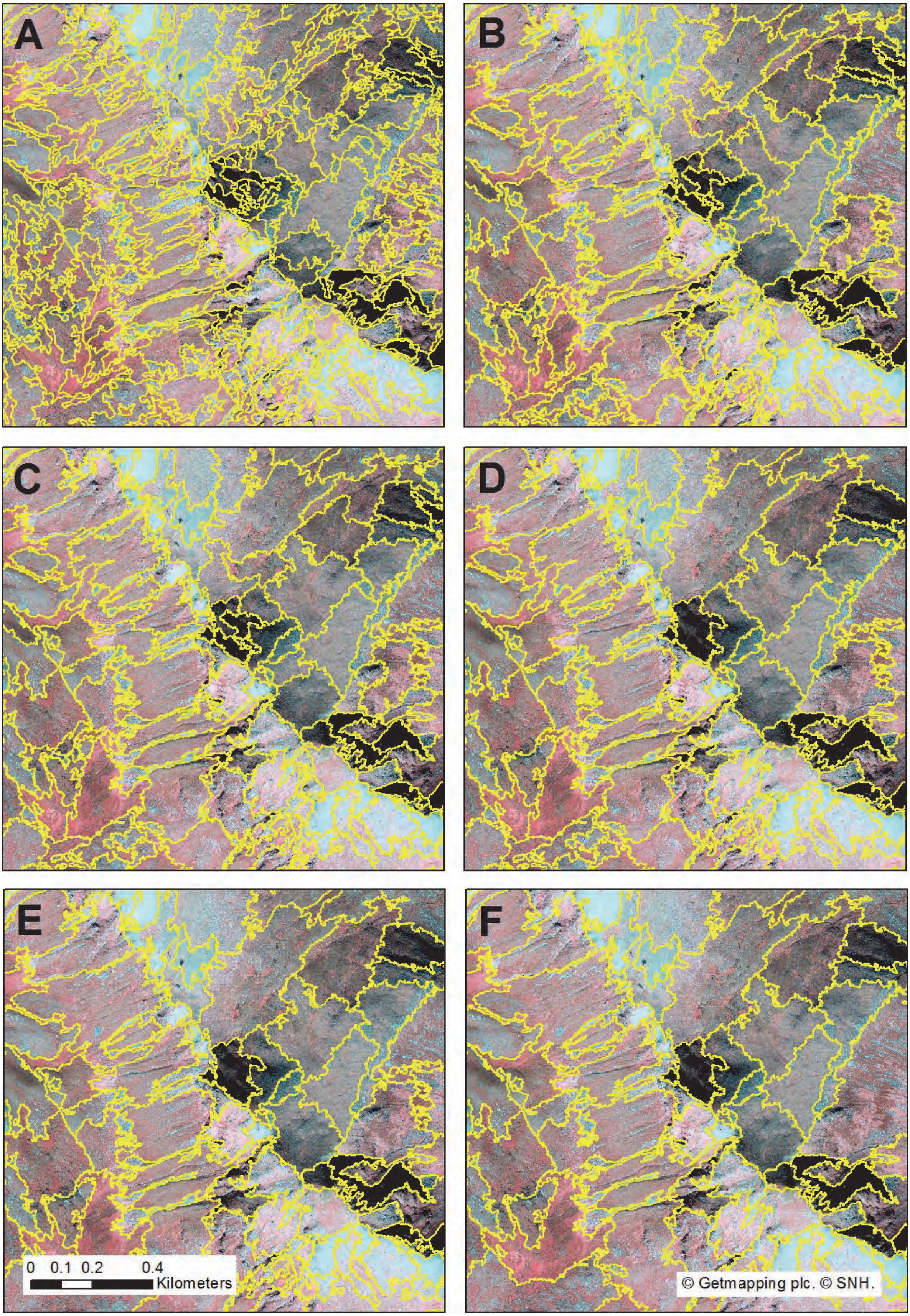


Figure 6. Segmentation examples from trial area at Beinn Eighe and Flowerdale Forest pilot site, showing impact of progressive increase in scale parameter (from A to F) reducing the number of objects (polygons) outlined in yellow.

It is important to note that one set of segmentation parameters is unlikely to produce a consistent output when moving from one geographical region to another and/or between imagery captured on different flights. The output will respond to the diversity, complexity and scale of habitats (= signals in the imagery) present. It will also be influenced by the imagery itself. For example, the time of year (season) and illumination levels on the day of capture can influence the contrast between different habitats, and whether or not they will be delineated accurately by the segmentation. Creating a segmentation will therefore always be an iterative process.

When producing segmentations, the best imagery from the available captures for each pilot site was used. This did not always imply the most recent image capture, but rather captures where the greatest contrast between habitats was apparent.

In the segmentation product received from Environment Systems, polygons had rasterised edges which result from boundaries being formed along the edge of individual square pixels. There were also a large number of very small polygons, an artefact of the masking process. To improve the appearance of the output and make it easier to work with, polygons were smoothed in ArcGIS, and small polygons (<0.05 ha in size) eliminated by dissolving them into neighbouring polygons. Finally, polygons were simplified to reduce the number of vertices and file size, and hence load speed, of the final product (Table 5). An example of the final segmentation output for the Caenlochan pilot site is shown in Figure 7.

Table 5. Area segmented for each pilot site and number of objects (polygons) before and after processing (= smoothing and eliminating polygons <0.05 ha in size).

	Beinn Eighe and Flowerdale	Caenlochan
Area segmented (ha)	23,437	40,787
Objects before processing	22,350	17,838
Objects after processing	9,998	14,130

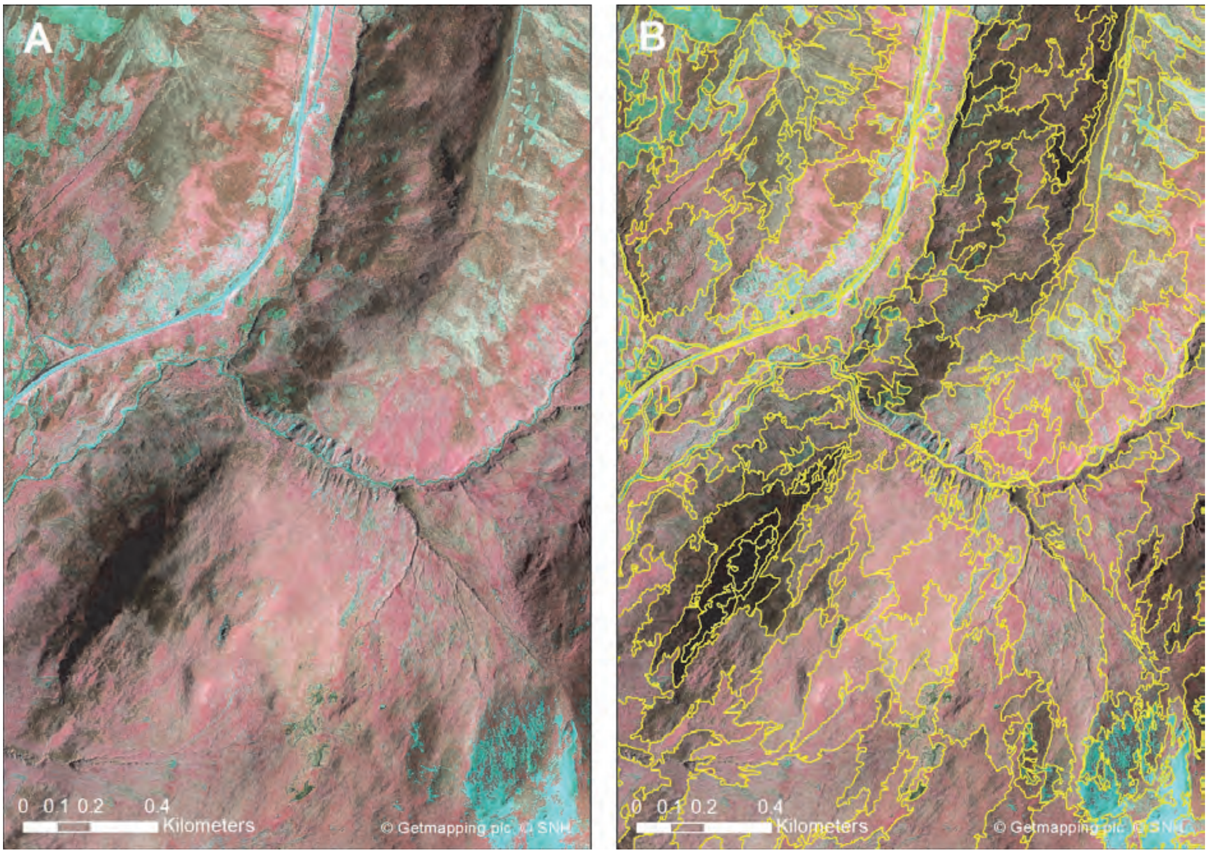


Figure 7. Example of the final segmentation output produced for the Caenlochan - Cairngorms pilot site: A – imagery only; B – segmentation (yellow polygons).

2.8 Mapping rules

Mapping rules were developed to provide a standardised framework for the mapping process, ensuring a consistent map output was produced at an appropriate level of detail and precision with regard to the target habitats of the mapping and potential future uses of the map. At the outset of the pilot, a workshop was held with internal (SNH) and external habitat experts to discuss and agree a set of mapping rules for the predicted suite of habitats that would be encountered in the Scottish uplands.

This included 22 upland Annex I habitats, and 10 non-Annex I habitats, which were grouped according to factors including: frequency of occurrence (widespread/rare); extent (extensive/small-scale); likelihood of detection in aerial imagery; and requirement for additional information to discriminate from other similar habitats (e.g. indicator species, geology data). Rules were then created for each group, including: minimum mappable units (MMUs); thresholds for allowable habitats; and a list of allowable habitats. These rules are presented in Annex 3. An example of the mapping rules developed for 'Group A' habitats (Annex 3) is provided in Table 6 below.

2.8.1 Minimum Mappable Unit

The minimum mappable unit (MMU) defines minimum patch size of a particular habitat that can be delineated as an individual polygon on the map. Any discrete patch of habitat that is smaller than the MMU is not delineated. It could, however, be included as a secondary habitat within a polygon dominated by another habitat, if it meets or exceeds the minimum cover or area threshold for inclusion (see below), either alone or if combined with one or more other patches of the same habitat.

2.8.2 Thresholds for allowable habitats

This rule is a means of simplifying the map output, enabling small amounts of secondary habitat to be overlooked during classification where they occur within an area otherwise dominated by another habitat. A cover and area threshold was identified, below which an agreed list of allowable habitats would not need to be included as secondary habitats by the classification.

2.8.3 Allowable habitats

A list of allowable habitats was specified for each habitat representing those which would typically occur in association with that habitat, and at low cover could be accepted as part of the broad spectrum of variation within the habitat.

Table 6. Example of mapping rules developed for Group A habitats.

EUNIS habitat	EUNIS code	Annex I code	Occurrence / extent	Map object / MMU*	Mapping rules	Allowable habitats
Blanket bogs	D1.2	H7130	Widespread habitat, principally occurring in extensive stands.	Polygon (single habitat or proportion of mosaic). MMU = 0.25 ha.	1. For a polygon to be labelled as a single Group A habitat, that habitat must cover ≥80% of the polygon. 2. Up to 20% of the polygon may consist of a combination of other allowable habitats. 3. If the area covered by another habitat is >10% OR >1 ha, it must be mapped as a secondary habitat.	Any other group A habitat, plus: D2.2, E1.71, E1.72x, E3.4, E3.512 / F4.13, E3.52, E4.11, E5.5x.
Siliceous alpine and boreal grasslands	E4.32€	H6150				Any other group A habitat, plus: D2.2C, E1.71, E1.72x, E3.52, E4.11, H3.51x, H5.3.
Boreo-alpine and arctic heaths	F2.25	H4060				Any other group A habitat, plus: D2.2C, E1.71, E1.72x, E3.52, E4.11, H3.51x.
Northern wet heaths	F4.11	H4010				Any other group A habitat, plus: D2.2, E3.4, E3.512 / F4.13, E1.71, E1.72x, E3.52, E5.31, E5.5x, F2.323, scattered trees.
Dry heaths	F4.2	H4030				Any other group A habitat, plus: D2.2, E3.4, E3.512 / F4.13, E1.71, E1.72x, E5.31, E3.52, E5.5x, F2.323, scattered trees.

2.9 Classification system

Habitats were classified according to EUNIS (European Nature Information System) (European Environment Agency, 2015) and EC Habitats Directive Annex I (European Commission, 2013; Joint Nature Conservation Committee, 2014) codes, following the 'Manual of terrestrial EUNIS habitats in Scotland' (Strachan, 2015) which provides correspondence between EUNIS, Annex I and NVC (National Vegetation Classification) systems (Rodwell, 1991-2000).

It should be noted that EUNIS and Annex I classifications lack detailed floristic and environmental data and description, and therefore interpretation of these classifications relied heavily upon on correspondence with the NVC, which is supported by extensive data and description. NVC was the system used when gathering habitat reference data in the field, and for subsequent development of interpretation indicators. NVC data was then converted to EUNIS and Annex I following Strachan (2015).

EUNIS is a pan-European hierarchical classification system of marine and terrestrial habitats. The INSPIRE Directive[4] requires EU member states to use EUNIS and Annex I codes to facilitate the exchange and analysis of habitat data across the EU. SNH has adopted EUNIS to provide a consistent framework for habitat data and mapping in Scotland.

Habitats were classified to the lowest possible level of EUNIS at all times, typically level three to four, sometimes level five. New sub-types developed by Strachan (2015) were applied, where relevant. Composite codes produced by Strachan (2015), which group together different EUNIS types which correspond to the same Annex I type, where not adopted. Instead, habitat polygons were coded with the equivalent Annex I habitat code, where relevant.

2.10 Data entry and attribution of polygons

To standardise the data entry process, and promote consistent and accurate attribution of polygons with EUNIS and Annex I habitat codes, a data structure was configured in ArcGIS with a drop down menu system from which EUNIS and Annex I habitat codes (and descriptions) could be selected and assigned to each polygon (Figure 8). To take account of mosaics, multiple habitats could be assigned to a polygon, and proportional cover assigned to each component habitat so that accurate area estimates could be derived. Proportions for all component habitats should add up to 1 for each polygon. The smallest proportion that could be assigned was 0.01 (1%).

[4] INSPIRE, Infrastructure for Spatial Information in Europe: http://inspire.ec.europa.eu/ [Accessed: 20 July 2017]

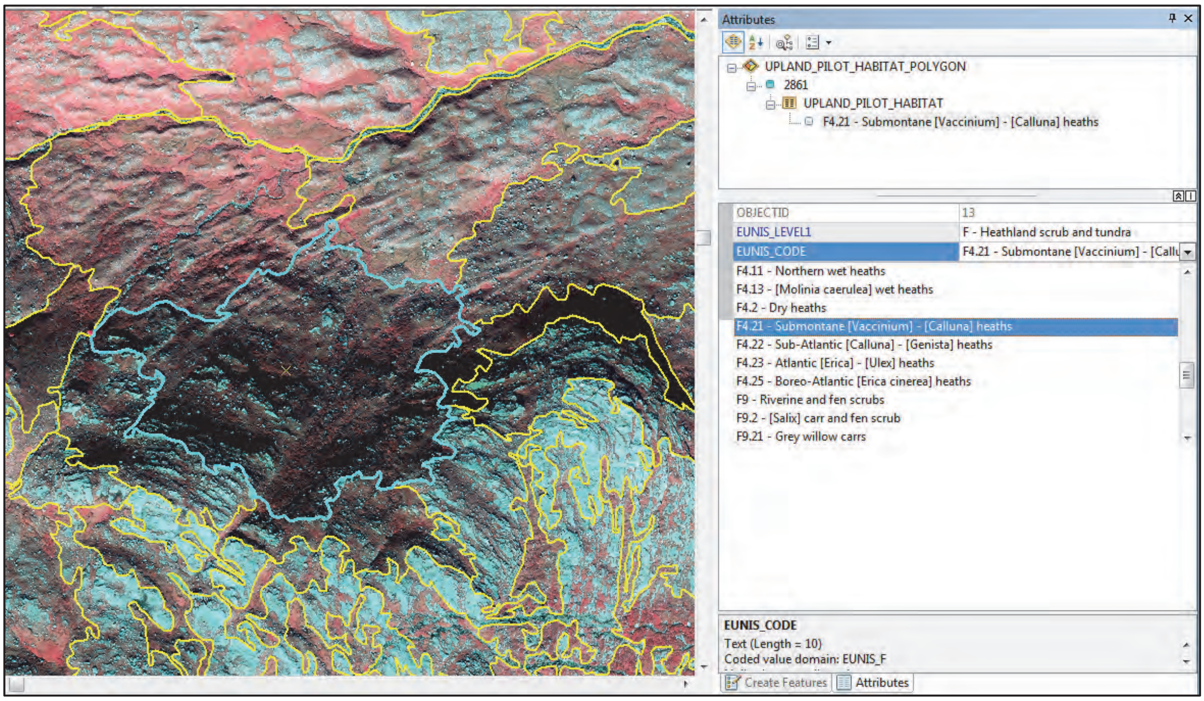


Figure 8. Example of data capture system in ArcGIS using drop down menu with EUNIS and Annex I codes, facilitating accurate and standardised attribution of polygons.

2.11 Mapping process – delineation and classification

Working systematically across the target area, utilising interpretation indicators, and according to mapping rules, each segmented polygon was examined in turn and the habitat(s) within it identified. A decision was made as to whether each polygon should be used unchanged, merged with its neighbour (if both segments contained the same habitat), or split (if discrete areas of more than one habitat were present at a size above the MMU) to create additional polygons.

A general overview was typically made between a scale of 1:15,000 and 1:10,000, enabling larger blocks of habitat to be viewed in relation to topography. Individual segments were then viewed between 1:5,000 and 1:3,000 to make decisions about merging and editing boundaries to reflect homogeneous areas within the imagery. Some habitats were readily recognisable at this scale and did not require closer examination to classify. For others, it was necessary to zoom-in to between 1:1,000 and 1:500 to view the texture, structure and composition of the vegetation to confirm identity of the habitat.

Classification commenced in the reconnaissance areas, where indicators had been developed and there was a degree of familiarity with habitats on the ground. The next step was to extend out across the site following areas of similar topography, looking for patterns, or repeating units, which related to known reference habitats within the reconnaissance areas. An OS 1 km grid was used as an overlay with individual 1 km grid squares used to aid systematic examination and classification of segmented polygons.

While instances of some habitats were quite distinct in the imagery, and there was a relatively high degree of certainty with which they could be identified, some were less distinct and there was a degree of uncertainty in classification. These could be ‘new’ habitats that hadn’t been encountered in the reconnaissance areas, variation within habitats which hadn’t been accounted for during development of indicators, or degraded examples of certain habitats which did not clearly conform to indicators for any particular habitat. Notes were added to polygons to indicate the need for a field visit and/or re-examination of the polygon when uncertainty had been resolved.

The end result was a final set of habitat polygons classified with EUNIS and Annex I codes and proportional cover for each component habitat (Figure 9).

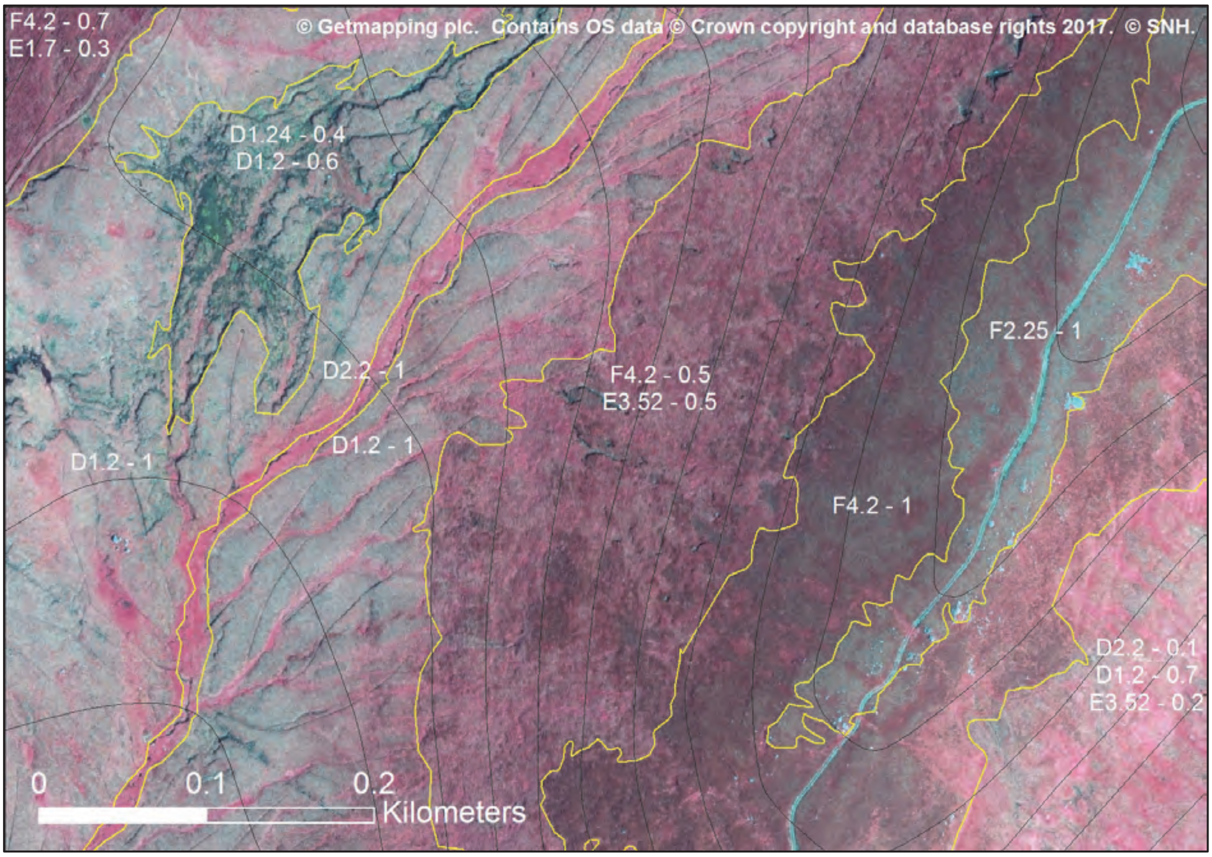


Figure 9. Example of classified map output showing habitat polygons (yellow outline) labelled with EUNIS habitat code(s) and proportional cover assigned to each.

2.12 Field checks / validation

Specific areas of uncertainty encountered during the classification process are ideally resolved by undertaking field checks. Information derived from these field visits is used to modify and update the indicators and the classified map to reflect this new information. At the same time, general validation of the map output can be undertaken to assess whether the classified data accurately reflects habitats on the ground, and this can also serve as a means to improve the confidence of the interpreter with the classification.

Due to time constraints, and the limited window of opportunity to get a survey team in field, validation was not undertaken before the accuracy assessment.

3. METHODS – ACCURACY ASSESSMENT

3.1 Selection of sample for field survey

The methodology for the accuracy assessment was developed following Congalton (1991), and Congalton and Green (2008), with the addition of SNH in-house statistical advice (Megan Towers pers. comm.). The accuracy assessment was based upon a field sample, collected by an independent survey team, which provided ‘reference data’ against which to assess the accuracy of the ‘classified data’ from the habitat map of each pilot site. The polygons for the field data sample were selected using stratified random sampling combined with cluster sampling. Broad habitat classes from the classified data were used as strata.

3.1.1 Assigning classes for stratified random sampling

The EUNIS / Annex I habitat data associated with the classified polygons was exported to Microsoft Excel and summarised. A number of broad habitat classes were created comprising one or more EUNIS types. While this was straightforward for polygons classified as one habitat type only, it was less so for polygons in which two or more habitats had been classified (i.e. a primary habitat with one or more secondary habitats). In order to be consistent when assigning classes, the following rules were applied:

Widespread habitats:

- If the proportional cover of the primary habitat was ≥ 0.7 and the secondary habitats, if present, were other widespread habitats, the polygon was assigned to the class that corresponded to the primary habitat.
- An exception to this rule was made for bare peat, which was often mapped as a secondary habitat alongside vegetated blanket bog. To ensure that bare peat was adequately represented in the overall sample, a polygon was included in the bare peat class where the proportion of bare peat was ≥0.4.
- Separate mosaic classes were created for commonly occurring mosaics of two widespread habitats where the proportional cover of the two component habitats was between ≥0.4 and ≤0.6.

Rare / small-scale habitats:

- To ensure they were adequately represented in the overall sample, a different approach was taken for rare or fragmentary habitats which, as well as being mapped as single habitat polygons, were often mapped as secondary habitats within a polygon of another widespread habitat.
- If a polygon contained a rare or fragmentary habitat with proportional cover of ≥0.15, the polygon was assigned to the relevant class for the rare or fragmentary habitat, irrespective of the cover of other habitats within the polygon.
- If there was more than one rare or fragmentary habitat within a polygon, priority was given to the rare or fragmentary habitat with the highest cover.

Once assigned to a habitat class, each polygon could represent only that habitat class within the accuracy assessment sample, irrespective of any other habitats that were classified within that polygon. This was important in order to meet statistical assumptions which imply that each mapped polygon can be included in the random sampling only once.

Details of the accuracy assessment habitat classes are presented in Annex 4, along with the total number of polygons assigned to each habitat class, and the number of samples visited during the accuracy assessment field survey.

3.1.2 Calculation of sample size

Once each polygon had been assigned to a habitat class, the following were calculated: (i) the total number of polygons per habitat class, and (ii) the proportion of polygons in each class out of the total number of polygons in the mapped area.

A statistical power analysis was undertaken to calculate a recommended minimum sample size in relation to the expected map accuracy and an acceptable confidence interval size. The exact binomial test (binom.test() in R v3.2.3) was used to generate confidence intervals for a range of map accuracy levels (75%, 80%, 85% and 90%), and a range of sample sizes (50, 100, 500 and 1,000). A generalised linear model (GLM) with binomial errors (as the response is binary – i.e. correct or not) was used to generate sample size estimations. Data was simulated under a range of scenarios and 1,000 stratified random samples were generated from this data. For each sample, a GLM (as described above) was fitted using the glm() function in R. The anova() function for each GLM was then used to ascertain if there was a significant difference between the habitats at the 5% significance level. The percentage of GLMs that had a significant difference was the power.

For a map with an expected accuracy of 75% and confidence interval width of 10%, a minimum of 315 samples was recommended across the two pilot sites.

When selecting sample size, the trade-off between the percentage of the mapped area sampled and the overall cost of fieldwork was taken in to account. Significantly increasing the sample size above the minimum recommended would increase the time and costs associated with collecting the field data. A final sample size of 360 samples was selected.

3.1.3 Selecting the stratified random sample

The habitat classes assigned above formed the individual ‘strata’ for the stratified random sample. The required number of samples per site was multiplied by the proportion of polygons contained within each habitat class to calculate the required number of samples per stratum. The required sample size was divided proportionally between the two pilot sites using the ratio of classified polygons at each site.

Cluster sampling was combined with random stratified sampling (rather than randomly selecting polygons over the whole mapped area) to reduce effort and cost associated with field data collection. Four clusters were created by identifying a polygon for a rare habitat type (e.g. D4.15€ alkaline fen), then selecting all of the polygons within a fixed radius of that habitat type. This was experimented with several times and a radius of 2 km decided upon as providing a sufficient cluster size to minimise potential issues with spatial autocorrelation of samples whilst at the same time maintaining a manageable sized area for the field surveyor to visit.

The selection of clusters considered the distribution of rare habitats across the mapped area as well as accessibility. Reconnaissance areas were excluded from the sample as well as those which overlapped with existing NVC survey data which had been used for training the classification.

The polygons that fell within the four clusters were then subjected to random sampling within each stratum (habitat class), using a random number generator in Excel, to select the required number of samples for each class. Samples within a class had an equal chance of being selected via random sampling irrespective of the cluster they occurred in – i.e. cluster identity/location had no influence on sample selection.

3.2 Collection of field data

Once the random sample was finalised it was provided to independent field surveyors, with expert knowledge of upland habitats, on tablets running ArcGIS Collector application. The samples consisted of 'blank' polygons (so the field surveyor was unaware of the classified data) which could be viewed over Ordnance Survey base map and aerial imagery backdrops. Consistent data entry was ensured by the use of drop-down menus for attributing the polygons with habitat data using EUNIS and Annex I classification systems (the same system used for the desk-based mapping process).

3.2.1 Field survey protocol

Field surveyors collected data according to the following protocol:

- (i) Visit each sample polygon
- (ii) Identify all habitats present within the polygon, either by walking a route through the polygon to sample the variation present and/or by viewing from a distance with binoculars.
- (iii) Estimate the proportional cover of each habitat (see note on assigning proportions below) using the aerial imagery to assist (by relating habitats observed on the ground to the colour/texture signals in the imagery).
- (iv) Enter the habitat and proportional data using the data entry system on the tablet. Classify each habitat to the lowest possible level of EUNIS and assign the appropriate Annex I habitat (where applicable). Enter each individual EUNIS habitat and its proportional cover as a separate record, even where they correspond to the same Annex I habitat.
- (v) Enter the NVC community codes in the comments field and note any ambiguities (should they occur) with regards to the EUNIS classification.
- (vi) Take a photograph of the vegetation in the polygon AND any rare/small-scale Annex I habitats occurring within a larger polygon of another extensive/widespread habitat (include a description of the photo in the Comment field).
- (vii) Once this information has been collated move on to the next polygon.

The following guidance was provided on assigning proportions:

- (i) For all widespread/extensive habitats, assign proportional cover to the nearest 0.1 (or 10%). Ignore small fragments of widespread/extensive habitats or small-scale non-Annex I habitats that occur within a polygon of another widespread/extensive habitat where the cover of the fragmentary habitat is <10% or total area is <1ha.
- (ii) For rare/small-scale Annex I habitats, assign proportion cover to the nearest 0.01 (1%).
- (iii) Rocky slope and scree – include all habitat whether associated vegetation is present or not, assign proportional cover to full extent of the rock face/crag or scree patch.
- (iv) Combined proportions of the individual habitats mapped in each polygon must add up to 1.

3.2.2 Habitat definitions

Field surveyors were also provided with clear definitions for a small number of potentially problematic habitats to avoid ambiguity over classification and ensure consistency between field and classified data and with each other. These were as follows:

- (i) *F4.2 dry heath* – all heath with upright *Calluna vulgaris* and other dwarf-shrubs should be classified as *F4.2*, irrespective of its position in relation to any perceived potential treeline (NVC types H10, H12, H16, H18, H21, H22).
- (ii) *F2.25 boreo-alpine and arctic heath* – heath with prostrate *C. vulgaris* and/or a sparse, open cover of other wind-pruned dwarf shrubs, and a generally smooth texture should be classified as *F2.25* (NVC types H10, H12, H13, H14, H15, H16, H17, H18, H19, H20, H21, H22). There will often also be much exposed stone, a high

cover of lichens and/or *Racomitrium lanuginosum* moss, and presence of alpine species.

