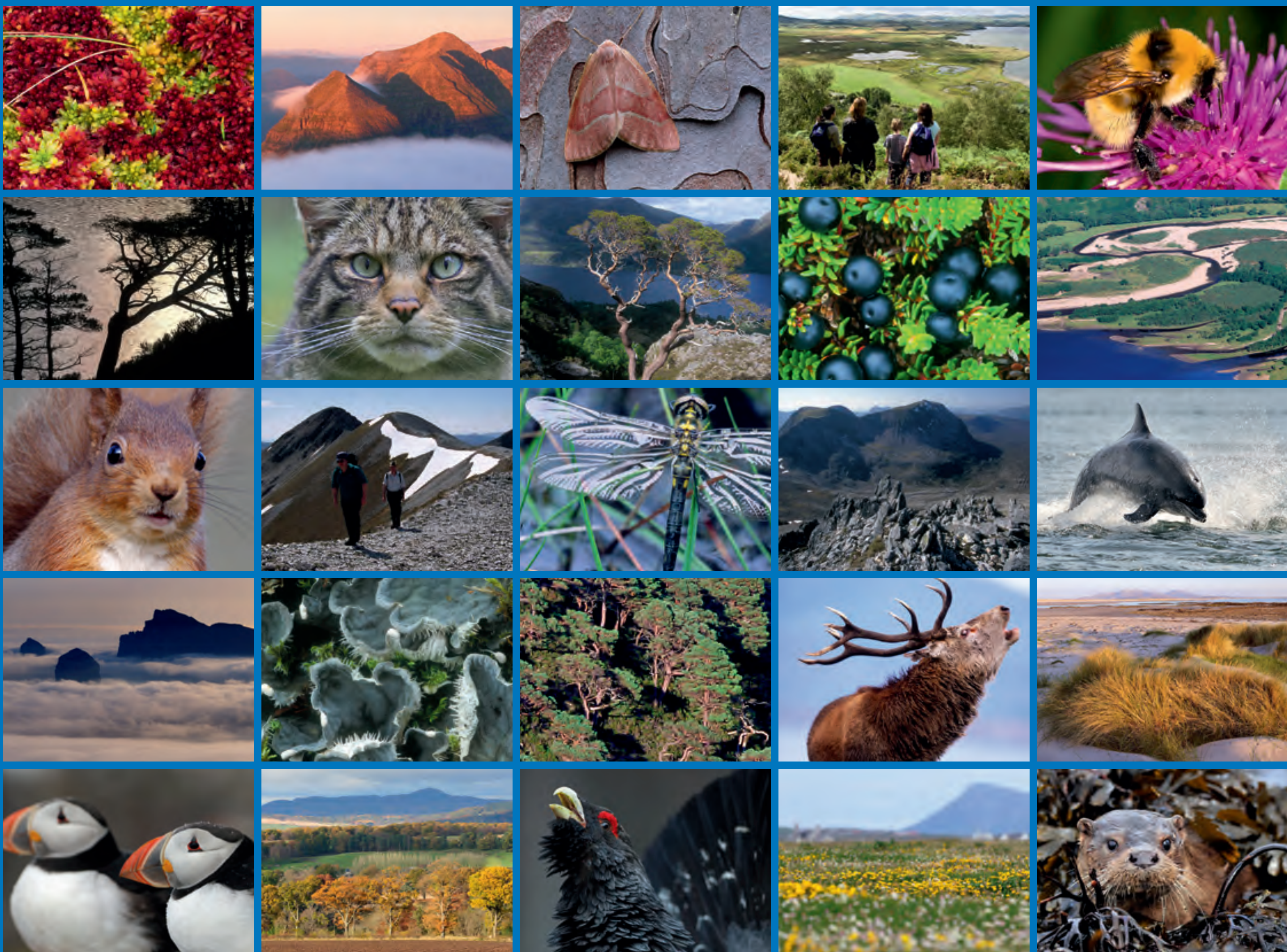
Scottish Natural Heritage
Commissioned Report No. 514

Remote sensing methodology: Fieldwork and additional rule base development for Scottish upland habitats



Scottish Natural Heritage
Dualchas Nàdair na h-Alba
All of nature for all of Scotland
Nàdar air fad airson Alba air fad

COMMISSIONED REPORT

Commissioned Report No. 514

Remote sensing methodology: Fieldwork and additional rule base development for Scottish upland habitats

For further information on this report please contact:

Sarah Smyth
Scottish Natural Heritage
Great Glen House
INVERNESS
IV3 8NW
Telephone: 01463 725000
E-mail: sarah.smyth@snh.gov.uk

This report should be quoted as:

Medcalf, K., Cameron, I., and Turton, N. (2012). Remote sensing methodology: Fieldwork and additional rule base development for Scottish upland habitats. *Scottish Natural Heritage Commissioned Report No. 514*

COMMISSIONED REPORT

Summary

Remote sensing methodology: Fieldwork and additional rule base development for Scottish upland habitats

Commissioned Report No.: Report No. 514 (Project no. 10604)
Contractor: Environment Systems Ltd.
Year of publication: 2012

Background

This work is a continuation of three previous studies, Medcalf *et al.,* (2011a), The GeoInformation Group, (2011) and Brown *et al.,* (2011), which outlined the potential for geoinformatic techniques and rule based approaches to use existing data to identify possible areas of upland Annex I habitat. The GeoInformation Group project developed a trial classification map for two study areas, one in Torridon and one in the Cairngorms.

This project consisted of two parts, a field validation campaign of the mapping produced by The GeoInformaiton Group, and then a demonstration of how the results from the fieldwork can be fed back into the rule base for the Western study area.

Main findings

- The field campaign identified the need for more detailed ecological training within the initial rule base. The results produced by the developed rules, support the use of Earth Observation techniques as a very useful method of classification of the widespread and distinct Annex I habitats in the uplands of Scotland, such as wet heath and blanket bog.

- The fieldwork information was of key importance to the project. Any EO-based project needs ground validation to understand the manifestation of the communities in each study area.

- A hierarchical classification is necessary, embedded with different levels of segmentation, to narrow in on candidate classes and reduce confusion with other similarly presenting habitats.

- Suitable data, comprehensive data processing steps and a high level of ecological understanding of plant community features and processes are all essential to develop a rule based approach.

- Thorough data preparation allows for a more accurate and transferable rule base, and would be essential for monitoring, where multiple date imagery would be compared. Topographic correction reduces confusion caused by shadows.

For further information on this project contact:
Sarah Smyth, Tel: 01463 725000
For further information on the SNH Research & Technical Support Programme contact:
Knowledge & Information Unit, Scottish Natural Heritage, Great Glen House, Inverness, IV3 8NW.
Tel: 01463 725000 or research@snh.gov.uk

Table of Contents **Page**

1.	**INTRODUCTION**		**1**
	1.1	Background to the project	1
	1.2	Background to remote sensing and rule development	2
	1.3	Accuracy assessment	5
	1.4	Further development of the rule base	5
2.	**METHODS**		**6**
	2.1	Accuracy assessment and field data collection	6
	2.2	Reworking the rule base method	8
3.	**RESULTS**		**12**
	3.1	Imagery	12
	3.2	Accuracy of the segmentation	12
	3.3	Field data results and final accuracy assessment	15
	3.4	Revised classification accuracy	16
	3.5	Visual comparison of identified classes and class rule features	18
	3.6	Mosaics and fuzzy mapping	23
4.	**DISCUSSION**		**26**
5.	**CONCLUSIONS AND RECCOMENDATIONS**		**28**
	5.1	Conclusions	28
	5.2	Recommendations	29
6.	**REFERENCES**		**30**
ANNEX 1: SAMPLING AREAS			**31**
ANNEX 2: FIELDWORK DATA CAPTURE FORM			**33**

Acknowledgements

The authors would like to acknowledge the input into this project of the Quadrat Scotland field team, Nikki Dayton, Ruth Maier, Tim Rafferty and Colin Wells.

The project team would also like to thank SNH staff for their input into the project in particular, Sarah Smyth, Sally Johnson, Graham Sullivan and Duncan Blake.

Glossary	
ATCOR-3	Topographic correction model
BAP	Biodiversity Action Plan
ENVI	Remote sensing software
EO	Earth Observation
GUI	Graphical User Interface
IRS	Indian Remote Sensing - Type of Earth Observation satellite
NDVI	Normalised Difference Vegetation Index
NIR	Near Infrared
NPV	Non-photosynthetic vegetation
NVC	National Vegetation Classification
PV	Photosynthetic vegetation
RGB	Red, Green, Blue
SPOT	Système Pour l'Observation de la Terre - Type of Earth Observation satellite
SWIR	Short-wave Infrared

1. INTRODUCTION

This report covers a two stage project; the first part of the project was the design of an accuracy assessment method for reporting upon the initial Earth Observation (EO) rule based method of habitat mapping developed under Scottish Natural Heritage Commissioned Report No. 495 where a rule based classification from EO data was developed for two study areas in Scotland. The second phase of this project was to continue the development of the initial rule base concepts, using new knowledge from the field checking to further develop the rule base to increase the accuracy of priority habitat mapping.