(iii) *Nardus* grassland (NVC type U5) – note the sub-community of this habitat and its corresponding EUNIS class. U5a,d,e = *E1.71* Nardus stricta *swards*; U5b is included in *E3.52 heath* Juncus *meadows and humid* Nardus stricta *swards*; U5c is included in *E1.72# species-rich* Nardus *grassland*.

(iv) Map bare peat in blanket bogs as *D1.24 wet bare peat and peat haggs on blanket bogs*, assign proportional cover as per other widespread/extensive habitats.

Once the field survey was complete, data was downloaded from the ArcGIS Collector application on the tablet, converted and imported into an ArcGIS geodatabase, then exported to Excel for analysis.

Of the 360 samples selected for field survey, 319 were successfully visited and classified by the field survey team and used as the field data sample. The remaining 41 were not visited due to time and access constraints.

3.3 Interpretation of results

Data was sorted according to the original habitat classes that were assigned to the classified data, then each sample was examined in turn and the field data compared with the classified data.

To be consistent with the classified data, the field data was interpreted according to the same mapping rules (Annex 3). To allow for differences in proportional cover estimates between the individual doing the classification and the individual collecting the field data, a tolerance of up to 20% was permitted between the proportional cover assigned to a habitat in the classified data and that assigned in the field data. This was particularly important when considering thresholds of other allowable habitats within polygons of a widespread/extensive habitat.

For example, if up to 10% of a single allowable habitat was permitted within a polygon of a widespread habitat (according to the mapping rules), i.e. it didn't have to be included as a component habitat by the classification, then with the 20% tolerance, up to 30% of a single other allowable habitat could be present in the field data without the classification being penalised for not including it as a component habitat. A 50% tolerance was also applied to the 1 ha area threshold for allowable habitats, meaning that a secondary habitat didn't have to be included by the classification unless its area was >1.5 ha OR >30%.

Taking account of the mapping rules, each sample was scored as either correct or incorrect. If incorrect, the category (habitat class) that the sample should have been assigned to was identified. If the primary habitat was correctly classified but a significant area of secondary habitat was overlooked, and/or if that secondary habitat should have been delineated as an individual polygon, then this was considered an error.

The data was then used to populate an error matrix for each of the pilot sites as per Congalton and Green (2008). This is the standard way to present accuracy assessment data, enabling the number of correct samples for each habitat class to be visualised along with the incorrect samples and the category to which they actually belong.

4. RESULTS

4.1 Beinn Eighe and Flowerdale pilot site

The habitat map produced for the Beinn Eighe and Flowerdale pilot site using the sCIR API technique is provided as a GIS polygon feature class in the supplementary material accompanying this report is available via the HabMoS dataset on SEWeb[5].

The results of the accuracy assessment are presented in an error matrix in Table 7 below. Columns in the error matrix represent the 'reference data' (field data) and rows represent the 'classified data' (mapped data). The 'column total' is the total number of samples assigned to a class ('habitat X') by the reference data. The 'row total' is the total number of samples assigned to 'habitat X' by the classified data.

Reading down a column in the error matrix, the number of samples correctly classified as 'habitat X' can be seen by reading along from the corresponding row in the classified data (= highlighted cells along the diagonal). If there are numbers in any of the other cells in a column, these represent 'errors of exclusion' (omission errors) where samples that should have been classified as 'habitat X' were incorrectly assigned to another habitat class.

Reading across a row in the error matrix for 'habitat X', if any of the cells in the row contain a number other than the corresponding column, these represent 'errors of inclusion' (commission errors) where samples called 'habitat X' in the classified data actually belong in another habitat class.

The 'producer's accuracy' is calculated by dividing the number of correct samples for 'habitat X' by the column total, and is a measure of 'omission error'. The 'user's accuracy' is calculated by dividing the number of correct samples for 'habitat X' by the row total, and is a measure of 'commission error'. Overall map accuracy is calculated by summing the total number of correctly classified samples in each habitat class (i.e. cells following the diagonal) divided by the total number of samples in the error matrix.

The overall accuracy of the Beinn Eighe and Flowerdale forest habitat map in the areas overlapped by the reference data sample was 78% (Table 7). With a confidence interval size of 10%, the true map accuracy can be predicted to lie between 73% and 83%.

[5] See Habitat Map of Scotland (HabMoS) dataset on Scotland's Environment website https://www.environment.gov.scot/our-environment/habitats-and-species/habitat-map-of-scotland/

Table 7. Error matrix presenting accuracy assessment results of habitat map derived from sCIR API technique at Beinn Eighe and Flowerdale pilot site.

		Reference (field) data												
		Blanket bog	Blanket bog / wet heath	Siliceous alpine grassland	Bracken	Alpine heath	Wet heath	Wet heath / alpine heath	Wet heath / dry heath	Dry heath	Siliceous scree	Siliceous rocky slope	Row total	User's accuracy
Classified (mapped) data	Blanket bog	27	3				2						32	0.84
	Blanket bog / wet heath	1	2				3						6	0.33
	Siliceous alpine grassland			8									8	1.00
	Bracken				2								2	1.00
	Alpine heath			1		4	1			2			8	0.50
	Wet heath	1	9				25	1					36	0.69
	Wet heath / alpine heath						1						1	0.00
	Wet heath / dry heath							1	2				3	0.67
	Dry heath					1			3	8			12	0.67
	Siliceous scree										15		15	1.00
	Siliceous rocky slope											14	14	1.00
	Column total	29	14	9	2	5	32	2	5	10	15	14	137	
	Producer's accuracy	0.93	0.14	0.89	1.00	0.80	0.78	0.00	0.40	0.80	1.00	1.00		Overall accuracy = 78%

The following sections provide a summary of the results for each of the 11 habitat classes derived from the Beinn Eighe and Flowerdale map. The corresponding EUNIS habitat codes for each habitat class are included in the headings [in square brackets], and within the text, and the Annex I codes (in ordinary brackets).

In this summary, errors with the mapping are emphasised as a means of highlighting where there is scope for improvement with the mapping method, rather than being truly reflective of the overall success of the method.

4.1.1 Blanket bog [D1.2] (H7130)

Of the 32 samples classified as *D1.2 blanket bog*, 27 were correct. Of the five incorrectly classified samples, three were *D1.2 blanket bog* / *F4.11 northern wet heath* mosaic, and two were *F4.11 northern wet heath* (these are 'commission errors' – samples assigned to the blanket bog class that should have been assigned to another habitat class).

D1.2 blanket bog was misclassified in a further two samples as *D1.2 blanket bog* / *F4.11 northern wet heath* mosaic (one sample), and *F4.11 northern wet heath* (one sample) (these are 'omission errors' – samples that should have been classified as blanket bog that were incorrectly assigned to another habitat class).

4.1.2 Blanket bog / Northern wet heath mosaic [D1.2 / F4.11] (H7130 / H4010)

This mosaic class was included in the accuracy assessment to incorporate polygons which had been classified as *D1.2 blanket bog* with a significant proportion (≥40% but ≤60%) of *F4.11 northern wet heath* as a secondary habitat, or vice versa.

Of the six samples classified as *D1.2 blanket bog* / *F4.11 northern wet heath* mosaic, two were correctly classified. Of the four incorrectly classified samples, 1 was 'pure' *D1.2 blanket bog*, three were 'pure' *F4.11 northern wet heath*.

D1.2 blanket bog / *F4.11 northern wet heath* mosaic was misclassified in a further 12 samples as *D1.2 blanket bog* (three samples), and *F4.11 northern wet heath* (nine samples).

4.1.3 Siliceous alpine and boreal grassland [E4.32€] (H6150)

Of the eight samples classified as *E4.32€ siliceous alpine and boreal grassland*, eight were correct. Discrimination between the two EUNIS types *E4.21* and *E4.32* by the classification was correct in all cases.

One sample of *E4.32€ siliceous alpine and boreal grassland* was misclassified as *F2.25 boreo-alpine and arctic heath*.

4.1.4 Bracken - sub-Atlantic Pteridium aquilinum fields [E5.31] (non-Annex 1)

Of the two samples classified as *E3.51 sub-Atlantic* Pteridium aquilinum *fields*, two were correct.

4.1.5 Boreo-alpine and arctic heath [F2.25] (H4060)

Of the eight samples classified as *F2.25 boreo-alpine and arctic heath*, four were correct. Of the four incorrectly classified samples, one was *E4.32€ siliceous alpine and boreal grassland*, one was *F4.11 northern wet heath*, and two were *F4.2 dry heath*.

F2.25 boreo-alpine and arctic heath was misclassified as *F4.2 dry heath* in one sample.

4.1.6 Northern wet heath [F4.11] (H4010)

Of the 36 samples classified as *F4.11 northern wet heath*, 25 were correct. Of the 11 incorrectly classified samples, one was *D1.2 blanket bog*, nine were *D1.2 blanket bog / F4.11 northern wet heath* mosaic, and one was *D1.2 blanket bog / F2.25 boreo-alpine and arctic heath* mosaic.

F4.11 northern wet heath was overlooked in a further seven samples, being primarily misclassified as *D1.2 blanket bog* (two samples), and *D1.2 blanket bog / F4.11 northern wet heath* mosaic (three samples).

4.1.7 Northern wet heath / Boreo-alpine and arctic heath mosaic [F4.11 / F2.25] (H4010 / H4060)

This mosaic class was included in the accuracy assessment to incorporate polygons which had been classified as *F4.11 northern wet heath* with a significant proportion (≥40% but ≤60%) of *F2.25 boreo-alpine and arctic heath* as a secondary habitat, or vice versa.

The one sample classified as *F4.11 northern wet heath / F2.25 boreo-alpine and arctic heath* mosaic was incorrect. It was actually 'pure' *F4.11 northern wet heath*.

F4.11 northern wet heath / F2.25 boreo-alpine and arctic heath mosaic was misclassified in as *F4.11 northern wet heath* in one sample and *F4.11 northern wet heath / F4.2 dry heath* mosaic in one sample.

4.1.8 Northern wet heath / Dry heath mosaic [F4.11 / F4.2] (H4010 / H4030)

This mosaic class was included in the accuracy assessment to incorporate polygons which had been classified as *F4.11 northern wet heath* with a significant proportion (≥40% but ≤60%) of *F4.2 dry heath* as a secondary habitat, or vice versa.

Of the three samples classified as *F4.11 northern wet heath / F4.2 dry heath* mosaic, two were correct, and one was *F4.11 northern wet heath / F2.25 boreo-alpine and arctic heath* mosaic.

F4.11 northern wet heath / F4.2 dry heath mosaic was misclassified as *F4.2 dry heath* in a further three samples.

4.1.9 Dry heath [F4.2] (H4030)

Of the 12 samples classified as *F4.2 dry heath*, eight were correct. Of the four incorrectly classified samples, three were *F4.11 northern wet heath / F4.2 dry heath* mosaic, one was *F2.25 boreo-alpine and arctic heath*.

F4.2 dry heath was misclassified as *F2.25 boreo-alpine and arctic heath* in a further two samples.

4.1.10 Siliceous scree of the montane to snow levels [H2.31€] (H8110)

Of the 15 samples classified as *H2.31€ siliceous scree of the montane to snow levels*, 15 were correct.

The reference (field) data recorded *H2.31€ siliceous scree of the montane to snow levels* as a significant component in a number of other sample polygons, suggesting that these areas had been overlooked by the classification. Following discussion with the field surveyor, it was concluded that this error is the result of differences in interpretation of the habitat definition, rather than genuine errors in the classified data (Colin Wells, pers. comm.). As such, these were not included as omission errors in the error matrix.

Variation in the way that different individuals interpret habitat definitions is a common source of error in habitat mapping. When considering a large scale mapping roll-out, such errors could be overcome by running training/familiarisation days to ‘calibrate’ the mapping team.

4.1.11 Siliceous rocky slope [H3.1#] (H8220)

Of the 14 samples classified as *H3.1# siliceous rocky slope*, 14 were correctly classified.

As above, there was some discrepancy between the classified data and reference data for this habitat type in a number of additional sample polygons. This was the result of differences in interpretation of the habitat definition by the field surveyor.

4.1.12 Discussion of result

Analysis of the accuracy assessment result (Table 7) revealed that a total of five widespread/extensive and two locally extensive upland Annex I habitats, and one widespread/extensive non-Annex I habitat, were successfully identified and mapped by the sCIR technique at the Beinn Eighe and Flowerdale pilot site. A further three mosaic classes were mapped with varying levels of success.

Two main sources of error / weaknesses with the classification were identified. These are as follows:

(i) *D1.2 blanket bog* vs. *F4.11 northern wet heath* vs. *D1.2 blanket bog / F4.11 northern wet heath mosaic*

The results described for *D1.2 blanket bog*, *F4.11 northern wet heath*, and *D1.2 blanket bog / F4.11 northern wet heath* mosaic highlight a limited amount of confusion between these habitat classes. In a small number instances, a ‘pure’ *D1.2 blanket bog* sample in the classified data was recorded as a ‘pure’ *F4.11 northern wet heath* sample by the field surveyor, or vice versa (Table 7). These represent genuine errors with the classification.

In a greater number of instances, a sample classified as ‘pure’ *F4.11 northern wet heath*, or one with only a small proportion of *D1.2 blanket bog* as a secondary habitat (i.e. ≤20%), or vice versa, was recorded as a *D1.2 blanket bog / F4.11 northern wet heath* mosaic by the field surveyor. These errors were also apparent the other way around – a small number of samples classified as *D1.2 blanket bog / F4.11 northern wet heath* mosaic were recorded by the field surveyor as *F4.11 northern wet heath* (with only a small proportion of *D1.2 blanket bog* as a secondary habitat), or vice versa. While these samples were assigned to the wrong habitat class by classification, they were not completely incorrect – either belonging to the single habitat class rather than the mosaic class, or vice versa.

Graminoid-rich forms of *F4.11 northern wet heath* share a similar suite of species as graminoid-rich forms of *D1.2 blanket bog* (in particular, NVC type M17). They can also occur in similar situations on flat ground. Where clues as to the depth of peat aren’t obvious from the imagery (e.g. raised/hagged peat edges are a good indicator of deep peat; visible stones/rocks of smaller sizes among the vegetation are a good indicator of shallower peat), there is potential for confusion between these habitat types.

The following comment was added by the field surveyor: *“Estimating proportions of habitats was often possible using the imagery – for rock and scree it was extremely clear. Sometimes the differences between wet heath and blanket bog were picked out nicely as* *different shades – but at other times the colours didn't seem to reflect the differences in types on the ground so well – so proportions were usually estimated using what one could actually identify in the field while traversing the polygons."* (Colin Wells, pers. comm.).

The above comment from the field surveyor alludes to some potential difficulty in identifying and assigning proportional cover to the two habitat types using imagery in the field. Some of the apparent error may be explained by discrepancy between proportions assigned by the field surveyor and those assigned in the classified data. This is particularly relevant when considering if a sample falls in the single habitat class or mosaic class.

These localised issues could be addressed and accuracy of the interpretation improved following targeted field checks.

(ii) *F2.25 boreo-alpine and arctic heath* vs *F4.11 northern wet heath* vs *F4.2 dry heath*

The results described for *F2.25 boreo-alpine and arctic heath*, *F4.2 dry heath*, plus *F4.11 northern wet heath* / *F2.25 boreo-alpine and arctic heath* mosaic, and *F4.11 northern wet heath* / *F4.2 dry heath* mosaic, highlight some limited confusion in classification between these habitat classes.

The field data confirms that these errors are confined to certain forms of *F4.11 northern wet heath* (NVC type M15c), *F4.2 dry heath* (H10b) and *F2.25 boreo-alpine and arctic heath* (H10b and H14), where they occur as a sparse cover of short, wind-pruned vegetation, with frequent *Calluna vulgaris*, on stony knolls and slopes (moraine deposits), typically amidst an extensive matrix of other forms of *F4.11 northern wet heath* and *D1.2 blanket bog*. The similar appearance of these vegetation types in the CIR imagery and equal likelihood of occurrence in the situations described above make them difficult to distinguish from one another. Field checking a sample of these polygons could help to improve the accuracy of mapping, but it is difficult to envisage how this issue could be resolved entirely.

It is worth noting that in situations where the above mentioned habitats and associated errors of classification occur, they comprise a very small proportion of the total vegetation cover, which is generally otherwise dominated by *F4.11 northern wet heath*. With that in mind, these localised errors are likely to be of limited significance to the overall accuracy and utility of the map.

4.2 Caenlochan – Cairngorms pilot site

The habitat map produced for the Caenlochan – Cairngorms pilot site using the sCIR API technique is provided as a GIS polygon feature class in the supplementary material accompanying this report is available via the HabMoS dataset on SEWeb[5].

The results of the accuracy assessment are presented in an error matrix in Table 8 below, and the following sections provide a summary of the results for each of 16 habitat classes derived from the map.

The overall accuracy level of the habitat map in the areas overlapped by the reference data sample was 76%. With a confidence interval size of 10%, the true map accuracy can be predicted to lie between 71% and 81%.

Table 8. Error matrix presenting accuracy assessment results of habitat map derived from sCIR API technique at Caenlochan – Cairngorms pilot site.

Classified (mapped) data	Reference (field) data →	Blanket bog	Blanket bog mosaic	Bare peat	Poor fen	Alkaline fen / Alpine pioneer	Acid grassland	Species-rich *Nardus* grassland	Wet grassland	Bracken	Siliceous alpine grassland	Snow-patch grassland	Alpine heath	Dry heath	Dry heath / acid grassland	Siliceous scree	Siliceous rocky slope	Row total	User's accuracy
	Blanket bog	32	4		1	1	2											40	0.80
	Blanket bog mosaic	1	1		2		1											5	0.20
	Bare peat			8														8	1.00
	Poor fen								1									1	0.00
	Alkaline fen / Alpine pioneer formations					9												9	1.00
	Acid grassland					2	16	3						1	3			25	0.64
	Species-rich *Nardus* grassland					1	1	8										10	0.80
	Wet grassland				1		1	1	2	1								6	0.33
	Bracken									3								3	1.00
	Siliceous alpine grassland						1				3	1						5	0.60
	Snow-patch grassland						1					1						2	0.50
	Alpine heath						1						6	4	1			12	0.50
	Dry heath		1				5							27	1			34	0.79
	Dry heath / acid grassland						1	1							4			6	0.67
	Siliceous scree															22		22	1.00
	Siliceous rocky slope					1											3	4	0.75
	Column total	33	6	8	4	14	30	13	3	4	3	2	6	32	9	22	3	192	
	Producer's accuracy	0.97	0.17	1.00	0.00	0.64	0.53	0.62	0.67	0.75	1.00	0.50	1.00	0.84	0.44	1.00	1.00		Overall accuracy = 0.76

4.2.1 Blanket bog [D1.2] (H7130)

Of the 38 samples classified as *D1.2 blanket bog*, 32 were correct. Of the six incorrectly classified samples, four were *D1.2 blanket bog* mosaics where blanket bog occurred in roughly equal proportion to other habitats – three were mosaics with *D2.22 poor fen* and/or *E1.71/E3.52 acid grassland*, the other was a mosaic with *F4.2 dry heath*. The remaining two incorrectly classified samples were *E3.52 acid grassland* (NVC types U5b/U6).

In addition, a significant area of *D2.22 poor fen* was overlooked in one blanket bog sample, and an area of *D4.1 rich fen* was overlooked in another sample, leading to two additional commission errors for the *D1.2 blanket bog* class.

D1.2 blanket bog was misclassified as *blanket bog mosaic* in one additional sample.

In a few instances, significant areas of secondary habitat were overlooked by the classification, mostly *D2.22 poor fen*, *E3.52 acid grassland*, and/or *E3.41 wet grassland*. The cover of these habitats, according to the field data, did not typically exceed 20% but polygons were often large so the cumulative area was >1ha but <5ha. Where these occurred as an intimate mix with *D1.2 blanket bog*, rather than clearly defined areas which could be delineated separately, the view was taken not to penalise the classification as these habitats could be considered part of the blanket bog complex.

4.2.2 Blanket bog mosaic [D1.2 / D2.22 or E1.71 or E3.52 or F4.2] (H7130 / none / none/ none / H4030)

This class was created for polygons where the proportion of *D1.2 blanket bog* was ≥0.4 and ≤0.6 with one or more additional habitats, including *D2.22 poor fen*, *E1.71/E3.52 acid grassland*, or *F4.2 dry heath*.

Of the five samples classified as blanket bog mosaic, one was correct. Of the four incorrect samples, one was *D1.2 blanket bog* (secondary habitats were mentioned by the field surveyor in the comments field but not included because they were "*all on deep peat*"), one was *E3.52 acid grassland*, two samples were *D2.22 poor fen*.

Blanket bog mosaic was misclassified as *D1.2 blanket bog* in a further four samples, and as *F4.2 dry* heath in one sample.

4.2.3 Bare peat [D1.24] (H7130)

Of the eight samples classified as *D1.24* bare peat, eight were correct. This is a distinctive and relatively easy habitat to detect in the context of a *D1.2 blanket bog* complex.

4.2.4 Poor fen [D2.22]

The one sample classified as *D2.22 poor fen* was actually *E3.41 wet grassland*. Some forms of *D2.22* (NVC type M6c and M6d) are superficially similar to *E3.41* (NVC type M23b) and *E3.42* (M23a), sharing the same dominant species and occurring in similar situations. Successful discrimination between these habitats is unlikely using aerial imagery alone.

D2.22 poor fen was misclassified as *blanket bog mosaic* in a further two samples, and *D1.2 blanket bog* in one sample.

4.2.5 Alkaline fens [D4.15€] (H7230) / Alpine pioneer formations [D4.24€] (H7240)

Of the nine samples classified as *D4.15€ alkaline fen*, nine were correct. Several examples of this rare/small-scale habitat were encountered during reconnaissance fieldwork which enabled a good search image to be developed and used to detect additional occurrences in other parts of the site.

The examples of *D4.15€ alkaline fen* that were successfully mapped tended to be larger in size and/or in situations where, for example, a number of smaller flushes occurred together across a slope, increasing the likelihood of detection. Indeed, *D4.15€ alkaline fen* was overlooked in a further five samples where it occurred as small/occasional flushes within areas of other widespread habitats.

However, flushes of varying sizes were often visible in the aerial imagery, enabling 'potential' occurrences of this habitat to be identified. These can act as areas of search to be checked during subsequent fieldwork to determine whether they are acid or alkaline flushes.

The field data also recorded *D4.1N hard water spring mires* (H7220) in three out of nine samples classified as *D4.15€ alkaline fen*. As a habitat feature that typically covers very small areas (only one or a few square metres), *D4.1N hard water spring mires* are unlikely to be detected using aerial imagery alone, and were not considered a realistic target of this mapping exercise. Successful mapping of this habitat will depend upon encountering occurrences during reconnaissance fieldwork, and/or visits to specific areas of search, and is intimately linked to field checking of 'potential' *D4.15€ alkaline fen* locations.

D4.24€ alpine pioneer formations were also recorded in one out of nine samples classified as D4.15€ alkaline fen, where it occurred in the same flush system – i.e. it was recorded as a minor secondary habitat in a polygon predominantly classified as *D4.15€ alkaline fen* by the field surveyor. *D4.15€ alkaline fen* and *D4.24€ alpine pioneer formations* are very similar habitats, occurring in channels flushed with base-rich ground water. Plant species composition is the key distinguishing factor, so fieldwork and/or indicator plant species datasets would be required to discriminate.

4.2.6 Acid grassland [E1.71/E1.72x/E3.52] (non-Annex 1)

The acid grassland class was created to combine several EUNIS types *E1.71* Nardus stricta *swards* (NVC types U5a,d,e), *E1.72x other* Agrostis-Festuca *grassland* (U4a,b,d,e) and *E3.52 Heath* Juncus *meadows and humid* Nardus stricta *swards* (U5b and U6) that were difficult to discriminate from aerial imagery alone.

Of the 20 samples classified as acid grassland, 16 were correct. Of the four incorrect samples, three were *F4.2 dry heath / acid grassland* mosaic (comment from field surveyor notes "grassy heath" in both of these instances), one was *F4.2 dry heath* (comment from field surveyor notes H12 with abundant *Juncus squarosus* and *Nardus*).

A proportion of *E1.72# species-rich* Nardus *grassland* was overlooked in three of 20 samples, and *D4.15€ alkaline fen* overlooked in two of 20 samples, leading to five additional commission errors for this class.

Acid grassland was misclassified in a further 14 samples, being primarily misclassified as *F4.2 dry heath* and a range of other grassland types.

4.2.7 Species-rich Nardus grassland [E1.72#] (H6230)

Of the nine samples classified as *E1.72# species-rich* Nardus *grassland*, eight were correct. The one incorrect sample was *E1.72x acid grassland*.

In six of these samples, *D4.15€ alkaline fen* had been correctly classified as a secondary habitat. In one sample, *D4.15€ alkaline fen* was overlooked by the classified data giving one additional commission error for the *E1.72# species-rich* Nardus *grassland* class.

Flushed *Nardus* grassland (NVC type U5c and CG10b/c) is relatively distinctive, and comprised the bulk of the *E1.72# species-rich* Nardus *grassland* successfully detected and classified at Caenlochan. Proximity to *D4.15€ alkaline fen* was used as a key indicator for this grassland type.

E1.72# species-rich Nardus *grassland* was overlooked in a further five samples, being primarily misclassified as *E1.71/E3.52 acid grassland*. In most instances the *E1.72# species-rich Nardus grassland* occurred as a secondary habitat within a larger polygon of acid grassland. Field checking of a sample of grassland polygons could help to improve detection in these instances.

4.2.8 Wet grassland [E3.4/E3.5] (non-Annex 1)

Of the six samples classified as *E3.4/E3.5 wet grassland*, two were correct. Of the four incorrect samples, one was *D2.22 poor fen*, one was *E1.72x acid grassland*, one was *E1.72# species-rich* Nardus *grassland*, and one was *E5.31 sub-Atlantic* Pteridium aquilinum *fields*.

E3.4/E3.5 wet grassland was also misclassified as *D2.22 poor fen* in one additional sample.

4.2.9 Bracken – sub-Atlantic Pteridium aquilinum *fields [E5.31] (non-Annex 1)*

Of the three samples classified as *E3.51 sub-Atlantic* Pteridium aquilinum *fields*, three were correct.

E3.51 sub-Atlantic Pteridium aquilinum *fields* was misclassified as *E3.4 wet grassland* in one sample.

4.2.10 Siliceous alpine and boreal grassland [E4.32€] (H6150)

Of the five samples classified as *E4.32€ siliceous alpine and boreal grassland*, three were correct. Of the two incorrect, one was *E3.52/E1.71 acid grassland* and one was *E4.116 acidocline snow-patch grassland*.

4.2.11 Acidocline snow-patch grassland [E4.116] (non-Annex 1)

Of the two samples classified as *E4.116 acidocline snow-patch grassland*, one was correct. The other was a mix of *E3.52 acid grassland* and tussocky *E1.72# species-rich* Nardus *grassland* – the texture and CIR signal of these grassland types would be similar to *E4.116*.

A further one sample was misclassified as *E4.32€ siliceous alpine and boreal grassland*.

4.2.12 Boreo-alpine and arctic heaths [F2.25] (H4060)

Of the 11 samples classified as *F2.25 boreo-alpine and arctic heaths*, six were correct (two of which were *F2.25 boreo-alpine and arctic heaths / E4.32€ siliceous alpine and boreal grassland* mosaics also correctly classified).

Of the six incorrect samples, four were *F4.2 dry heath*. It is worth noting that for three of these samples polygons were tagged with ‘check’ indicating some degree of uncertainty during classification. Field checking could have significantly improved this result. One sample was a *F4.2 dry heath / acid grassland* mosaic.

One sample contained some *F2.25 boreo-alpine and arctic heath* but with a significant area of *acid grassland* that had not been included in the classification, resulting in one additional commission error for this class. The polygon was tagged with 'check' indicating some uncertainly in classification.

4.2.13 Dry heath [F4.2] (H4030)

Of the 34 samples classified as *F4.2 dry heath*, 27 were correct. Of the seven incorrect samples, one was *D1.2 blanket bog* mosaic, one was *F4.2 dry heath* / *E1.7 acid grassland* mosaic, and five were *E1.71/E1.72x/E3.52 acid grassland*.

In four of the five samples that were *acid grassland*, comments by the field surveyor mentioned the presence of grassy dry heath (NVC types H12/H18) within the polygon and/or frequent *Vaccinium myrtillus* among the grassland. In the other acid grassland sample, the field surveyor commented that it was derived from burning of blanket bog.

The above errors suggest that too much weight was given to the dwarf-shrub signal, rather than the grassland signal, during interpretation and ultimately highlights some difficulty in discriminating between grassy-heath and heathy-grassland.

F4.2 dry heath was overlooked in a further five samples, being primarily misclassified as *F2.25 alpine and boreal heath* (four samples).

4.2.14 Dry heath / acid grassland mosaic [F4.2 / E1.71 or E3.52] (H4030 / none)

This class was created for polygons where the proportion of *F4.2 dry heath* was ≥0.4 and ≤0.6 with *E1.71/E3.52 acid grassland* as the secondary habitat.

Of the six samples classified as this mosaic class, four were correct. Of the two incorrect, one was *E1.71/E3.52 acid grassland* (the field surveyor mentioned small patches of dry heath in the comments) and one was *E1.72# species-rich* Nardus *grassland* (dry heath was included as a minor secondary habitat by the field surveyor).

A further three *F4.2 dry heath* / *acid grassland* mosaic samples were misclassified as acid grassland, plus one as *F2.25 boreo-alpine and arctic heath,* and one as *F4.2 dry heath*.

This further compounds some issues in discrimination between grassy-heath and heathy-grassland.

4.2.15 Siliceous scree of the montane to snow levels [H2.31€] (H8110)

Of the 22 samples classified as *H2.31€ siliceous scree of the montane to snow levels*, 22 were correct.

4.2.16 Siliceous rocky slopes with chasmophytic vegetation [H3.1#] (H8220)

Of the three samples classified as *H3.1# siliceous rocky slopes with chasmophytic vegetation*, three were correct.

In one of sample, an area of *D4.15€ alkaline fen* was overlooked leading to an additional commission error for this class.

4.2.17 Discussion of result

Analysis of the accuracy assessment result (Table 8) revealed that a total of ten widespread/extensive and two locally extensive upland habitats (six of which were Annex I), two rare/small scale Annex I habitats were successfully mapped at the Caenlochan pilot site. A further two mosaic classes were mapped with varying levels of success.