1.1 Background to the project

This work is a continuation of three previous studies:

- Medcalf K., Turton, N., Jarman, M. and Keyworth, S. (2011a). Inventory of terrestrial and freshwater BAP priority habitats and Annex I habitats*. Scottish Natural Heritage Commissioned Report* No. 445.
- The GeoInformation Group (2011). Inventory of upland BAP and Annex I habitats – Methodology for mapping upland habitats*. Scottish Natural Heritage Commissioned Report No. 495*
- Brown, I., Gimona, A., Poggio, L., Castellazzi, M., Aitkenhead, M. & Brooker, R. (2011). Inventory of Upland BAP and Annex I habitats – Developing habitat inventories. Scottish Natural Heritage Commissioned Report No. 494

These reports outlined the potential for geoinformatic techniques and rule based approaches to use existing data to identify areas of potential to be Annex I habitats. The GeoInformation Group (2011) project developed a trial classification map for two areas, one in Torridon and one in the Cairngorms. The project concentrated on Annex I habitats, only referring to priority habitats where there was no Annex I equivalent. The project also compared the rule based approach to digitising from aerial photography or using simpler remote sensing techniques.

In parallel to these projects the Crick Framework has been developed. This provides a tiered structure to explain how EO techniques can be used for habitat mapping. The framework gives detailed information on the use of EO techniques for identifying BAP Priority habitats and Habitats Directive Annex I habitats, including what techniques have so far been developed, what the potential of EO is for that habitat and what contextual data is like to also be required. The Crick Framework gives a useful starting point to understand the possibilities for remote sensing for the habitats under consideration within the two pilot areas (Medcalf *et. al.*, 2011b).

In order to better understand the potential for EO in Scotland it was decided that this project should include a field validation of the trial classification. This would provide a useful accuracy assessment of the technique, as well as providing additional information to refine the rule base further.

This report outlines the field checking project and the initial results and then goes on to demonstrate how the results from the field checking have been fed back into the rule base in terms of a more sophisticated segmentation, a revised classification and a resultant enhanced accuracy for the western study area. Time did not permit the eastern study area to be re-worked, but the report outlines how a more sophisticated segmentation rooted in ecological theory, would also enhance the classification and rules for the eastern area to result in similar accuracies.

Recommendations are given as to how remote sensing could be incorporated into a wider priority and BAP habitat mapping exercise to enable Scotland to monitor and report on the extent and condition of the internationally significant habitats.

1.2 Background to remote sensing and rule development

Optical remote sensing allows us to use images gathered either from satellites or airborne platforms to understand the surface of the earth. These techniques have been used for many years with manual interpretation of red/ green/ blue aerial photography. The satellite imagery typically includes a record of information of the earth's surface at wavelengths different to those visible to the naked eye. These include the Near Infra Red (NIR) bands and the Shortwave Infrared Bands (SWIR). These bands are particularly useful for land cover mapping as they have a close relationship to the vegetation and a strong spectral signal.

Figure 1, shows the reflectance curve for vegetation. The x axis shows the electromagnetic spectrum with the Blue, Green, Red visible part of the spectrum and then the longer wavelengths into the NIR and SWIR.