The following key sources of error / weaknesses with the classification were identified:

(i) *F2.25 boreo-alpine and arctic heath* vs *F4.2 dry heath*

As for the Beinn Eighe and Flowerdale pilot site, there was some error in discrimination between *F2.25 boreo-alpine and arctic heath*, and *F4.2 dry heath* at the Caenlochan pilot site. This predominantly operated in one direction, with over-classification of *F2.25 boreo-alpine and arctic heath* at the expense of *F4.2 dry heath*. These errors were concentrated in the altitudinal transition zone between the two habitats where *F4.2 dry heath* becomes increasingly wind-clipped and open but not fully alpine in character.

A more conservative approach to classification of *F2.25 boreo-alpine and arctic heath*, and targeted field checking of a sample of 'potential' *F2.25* polygons in the transition zone, would improve the accuracy of mapping of these habitats.

(ii) *F4.2 dry heath* vs *E1.71/E3.52 acid grassland* vs *F4.2 dry heath / acid grassland mosaic*

A small amount of confusion also occurred in discrimination between *F4.2 dry heath*, *E1.71/E3.52 acid grassland*, and *F4.2 dry heath / acid grassland* mosaic. This represents a weakness in interpretation between grassy-heath and heathy-grassland. In particular, rough, tussocky *Nardus* grassland with a low frequency of the dwarf-shrubs *Vaccinium myrtillus* and/or *Calluna vulgaris* can appear very similar to short-cropped dry heath with a high frequency of *Nardus* and other graminoids.

Such errors are not surprising, and represent similar challenges faced in the field when classifying habitats of heavily grazed landscapes, where vegetation exists on a continuum between dry heath, grassy-heathland, heathy-grassland and acid grassland. Further still, there are likely to be differences in the way that individual field surveyors interpret these types.

General field validation and/or targeted field checking of a selection of borderline dry heath / acid grassland polygons would improve accuracy of discrimination of these habitats.

(iii) Acid grassland

One of the main limitations of the interpretation and implementation of EUNIS classification at Caenlochan was discrimination between different types of acid grassland. *Nardus*-dominated grasslands (NVC type U5) have a distinctive spectral signature but some difficulty occurs when applying EUNIS which places moist *Nardus stricta* swards (NVC type U5b) in *E3.52 Heath* Juncus *meadows and humid* Nardus stricta *swards* (along with NVC type U6), separate from drier swards (U5a,d,e) which fall in *E1.71* Nardus stricta *swards*. Stands occurring in close proximity to *D1.2 blanket bog* can be classified as *E3.52* with a certain degree of confidence, but elsewhere the distinction of this type and drier *E1.71* swards is difficult; slope is helpful but not definitive. Where uncertainty is present, the only solution is to map at EUNIS level 1 '*E Grasslands and lands dominated by forbs, mosses or lichens*' and tag as *Nardus stricta* sward *E1.71 or E3.52*. Similarly, *E1.72x other* Agrostis-Festuca *grassland* is not always distinct from *E1.71/E3.52*.

This weakness was recognised during classification of the pilot site, and as a result these EUNIS types were combined to create an 'acid grassland' class. Moving forward, the creation of a new EUNIS composite ‘acid grassland’, incorporating *E1.71, E1.72x* and *E3.52*, would help to overcome this problem.

5. DISCUSSION

5.1 The sCIR API technique can deliver accurate mapping of upland habitats

Development and application of the sCIR API technique at two 100 km^2 pilot sites in Scotland has demonstrated that this method can deliver accurate mapping of a broad range of upland habitats to EC Habitats Directive Annex I or equivalent EUNIS level.

All five widespread/extensive (*D1.2 blanket bog*; *E4.32€ siliceous alpine and boreal grasslands*; *F2.25 boreo-alpine and arctic heaths*; *F4.11 northern wet heaths*; *F4.2 dry heaths*) and two locally extensive (*H2.31€ siliceous scree*; *H3.1# siliceous rocky slope*) upland Annex I habitats, and a further 7 widespread non-Annex I habitats, were successfully mapped to an overall accuracy level of 75-80%.

In addition, the ability of this method to detect significant examples of rare/small-scale Annex I habitats (*D4.15€ alkaline fen*; *E1.72# species-rich Nardus grassland*), predicted to be more challenging to map, was demonstrated at Caenlochan, as was an ability to identify areas of search for targeted field survey of other habitats not discernible from the imagery alone (e.g. *D4.1N hard water spring mires* via association with *D4.15€ alkaline fen*).

It should be noted that the majority of errors with the classification were related to localised confusion between habitats which exhibit a certain degree of similarity in terms of dominant species and the situations that they occupy (e.g. *F2.25 boreo-alpine and arctic heaths* vs *F4.2 dry heaths*), and/or discrimination between 'pure' stands of a habitat and mosaics with other superficially similar habitats (e.g. *D1.2 blanket bog* vs. *F4.11 northern wet heaths*), and hence these errors are, to an extent, understandable.

Due to time constraints, a very limited amount of field checking or validation of draft map outputs was undertaken before the accuracy assessment. Inclusion of this critical step, a normal part of the mapping process, would likely increase accuracy levels significantly above those reported here by addressing some localised confusion between superficially similar habitats.

5.2 Potential contribution of the sCIR API technique to upland mapping

Based on habitats successfully mapped at the two pilot sites, projections were made about the potential application of the sCIR API technique for mapping the full suite of 32 (Annex I or equivalent level) habitats which occur across the Scottish uplands, along with the relative intensity of fieldwork required to map them successfully. This analysis is presented in Table 9 where groupings of the 22 Annex I habitats are considered first, followed by groupings of the 10 non-Annex I habitats.

Of the 32 upland habitats, 17 are widespread in Scotland, mostly occurring in extensive stands, and through a combination of spectral signal and knowledge of the landscape they occupy and the ecological conditions they require are relatively easy to detect in the imagery (Groups A, B, F to I, Table 9). The sCIR API technique has the potential to offer full mapping of these habitats, which together comprise the vast bulk of the uplands, with only a low intensity of on-going fieldwork required to resolve specific areas of uncertainty encountered during classification.

Some localised exceptions occur, particularly among non-Annex I grasslands and forb-dominated habitats (Groups G & H, Table 9), which although readily recognisable at a higher level, may sometimes require a moderate level of field checking to separate from other superficially similar habitats (if desirable to classify them below EUNIS level one or two). Rather than visiting all examples, however, targeted checks of a small sample of grasslands sharing a similar spectral signature and/or occupying a similar range of site conditions would be sufficient to facilitate accurate classification and extrapolation over the local target area.

The remaining 15 habitats (Groups C, D & E, Table 9) are relatively rare, or at best locally frequent, in the Scottish uplands. They generally occur in small-scale stands and require ancillary information (e.g. knowledge of underlying geology and/or indicator species) to identify them, and are potentially more challenging to detect and classify using aerial imagery alone. Collectively, the locations in which these habitats occur comprise a very small proportion of the total upland area.
Eleven of these 15 habitats can be further divided in to:

(i) Group C. Six habitats that typically occur in stands large enough to be seen in the imagery and, with a degree of 'local' knowledge gained from reconnaissance fieldwork and/or ancillary data, 'potential' occurrences can be detected, a sample of which would require field visits to confirm and distinguish from other superficially similar habitats. For example, stony flushes can be readily detected in the imagery where more frequent or locally extensive. Field visits would be required to determine if they are acid or alkaline, and to distinguish *D4.15€ alkaline fen* from *D4.24€ alpine pioneer formations* (via indicator species) in areas where both may occur. While visits to a large proportion of 'potential' occurrences would be necessary, detection in the imagery enables fieldwork to be targeted directly to the areas where it is most required.
(ii) Group D. Five habitats that are too small or difficult to determine from imagery alone (e.g. *D4.1N hard water spring mires* which occur as very small patches; *E5.59 oro-boreal tall-herb communities* which are often in shadow in imagery due to their cliff or crag locations). All instances require a field visit to confirm plant species composition and extent. The sCIR API technique can optimise the efficiency of this process by utilising ancillary data or local knowledge combined with landscape features to identify specific areas of search for fieldwork. For example, detailed geology data could be used to detect outcropping of base-rich rock. Scree patches occurring in proximity to this outcropping would be targeted for field visits to check for *H2.4€ calcareous and calcshist screes* (rather than checking all scree patches encountered during mapping, the majority of which are *H2.31€ siliceous scree*). Similarly, networks of pools and depressions are readily visible among areas of *D1.2 blanket bog* in the imagery. Combined with a dataset showing the distribution of *Rhynchospora alba,* target areas for field visits to search for *D2.37* Rhynchospora alba *quaking bogs* could be identified.

The remaining four rare/small-scale habitats (Group E, Table 9) have much of their extent already known, either via existing habitat maps produced for designated sites and/or other datasets. There is limited potential for the sCIR API technique to contribute significantly to further mapping of these habitats, apart from offering more accurate delineation of known locations for *E1.B1 Atlantic heavy-metal grassland*; *E1.26 Sub-Atlantic semi-dry calcareous grassland*; *H3.511€ limestone pavements*, using existing surveys as reference data. Field checks of re-mapped areas would be required to confirm accuracy of classification and extent of the feature. It should be noted that as well as being of small total extent, these habitats are all restricted to limited geographical areas due to their specialised substrate requirements.

The last of these four habitats is *F2.1# sub-Arctic* Salix *spp. scrub*, a habitat of ledges on steep, shaded cliffs and gullies, comprising small populations (often <50 plants) of montane *Salix* spp. This habitat is difficult or impossible to see in the imagery, and although many locations are already documented in the Montane Scrub Database (a point-based dataset), more accurate mapping of these locations requires targeted field survey in all instances. However, opportunistic detection of this habitat is likely during field survey targeted to areas of search for other rare/small-scale habitats which occur in similar situations (e.g. *E5.59 oro-boreal tall-herb communities*).

In summary, it can be concluded that the sCIR API technique has potential to offer full mapping of all 17 widespread/extensive upland habitats to Annex I or equivalent level with a low intensity of fieldwork. Significant examples of a further 11 rare/small-scale Annex I habitats can be mapped by identifying ‘potential’ occurrences and specific areas of search for targeted fieldwork. A higher intensity of fieldwork will be required to successfully map these rare/small-scale habitats, but this is localised to the small proportion of the uplands in which they occur. The potential contribution to mapping the remaining four rare/small-scale habitats is limited to more accurate delineation of known locations and/or opportunistic detection during fieldwork.

Table 9. Potential contribution of the sCIR API technique for mapping the full suite of habitats that occur across the Scottish uplands

Group	EUNIS habitat	EUNIS code	Annex I code	Occurrence / extent	Capability to map and detect using sCIR API method	Fieldwork* intensity	Potential contribution of sCIR API technique
A	Blanket bogs	D1.2	H7130	Widespread / extensive	Relatively easy to detect and map. Limited amount of confusion with other habitats – can be resolved with field checks.	LOW	Full mapping with limited amount of field checking.
	Siliceous alpine and boreal grasslands	E4.32€	H6150				
	Boreo-alpine and arctic heaths	F2.25	H4060				
	Northern wet heaths	F4.11	H4010				
	Dry heaths	F4.2	H4030				
B	Siliceous scree of the montane to snow levels	H2.31€	H8110	Locally extensive	Relatively easy to detect and map. Potential for localised confusion with calcareous rock habitats –informed by geology data.	LOW	Full mapping with limited amount of field checking.
	Siliceous rocky slopes with chasmophytic vegetation	H3.1#	H8220				
C(i)	Transition mires and quaking bogs	D2.33€	H7140	Rare / medium to small-scale	Possible to detect where extensive or locally frequent. Targeted field checks required to distinguish from other superficially similar habitats.	MED	Full mapping of the most significant areas / examples, and a proportion of smaller examples with targeted field checking.
	Species-rich *Nardus* grassland, on siliceous substrates in mountain areas	E1.72#	H6230				
	Alpine and subalpine calcareous grasslands	E4.12€	H6170				
	Juniperus communis scrub	F3.16#1	H5130				
C(ii)	Alkaline fens	D4.15€	H7230	Rare / small-	Flushes can be detected	HIGH	Full mapping of the

Group	EUNIS habitat	EUNIS code	Annex I code	Occurrence / extent	Capability to map and detect using sCIR API method	Fieldwork* intensity	Potential contribution of sCIR API technique
	Alpine pioneer formations of the *Caricion bicoloris-atrofuscae*	D4.24€	H7240	scale	where more extensive or locally frequent. Geology data could help to identify areas of search. Field checks required to confirm acid / alkaline / indicator species.		most significant areas / examples, and a proportion of smaller examples with targeted field checking.
D	*Rhynchospora alba* quaking bogs	D2.37	H7150	Rare / small-scale	Difficult or too small scale to detect in imagery. Geology data and/or plant species datasets could help to identify areas of search. Field survey required to establish presence of indicator species and map extent.	V.HIGH	Effective targeting of fieldwork to likely areas of search. Fieldwork required to confirm all occurrences.
	Hard water spring mires	D4.1N	H7220				
	Oro-boreal tall-herb communities	E5.59	H6430				
	Calcareous and calcshist screes of the montane to alpine levels (*Thlaspietea rotundifolii*)	H2.4€	H8120				
	Alpine and sub-mediterranean chasmophyte communities	H3.25	H8210				
E(i)	Atlantic heavy-metal grassland	E1.B1	H6130	Rare / small-scale	Many locations and much of extent within designated sites or otherwise known. Requires field survey.	HIGH	Limited. More accurate delineation of known locations. Opportunistic detection during field checks for other habitats.
	Sub-Atlantic semi-dry calcareous grassland	E1.26	H6210				
	Limestone pavements	H3.511€	H8240				
E(ii)	Sub-Arctic *Salix* spp. scrub	F2.1#	H4080	Rare / small-scale	Potential for detection limited due to very small scale. Covered by existing scrub	V.HIGH	Limited. Opportunistic detection during reconnaissance

Group	EUNIS habitat	EUNIS code	Annex I code	Occurrence / extent	Capability to map and detect using sCIR API method	Fieldwork* intensity	Potential contribution of sCIR API technique
					dataset. Requires field survey.		fieldwork, validation or targeted searches for other habitats.
F	Sub-Atlantic *Pteridium aquilinum* fields	E5.31	Non-Annex I	Widespread / extensive	Relatively easy to detect and map. Limited confusion with other habitats.	LOW	Full mapping with limited amount of field checking.
G	Closed non-Mediterranean dry acid and neutral grassland (*Nardus stricta* swards; Other *Agrostis-Festuca* grassland) Moist or wet eutrophic and mesotrophic grassland Moist or wet oligotrophic grassland (Acidocline purple moorgrass meadows; Heath *Juncus* meadows and humid *Nardus stricta* swards)	E1.7 (E1.71; E1.72x) E3.4 E3.5 (E3.512; E3.52)	Non-Annex I Non-Annex I Non-Annex I		Readily identifiable at a higher level. Potential for confusion between habitats in this group, and with other superficially similar habitats. Can be resolved with field checks / local familiarisation gained during reconnaissance.	LOW / MED	Full mapping with moderate level of field checking (or map to higher level only with limited field checking).
H	Poor fens and soft-water spring mires *Rhytidiadelphus-Deschampsia* snowbed; Boreo-alpine *Deschampsia-Anthoxanthum*	D2.2 E4.11 (E4.115x; E4.116	Non-Annex I Non-Annex I	Widespread / medium to small-scale	Possible to identify through combination of imagery and context. Potential for confusion with other similar habitats. Can be resolved with field checks / local familiarisation gained during	LOW / MED	Full mapping with moderate level of field checking (or map to higher level only with limited field checking).

Group	EUNIS habitat	EUNIS code	Annex I code	Occurrence / extent	Capability to map and detect using sCIR API method	Fieldwork* intensity	Potential contribution of sCIR API technique
	communities				reconnaissance.		
	Alpine and subalpine fern stands	E5.5B	Non-Annex I				
	Luzula sylvatica-Vaccinium myrtillus tall-herb community	E5.5x	Non-Annex I				
I	Sparsely- or un-vegetated habitats on mineral substrates not resulting from recent ice activity	H5.3	Non-Annex I	Widespread / locally extensive	Relatively easy to detect and map. Limited confusion with other habitats.	LOW	Full mapping with limited amount of field checking.
	Non-limestone rock slabs	H3.51x	Non-Annex I				

*Fieldwork intensity (instances requiring field check/visit to map accurately): LOW <10%; MED 10-50%; HIGH 50-90%; V.HIGH >90%

5.3 Mapping speed and potential for improvement

As well as assessing the accuracy and potential application of the sCIR API technique for mapping habitats across the Scottish uplands, a key element of this work was to identify the time and cost implications of a larger-scale roll-out across the upland survey gap.

Mapping speed was estimated by recording the approximate time required to classify two randomly selected 4 km^2 areas at each of the two pilot sites. This was undertaken after the initial 'learning' period, when a degree of familiarisation of the technique and interpretation of habitats had been gained by the mapper.

Estimates for the four areas were used to calculate the number of person days required for desk-based mapping of 100 km^2 of upland ground (Table 10, scenario A). In addition, the number of person days required for the following key tasks was calculated: (i) initial reconnaissance fieldwork; (ii) development and refining of habitat interpretation indicators; (iii) field validation and visits to areas of search for rare/small-scale habitats (based on analysis of polygons tagged with 'field check'); (iv) additional input from in-house GIS specialists / external contractors to produce segmentation.

Table 10. Time estimates (person days) per 100 km^2 to implement the sCIR API technique for: Scenario A: development stage at pilot sites; Scenario B: projected optimum for large scale roll-out (with assumed efficiencies).

Task	Scenario A: Development (pilot sites)	Scenario B: Projected optimum (full roll-out)
Mapping / classification	20	10
Reconnaissance fieldwork	2	0.5-1*
Development / refining of interpretation indicators	3	1
Field validation / visits to targeted areas of search	5	1.5-3*
Specialist input	5	2.5
Person days per 100 km^2	35	15.5 – 17.5

*Minimum and maximum days allocated to fieldwork depending on distance from office base and remoteness (see Annex 5 for explanation).

As experience of applying the sCIR API technique increased, it was concluded that the segmentation produced for the two pilot sites was too detailed, the output containing many intricate and complex-shaped polygons. The process of examining and interpreting the segmentation, merging similar neighbouring polygons, and re-shaping/simplifying boundaries, was hindering mapping speed considerably. Further still, the level of detail imposed by the mapping rules, particularly with regards to minimum mappable units (MMU) and thresholds for inclusion of secondary habitats (see Mapping Rules in Annex 3) was also considered to be constraining mapping speed to an extent. Moving forward, application of a simplified segmentation and mapping rules (within the constraints of the intended utility of the final map output) is recommended to facilitate improved mapping speed.

Mapping speed will also increase over time with further refinement of the interpretation indicators and experience and confidence of the individual(s) doing the mapping. Speed of classification will also vary considerably according to the scale and complexity of habitats present in the target area. The two pilot areas examined in this study were relatively complex compared to vast areas of the uplands where extensive repeating units of a small number of habitats may occur over many square kilometres. However, desk-based mapping speed is ultimately limited by the area that can be realistically and sensibly assessed in the stereo imagery by an individual mapper in one day, the upper limit of which, on average, is estimated to be 10 km^2.

It is also important to note that moving from one area to another requires a degree of familiarisation with the suite of habitats present in that area and the local variation within them, along with changes in imagery capture dates and seasons. Focusing mapping work on one geographical area at a time would optimise the use of information from initial reconnaissance field visits, harness efficiencies gained through familiarisation of the mapper with the local suite of habitats and targeted deployment of supplementary fieldwork. A bio-geographical approach, focusing on one distinct region at a time, is therefore recommended for roll-out of this technique.

With the above points in mind, time estimates derived from mapping the 100 km^2 pilot sites were further refined when considered in the context of a larger-scale roll out across the upland survey gap, focusing on one region at a time (Table 10, scenario B). Considerable efficiencies over time estimates generated for the pilot sites were assumed, these included: (i) application of a much simplified segmentation, and producing this in-house rather than via external contractors, (ii) further increase in desk-based mapping speed gained through experience, (iii) familiarisation of the interpreter with the local suite of habitats and variation present with them in a given biogeographic region, (iv) optimisation of fieldwork time and logistics, and requirement for specialist input, when working over larger areas (Table 10, scenario B).

5.4 Cost estimates for full roll out of the sCIR API technique across the uplands

Utilising the refined time estimates (Table 10, Scenario B), a detailed costing analysis was undertaken for a full roll-out of the sCIR API technique across the HabMoS upland survey gap (2.7 million ha), using Natural Heritage Futures Zones as geographical regions for mapping (Annex 5, Maps 1A & 1B), with the costs being modelled on an in-house SNH team (Annex 5, Table 1).

Staff time for all elements of this work was included: desk-based mapping and fieldwork; management of GIS and imagery datasets; logistical aspects of fieldwork; and project management. Travel and subsistence costs for fieldwork, and initial and on-going costs of purchasing equipment and software licences were also considered.

This analysis revealed that mapping the full upland survey gap utilising the sCIR API technique would cost in the region of £1.8 million and would take six years to complete with the specified team of five mapping officers, including an initial three month training period (Annex 5, Table 2). The average cost would be £0.68 per hectare.

For comparison, estimates were also generated for full field survey of the same area undertaken by external contractors charging a fixed daily rate (Annex 5, Table 3). These indicate the cost for full field survey to be the region of £4 million and would require 67 person years to complete (or a team of 11 surveyors for six years). The average cost would be £1.50 per hectare. Delivering full field survey of this area would not only be challenging, costly and time consuming, but finding a sufficient number of suitably experienced contractors with available time to commit to such work would likely be prohibitive.

5.5 Conclusions and Recommendations

The Upland Mapping Pilot has demonstrated that the stereo colour infrared (sCIR) aerial photo interpretation (API) technique with complementary targeted fieldwork is suitable for roll out across the upland survey gap, with potential to offer accurate mapping of the vast majority of habitats that occur in the Scottish uplands to Annex I or equivalent level.

This remote sensing approach offers significant time and cost savings over full field survey but offers at least a comparable level of map detail, collated according to standardised mapping rules and data capture process. This high quality map output would lend itself to easy integration with existing Habitat Map of Scotland data, and serve as a vital baseline for future analysis at both landscape-scale and individual site level.

Individuals experienced in upland field survey are required to deliver the desk-based mapping and associated fieldwork needed to apply this technique. With experience, rapid assessment of upland habitats, facilitated by high-resolution sCIR aerial imagery, is achievable via the manual interpretation process. Deployment of this mapping method would be most efficient when targeting one geographic region at a time.

As well as the vast majority of mapping being desk-based, the sCIR API technique offers efficient use of costly fieldwork by targeting it to areas where it is most required: (i) initial reconnaissance to inform the development of interpretation indicators; (ii) field checking to resolve areas of uncertainty encountered during classification (and general validation of classified map output); (iii) visits to specific areas of search for rare/small-scale habitats.

While this technique is admittedly still relatively labour intensive, requiring manual interpretation of aerial imagery, the complexity and variation within habitats present across the uplands necessitates this approach rather than alternative approaches based upon automated classification of lower resolution satellite imagery (e.g. Medcalf et al 2015) which have so far demonstrated limited success in the uplands.

However, it is acknowledged that, with significant expert input, there is considerable scope for further development of automated object-based classification approaches and potential future integration with the sCIR API technique.

Application of the sCIR API technique is still in its relative infancy in Scotland and, as much of this work is iterative, accuracy and efficiency will continue to improve with further implementation. The following is recommended as a way forward:

(i) Further development of habitat interpretation indicators to address specific weaknesses identified during this study and incorporate the full suite of habitats encountered across the uplands.
(ii) Publication of these indicators in a Mapping Manual, along with a revised and simplified set of mapping rules, defining the framework for wider application of this technique.
(iii) Refining of the segmentation process to produce a less detailed output, testing its application and the impacts on mapping speed and map output.
(iv) Adoption of this method, and assumed future efficiencies, for full roll-out across the HabMoS upland survey gap, focusing on one geographic region at a time.
(v) Development and integration of complementary automated classification methods using satellite imagery, if and when they become suitably developed in the future.

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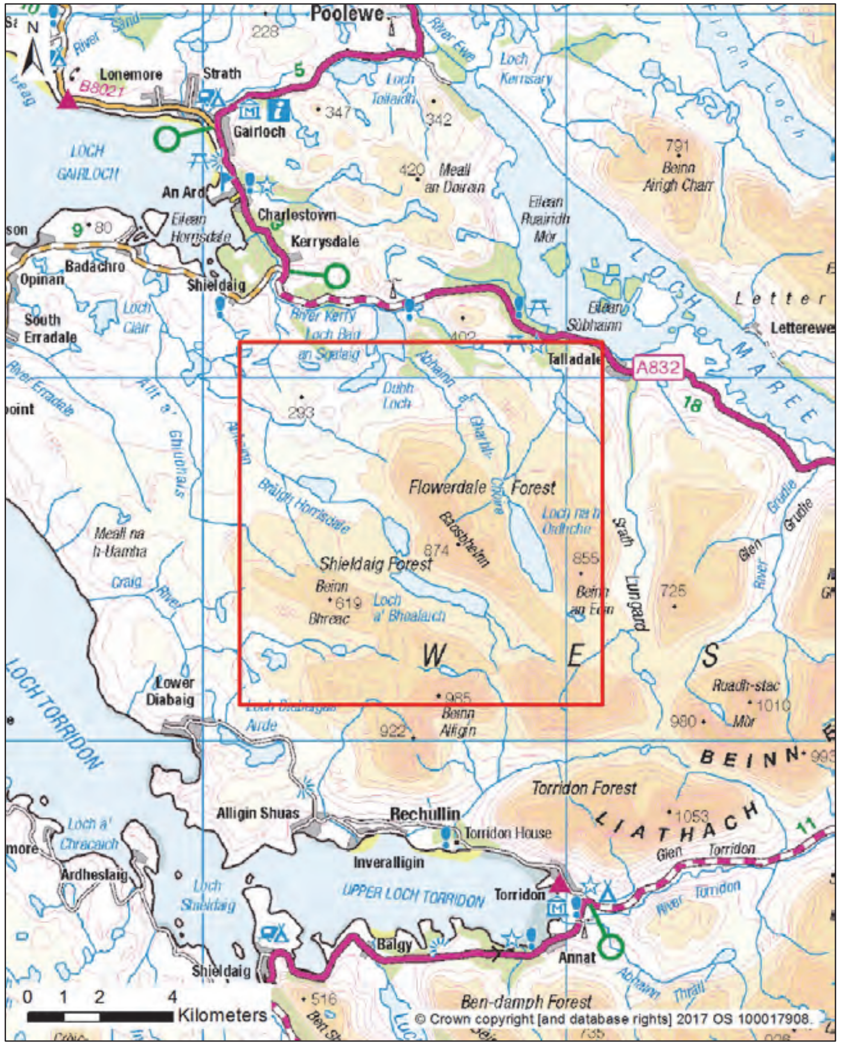
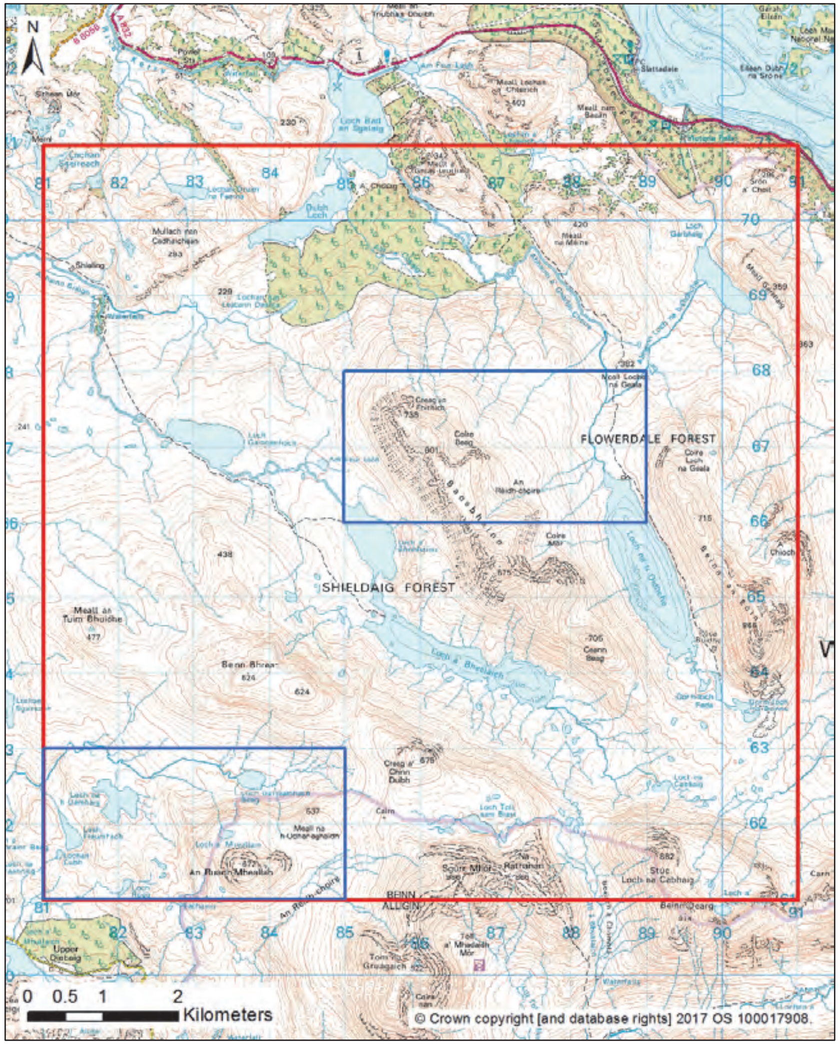
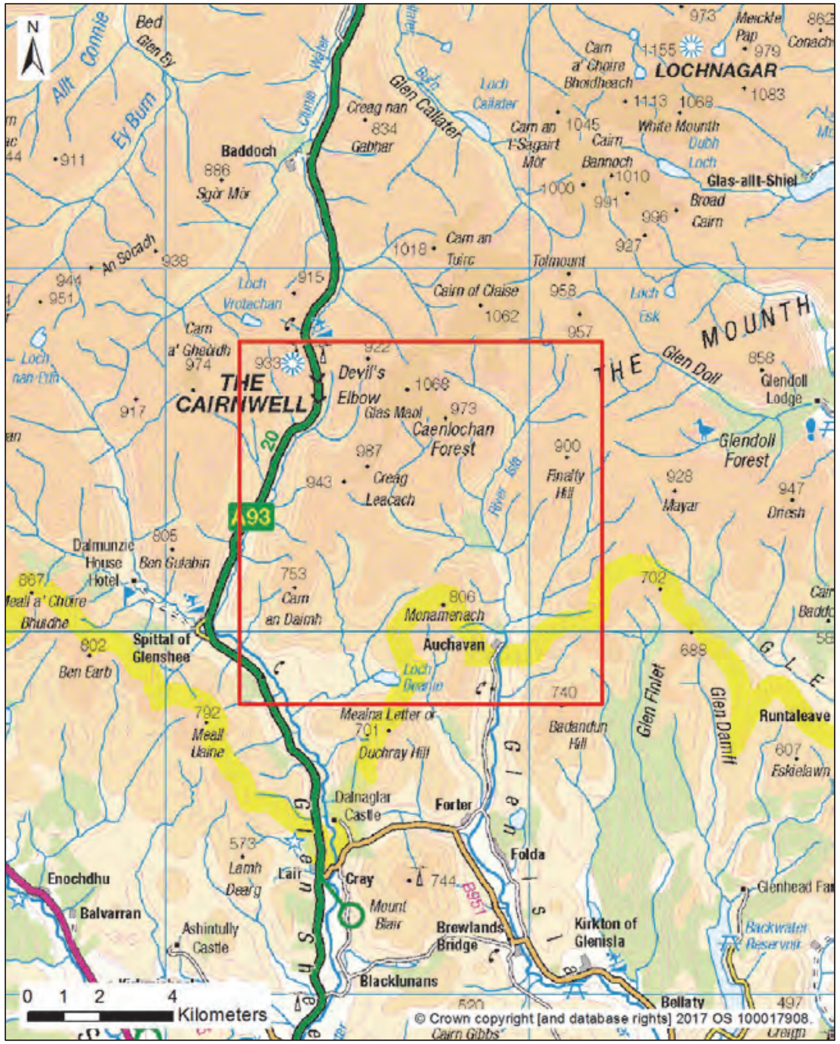
ANNEX 1: MAPS SHOWING LOCATION OF PILOT SITES AND RECONNAISSANCE AREAS



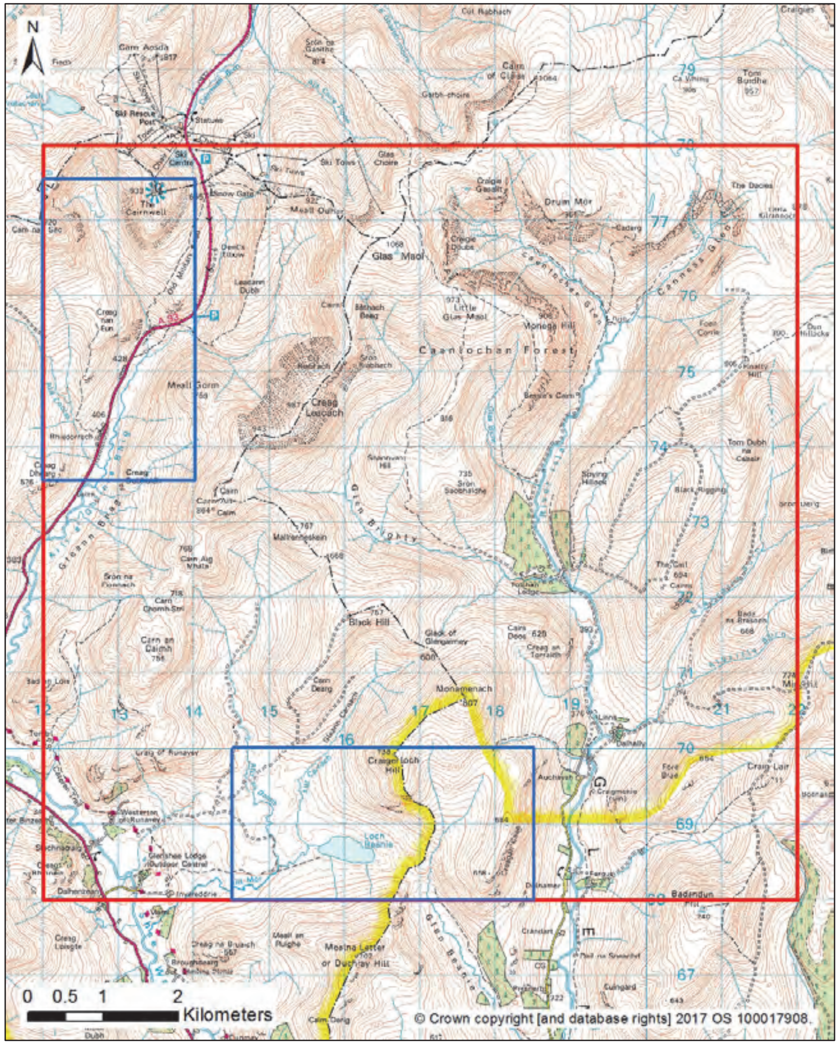
Map 1A. Location of Beinn Eighe and Flowerdale Forest pilot site (red line).



Map 1B. Location of two reconaissance areas (blue line) at Beinn Eighe and Flowerdale Forest pilot site (red line).



Map 2A. *Location of Caenlochan - Cairngorms pilot site (red line).*



Map 2B. *Location of two reconaissance areas (blue line) at Caenlochan - Cairngorms pilot site (red line).*

ANNEX 2: HABITAT INTERPRETATION INDICATORS DEVELOPED FOR THE UPLAND MAPPING PILOT

This Annex presents interpretation indicators developed by the SNH Upland Mapping Pilot to aid manual classification of upland habitats using high resolution stereo colour near-infrared (sCIR) aerial imagery.

Habitats are classified according to the European Nature Information System (EUNIS), with correspondence to EC Habitats Directive Annex I and National Vegetation Classification (NVC) systems, as per Strachan 2015. It should be noted that the first two classifications lack detailed floristic and environmental data and description, and therefore these classifications, and hence the interpretation indicators presented here, rely heavily on correspondence with the NVC, which is supported by extensive data and description.

The following factors were considered (where relevant) when developing indicators for each habitat of interest:

(i) Spectral signal (colour, tone, intensity)
(ii) Physiognomy (vegetation height, structure, texture, density)
(iii) Dominant species
(iv) Size, shape, pattern (of vegetation/habitat stand)
(v) Site conditions (slope, aspect, altitude, exposure)
(vi) Substrate (soil, moisture regime, nutrients, geology)
(vii) Landscape context
(viii) Management and other anthropogenic impacts
(ix) Known geographical distribution

The information presented here draws heavily upon the works of Rodwell (1991-2000) and Averis *et al*. (2004) for descriptive and contextual information on upland habitats, as well as data gathered during reconnaissance fieldwork at Beinn Eighe and Flowerdale, Caenlochan in the Cairngorms, and the Moffat area in the Southern Uplands, and subsequent study of relationships between field data and aerial imagery.

It is incorrect to assume that habitats will always have a consistent appearance in the imagery – they can vary considerably between different biogeographic regions, and in some cases within biogeographic regions according to altitude, exposure, species composition, impacts of management, as well as capture date (season) of the imagery, and illumination levels on the day of capture. Indicators and illustrations provided here are for guidance only and require considerable upland habitat expertise, gained through familiarisation with habitats in the field, in order to apply them successfully.

This work is confined to those habitats encountered at the above-mentioned sites and does not currently represent a complete list of upland habitats. Indicators were developed using known reference examples of habitats in the field and/or existing habitat survey data.

For each habitat included in the subsequent sections, the following information is presented:
EUNIS code; EUNIS name; (Annex I code); corresponding NVC types (* partial correspondence only); descriptive indicators; colour signal in the imagery – CIR (colour near-infrared) and RGB (true colour – red, green, blue); mapping approach / constraints; example illustrative image(s) of habitat in CIR and RGB imagery.

D1.2 Blanket bogs (H7130)

NVC types: M17*, M18*, M19*, M20*, M1*, M2*, M3* (M15*, M25* on deep peat).

Descriptive indicators:

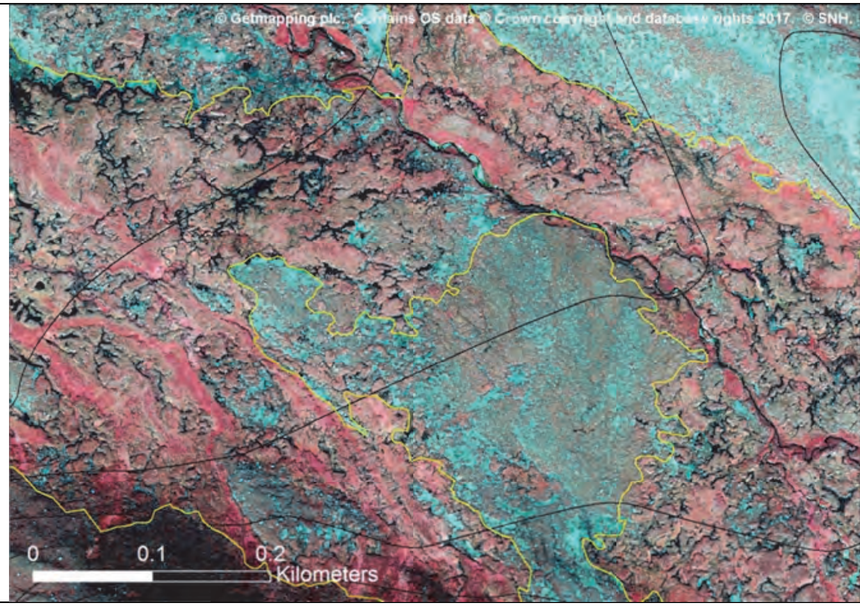
- Widespread habitat, principally occurring in extensive stands.
- On flat/gently sloping ground (0-15º). Low to high altitude.
- Extensive areas of peatland that blanket the landscape, covering whole watersheds, along flat valley bottoms, wide depressions, gentle slopes, terraces, flat summits, shoulders of hills, and level mountain plateaux.
- Shape follows breaks in slope.
- Deep blanket of peat – flat/level appearance, little/no exposed stone/rock, often with raised bare peat edges (indicative of depth) and/or bare, eroded hagged peat in irregular shaped patches or gullies (if extensive, these should be mapped separately as D1.24 – see below).
- Peat substrate is wet/waterlogged – surface often perforated with pools, hollows or channels, open water or *Sphagnum*-filled, often with raised hummocks between.
- Vegetation is rough/tussocky in texture, typically 10-20(-30) cm tall, with *Eriophorum vaginatum* over a wet carpet of *Sphagnum* moss, either with *Calluna vulgaris* and other dwarf-shrubs, and/or tussock-forming graminoids including *Molinia caerulea* and *Trichophorum germanicum*.
- May have drainage grips/channels (straight or curving lines often in a regular pattern) across surface. *Calluna*-dominated bogs may be subject to muirburn.

Colour signal in aerial imagery:

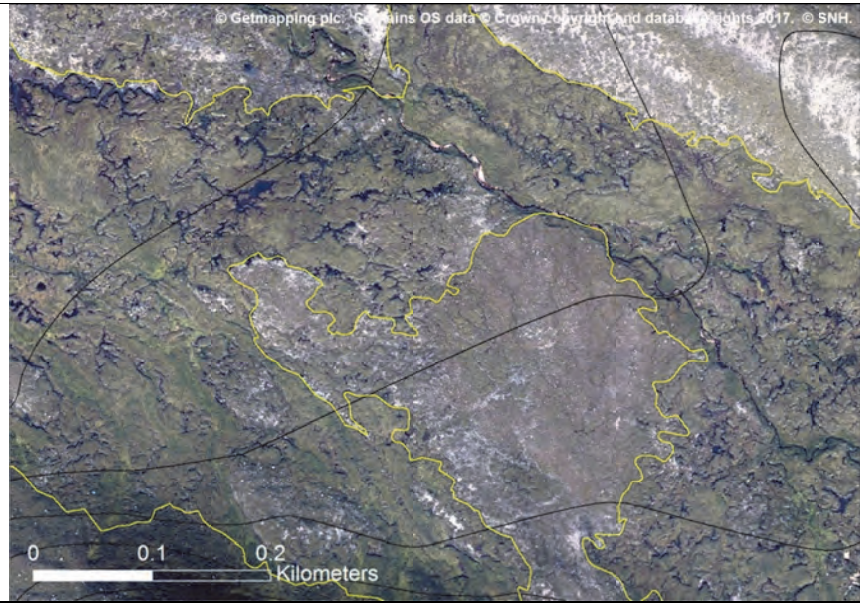
- CIR – cool white-pink or white-blue mixed with: (i) dull red-pink in summer and white-grey in winter/early spring = graminoid-rich, or (ii) dull red-brown in summer and winter = *Calluna*-dominated; +/- green/black bare peat patches/gullies/hags, black, rounded bog pools, often in extensive systems, or white sphagnum-filled channels. Colour signal often variable across bog, influenced by wetness.
- RGB – mix of straw-yellow, dull green, and brown, with black bare peat.

Mapping approach / constraints:

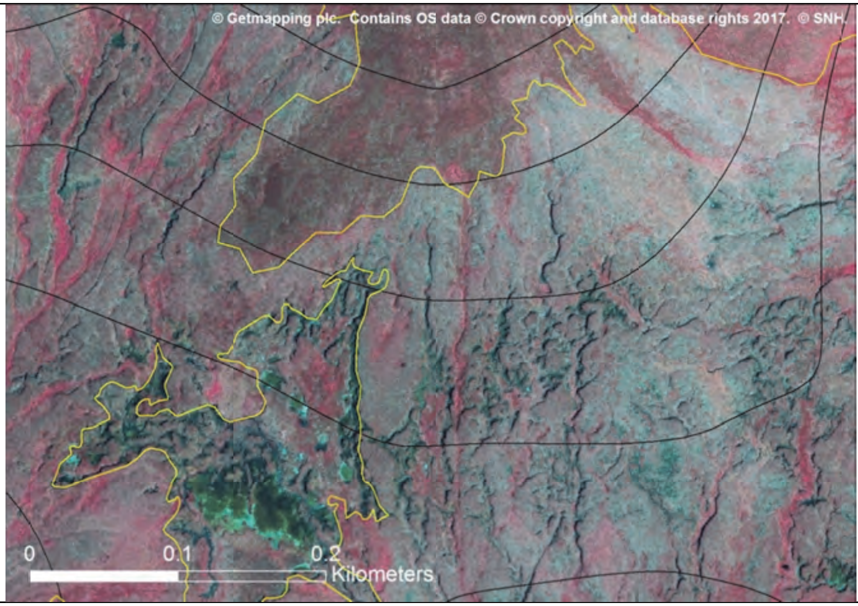
- Distinctive habitat, readily recognised in imagery. Can be mapped accurately with a limited amount of field checking. Potential for some confusion with F4.11 on low-lying flat ground in northwest Scotland where a higher frequency of field checking may be required.
- Map areas with extensive bare peat/hags separately (as D1.24).



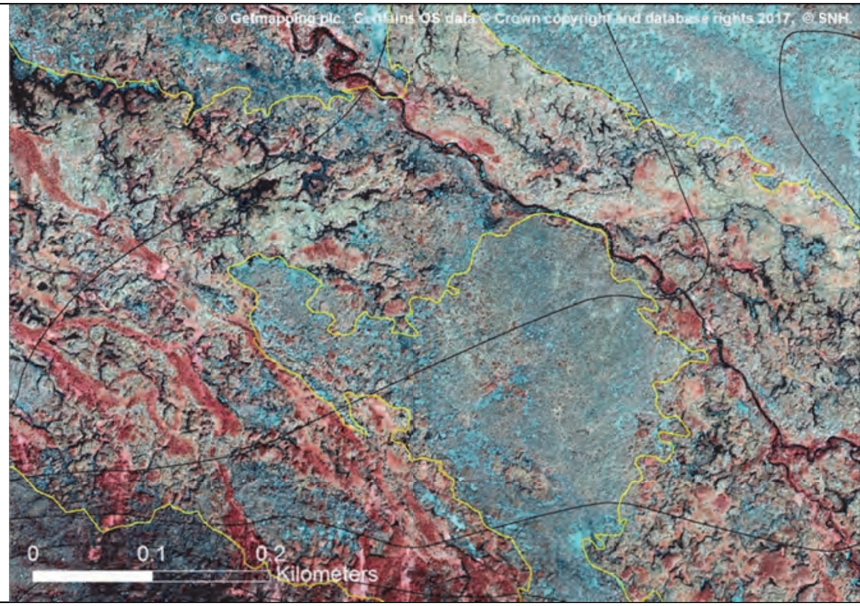
CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – white-pink D1.2 intersected in centre and above by sparse, stony F4.11.



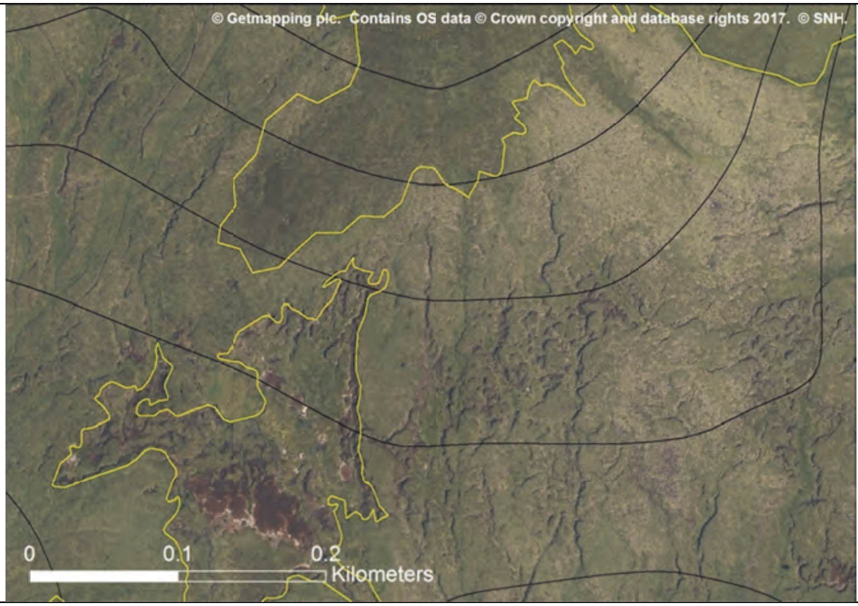
RGB – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – (as above) straw-yellow, dull green, brown D1.2.



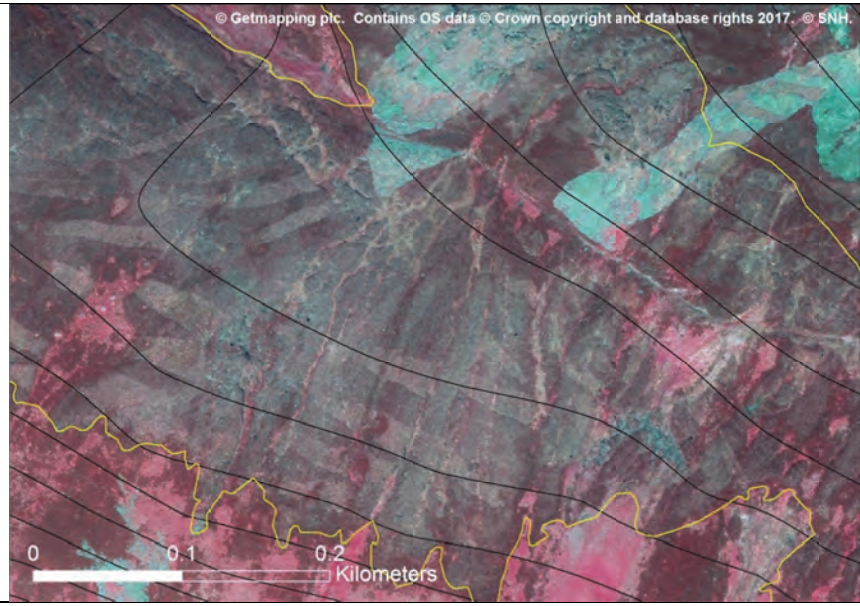
CIR – 11/07/2014 (summer) – Caenlochan – cool white-blue D1.2 with red-pink D2.22 along drainage lines, and a high frequency of green/black D1.24.



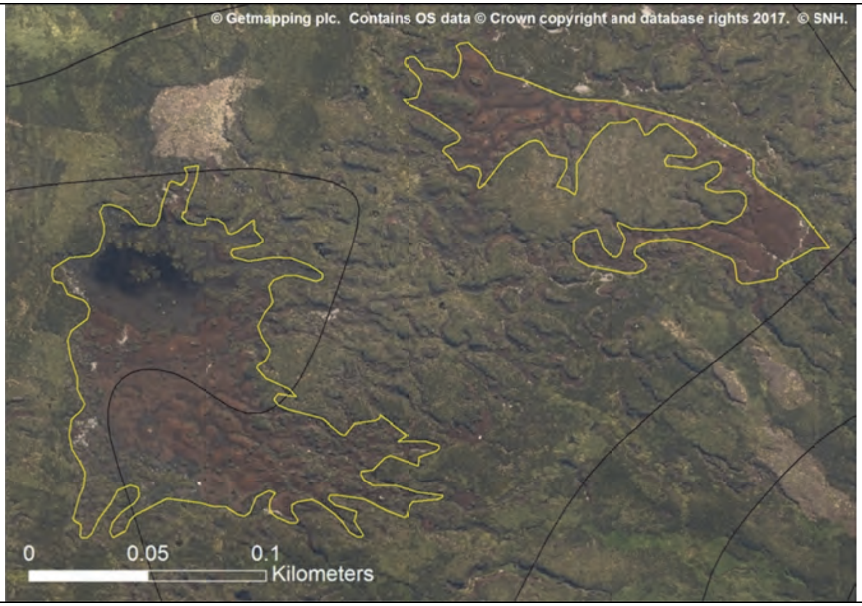
CIR – 13/05/2009 (spring) – Beinn Eighe & Flowerdale – (as above) white-grey D1.2 before new growth of vegetation in spring.



RGB – 11/07/2014 (summer) – Caenlochan – (as above) straw-yellow D1.2 with mid-green D2.22 along drainage lines, and a high frequency of brown D1.24.



CIR – 11/07/2014 (summer) – Caenlochan – strips of muirburn on D1.2, larger more recent burns (top right) appearing blue-green, older burns pale pink-brown.

D1.24 Wet bare peat and peat hags on blanket bogs (H7130)	
NVC types: none. *Descriptive indicators:* • Irregular, bare/un-vegetated patches or wide channels occurring in association with blanket bog (see descriptive indicators for D1.2). • Mostly small in size but can be very large/extensive. In extreme cases, the vast majority of blanket bog vegetation may have eroded, exposing the entire peat surface. • Often with scattered fragments of blanket bog vegetation (raised up above height of bare peat) where erosion is on-going, and/or being re-colonised by graminoid-rich vegetation. • Peat surface may be dry or wet, often varies across area if extensive. *Colour signal in aerial imagery:* • CIR – bare peat has green/black signal and generally smooth texture (due to weathering). Wet peat is black, drier is green. Can have some bare stone/gravel where peat has eroded down to underlying material – bright white-blue with grainy texture. • RGB – bare peat is brown/black. Bare stone/gravel – white/grey. *Mapping approach / constraints:* • Map as mosaic with blanket bog unless discrete patches occur above MMU (see mapping rules). • Distinct and readily recognisable habitat can be mapped with little/no field checking.	*CIR – 11/07/2014 (summer) – Caenlochan – extensive areas of green/black bare peat (D1.24) delineated in yellow, surrounded by D1.2 with peat hags.*  *RGB – 11/07/2014 (summer) – Caenlochan – (as above) extensive areas of brown/black bare peat (D1.24) delineated in yellow.*

D2.22 *Carex nigra*, *Carex canescens*, *Carex echinata* fens (non-Annex I)

NVC types: M6, M7.

Descriptive indicators:

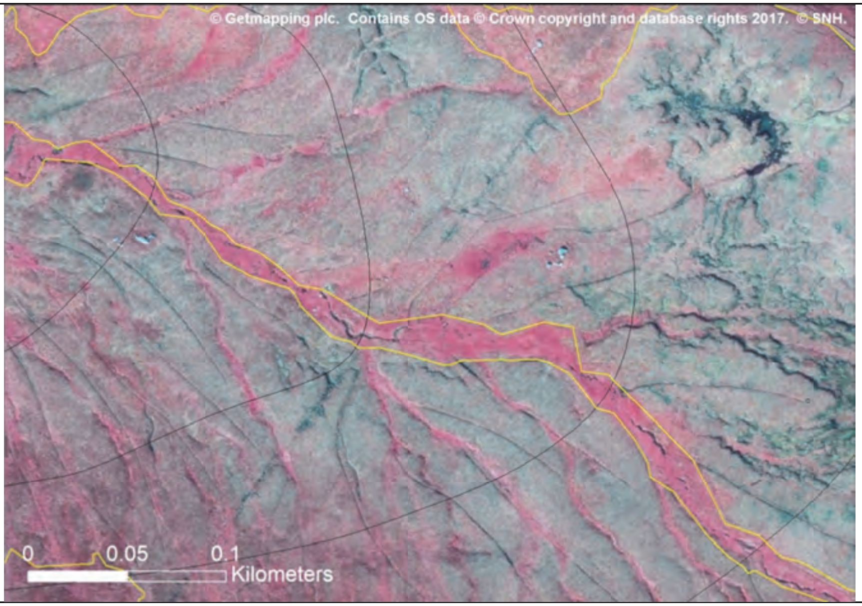
- Widespread habitat, occurs in small-scale stands.
- A sward of small sedges (including *Carex echinata*, *C. nigra*, *C. panicea*) or tall rushes (*Juncus effusus* or *J. acutiflorus*) over a wet carpet of *Sphagnum* moss.
- Occurs in wet hollows/depressions, acid flushes, drainage lines on hillsides, shallow gullies, along the margins of streams through D1.2, E1.7, F4.11 and F4.2.
- On deep, wet, peaty soil irrigated with acidic ground water.

Colour signal in aerial imagery:

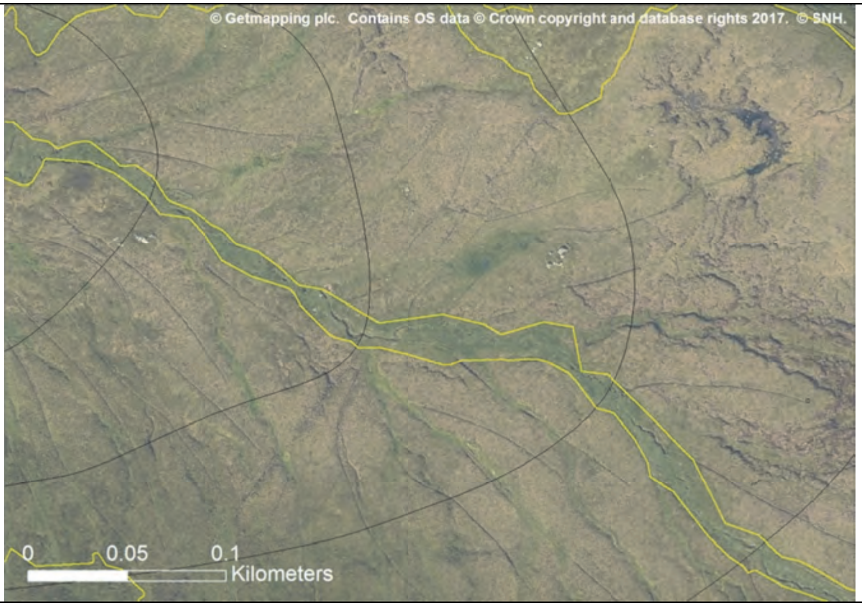
- CIR – signal varies depending upon dominant species. Stands with a thick sward of small sedges appear bright red-pink mottled with duller pink and have smooth texture; stands with tall, spiky-leaved *J. effusus* or *J. acutiflorus* appear dark red-brown and have rough/tussocky texture. High quantities of dead graminoid litter appear white in winter and early spring.
- RGB – Stands with thick sward of small sedges appear dull mid-green mottled with yellow-green and have smooth texture; stands with tall *J. effusus* or *J. acutiflorus* appear dark green, speckled with dark brown and have rough/grainy texture.

Mapping approach / constraints:

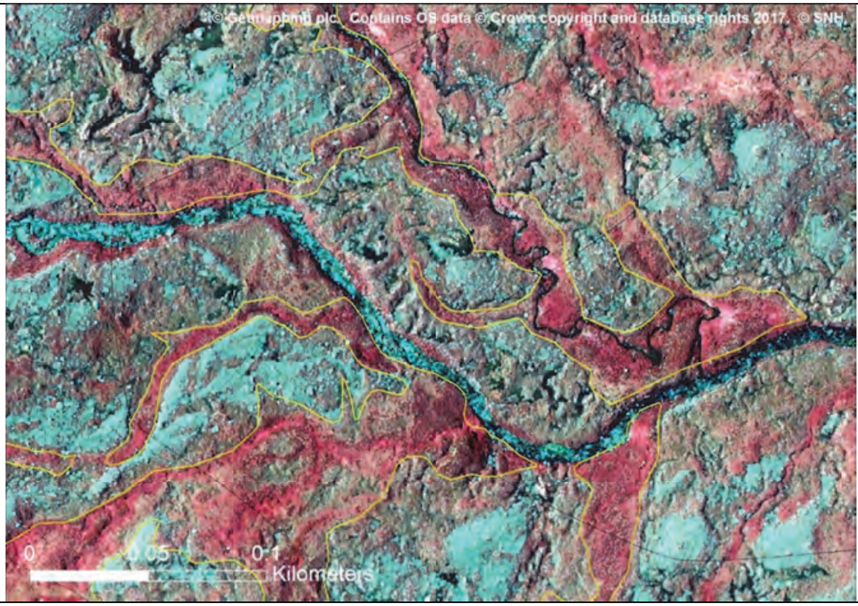
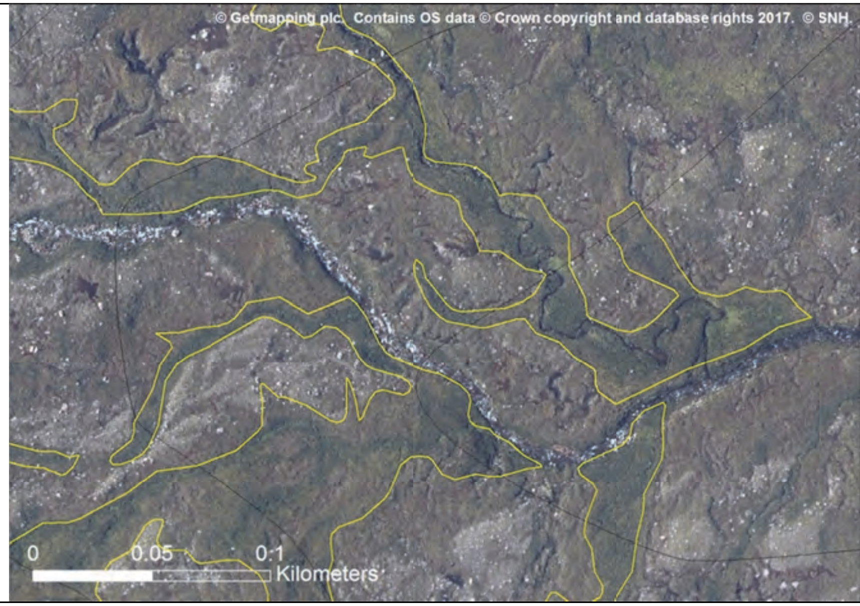
- Shape/context is important in distinguishing this habitat type, which often occurs as a small-scale secondary habitat within stands of other widespread habitats.
- Difficulty in separating *J. effusus* or *J. acutiflorus*-dominated stands from E3.41/E3.42.