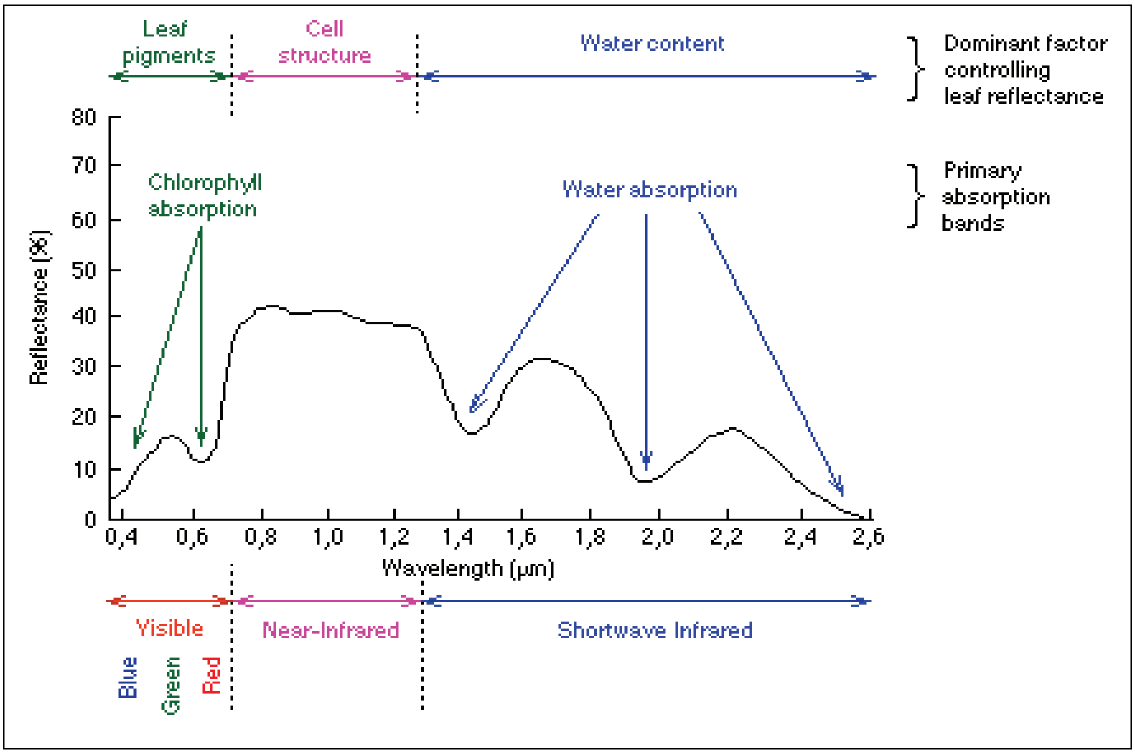


Figure 1 - The spectral reflectance curve for vegetation (adapted from Swain and Davis, 1978)

The NIR signal is particularly useful for recording vegetation types as its strength is related to the leaf structure. Unlike green light which is reflected form the top surface of the leaf and red and blue light which are absorbed and used in photosynthesis, NIR light passes through the top surface of the leaf but is generally reflected from the lower surface, therefore the more open and productive the vegetation the higher the NIR signal. Species such as rye grass have a much stronger signal in the NIR band than, for example, a leaf of bilberry, even though the RGB light signal could be very similar. This is shown in Figure 2.

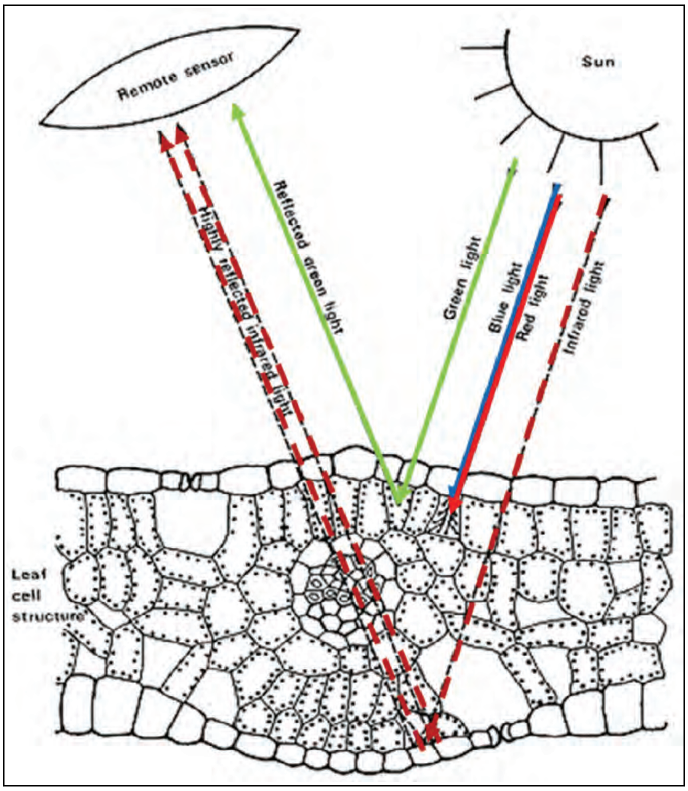


Figure 2 - The profile through a leaf and how light is reflected and absorbed (adapted from Lucas, 2010)

Within the SWIR bands the signal is influenced by the water content of the vegetation and the soil and therefore can be useful for separating wet habitats such as bogs from those with similar species but on a drier soil type such as dry heath.