CIR – 11/07/2014 (summer) – Caenlochan – red-pink D2.22 (sedge-dominated) along stream margins through D1.2, and at low frequency along drainage lines.



RGB – 11/07/2014 (summer) – Caenlochan – (as above) mid-green D2.22 (sedge-dominated).

	
CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – red-brown D2.22 (tall Juncus sp.-dominated) along stream margins through D1.2 and F4.11.	*RGB – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – (same as image to left) dark green D2.22 (tall Juncus sp.-dominated).*

D2.2C Soft water spring mires (non-Annex I)

NVC types: M31-33, M35-36.

Descriptive indicators:

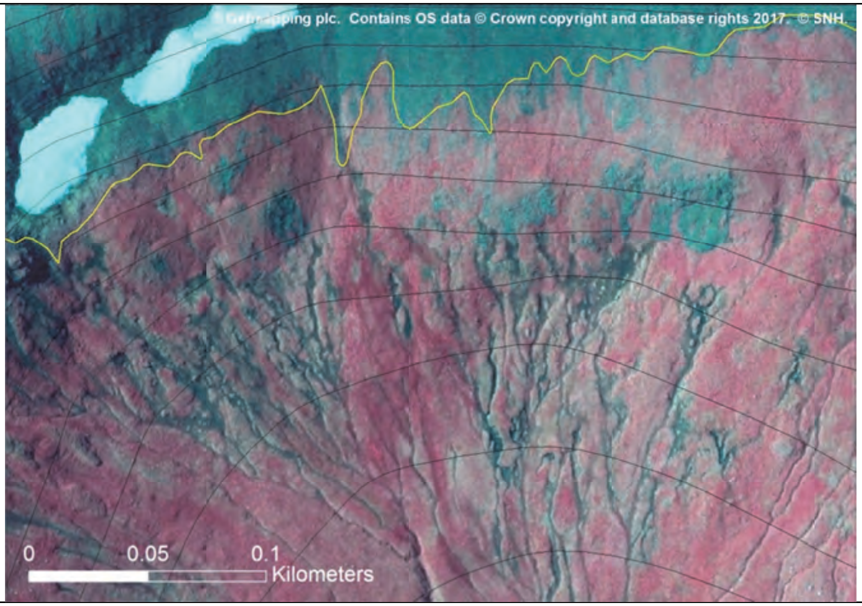
- Widespread habitat, occurs in small-scale stands.
- Thick mat of bryophyte-dominated vegetation, with a scattering of small vascular plants.
- Occurs around margins of spring heads, small streams, and flat ground around late snow beds, irrigated with cold, acid water.
- Generally occurs above 400 m altitude. On upper slopes, sides of gullies, in corries and on high plateaux.
- Typically forms patches of only a few square metres in size. Look for lines of springs/irregular channels.
- May grade to D2.22 further down slope.

Colour signal in aerial imagery:

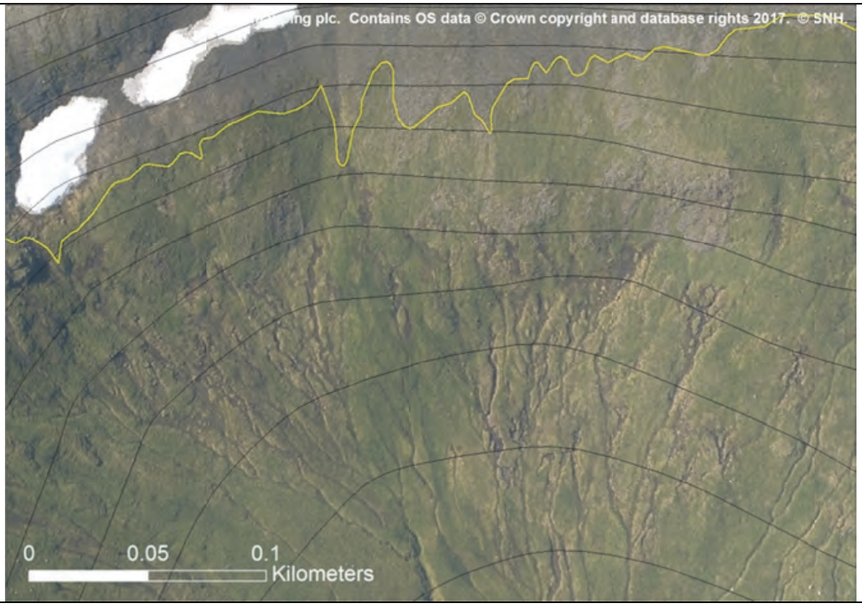
- CIR – dark black-blue/green signal in irregular shaped flushed channels (at top of = spring head).
- RGB – grey-black.

Mapping approach / constraints:

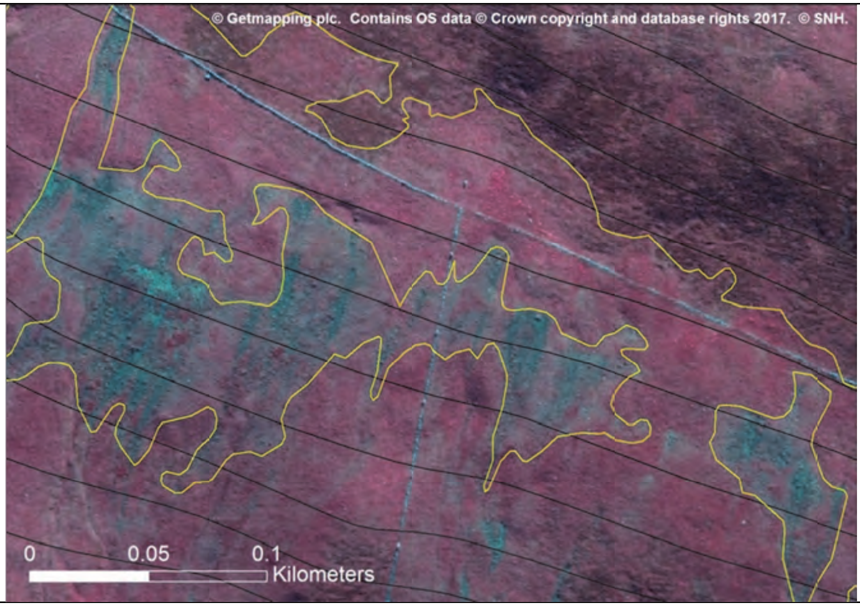
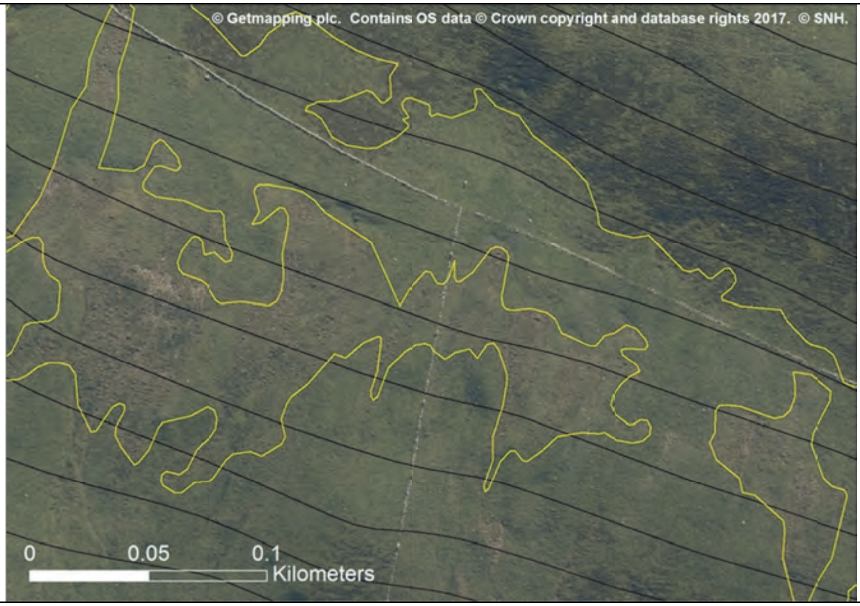
- Shape/context is important in distinguishing this habitat type, which often occurs as a small-scale secondary habitat within stands of other widespread habitats.



CIR – 11/07/2014 (summer) – Caenlochan – dark black-green D2.2C in flushed channels in late snowbed with bright red-pink E4.115x and white-pink E4.32€.



RGB – 11/07/2014 (summer) – Caenlochan – (as above) dark grey-black D2.2C in flushed channels in late snowbed.

D4.15€ Alkaline fens (H7230) / D4.24€ Alpine pioneer formations (H7240)	
NVC types: H7230: M9*, M10*, M11*. H7240: M10*, M11*, M12*, M34. *Descriptive indicators:* • Rare habitat, occurring in small-scale stands. • Confined to locations where underlying geology permits flushing with base-rich ground water. • Open, flushed/wet channels on slope (constantly irrigated), often with much bare stone, gravel or other fine mineral substrate; • Small in size, often <10m^2. • Linear/oblong/oval (but irregular) in shape, in vertical strips following track of water downslope from springhead. • Often occurring as series of scattered flushes along slope, occasionally as a more extensive interconnected network of flushed channels (as in image to right). • Vegetation cover is sparse, typically short (<5 cm) and open (occasionally taller, 20-30 cm = M10 with *Schoenus nigricans*), primary cover comprises sedges and mosses. *Colour signal in aerial imagery:* • CIR – wet, open channel with bare mineral substrate is primary signal (vegetation is sparse) – mix of cool white-blue and black-green. • RGB – wet, open channel with bare mineral substrate is white-grey and light brown – less distinct than in CIR. • Constant signal in imagery regardless of season. *Mapping approach / constraints:* • Open, stony flushes have a distinct spectral signal. • Geology data / indicator species data sets / field checking are required to separate from superficially similar acid flushes, e.g. F4.11 (stony M15a flushes), and to distinguish D4.15€ and D4.24€.	*CIR – 11/07/2014 (summer) – Caenlochan – white-blue D4.15€ in network of stony flushes on slope, mapped as mosaic with E1.72#.*  *RGB – 11/07/2014 (summer) – Caenlochan – D2.2C white-grey D4.15€ in network of stony flushes on slope. Stony flushes less distinct.*

E1.71 *Nardus stricta* swards (non-Annex I)

NVC types: U5* (excludes U5b = E3.52, and U5c = E1.72#).

Descriptive indicators:

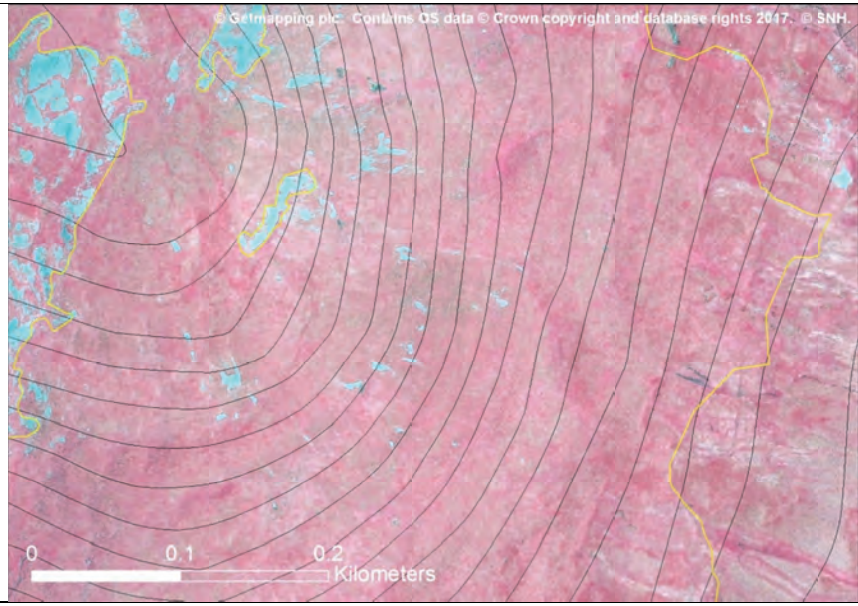
- Widespread habitat, principally occurring in extensive stands. Scarce in the western Highlands.
- Grassland of mid-altitude (300 to 700 m, occasionally to 850 m) slopes (gentle to steep) on moist, peaty mineral soils, which are acid and nutrient poor.
- *Nardus stricta* is dominant or co-dominant with other small grasses, including *Festuca ovina*, *Agrostis capillaris* and *Anthoxanthum odoratum*, there is often a scattering of *Vaccinium myrtillus,* tightly grazed, and some stands can be very mossy.
- Habit of *Nardus* is key to structure of this grassland, the tightly-packed tussocks of fine, wiry leaves giving a fine-scale rough appearance. Sward is short, 5 to 15(-20) cm.
- Typically occurs in landscapes shaped by a long history of heavy grazing by domestic livestock and/or red deer.

Colour signal in aerial imagery:

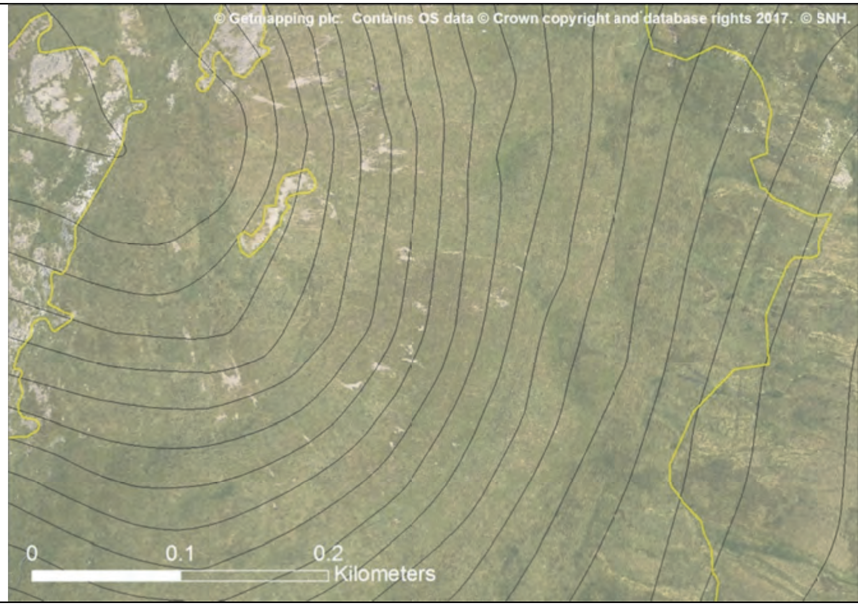
- CIR – consistent dull pink-white signal from *Nardus* across stand (in summer), often mottled with darker pink areas (from patches of *V. myrtillus* and/or broader-leaved graminoids including *Agrostis* spp. and *Carex* spp.).
- RGB – dull mid-green mottled with pale straw-white.

Mapping approach / constraints:

- Classify as E1.7 where not possible to distinguish from E1.72x or E1.72#.
- *Nardus*-dominated grasslands have a distinctive spectral signal but some difficulty occurs with EUNIS classification which places moist *Nardus stricta* swards (U5b) in E3.52. Stands occurring in close proximity to D1.2 can be classified as E3.52 with a certain degree of confidence, but elsewhere the distinction of this type and drier *Nardus* swards (U5a,d,e) is difficult, slope is helpful but not definitive. At present, the only solution is to map at EUNIS level 1 and tag as *Nardus stricta* sward E1.71 or E3.52. A new EUNIS composite ‘acid grassland’, incorporating E1.71 and E3.52 (and E1.72x), would help to overcome this problem.
- The rough appearance of this grassland, and presence of *V. myrtillus* in the sward, can lead to some potential confusion with heavily grazed F4.2.



CIR – 11/07/2014 (summer) – Caenlochan – extensive stand of dull pink-white E1.71 on slope.



RGB – 11/07/2014 (summer) – Caenlochan – (as above) extensive stand of straw-white E1.71 on slope.

E1.72# Species-rich *Nardus* grassland, on siliceous substrates in mountain areas (H6230)

NVC types: CG10*, CG11, species-rich stands of U4* & U5* (mainly U4c & U5c).

Descriptive indicators:

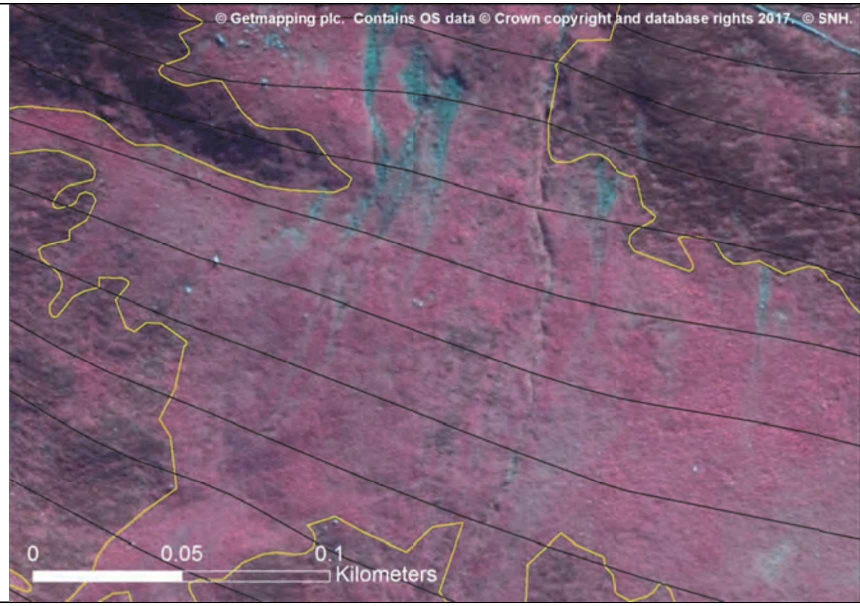
- Rare habitat, generally small-scale, only occasionally locally extensive.
- Localised to areas where base-rich enrichment occurs within otherwise siliceous geology.
- Occurs on shallow, brown, often silty soils, where base status is enriched by irrigation with base-rich ground water and/or weathering of base-rich rock.
- Substrate must contain some silica to fit the Annex I type, examples on limestone are not included (these equate to E1.26 / H6210). Enclosed stands in upland landscapes are included in the Annex I type.
- On a wide range of slopes, aspects and altitudes up to 900 m.
- Smooth, short, 5 to 10(-15) cm, graminoid-rich vegetation – mix of small grasses, sedges, abundant small forbs, often with a high cover of moss. Low productivity sward, often preferentially grazed (due to high nutrient status).
- Look for evidence of flushing within grassland or upslope, or bands of grassland below and among rock outcrops or scree patches.
- Important / extensive examples occur on flushed alluvial soils along watercourses in upland glens.

Colour signal in aerial imagery:

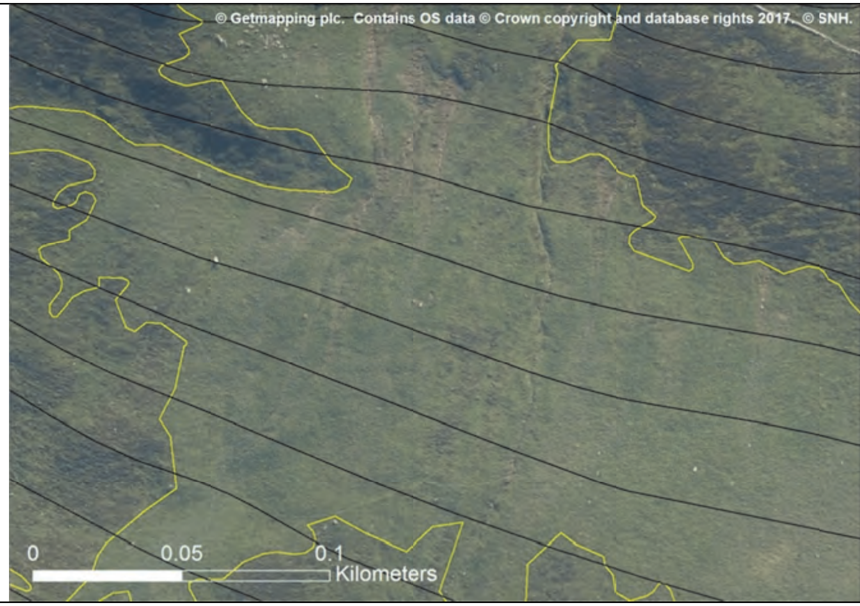
- CIR – dull white-pink, mottled with areas of brighter pink, generally smooth but can be tussocky (e.g. flushed U5c). Where soil is shallow and stony and/or flushed, dull white-blue/green patches will be present among the grassland.
- RGB – dull blue-green or dull green with patches of brighter green. Patches of this grassland stand out amidst bight green E1.72x and pale E1.71 swards in summer imagery.

Mapping approach / constraints:

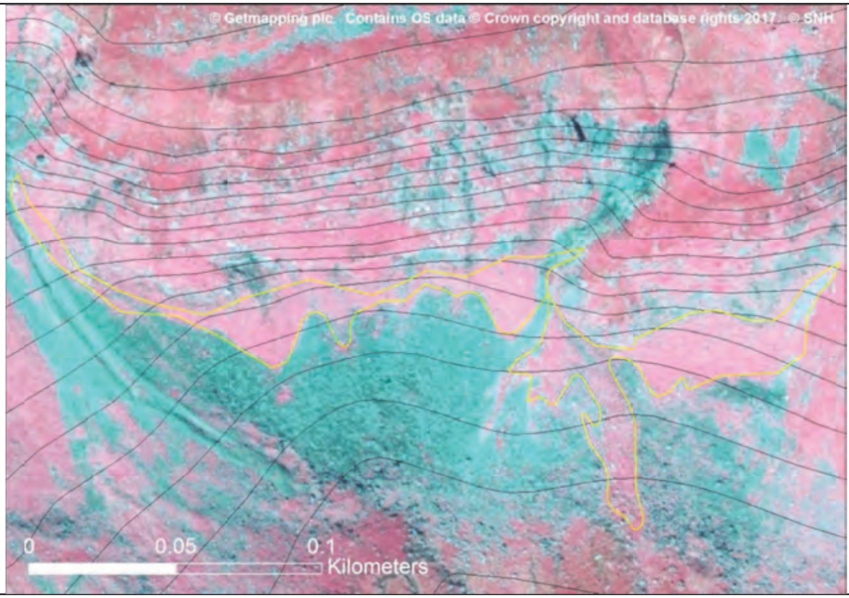
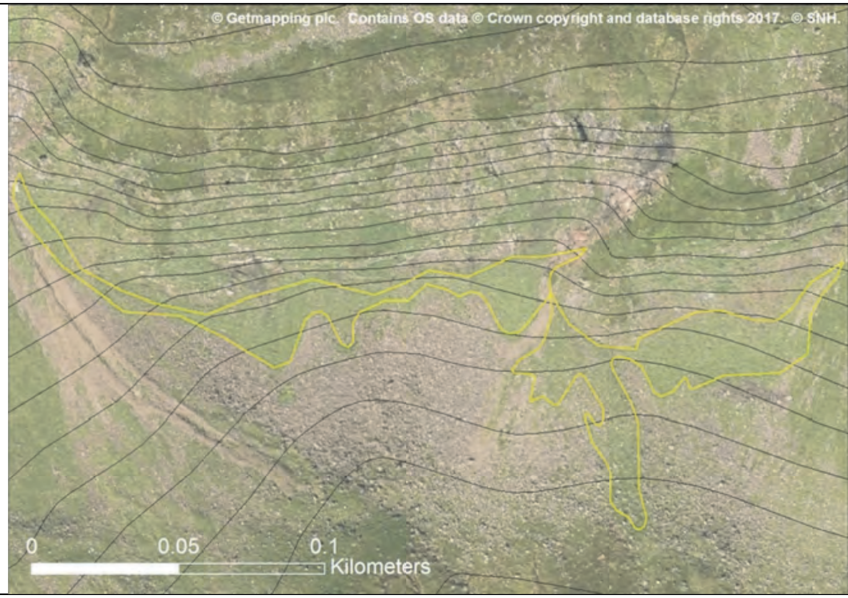
- Geology or soil data could be used to identify broad areas of search for this habitat where base-rich enrichment occurs within siliceous geology. Resolution of this data is unlikely to be sufficient to identify localised/small-scale occurrences – fieldwork will be required to detect these.
- Easily confused with acid grassland, particularly E1.71 and E1.72x, which share similar spectral signal. Field checking a sample of 'potential' E1.72# stands will improve the accuracy of mapping of this grassland type. Where there is uncertainty, classify as E1.7 initially, and tag with note to field check.



CIR – 11/07/2014 (summer) – Caenlochan – E1.72# on slope, dull white-pink mottled with brighter pink, note white-blue stony D4.15€ flushes.



RGB – 11/07/2014 (summer) – Caenlochan – (as above) E1.72# on slope, dull blue-green with patches of brighter green.

	
CIR – 11/07/2014 (summer) – Caenlochan – white-pink E1.72# in band on slope below rock face and above scree.	*RGB – 11/07/2014 (summer) – Caenlochan – (same as image to left) dull blue-green E1.72#.*

E1.72x Other *Agrostis-Festuca* grassland (non-Annex I)

NVC types: U4* (excludes herb-rich forms, mainly U4c = E1.72#).

Descriptive indicators:

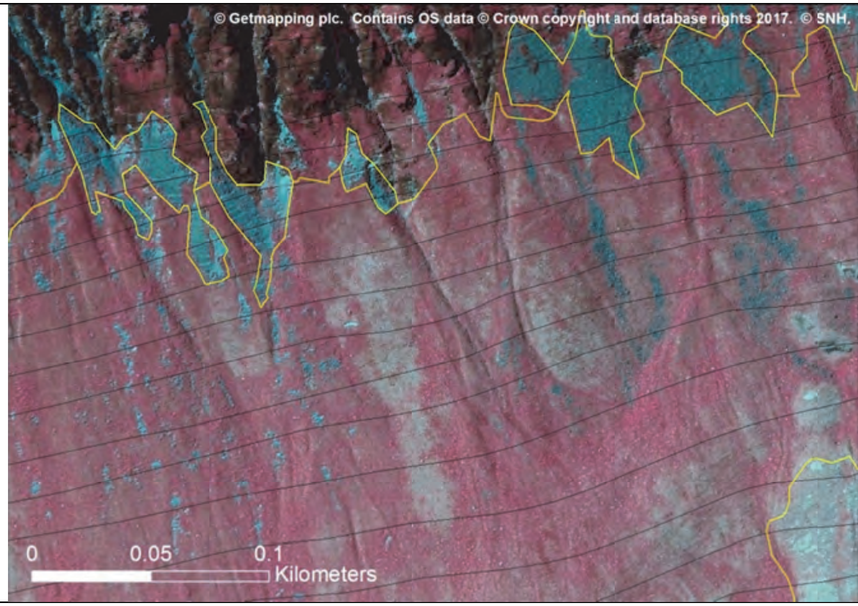
- Widespread habitat, principally occurring in extensive stands.
- Grassland of free-draining, acid, mineral soils on middle to upper hill slopes (and enclosed low-lying pastures), at altitudes of 150 to 500 m, rarely to 800 m.
- Sward of small grasses, including *Festuca ovina*, *Agrostis capillaris* and *Anthoxanthum odoratum*, with a thick carpet of mosses.
- Typically short-cropped, 5 to 15 cm, smooth sward, occasionally rough and tussocky.

Colour signal in aerial imagery:

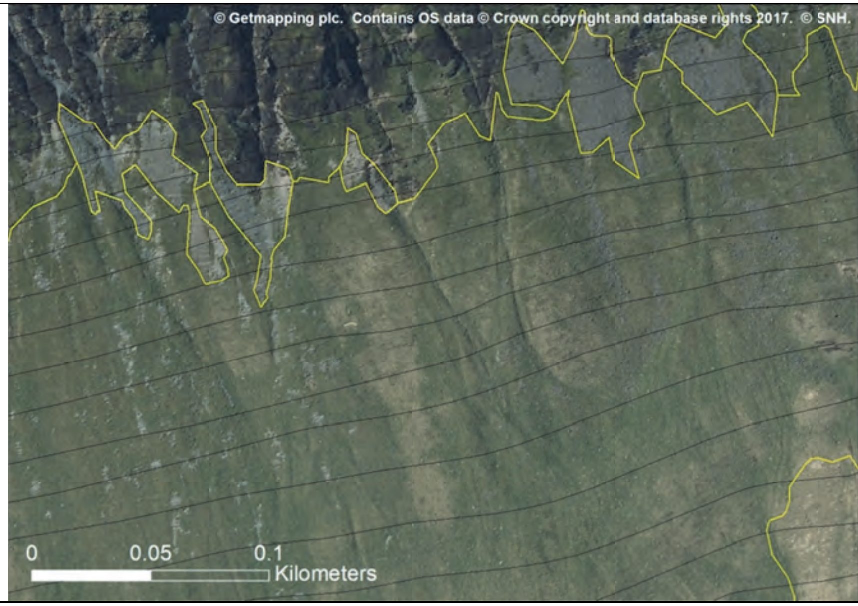
- CIR – uniform bright pink signal (consistent through the seasons).
- RGB – uniform bright green signal (consistent through the seasons).

Mapping approach / constraints:

- Classify as E1.7 where not possible to distinguish from E1.71 or E1.72#.



CIR – 13/05/2009 (spring) – Southern Uplands – bright pink E1.72x (plus E1.72#) on heavily grazed slope below white-blue H2.31€ and red-brown F4.2.



RGB – 2014 13/05/2009 (spring) – Southern Uplands – (as above) bright green E1.72x (plus E1.72#).

E3 Seasonally wet and wet grasslands (non-Annex I) [E3.41 Atlantic and sub-Atlantic humid meadows; E3.42 *Juncus acutiflorus* meadows; E3.512 Acidocline purple moorgrass meadows; E3.52 Heath *Juncus* meadows and humid *Nardus stricta* swards]

NVC types: M23b* (E3.41); M23a (E3.42); M25* (E3.512); U5b, U6 (E3.52).