Using the information from a satellite image to develop a rule base involves several stages of development:

1.2.1 Building an image stack

The remote sensing software allows for multiple bands (e.g. Red, green NIR SWIR) from multiple sensors to be used at the same time. This allows temporal vegetation features such as the change in growth form of bracken; from largely dead material in spring, to very productive living material in midsummer, to be included in an ecological rule base. Contextual layers such as roads and rivers from OS MasterMap and a digital terrain model can be included in the stack of data.

In order to make sure that all the data can be used together in a single coherent rule base it is necessary to have extremely accurate and robust data preparation techniques. Furthermore if the rule base is to be transferable and available to be run again on the acquisition of new imagery for a monitoring project then the imagery needs to be put into a standard form so that the values are consistent and comparable.

1.2.2 Development of the segmentation

Segmentation is a remote sensing technique where the computer examines every part (pixel) of an image and draws lines around those which are similar in colour and 'texture'; it does not classify them, it simply picks out areas of similar characteristics. It is possible to use any information from the image stack to base the segmentation upon. It is also possible to segment one part of the image, for example the agricultural fields, using one set of criteria (e.g. a large sized object with a high, even, NIR signal) from natural habitats (e.g. a smaller object with high green values). This technique of introducing different segmentation depending on the habitat of interest is very useful when dealing with the situation where some habitats are very common and form large objects and some are rare and form long thin objects.

The initial rule base developed by The GeoInformation Group (2011), used a single, simple segmentation technique using all the bands and the altitude information from the DTM to give a medium sized object. Those objects that were then classified as the same classes were then merged together into very large polygons. This approach was used in the pilot to give an initial look at the data and there is therefore much scope for the development of a more sophisticated segmentation based on the ecological manifestations of the habits within the landscape context. This theme is developed in this report. The level of detail it is possible to pick up depends upon the pixel size of the image**. Error! Reference source not found.** below demonstrates this effect. The dark purple area illustrates a region of alpine heath within a wider environment of turquoise dry heath and green blanket bog. With the finest pixel size the exact edge of each of the features can be picked up. With the medium pixel size the edge pixels of the purple area fall half into one pixel and half into another leading to a mixed single and a less accurate delineation. With the largest pixel size the purple area is such a small part of one pixel that is unlikely to be distinguished at all.

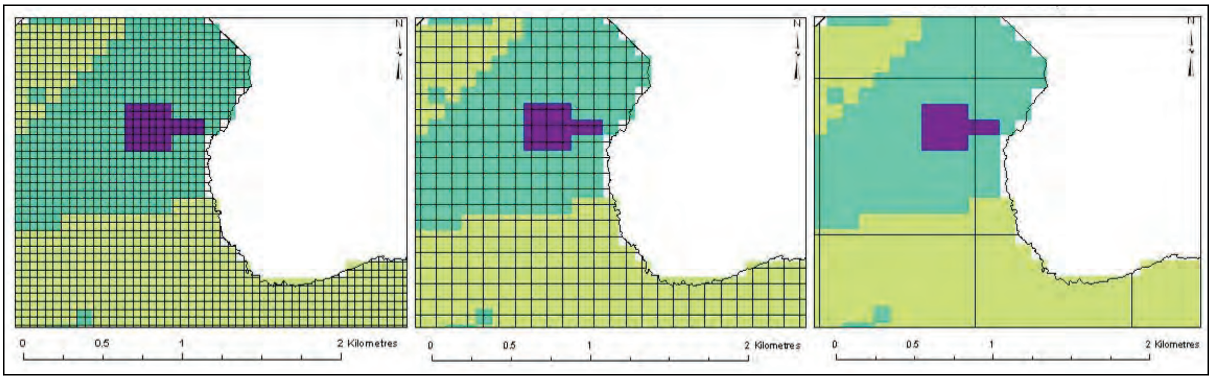


Figure 3 - Diagrammatic representation of habitat patch in relation to pixel size