Descriptive indicators:

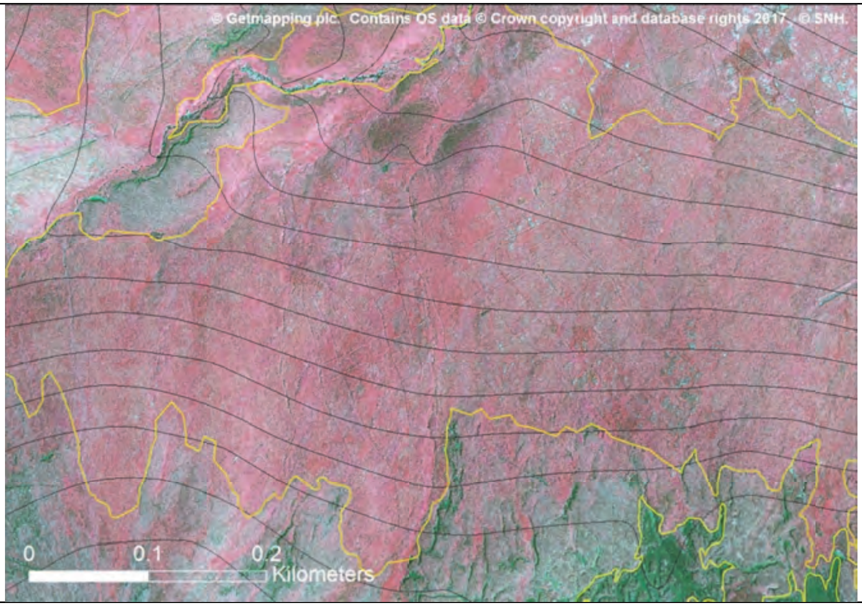
- Group of widespread habitats, which principally form extensive stands.
- On flat or gently sloping ground, with moist or permanently wet, peaty soils – along level valley bottoms, shallow (or concave) slopes, strips along stream margins, acid hillside flushes, and on wet, peaty plateaux.
- Tall (15 to >50 cm), dense, tussocky grasslands dominated by either *Juncus effusus* (E3.41), *J. acutiflorus* (E3.42), *Molinia caerulea* (E3.512), *J. squarrosus* and/or *Nardus stricta* (E3.52), interspersed with other graminoids, forbs and/or mosses.
- Often occur as components of extensive mosaics with other widespread habitats. E3.512 and E3.52 can occur on degraded blanket bog. E3.41 and E3.42 are most extensive on degraded upland pastures. May have networks of wet channels and/or straight lines of drainage grips.

Colour signal in aerial imagery:

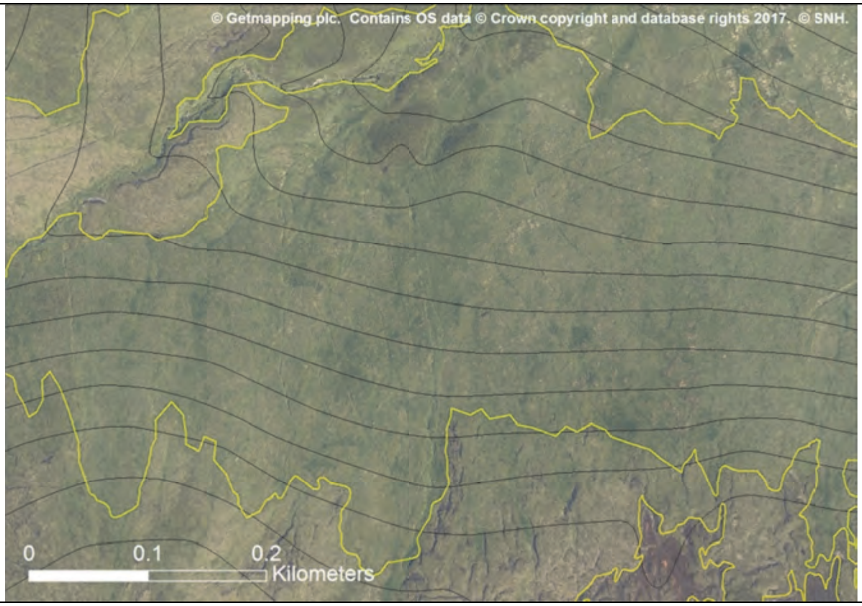
- CIR – dark red-brown, tall, dense clumps of spiky-leaved *Juncus* spp (E3.41/E3.42); bright-pink tussocks of broad-leaved *Molinia* (E3.512); dull pink-white wiry-leaved *Nardus* or red-brown, spiky *J. squarrosus*, mottled with pink of other small graminoids (E3.52). In winter and early spring stands appear white due to large volumes of dead graminoid litter. Red/brown *Juncus* spp. sometimes persist through winter.
- RGB – dark green, speckled with dark brown (E3.41/E3.42), bright mid-green (E3.512); pale straw-white *Nardus*, or dark-green/brown *J. squarrosus* mottled with patches of mid-green (E3.52).

Mapping approach / constraints:

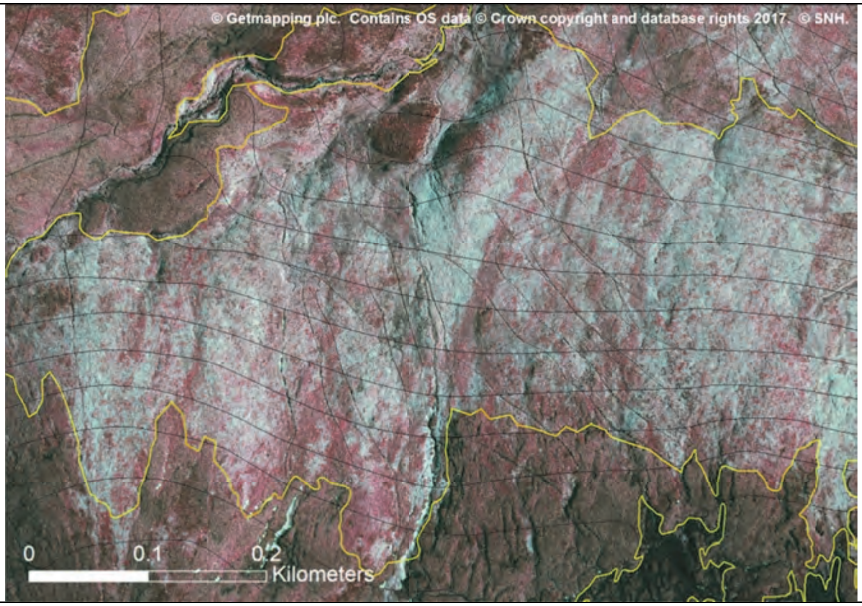
- Wet, tussocky grasslands are generally distinctive at a higher level, but can be difficult to separate at EUNIS level 4 or lower. Classify at level 2 or 3 where there is uncertainty.
- Potential for confusion of *Juncus effusus* /*J. acutiflorus*-dominated stands of D2.22 with E3.41 / E3.42.
- *Nardus*-dominated stands of E3.52 can be difficult to separate from E1.71, but E3.52 generally occurs on gentler slopes.



CIR – 11/07/2014 (summer) – Caenlochan – E3.52, dull white-pink (Nardus), red-brown (J. squarrosus) mottled with pink, on gentle slope below montane D1.2.



RGB – 11/07/2014 (summer) – (as above) mottled straw-white, mid-green and dark-green E3.52.

	
	CIR – 25/05/2013 (spring) – Caenlochan – (as above) white signal from dead graminoid litter in E3.52 in spring before new growth commence, drains visible.

E5.31 Sub-Atlantic *Pteridium aquilinum* fields (non-Annex I)

NVC types: U20.

Descriptive indicators:

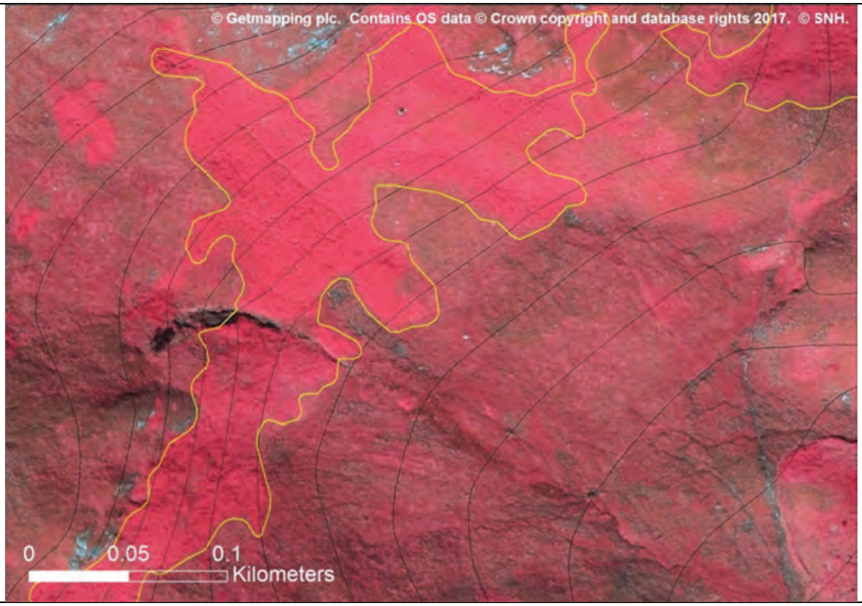
- Widespread habitat, principally occurring in extensive stands.
- Vegetation dominated by *Pteridium aquilinum* occurring in extensive stands or discrete, irregular-shaped patches on lower hill slopes, typically below 450m but can extend to 600 m.
- Occurs on deep, moist but well-drained, acidic and infertile soils.
- *P. aquilinum* produces tall (0.5 to >1.5 m), wide fronds, and typically grows in high density stands, often 'spreading' at the edges. Stands have a rough/bushy appearance.
- Vegetation shows a marked seasonal contrast, fronds emerge and open in spring, and persist as tall, dense, dark-green vegetation through summer, then die back in autumn turning red-gold as they senesce. Dead fronds lie as a thick layer of brown littler on the ground through winter.
- Usually occurs as patches scattered among E1.7, F4.11 or F4.2.

Colour signal in aerial imagery:

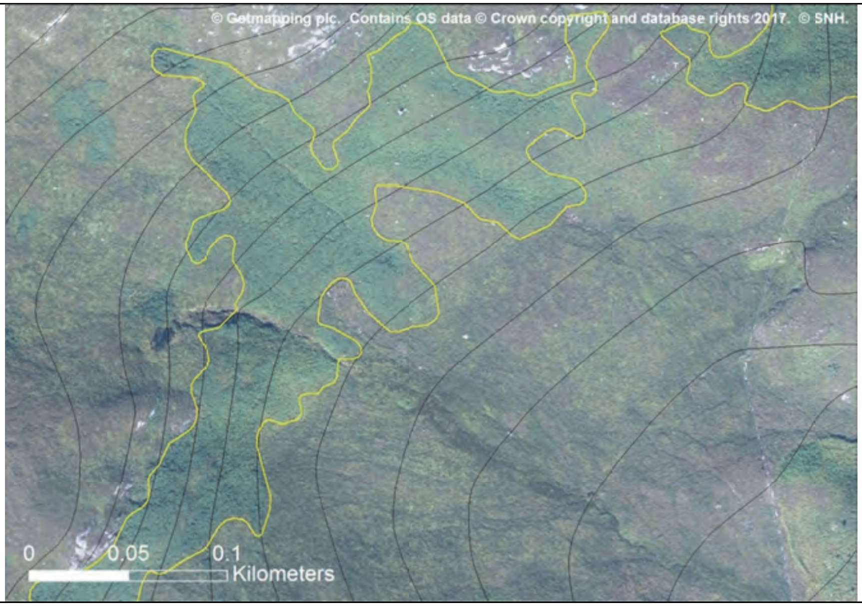
- CIR – spring/summer = bright pink-red (living fronds), dense with rough texture; autumn/winter = pale white-green signal of dead litter (sometimes mottled with pink of underlying grassland).
- RGB – spring/summer = dark-green with rough texture; autumn/winter = bright red-gold/light-brown of senescent fronds or brown of dead litter.

Mapping approach / constraints:

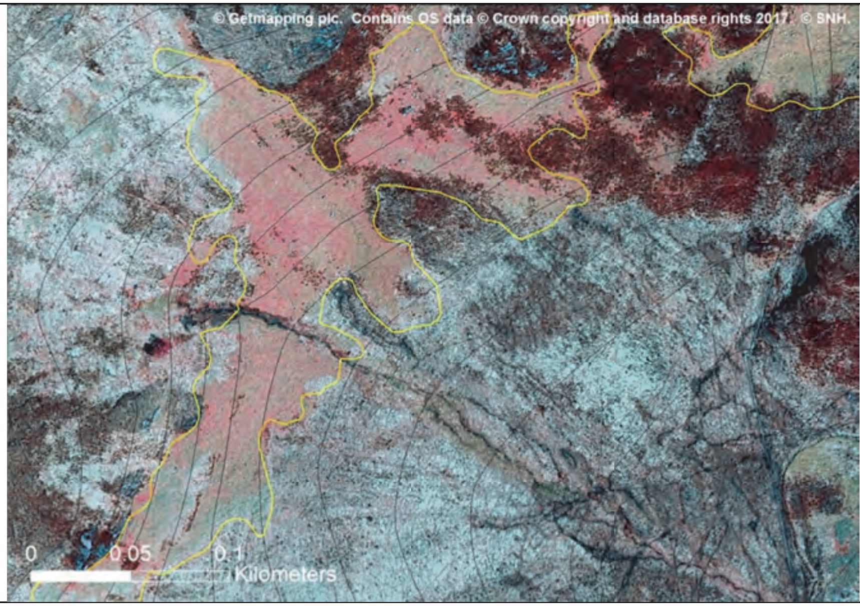
- Distinct and readily recognisable habitat can be mapped with little/no field checking.



CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – bright pink-red signal of E5.31 with rough texture surrounded by F4.11.



RGB – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – (as above) dark-green E5.31.

	
	CIR – 13/05/2009 (spring) – Beinn Eighe & Flowerdale – (as above) E5.31 with white-green signal from dead litter (mottled pink is underlying grassland).

E4.115x *Rhytidiadelphus-Deschampsia* snowbed / E4.116 Boreo-alpine *Deschampsia-Anthoxanthum* communities (non-Annex I)

NVC types: U13a (E4.116); U13b (E4.115x)

Descriptive indicators:

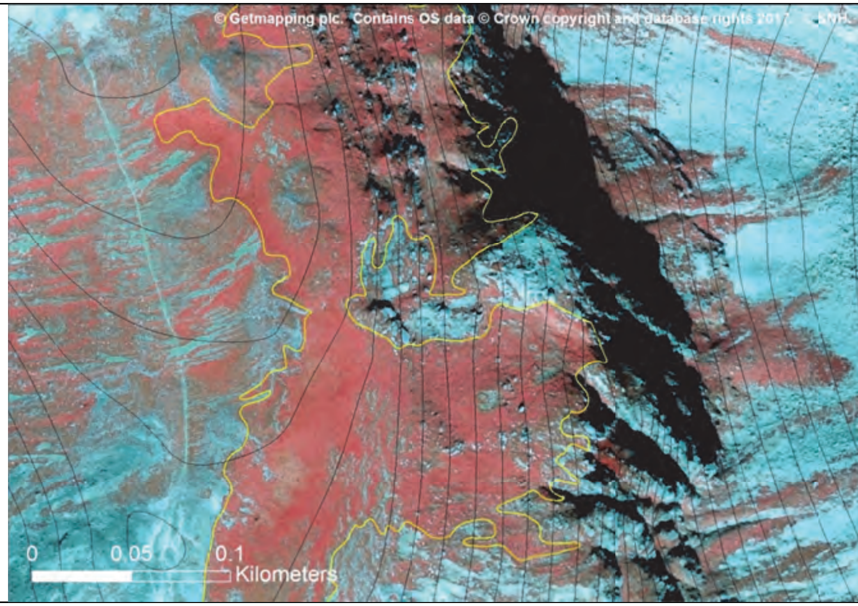
- Widespread habitat, principally occurring in extensive stands. Found throughout the Highlands, most extensive in the west.
- A grassland of two situations – E4.115x on rims and shaded upper slopes of corries, and terraces on high plateaux, where snow lies late in to the spring (irrigated by snowmelt); E4.116 found on high, steep, shaded slopes, headwalls of corries and below cliffs, flushed/irrigated with cold acid water.
- E4.115x is a mossy snowbed grassland comprising a thick layer of pleurocarpous mosses, dotted with tufts of *Deschampsia cespitosa*, and other small graminoids and forbs.
- E4.116 is a short, dense, tufted grassland with *D. cespitosa* plus small grasses, including *Festuca ovina*, *Agrostis canina* and *Anthoxanthum odoratum*, plus an under-layer of large pleurocarpous mosses.

Colour signal in aerial imagery:

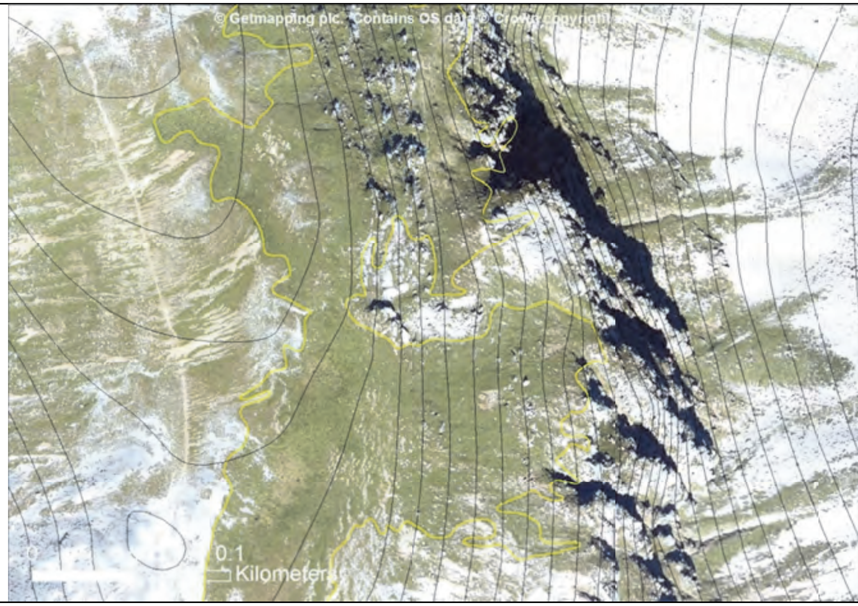
- CIR – thick, almost ‘fluffy’ bright pink (E4.116), or red-pink (E4.115x).
- RGB – mid-green (E4.116), or mottled dark-green and yellow (E4.115x).

Mapping approach / constraints:

- Map as E4.11 where not possible to distinguish EUNIS level 5 type.
- Location/situation is important for distinguishing this grassland type which shares a similar spectral signal to E1.72x grasslands.
- Often in mosaic with E4.32€, and can grade in to one another. E4.116 / E4.115x generally has much ‘thicker’ appearance and brighter red-pink signal than dull silvery-pink/red-brown or pale blue-white of E4.32€ stands.



CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – darker red-pink E4.115x in hollows near summit; lighter pink E4.116 on steep slope below.



CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – (as above) dark-green E4.115x in hollows near summit; mid-green E4.116 on steep slope below.

E4.32€ Siliceous alpine and boreal grasslands (H6150) [E4.115# *Polytrichastrum-Kiaeria* snowbed; E4.117 Boreo-alpine herb-rich acid snowbed communities; E4.21 Oroboreal *Carex bigelowii-Racomitrium* moss-heaths; E4.32 Oroboreal acidocline grassland]

NVC types: U7, U8, U9, U10, U11, U12, U14.

Descriptive indicators:

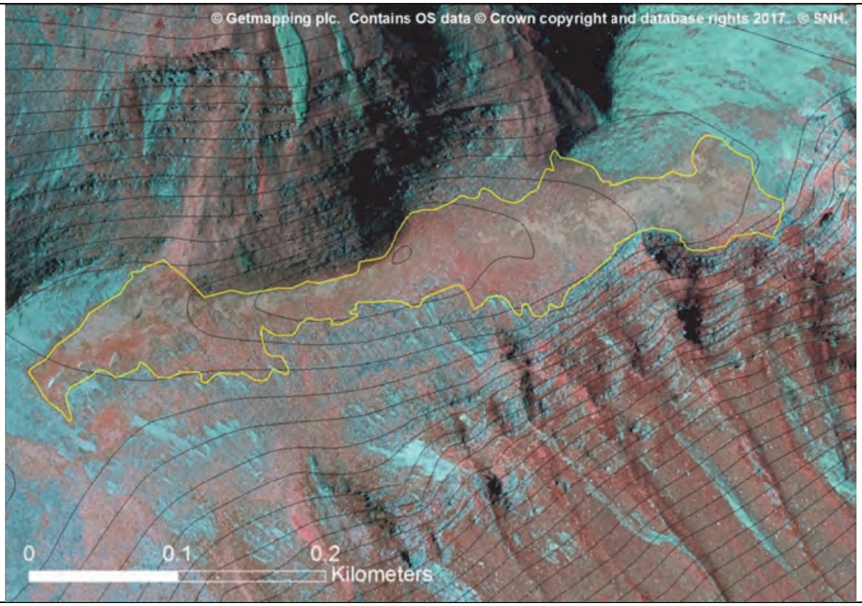
- Widespread habitat, principally occurring in extensive stands. Most frequent in the Highlands.
- Occurs at high altitude on wind-swept mountain ridges, summits, and plateaux, exposed shoulders and upper slopes, and areas of late snow-lie, including shaded backs/sides/floors of corries, steep-sided gullies, and hollows on high slopes and mountain tops.
- Lower altitudinal limit is around 500 m on the west coast islands grading to 900 m in the central Highlands. Occurs on flat ground and gentle to steep slopes. Often associated with F2.25 or montane D1.2.
- Smooth, short (<5 cm tall) vegetation, dominated by mosses (including silvery-leaved *Racomitrium lanuginosum*) and/or small fine-leaved graminoids including *Carex bigelowii, Juncus trifidus* and/or *Nardus stricta*. Shaped by harsh climatic conditions – exposure to wind and severe cold.
- Can occur as a continuous carpet, broken patches among extensive scree or fell-field habitats, or a sparse cover of moss and scattered graminoids over/among bare stone and gravel. Stands sometimes patterned with solifluction terraces or raised hummocks of *Racomitrium* moss.

Colour signal in aerial imagery:

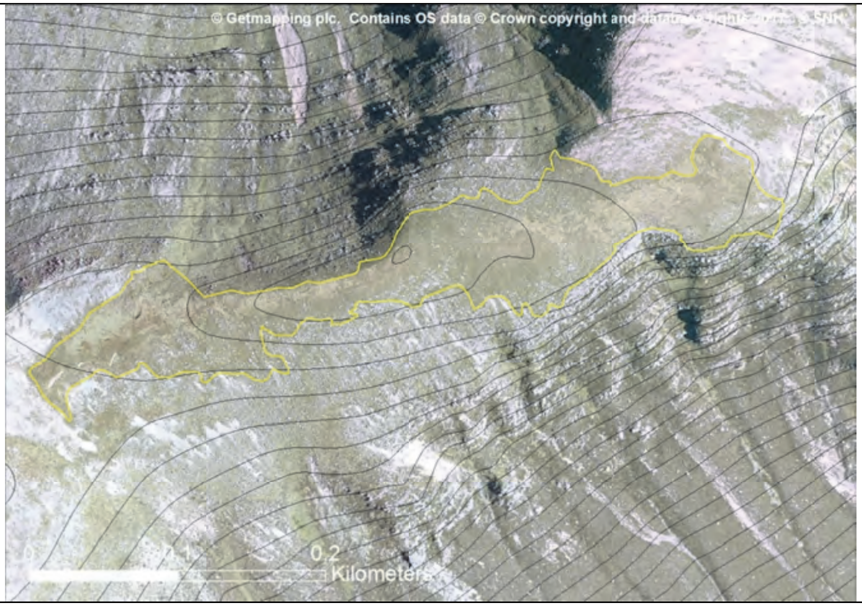
- CIR – variable signal depending on species composition/community. *Nardus*-dominated = flat, pale blue-white, sometimes mottled with dull-pink (*Trichophorum germanicum* and/or *Vaccinium myrtillus or Empetrum nigrum)*; *Racomitrium* (and graminoid)-dominated = dull silvery-pink/red-brown; bryophyte-dominated snow-bed = dark blue-green.
- RGB – *Nardus*-dominated = pale white-yellow; *Racomitrium* (and graminoid)-dominated = dull silvery-grey/green; snow-bed = light purple-brown.

Mapping approach / constraints:

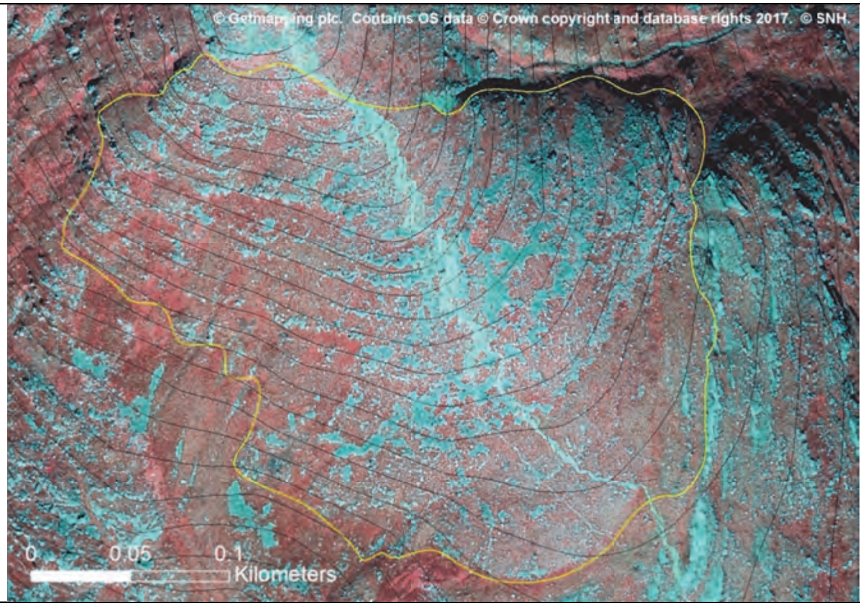
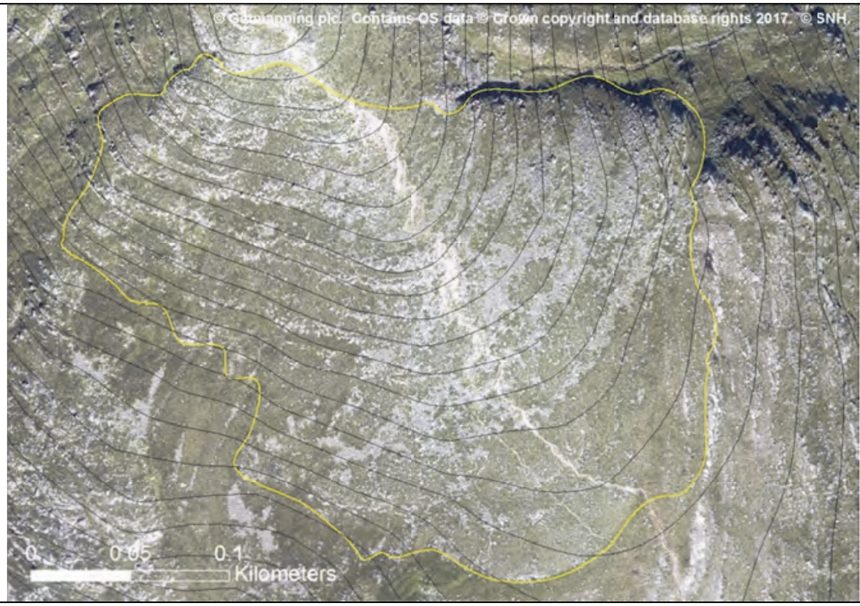
- Map as composite except where individual types are distinct.
- Potential confusion with F2.25 – E4.32€ has smoother, more consistent signal, compared to mottled/micro-roughness of F2.25 from dwarf-shrubs. *Vaccinium*/*Empetrum*-dominated F2.25 has bright red-pink CIR signal compared to dull silvery-pink/red-brown of E4.21.



CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – silvery-pink/red-brown E4.21 and blue-white E4.32 on high, flat summit.



RGB – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – (as above) silvery-grey *E4.21 and pale white-yellow E4.32 on high, flat summit.*

F2.25 Boreo-alpine and arctic heaths (H4060)	
NVC types: H10*, H12*, H13-15, H16*, H17, H18*, H19-20, H21*, H22*. *Descriptive indicators:* • Widespread habitat, principally occurring in extensive stands. Most frequent in the Scottish Highlands. • Occurs on exposed ridges, upper slopes and summits of hills at moderate to high altitude on gentle and steep slopes. • More common above 750 m altitude in the east, and above 400 m in the west, but there is no definitive line above which it occurs – exposure and/or snow-lie, which suppress the growth of dwarf-shrubs, are the critical factors rather than altitude. • Substrate is shallow and acid, often damp but with a high frequency of gravel, rock and/or boulders. • Vegetation comprises a sparse, open (often broken) cover of short, prostrate/wind-pruned dwarf-shrubs (<5 cm tall), including *Calluna vulgaris*, *Vaccinium myrtillus*, and *Empetrum nigrum*, and can have much exposed stone or bare gravel substrate, and/or lichen or *Racomitrium* moss among the dwarf-shrubs. • Short/smooth/open appearance is critical in distinguishing this habitat from the tall/rough/closed dwarf-shrub canopy of F4.2. *Colour signal in aerial imagery:* • CIR – bright red-pink signal of *V. myrtillus / E. nigrum,* and/or red-brown of *Calluna*, mixed/mottled with cool white-blue of gravel/rock and/or white-green of lichen/moss – with fine-scale clumped pattern/micro-roughness from prostrate mats or wind-pruned patches of dwarf-shrubs. • RGB – mottled green or brown of dwarf-shrubs with white-grey of exposed stone or lichens/moss. *Mapping approach / constraints:* • Potential for confusion with F4.2, especially in the altitudinal transition zone where frequent patchy occurrences of both habitats may occur (F4.2 in sheltered areas and F2.25 in exposed). • Similarly, confusion of the above and some forms of F4.11 may occur in the northwest where all three can occur on the tops and sides of sparsely-vegetated stony knolls, and spectral signals are indistinct. A higher frequency of field checking will be required in these situations. • Potential for some confusion with E4.32€, this generally has smoother or more consistent signal, compared to mottled/micro-roughness of F2.25.	 *CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – mottled red-brown and white-blue of stony F2.25, with patches of H2.31€, on exposed high slopes.*  *RGB – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – (as above) mottled brown and white-grey of stony F2.25.*

F4.11 Northern wet heaths (H4010)

NVC types: M15*, M16*.

Descriptive indicators:

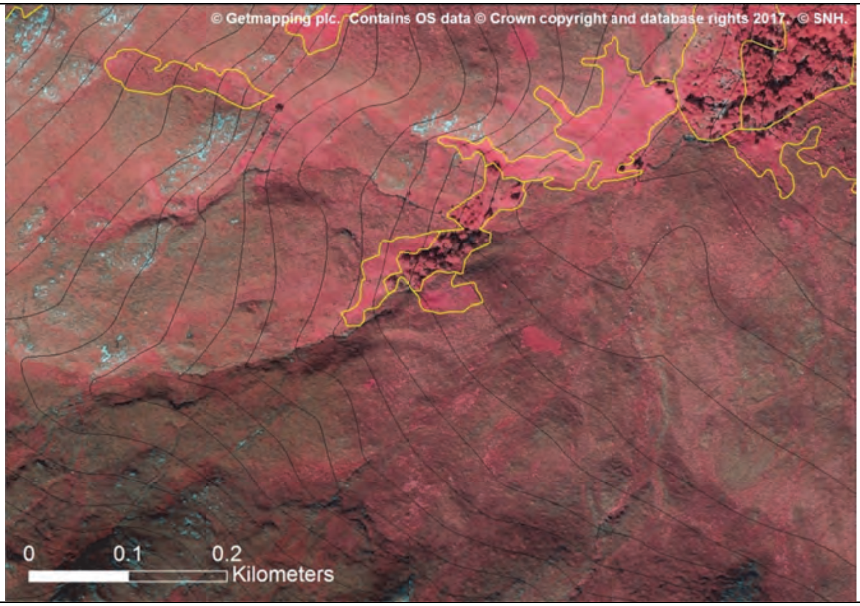
- Widespread habitat, principally occurring in extensive stands. Most frequent in high rainfall areas of west and north Scotland, where it is often the predominant vegetation cover of gentle to moderate slopes at low to middle altitudes. Moving east and south, its occurrence is more local.
- Occurs on shallow, wet/poorly drained, acidic, peaty soil, often formed over moraines and there can be much exposed rocky substrate (gravel/stone/boulders), or in wet channels and runnels where it resembles an acid flush. It also occurs on deeper peat where D1.2 has been degraded through excessive burning and grazing.
- Comprises a mix of dwarf-shrubs, *Calluna vulgaris* and *Erica tetralix,* and graminoids, *Trichophorum germanicum* and *Molinia caerulea*, which can vary considerably in their relative proportions between different stands.
- Very variable structure, ranging from tall (15 to 40 cm), rough/shaggy vegetation with luxuriant *C. vulgaris, E. tetralix* and *M. caerulea*, to shorter (<15 cm), smoother stands with a sparse cover of these species and a high cover of *T. germanicum* and/or other small graminoids. Often varies across stands according to wetness and depth of substrate.

Colour signal in aerial imagery:

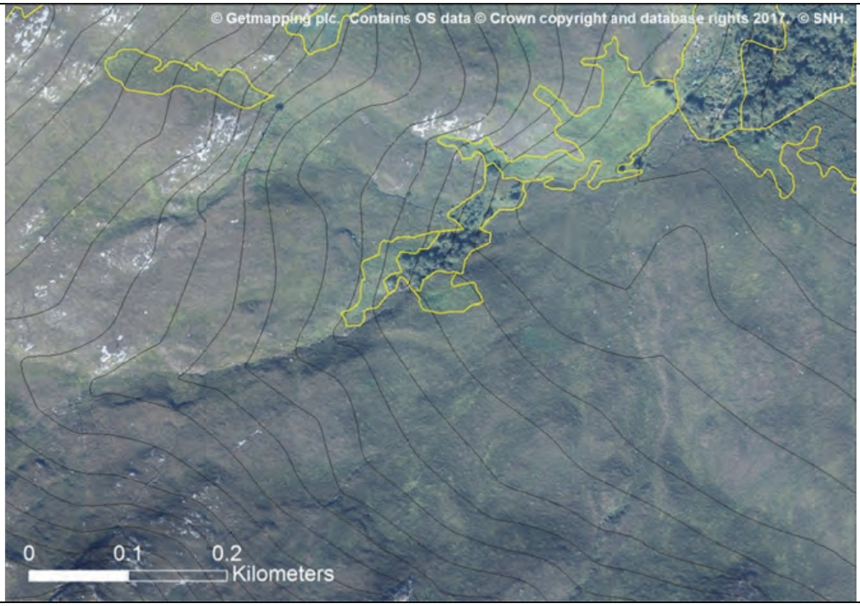
- CIR – variable/mottled signal with dull white-pink, orange, red-brown, bright pink, plus white-blue of exposed stone or gravel substrate, often with a rough/shaggy texture. In winter, dead graminoids, including *Molinia,* give white signal mixed with grey and flecks of red-brown *Calluna* (helpful for distinguishing from E3.512/ F4.13 which is pure white in winter).
- RGB – light green, bright green, brown plus white-grey stone.

Mapping approach / constraints:

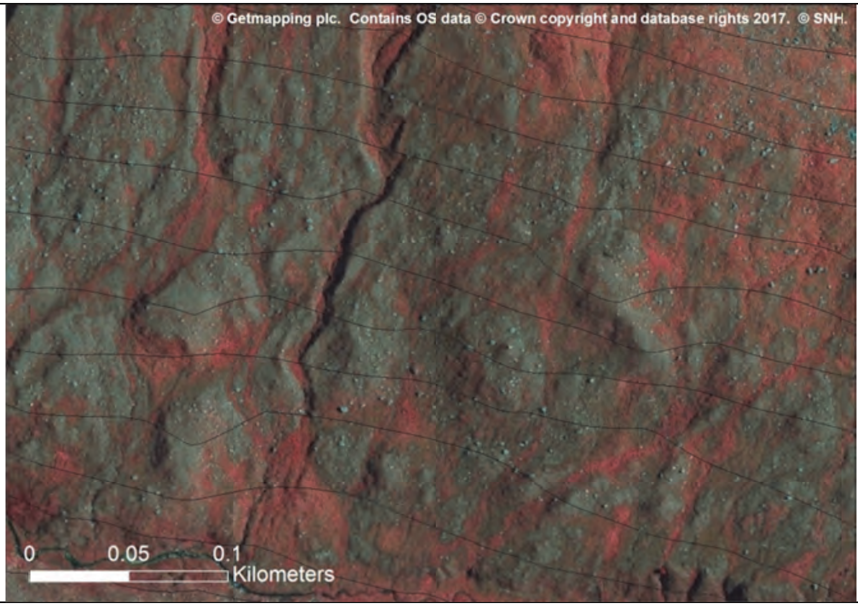
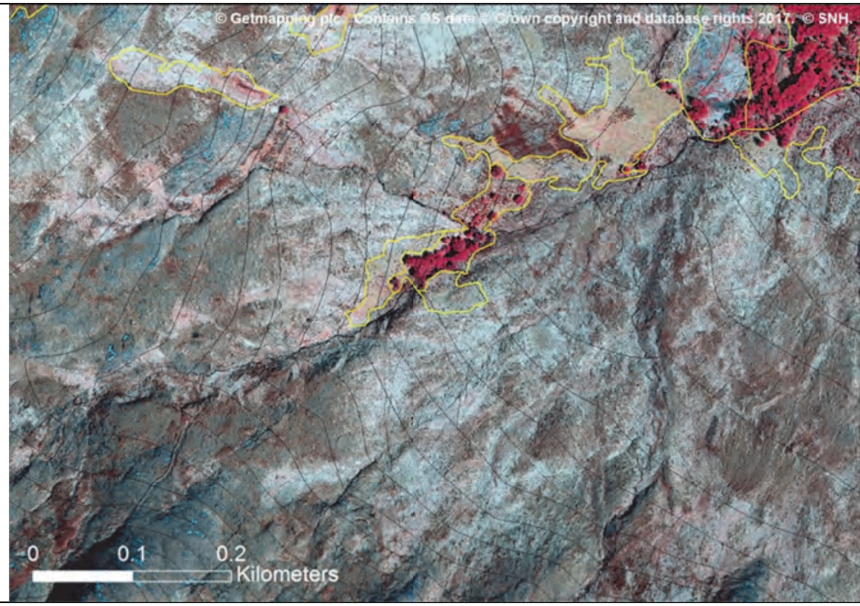
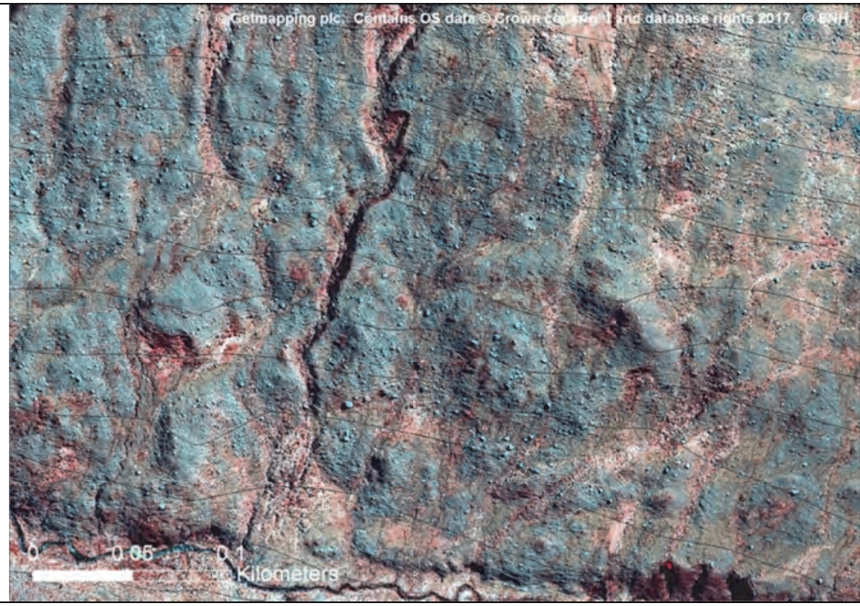
- Spectral signal is very variable but habitat readily recognisable upon consideration of context and extent.
- Potential confusion with F2.25 and F4.2 in northwest Scotland where all three can occur in similar situations on the tops and sides of sparsely-vegetated stony knolls, and the spectral signals are indistinct.
- Potential for limited confusion with D1.2 on low-lying flat ground in northwest Scotland where a higher frequency of field checking may be required.



CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – extensive stand of F4.11 (main area) with mottled dull white-pink, red-brown, and brighter pink.



RGB – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – (as above) mottled green, bright green, brown of F4.11.

	
CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – sparse F4.11 over shallow, stony substrate – mottled pink, orange, red-brown, and white-blue.	*CIR – 13/05/2009 (spring) – Beinn Eighe & Flowerdale – (as above) F4.11 following winter as white mixed with grey and flecks of red-brown.*
	
CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – (as above) sparse F4.11 – mottled green, bright green, brown and white-grey.	*CIR – 13/05/2009 (spring) – Beinn Eighe & Flowerdale – (same as image to left) sparse F4.11 after winter – mottled white, grey, red-brown, and white-blue.*

F4.2 Dry heaths (H4030)

NVC types: H10*, H12*, H16*, H18*, H21*, H22*.

Descriptive indicators:

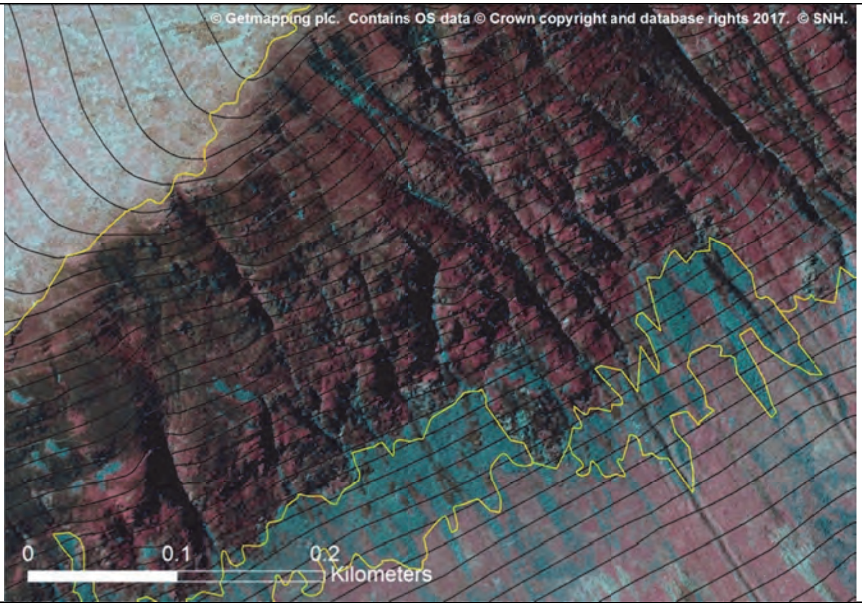
- Widespread habitat, principally occurring in extensive stands. Most frequent in central and eastern Highlands, more local towards the west.
- On moderate to steep, well-drained slopes. Shape follows steep/free-draining ground. Low to high altitude, excluding the alpine zone.
- Stands more exclusively confined to steep slopes in high rainfall areas of west compared with drier east.
- Dominated by tall/upright, dense dwarf-shrubs (15 to 50 cm tall), *Calluna vulgaris, Erica cinerea* and/or *Vaccinium myrtillus, V. vitis-idaea*, with a rough/shaggy texture. Dwarf-shrub canopy is more open/less continuous and stands characterised by a higher cover of small graminoids, forbs and/or moss where heavily grazed, recently burnt or on shallow, stony soil.
- Can have frequent burnt patches, where managed as grouse moor, creating a patchwork of bare ground and *Calluna* of varying ages.

Colour signal in aerial imagery:

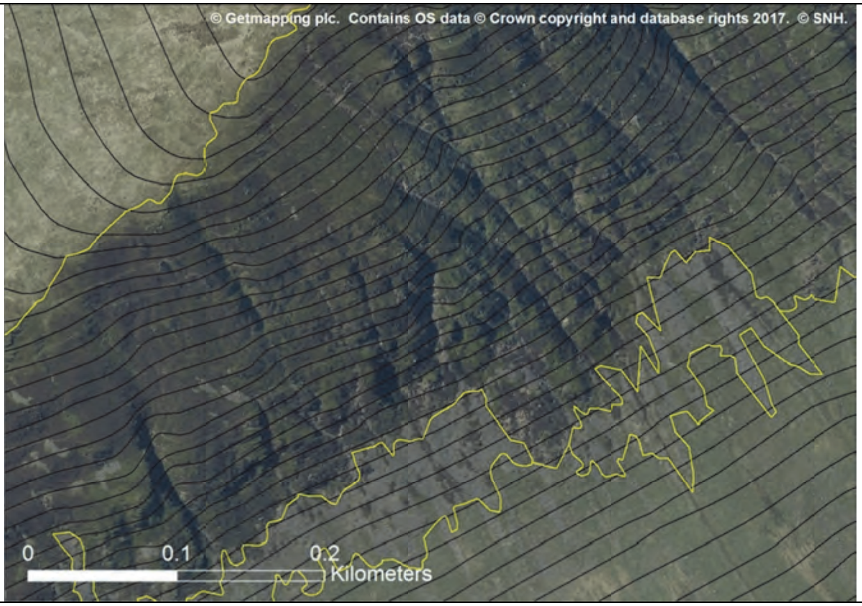
- CIR – *Calluna*-dominated – dark red-brown signal, *Vaccinium*-dominated – bright red-pink. Black shadow on edge of bushes indicative of texture and height. Burnt patches are pale blue/green mottled with pink and red/brown tones following re-growth of graminoids and dwarf-shrubs.
- RGB – *Calluna*-dominated – dark-brown, *Vaccinium*-dominated – bright green. Burnt patches are light-brown.

Mapping approach / constraints:

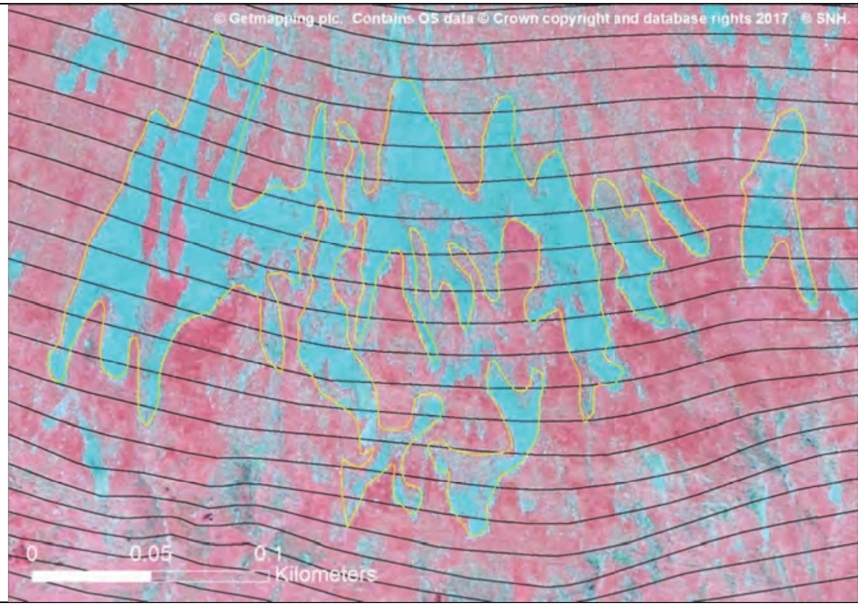
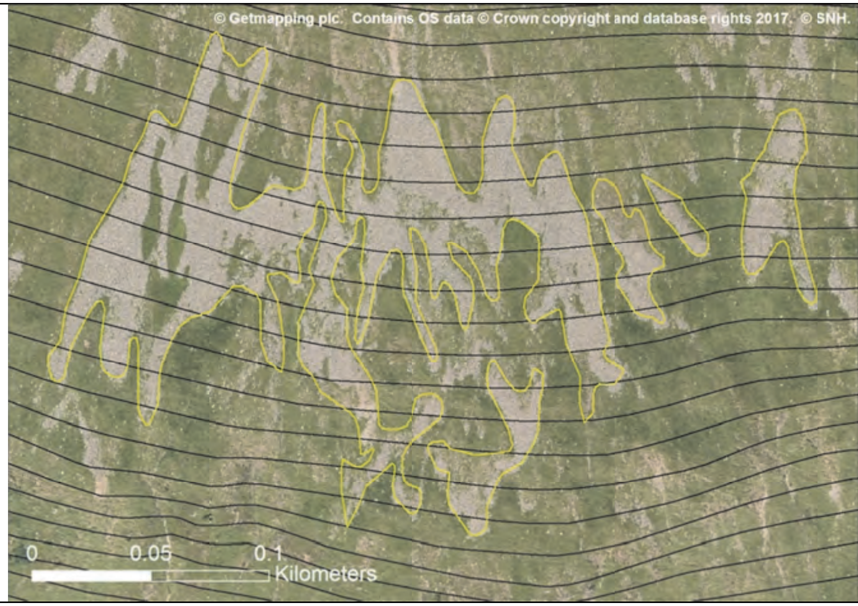
- Readily recognisable habitat where it forms extensive stands.
- Potential for confusion with F2.25, especially in altitudinal transition zone where F4.2 becomes increasingly short and wind-pruned but not fully alpine in character. Field checking a sample of polygons in this zone will improve accuracy.



CIR – 13/05/2009 (spring) – Southern Uplands – F4.2 on steep slope with mix of dark red-brown (Caluna vulgaris) and red-pink (Vaccinium myrtillus).



RGB – 13/05/2009 (spring) – Southern Uplands – (as above) F4.2 with mix of dark-brown (C. vulgaris) and bright green (V. myrtillus).

H2.31€ Siliceous scree of the montane to snow levels (H8110)	
NVC types: includes U18*, U21* (and other non-NVC). *Descriptive indicators:* • Widespread, locally extensive habitat. Can occur at any altitude, but only upland examples meet the Annex I definition. • Frost-shattered rock fragments (sides touching each other) occurring in defined patches or extensive fields (includes acid rock types such as quartzite, granite and sandstone). • Accumulating on slopes or at the base of slopes below cliffs (the source of the frost-shattered rock), or forming extensive fields on mountain summits and high plateaux. • Scattered tufts or patches of ferns may occur between the boulders, along with other grazing-sensitive species. • Scree patches have an irregular shape. Rock fragments have a rough/grainy texture. *Colour signal in aerial imagery:* • CIR – rock is bright white-blue (sky blue), with dark shadows around edges of individual boulders which give grainy texture when examined closely (helpful for distinguishing from smooth rock). Tufts of fern appear as bright pink-red. • RGB – rock is white-grey, with black shadows around edges of boulders. Tufts of fern appear as dark green. • Rock has a consistent spectral signal through seasons. In winter, dead fern tufts appear white in CIR and straw-yellow/brown in RGB. *Mapping approach / constraints:* • Classify all potential habitat as this type, whether it supports fern flora or not. Map to edge of scree patch/field. • Where many small intricate scree patches occur together, and if not delineated individually by the segmentation, draw boundary to furthest extent of scree patches and classify as mosaic with surrounding habitat. • Isolated patches of other habitats, including F4.2, F2.25, E4.32€, may occur within scree – classify as secondary habitat as per mapping rules. • Scree has a distinctive spectral signal and can be readily recognised at a higher level. Geology data / indicator species data sets / field checking are required to distinguish from H2.4€.	 *CIR – 11/07/2014 (summer) – Caenlochan – patches of white-blue H2.31€ on steep slope.*  *RGB – 11/07/2014 (summer) – Caenlochan – (as above) patches of white-grey H2.31€ on steep slope.*

H2.4€ Calcareous and calcshist screes of the montane to alpine levels (*Thlaspietea rotundifolii*) (H8120)	
NVC types: includes OV38*, OV40* (and other non-NVC). *Descriptive indicators:* • Rare and small-scale habitat, confined to areas where outcropping and subsequent weathering of base-rich rock types occur, including limestone, calcareous-schists and basic igneous rocks, such as serpentine and basalt. Can occur at any altitude, but only upland examples meet the Annex I definition. • Indicators are largely the same as those for H2.31€ Siliceous scree of the montane to snow levels. • May be present as distinct bands among siliceous scree. *Colour signal in aerial imagery:* • As for H2.31€. *Mapping approach / constraints:* • Where available, use detailed geology data to identify locations where outcropping of base-rich rock types may occur, and/or indicator plant species datasets to define areas of search. Map ‘potential’ calcareous scree patches using imagery. Undertake field visits to the locations to determine the presence of indicator species and confirm and map the extent of the feature. • List of possible indicator species to identify areas of search are the following ferns, *Asplenium ruta-muraria*, *A. trichomanes*, *A. viride*, *Cystopteris fragilis,* and *Polystichum lonchitis*, plus *Gymnocarpium robertianum*.	

H3.1# Siliceous rocky slopes with chasmophytic vegetation (H8220)

NVC types: includes U18*, U21* (and other non-NVC).

Descriptive indicators:

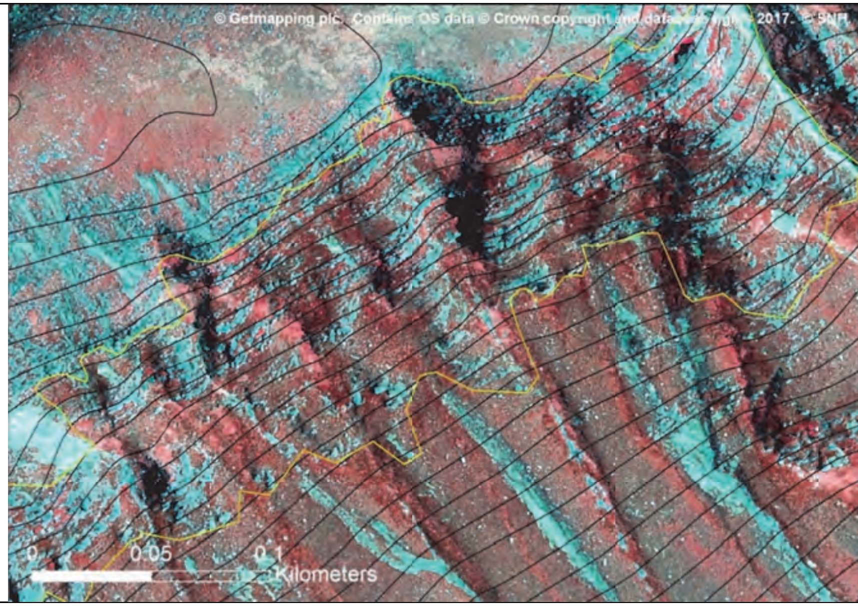
- Widespread, locally extensive habitat. Can occur at any altitude.
- Vertical, or near vertical, rock face/crag/cliff (comprised of siliceous rock such as quartzite, granite and sandstone) with cracks/crevices/fissures.
- Visible as bands of rock running horizontally across slope, or scattered/isolated outcrops, with broken/jaggy edges.
- Bryophytes and small vascular plants growing in the rock crevices (= chasmophytic vegetation).

Colour signal in aerial imagery:

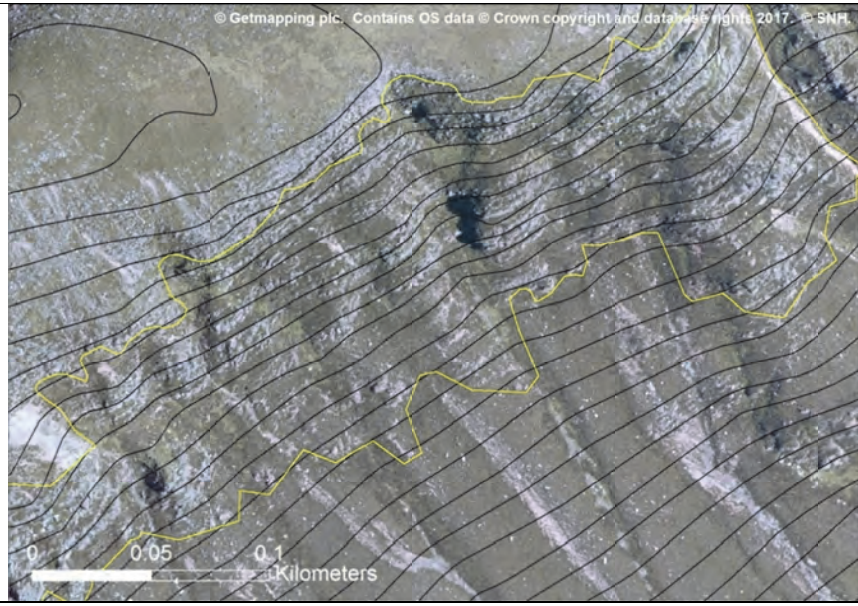
- CIR – bare rock is bright white-blue, deep cracks/crevices/fissures appear black, large areas of the rock face may also be obscured by black shadow (indicating steepness). Vegetation is sparse and unlikely to be detectable in imagery.
- RGB – bare rock is white-grey, deep cracks/crevices/fissures appear black.
- Rock has a consistent spectral signal through seasons.

Mapping approach / constraints:

- Classify all potential habitat as this type, whether it supports the characteristic plants in crevices or not – map entire rock face/crag/cliff.
- Flat/smooth siliceous rock slab should be classified as H3.51x.
- Vegetated ledges, terraces and slopes among the cliff face should be classified separately according to mapping rules.
- Where many discrete rock outcrops/cliffs occur together, and if not delineated individually by the segmentation, draw boundary to furthest extent of rock outcrops in group and classify as mosaic with surrounding habitat.
- Rocky slope has a distinctive spectral signal and can be readily recognised at a higher level. Geology data / indicator species data sets / field checking are required to distinguish from H3.25 which occur on base-rich rock outcrops and have identical spectral signal.

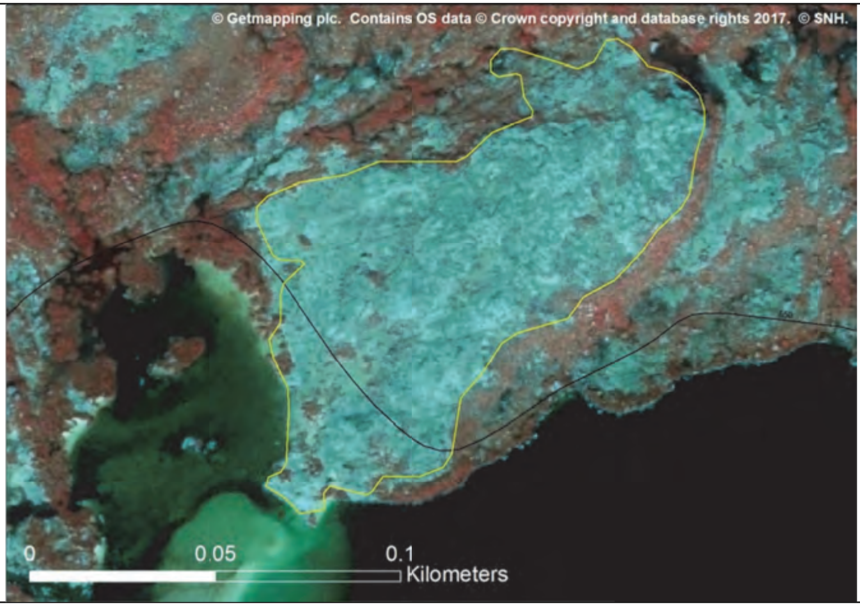


CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – white-blue H3.1# in bands on near-vertical slope.



CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – (as above) white-grey H3.1# in bands on near-vertical slope.

H3.25 Alpine and sub-mediterranean chasmophyte communities (H8210)	
NVC types: includes OV39*, OV40* (and other non-NVC). *Descriptive indicators:* • Rare and small-scale habitat, confined to areas with outcropping of base-rich rock, including limestone and calcareous-schists. Can occur at any altitude. • Indicators are largely the same as those for H3.1# Siliceous rocky slopes with chasmophytic vegetation. • May be present as distinct bands among H3.1#. *Colour signal in aerial imagery:* • As for H3.1#. *Mapping approach / constraints:* • Where available, use detailed geology data to identify locations where outcropping of base-rich rock types may occur and/or indicator plant species datasets to define areas of search. Map 'potential' calcareous rocky slope using imagery. Undertake field visits to the locations to determine the presence of indicator species and confirm and map the extent of the feature. • List of possible indicator species to identify areas of search are the following ferns: *Asplenium ruta-muraria*, *A. trichomanes*, *A. viride*, *Cystopteris fragilis,* and *Polystichum lonchitis*.	