1.2.3 Classification

Once each object is identified within the image it is possible to build up the rule base and classify the object depending on its ecological manifestation through spectral and landform characteristics. Plants of different species are visually different in all wavelength regions, especially those beyond the visible spectrum, the rule base allows the separation of object based upon these differences and variation with features such as:

- Moisture content
- Surface roughness (manifested as shade)
- Productivity
- Proportions of live and dead material
- Amount of woody material (i.e., biomass)
- The dominant plants of the community spectral signature
- The location of the community in terms of landform

- The relationship of the community with the surrounding vegetation
- Specific differences in growth form, in early spring (leaf off) to mid-summer (leaf on)

The advantage of using an object is that it has a real world significance and reduces the 'noise' introduced when trying to classify each individual 'pixel', it also allows consideration of features such as landscape context to be built into the classification.

1.3 Accuracy assessment

The field work analysis had two main purposes; the first was to check the existing initial remote sensing classification and the second was to collect data to allow an enhancement of the rule base. In order to understand the accuracy of the maps a sampling regime was designed that looked at both the segmentation and classification. Because the rule base approach depends on the segmentation as well as the classification the sampling was designed to evaluate the objects as well as their classification. Errors are not randomly distributed throughout a remote sensing map; they tend to form in specific locations. For example:

- In shaded areas on steep slopes where the spectral signature differs,
- Where for some reasons the habitat has a different appearance because of an added species, for example gorse scrub in a heathland,
- Habitats, that because of management/anthropogenic influence e.g. accidental burn, have an unusual phenotypic appearance,
- Areas of ecotones or mosaics.

Therefore we designed the sampling regime to allow the areas to be examined to fall into two groups, these are called 'A' and 'B' sampling subsets (see Annex 1). This would allow us to understand if there was any spatial difference between the accuracy of each group. This split had the additional advantage that it allows further training of the data using one set of field points whilst maintaining the other set to show accuracy results.

Within any habitat accuracy assessment, there are two main types of errors; an over-recording of habitat or missing areas of habitat. The sampling strategy developed covered both of these types of errors.

1.4 Further development of the rule base

There were several features commonly used in the development of object orientated rule base development that had not been incorporated into the original trial comparison (Lucas *et al*, 2011). This included high level radiometric and atmospheric correction so that multiple images could be directly compared in the same rule base. In addition a technique called topographic reflection could be built-in which helps 'even out' the signal from steeply sloping ground and avoids some of the problems of shadowing. In addition a technique called spectral unmixing allows for three additional data layers to be incorporated, these are Non-photosynthetic vegetation (NPV), Photosynthetic vegetation (PV) and shade. All of these features were incorporated into the new rule base for the western target area. In addition it is possible to build in additional detail by including finer scaled data such as NIR aerial photography into segmentation and classification. These additional levels of detail are out of scope of this project for specific inclusion in the data analysis, but do represent opportunities for inclusion in future projects.

2. METHODS

2.1 Accuracy assessment and field data collection

2.1.1 Spatial design of sampling method

Two features were considered during the sampling design; sample size and number. With sample size, it was important to ensure enough points were selected to allow statistical analysis of the data. However, with such large areas and difficult terrain it was also important to ensure that the field staff were able to visit sufficient polygons within a reasonable amount of time and effort. Because the area was too large to allow for a completely random sampling regime the initial rule base was taken as a broad indication of habitat types and recording effort targeted on these areas. This approach also allowed land owners to be contacted and data from sufficient numbers of polygons to be collected for the analysis, even if some areas originally selected could not be visited. This allowed a sensible field work system, but did have the issue that if the initial classification was inaccurate for some classes, then there may not be sufficient replicates of that class available for re-training and testing the data, as insufficient examples would have been visited.

When using data from individual points within a polygon to assess accuracy, as suggested in Congalton and Green (2009), 50 sampling points per class are recommended. The sample was based on the likely classes from the original classification. Considering whole polygons at each sampling location provides significant advantages that include:

- The understanding of the accuracy of the mapped units in terms of their polygon shapes and segmentation.
- An incorporation of the minimum mapping unit.
- By considering the objects identified by the system it provides a way of assessing whether examples of pure habitats are being accurately identified or whether mosaics of different habitats are being identified as objects.