H3.51x Non-limestone rock slabs (non-Annex I)	
NVC types: none. *Descriptive indicators:* • Widespread, locally extensive habitat. Can occur at any altitude. • Flat or gently sloping, smooth slabs of rock (shaped by ice action), largely devoid of vegetation except in occasional hollows/pits/depressions where organic substrate has accumulated. • Lacking clint and grike appearance of limestone pavement. *Colour signal in aerial imagery:* • CIR – bare rock is bright white-blue/grey. Often with localised areas of dull-pink vegetation in hollows. Smooth rather than grainy texture (of scree or gravel), and lacking frequent black fissures, cracks and heavy shadow (as seen on rocky slope habitats). • RGB – bare rock is white-grey. Localised areas of dull-green/brown vegetation. *Mapping approach / constraints:* • Readily identified habitat with distinct spectral signal. Can cover extensive areas when it should be classified separately rather than considered part of the substrate. Map as single habitat or secondary as per mapping rules.	 *CIR – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – extensive slab of white-blue H3.51x.*  *RGB – 26/08/2014 (summer) – Beinn Eighe & Flowerdale – (as above) extensive slab of white-grey H3.51x.*

ANNEX 3: MAPPING RULES DEVELOPED FOR THE UPLAND MAPPING PILOT

General rules for all habitats:

1. Avoid mapping mosaics whenever possible.
2. Mapping small polygons is preferable to mapping mosaics where discrete areas of habitat are present.
3. Where complex mosaics occur, e.g. when a primary group A habitat is <80% of polygon and other habitats are >20% combined BUT none of them individually is >10% OR >1 ha – re-draw / split the polygon to remove a simpler area of group A habitat and define a new mosaic polygon where one or more secondary habitats is >10% OR >1 ha.
4. When a notable restricted habitat (group C to F) is being mapped as part of a mosaic with a group A habitat, the restricted habitat should not be considered part of the 20% of other allowable habitats, i.e. the 20% rule applies to the group A habitat.

Specific rules for individual habitat groupings:

Group	EUNIS habitat	EUNIS code	Annex I code	Occurrence / extent	Map object / MMU*	Mapping rules	Allowable habitats
A	Blanket bogs	D1.2	H7130	Widespread habitat, principally occurring in extensive stands.	Polygon (single habitat or proportion of mosaic). MMU = 0.25 ha.	1. For a polygon to be labelled as a single Group A habitat, that habitat must cover ≥80% of the polygon. 2. Up to 20% of the polygon may consist of a combination of other allowable habitats. 3. If the area covered by another habitat is >10% OR >1 ha, it must be mapped as a secondary habitat.	Any other group A habitat, plus: D2.2, E1.71, E1.72x, E3.4, E3.512 / F4.13, E3.52, E4.11, E5.5x.
	Siliceous alpine and boreal grasslands	E4.32€	H6150				Any other group A habitat, plus: D2.2C, E1.71, E1.72x, E3.52, E4.11, H3.51x, H5.3.
	Boreo-alpine and arctic heaths	F2.25	H4060				Any other group A habitat, plus: D2.2C, E1.71, E1.72x, E3.52, E4.11, H3.51x.
	Northern wet heaths	F4.11	H4010				Any other group A habitat, plus: D2.2, E3.4, E3.512 / F4.13, E1.71, E1.72x, E3.52, E5.31, E5.5x, F2.323, scattered trees.
	Dry heaths	F4.2	H4030				Any other group A habitat,

Group	EUNIS habitat	EUNIS code	Annex I code	Occurrence / extent	Map object / MMU*	Mapping rules	Allowable habitats
							plus: D2.2, E3.4, E3.512 / F4.13, E1.71, E1.72x, E5.31, E3.52, E5.5x, F2.323, scattered trees.
B	Siliceous scree of the montane to snow levels	H2.31€	H8110	Widespread habitat, occurring in locally extensive stands. Relatively easily identified at a higher level but ancillary information / field checking required to separate from similar calcareous rock habitats.	Polygon (single habitat or proportion of mosaic). MMU = 0.05 ha.	As for group A, plus 4. Record group B habitat as a mosaic component where >5% of polygon.	All group A habitats (except blanket bog), plus: D2.2, E1.71, E1.72x, E4.11, E5.5B, E5.31, F2.323, H3.51x, H5.3, scattered trees.
	Siliceous rocky slopes with chasmophytic vegetation	H3.1#	H8220				All group A habitats (except blanket bog), plus: D2.2, E1.71, E1.72x, E4.11, E5.31, E5.5x, E5.5B, F2.323, H3.51x, H5.3, scattered trees.
C	Atlantic heavy-metal grassland	E1.B1	H6130	Rare, small-scale habitat, only occasionally locally extensive. Relatively easily identified at a higher level but ancillary information / field checking required to separate from similar habitats.	Polygon (where possible) OR point. No MMU.	1. Map all examples as single habitat or as proportion of mosaic.	
	Sub-Atlantic semi-dry calcareous grassland	E1.26	H6210				
D	Species-rich *Nardus* grassland, on siliceous substrates	E1.72#	H6230	Rare, small-scale habitat, occasionally	Polygon only (single habitat or	1. Map all examples as single habitat or proportion of mosaic.	

Group	EUNIS habitat	EUNIS code	Annex I code	Occurrence / extent	Map object / MMU*	Mapping rules	Allowable habitats
	in mountain areas			locally extensive. Relatively easily identified at a higher level but ancillary information / field checking required to separate from similar habitats.	proportion of mosaic). MMU = 0.25 ha.		
E	Sub-Arctic *Salix* spp. scrub	F2.1#	H4080	Rare, small-scale habitat, only occasionally locally extensive. Small scale and scarcity make precision of mapping important.	Polygon where possible (single habitat or proportion of mosaic) OR point. No MMU.	1. All stands that meet criteria to be mapped.	
	[*Juniperus communis*] scrub	F3.16#1	H5130				
	Limestone pavements	H3.511€	H8240				
F(i)	*Rhynchospora alba* quaking bogs	D2.37	H7150	Rare, small-scale habitat, only occasionally locally extensive. Small scale and scarcity make precision of mapping important. Ancillary information (geology / indicator species datasets) and	Polygon only (proportion of mosaic). No MMU.	1. Map all examples.	
F(ii)	Transition mires and quaking bogs	D2.33€	H7140		Polygon only (single habitat or proportion of mosaic). MMU = 0.05 ha.		
	Alpine and subalpine calcareous grasslands	E4.12€	H6170				
	Calcareous and calcshist screes of the montane to	H2.4€	H8120				

Group	EUNIS habitat	EUNIS code	Annex I code	Occurrence / extent	Map object / MMU*	Mapping rules	Allowable habitats
	alpine levels (*Thlaspietea rotundifolii*)			field checking required for accurate mapping.			
	Alpine and sub-mediterranean chasmophyte communities	H3.25	H8210				
F(iii)	Hard water spring mires	D4.1N	H7220		Polygon (proportion of mosaic) OR points. No MMU.		
	Alkaline fens	D4.15€	H7230				
	Alpine pioneer formations of the *Caricion bicoloris-atrofuscae*	D4.24€	H7240				
	Oro-boreal tall-herb communities	E5.59	H6430				
G	Sub-Atlantic [*Pteridium aquilinum*] fields	E5.31	Non-Annex I	Widespread habitat occurring in extensive stands.	Polygon (single habitat or proportion of mosaic). MMU = 0.25 ha.	1. For a polygon to be labelled as a single Group G habitat, that habitat must cover ≥80% of the polygon. 2. Up to 20% of the polygon may consist of a combination of other allowable habitats. 3. If the area covered by another habitat is >10% OR >1 ha, it must be mapped as a mosaic	Any group A, B, G, H, I habitat (as appropriate).
	Closed non-Mediterranean dry acid and neutral grassland ([*Nardus stricta*] swards; Other *Agrostis-Festuca* grassland)	E1.7 (E1.71; E1.72x)	Non-Annex I				
	Moist or wet eutrophic and	E3.4	Non-Annex I				

Group	EUNIS habitat	EUNIS code	Annex I code	Occurrence / extent	Map object / MMU*	Mapping rules	Allowable habitats
	mesotrophic grassland					component.	
	Moist or wet oligotrophic grassland (Heath [*Juncus*] meadows and humid [*Nardus stricta*] swards; Acidocline purple moorgrass meadows	E3.5 (E3.512; E3.52)	Non-Annex I				
	Boreo-alpine acidocline snow-patch grassland and herb habitats (*Rhytidiadelphus-Deschampsia* snowbed; Boreo-alpine [*Deschampsia*]-[*Anthoxanthum*] communities	E4.11 (E4.115x ; E4.116	Non-Annex I				
H	Poor fens and soft-water spring mires	D2.2	Non-Annex I	Widespread habitat occurring in small-scale stands.	Polygon (single habitat or proportion of mosaic). MMU = 0.25 ha.	1. Rules for group A, B, and G habitats imply that only extensive examples of these habitats will be mapped as individual polygons.	
	Alpine and subalpine fern stands	E5.5B	Non-Annex I				
	Luzula sylvatica-Vaccinium myrtillus tall-herb community	E5.5x	Non-Annex I				
I	Sparsely- or un-	H5.3	Non-	Widespread	Polygon	1. Rules for group A, B,	

Group	EUNIS habitat	EUNIS code	Annex I code	Occurrence / extent	Map object / MMU*	Mapping rules	Allowable habitats
	vegetated habitats on mineral substrates not resulting from recent ice activity		Annex I	habitat, locally extensive.	(single habitat or proportion of mosaic). MMU = 0.25 ha.	and G habitats imply that only extensive examples of these habitats will be mapped as individual polygons.	
	Non-limestone rock slabs	H3.51x	Non-Annex I				
J	Woodland (Broadleaved deciduous woodland; Coniferous woodland)	G (G1; G3)	Non-Annex I	Widespread habitat, principally occurring in extensive stands. Most woodland (including Annex I types) mapped by existing Native Woodland Survey of Scotland (NWSS) and National Forest Inventory (NFI) datasets, these areas are masked out from segmentation. Additional woodland not covered by these datasets may be encountered, including new planting schemes.	Polygon (single habitat or proportion of mosaic). MMU = 0.5 ha.	1. Areas masked out as woodland (using NWSS/NFI datasets) should be automatically coded using attributes of masking data to basic level of EUNIS. 2. Map additional woodland (≥0.5 ha with ≥20% canopy cover, as per NWSS) which occurs outwith NWSS/NFI datasets as individual polygons, classified to EUNIS level 2. 3. Contiguous stands of open-ground habitats spanning either side of a woodland planting fence, but outwith areas covered by NWSS/NFI, should be mapped as single upland habitat	

Group	EUNIS habitat	EUNIS code	Annex I code	Occurrence / extent	Map object / MMU*	Mapping rules	Allowable habitats
						polygons. 4. Open-ground habitats completely within planting fences but outwith NWSS/NFI datasets should be mapped as upland open-ground habitat subject to a MMU of 1 ha.	
K	Inland surface waters (water bodies); Constructed, industrial and other artificial habitats (roads, tracks, buildings)	C; J		Localised occurrences in upland areas. OS Vector Map District (VMD) used to mask out roads, buildings and water bodies from segmentation.	Polygon. No MMU.	1. Masked-out roads, buildings and water bodies (using VMD) should be coded using attributes of masking data to EUNIS level 1. 2. If segmentation pulls out any of these features which have not been masked-out, these polygons should be retained and coded to EUNIS level 1. 3. If a track, building or water body is present as part of a larger polygon, not delineated individually, it should be recoded as a proportion of the larger polygon.	

*MMU = minimum mappable unit.

ANNEX 4: DESCRIPTION OF HABITAT CLASSES CREATED FOR ACCURACY ASSESSMENT

Habitat class	Frequency / extent	EUNIS code (Annex I code)	Cover threshold (proportion)	Beinn Eighe: polygons (samples)	Caenlochan: polygons (samples)
Blanket bog	Widespread / extensive	D1.2 (H7130)	≥ 0.7	187 (32)	326 (38)
Blanket bog mosaic	Widespread / extensive	D1.2 (H7130) / F4.2 (H4030) / D2.22 / E1.71 / E3.4 / E3.52	≥0.4 and ≤0.6	-	41 (5)
Blanket bog / wet heath mosaic	Widespread / extensive	D1.2 (H7130) / F4.11 (H4010)	≥0.4 and ≤0.6	43 (6)	-
Bare peat	Widespread / extensive	D1.24 (H7130)	≥ 0.4	-	75 (8)
Poor fen	Widespread / small-scale	D2.22	≥ 0.7	4 (0)	10 (1)
Alkaline fen / alpine pioneer formations	Rare / small-scale	D4.15€ (H7230) / D4.24€ (H7240)	≥ 0.15	-	75 (9)
Acid grassland	Widespread / extensive	E1.71, E1.72x, E3.52	≥ 0.7	-	232 (20)
Species-rich *Nardus* grassland	Rare / small-scale	E1.72# (H6230)	≥ 0.15	-	77 (9)
Wet grassland	Widespread / extensive	E3.4, E3.5 excluding E3.52	≥ 0.7	-	47 (6)
Acidocline snow-patch grassland	Locally extensive	E4.116	≥ 0.7	-	12 (2)
Siliceous alpine and boreal grassland	Widespread / extensive	E4.32€ (H6150)	≥ 0.7	37 (8)	49 (5)
Bracken	Widespread / extensive	E5.31	≥ 0.7	11 (2)	24 (3)
Alpine and boreal heath	Widespread / extensive	F2.25 (H4060)	≥ 0.7	36 (8)	88 (11)
Wet heath	Widespread / extensive	F4.11 (H4010)	≥ 0.7	196 (36)	-
Wet heath /	Widespread	F4.11	≥0.4 and ≤0.6	5 (1)	-

Habitat class	Frequency / extent	EUNIS code (Annex I code)	Cover threshold (proportion)	Beinn Eighe: polygons (samples)	Caenlochan: polygons (samples)
alpine and boreal heath mosaic	/ extensive	(H4010) / F2.25 (H4060)			
Wet heath / dry heath mosaic	Widespread / extensive	F4.11 (H4010) / F4.2 (H4030)	≥0.4 and ≤0.6	14 (3)	-
Dry heath	Widespread / extensive	F4.2 (H4030)	≥ 0.7	72 (12)	283 (34)
Dry heath / acid grassland mosaic	Widespread / extensive	F4.2 (H4030) / E1.71, E1.72x, E3.52	≥0.4 and ≤0.6	-	50 (6)
Siliceous scree	Locally extensive	H2.31€ (H8110)	≥ 0.15	96 (15)	191 (22)
Siliceous rocky slope	Locally extensive	H3.1# (H8220)	≥ 0.15	87 (14)	28 (3)

ANNEX 5: COSTING FOR FULL ROLL-OUT OF SCIR API METHOD ACROSS THE UPLAND SURVEY GAP IN DEFINED GEOGRAPHIC AREAS OF SCOTLAND

The following describes details of the costing exercise for a roll-out of the sCIR API technique to map the full suite of habitats encountered across the HabMoS upland survey gap, delivered by an in-house SNH team. It should be noted that costs are approximate, and generated only in order to estimate the magnitude of costs for a full roll-out.

Staff time for the following elements of this work was considered: (i) desk-based mapping and fieldwork; (ii) management of GIS and imagery datasets; (iii) logistical aspects of fieldwork; and (iv) project management. Travel and subsistence for fieldwork and on-going costs of purchasing software licences and blockfiles for stereo imagery were also included.

Natural Heritage Futures (NHF) zones were used to divide Scotland into geographical areas to act as focal points for mapping (Map 1A). The area of upland survey gap in each NHF zone was calculated (Map 1B).

Time estimates were then generated for desk and field-based mapping work by applying the following basic formula per 100 km^2 of upland survey gap: 10 days desk-based mapping + 1 day to develop / refine local interpretation indicators + [2 days fieldwork + travel from office multiplier + remoteness multiplier (see below)] + 2.5 days specialist input.

Travel from office – the travel time from office to the centre of each NHF zone was calculated (by car, plane and/or ferry), and each zone assigned a category: L (<1.5 hours), M (1.5 – 3 hours), H (3 – 6 hours).

Remoteness – Scotland's wildness (remoteness from public mechanised access) dataset (© SNH) was used to calculate the average time to walk to the upland survey gap for each NHF zone (dataset takes account of distance, relative slope, ground cover and barrier features such as open water and very steep ground), and each zone was assigned a category: L (<40 min), M (40 – 80 min), H (80 – 120 min).

The following multipliers (days) were added per day in the field for both 'travel from office' and 'remoteness': L (0), M (0.25), H (0.5). Taking account of multipliers assigned to a particular NHF zone, each 100 km^2 square of upland survey gap could have a minimum of 2 and a maximum of 4 days allocated to fieldwork.

The number of days allocated to desk-based mapping work, fieldwork, and specialist input was summed for each NHF zone and divided by 200 (the number of mapping days per year out of a total of 212 SNH working days) to give the number of person years. Based on the mapping team outlined in Table 1, equating to 3.75 FTE mappers, salary costs, not including inflation, were generated for each of the 21 NHF zones (Table 2).

Front-loaded start-up costs of establishing a new team, requiring a 3 month training period, plus costs of buying computer equipment, software and PPE for each staff member were also included (Table 2).

Fieldwork travel and subsistence costs were also calculated for each NHF zone (Table 2). For zones distant from the office ('M' or 'H' travel time), it was assumed that fieldwork would be undertaken over a 5 day trip, traveling from office to field on day 1, and back on day 5. For every 5 days of fieldwork, 4 overnight stays were allocated. Mileage estimates for each 5 day trip included one return trip from office (average of distance from office to centre of zone, and office to two furthest extremes of zone), plus additional mileage for travelling to and from accommodation and field sites each day.

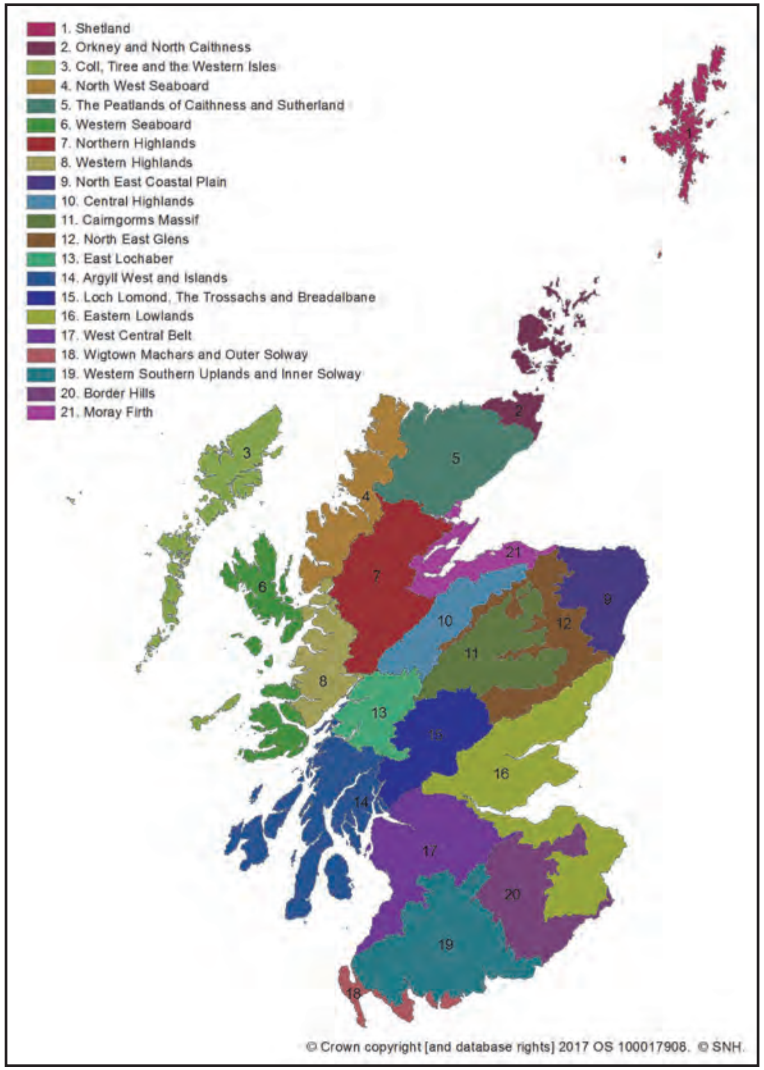
For zones closer to the office ('L' travel time), 2 overnight stays were allocated for every 5 days in the field, assuming travel to and from office and field on most days, with occasional overnight stays required in more distant parts of the zone. Mileage estimates included three return trips from office to zone, plus travel to and from accommodation on the two days with overnight stays.

Additional travel costs for NHF zone 1 (Shetland), 2 (Orkney) and 3 (Western Isles) included costs of flights and/or ferry trips to islands, and assumed use of SNH pool cars from local area office to travel to field sites when on islands.

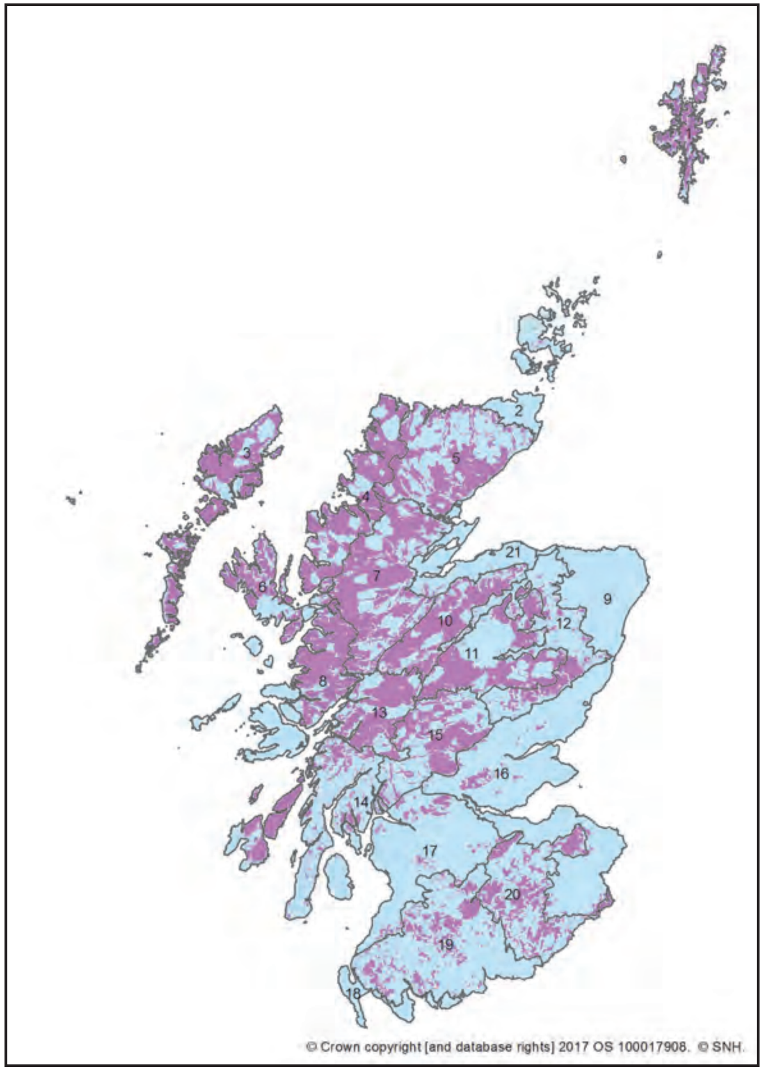
Accommodation rates of £65 per night plus £25 per night subsistence (based on standard SNH rates 2016/17) were applied to the number of overnight stays required, and a mileage rate of £0.35 per mile (cost to SNH of using pool vehicles) applied to mileage estimates.

On-going costs of: (i) purchasing blockfiles from Getmapping, and (ii) software maintenance were also included.

For comparison, the cost of surveying the HabMoS upland survey gap by full field survey was also calculated (Table 3). It was assumed this would be delivered by external contractors charging a fixed daily rate of £300 per day, including travel and subsistence (estimate based on a number of previous NVC survey contracts). An average figure of 3 km^2 surveyed in the field per day was applied, higher than the standard figure of 2 km^2 typically quoted for full NVC field survey, based on some assumed efficiencies gained due to less detailed Annex I (or equivalent) level of mapping detail, no requirement for collection of quadrat data, and use of GIS mapping application on portable tablet in the field. For each day spent in the field, 0.5 day was allocated for associated desk-based work, including preparation for field visits and final digitisation/tidying up of map data (Table 3).



Map 1A. Natural Heritage Futures Zones.



Map 1B. Upland survey gap (purple) in Natural Heritage Futures Zones.

Table 1. Roles and responsibilities for in-house SNH upland mapping team.

Role	Grade	FTE	Key tasks
Project Manager	E	0.4	– Overall management of project. – Line-manage D-grade staff. – Strategic direction and link with senior management. – Responsible for budget and progress reporting.
Mapping Officer / Co-ordinator	D	0.5 / 0.5	– Training other staff in mapping method. – Co-ordination of mapping work. – Responsible for communications (including land owner access agreements). – Line-manage C-grade post. – Remainder of time (0.5 FTE): undertake upland habitat mapping using sCIR API technique – both desk and field based work.
Mapping Officer	D	3	– Responsible for undertaking all aspects of upland habitat mapping using sCIR API technique – both desk and field based work. – Production of high-quality GIS dataset of Annex I and EUNIS coded habitat polygons – across the upland survey gap.
Assistant Mapping Officer	C	1	– Responsible for organising fieldwork – including logistics, access arrangements, and equipment. – Responsible for obtaining and managing GIS data and imagery and setting up tablets for fieldwork. – Assist with production of progress reports and maps. – Remainder of time (0.25 FTE): assist with upland habitat mapping using sCIR API technique – both desk and field based work.
GIS Support (via SNH Geographic Information Group	n/a	n/a	– Provide specialist GIS support, including analysis and data management tasks, and deliver training for new staff in these tasks. – Order imagery and blockfiles from Getmapping.
Admin Officer (via existing resource)	n/a	n/a	– Help with arranging accommodation and travel. – Ordering equipment.

Table 2. Costing for in-house SNH team to apply sCIR API mapping technique in Natural Heritage Futures Zones across the HabMoS upland survey gap.

NHF Zone number / name	Upland gap (ha)	% of total gap[1]	Mapping person years[2]	Mapping team years [3]	E-grade 0.4 FTE (£)	D-grade 4 FTE (£)	C-grade 1 FTE (£)	Total staff cost (£)[4]	Fieldwork T&S (£)[5]	Additional costs (£)[6]	Total cost (£)
1. Shetland	87,865	3.3	0.7	0.2	4,843	38,965	8,075	51,882	3,569	2,007	57,458
2. Orkney and North Caithness	4,960	0.2	0.0	0.0	282	2,266	470	3,018	494	202	3,714
3. Coll, Tiree and the Western Isles	193,313	7.3	1.6	0.4	10,977	88,326	18,303	117,606	8,136	4,476	130,218
4. North West Seaboard	239,053	9.0	2.0	0.5	13,574	109,225	22,634	145,433	7,914	5,404	158,751
5. The Peatlands of Caithness and Sutherland	240,992	9.0	2.0	0.5	13,282	106,872	22,146	142,301	6,711	5,560	154,572
6. Western Seaboard	93,488	3.5	0.8	0.2	5,152	41,459	8,591	55,203	2,788	2,211	60,202
7. Northern Highlands	339,852	12.8	2.8	0.7	18,730	150,714	31,231	200,675	6,296	7,615	214,586
8. Western Highlands	185,372	7.0	1.6	0.4	10,526	84,698	17,551	112,775	6,121	4,260	123,156
9. North East Coastal Plain	219	0.0	0.0	0.0	12	94	20	125	53	181	359
10. Central Highlands	181,979	6.8	1.5	0.4	10,030	80,702	16,723	107,455	3,645	4,221	115,321
11. Cairngorms Massif	208,759	7.8	1.8	0.5	11,854	95,383	19,766	127,003	6,633	4,726	138,363
12. North East Glens	84,978	3.2	0.7	0.2	4,683	37,685	7,809	50,178	2,444	1,994	54,615
13. East	143,879	5.4	1.2	0.3	8,170	65,739	13,623	87,532	4,613	3,352	95,497

Lochaber											
14. Argyll West and Islands	133,130	5.0	1.1	0.3	7,560	60,828	12,605	80,993	5,217	3,124	89,333
15. Loch Lomond, The Trossachs and Breadalbane	165,169	6.2	1.4	0.4	9,103	73,247	15,179	97,529	4,619	3,787	105,934
16. Eastern Lowlands	36,318	1.4	0.3	0.1	2,002	16,106	3,338	21,445	1,221	880	23,545
17. West Central Belt	38,777	1.5	0.3	0.1	2,137	17,196	3,563	22,897	1,304	891	25,091
18. Wigtown Machars and Outer Solway	672	0.0	0.0	0.0	37	298	62	397	276	183	855
19. Western Southern Uplands and Inner Solway	123,005	4.6	1.0	0.3	6,779	54,549	11,304	72,632	4,373	2,881	79,887
20. Border Hills	155,506	5.8	1.3	0.4	8,830	71,052	14,724	94,606	5,884	3,585	104,074
21. Moray Firth	6,775	0.3	0.1	0.0	351	2,822	585	3,758	49	208	4,015
Total	2,664,061	100	22.3	5.9	148,914	1,198,227	248,301	1,595,442	82,356	61,749	1,739,546
Front-loaded costs[7]	-	-	1.0	0.3	6,263	50,394	10,443	67,100	-	18,000	85,100
Total + front-loaded costs	2,664,061	100	23.2	6.2	155,177	1,248,622	258,744	1,662,542	82,356	79,749	1,824,646

[1] % of total upland survey gap (= 2,664,061 ha) within zone; [2] Mapping person years required to undertake all desk and field based work to map upland gap within zone (based on 200 mapping days per year); [3] Actual years required to map zone by team = mapping person years divided by the number of FTE mappers in the team (= 3.75); [4] Total cost of E+D+C grade staff salaries over actual years required to map zone by team (based on SNH staff cost rates for 2017/18); [5] Travel and subsistence costs for fieldwork; [6] Additional on-going costs, including software licences and costs associated with stereo imagery; [7] Front-loaded start-up costs, including 3 month training period for mapping staff, and initial purchase of computer equipment, software and PPE.

Table 3. Approximate costing for full field survey of HabMoS upland survey gap by external contractors.

	Pilot area (100 km^2)	Upland survey gap (26640 km^2)
Fieldwork days (3 km^2 surveyed per day)	33	8880
Desk days (0.5 day prep./data entry/digitisation per day in field)	17	4440
Total days	50	13320
Person years	0.25	66.6
Cost (@ £300 per day incl. T&S)	£15,000	£3,996,092

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