The pilot classification data were skewed in terms of polygon size, with many hundreds of small polygons and a few extremely large ones in seven of the most frequent habitat type classes. Therefore, the initial sample consisted of a range of both the very large and small polygons in order to give a balanced view of the area of study.

In the western pilot area, five of the habitat types were common and present as very large blocks; in the east three were common and present as very large blocks. As a result of the skewed nature of these particular datasets ‘large polygons’ were defined as the largest 10% of polygons in each class with the remaining 90% of the polygons in that habitat class being termed 'small polygons'. In order to provide some stratification whilst still giving a random selection, six of the large, (several hundred hectare) polygons were selected at random, followed by the sample of small polygons selected within a 2km buffer of each large polygon. This method enabled the survey team to maximise the field effort while ensuring that all the habitat classes were well-represented. A 2km buffer was selected as it allowed sufficient distance from the large polygon to cover all the different land forms, e.g. mountain top, slope and valley bottom, as well as giving enough polygons to choose a random selection. It also gave a targeted area of about 4 – 10km within each ‘zone’ for field work, ensuring that most of the field time was spent identifying habitats rather than walking between samples.

These six areas were further allocated into two sets, each of which contained three zones (Set A and Set B); see Figure 4. These zones were allocated on the basis of estate access combined with geographic spread and ensured each set ‘A and B’ contained replicates of all the habitats. As always with a study of this nature, there is a trade-off between statistical rigour and meeting the constraints of the field team's time and access restrictions. The sample selection maps for the field analysis are shown in Annex 1.

A 1 large polygon and many small polygons	B 1 large polygon and many small polygons	A 1 large polygon and many small polygons
B 1 large polygon and many small polygons	A 1 large polygon and many small polygons	B 1 large polygon and many small polygons

Figure 4 - Diagrammatic representation of the sampling strategy

The use of the 'A' and 'B' stratification gave two datasets which could be used for further development. The 'A' polygons were reserved to test the re-worked classification and the 'B' field work polygons used to help train the new classification.

Several features and classes from the original pilot area classification were excluded from this analysis exercise, including:

- Very small polygons: Spatial resolution is a key factor in an object-orientated rule base approach. An object with four or five pixels (Radoux *et. al.*, 2006) gives the best chance of accurate classification, unless the class has been specifically designed to be found using contrast to the surrounding land, together with a very targeted, small scale segmentation. The satellite imagery had a 23m (IRS) or 20m (SPOT 4) resolution. Therefore, a group of four pixels covered about 0.25 ha. A minimum mapping unit was therefore instigated and any polygon less than 0.25 ha was dismissed from the analysis as likely to be cartographic noise.
- Sliver features between polygons were also removed from the data layer and not considered in the analysis.
- Many of the Annex I habitats in particular cover very small and precise locations. These include features such as H7150 depressions on peat substrates of the *Rhynchosporion*. These are rare and small habitats and not the focus of this project and were therefore not considered.

2.1.2 Field work

The project developed an electronic data collection form on a Trimble NOMAD hand held field data collection device. These devices include a GPS receiver to map the location of the polygon at which the survey was taken as well as the information about the area. The use of these devices also increased efficiency and prevented transcribing errors. The field recording form can be found in Annex 2.

The following features were analysed:

- Was the polygon a classic example of the habitat? (Did the classification match the habitat on the ground?)
- Was the size and shape of the polygons correct?
- Was the polygon part of a complex mosaics?
- Was the habitat visible as a discrete area on the imagery?

2.1.3 Statistical analysis

In terms of accuracy the key statistics (Congalton, 1991) were calculated. This included:

- Producer's accuracy: the proportion of reference points in a mapped category that has been correctly mapped.
- User's accuracy: the proportion of a mapped category that has been correctly mapped.
- Overall accuracy: the percentage of points correctly classified by the mapping.

2.2 Reworking the rule base method

Following on from the field work it was decided that the rule base should be re-worked in the light of the knowledge gained to increase the accuracy.

2.2.1 Imagery

The imagery for the western areas was obtained in a partially corrected (in remote sensing terms) format. This made it difficult to instigate full and complete imagery correction. In order to re-work the rule base to take into account a topographic correction and in order to have a standardised data set the imagery was re-acquired in its raw ‘1a format’ and re-worked. The results of the topographic correction algorithm applied are outlined below. There was insufficient time to re-work the imagery for the eastern area and provide a classification.

The steps that were taken to re-work the imagery are shown in Figure 5 and include the following stages:

- Correction to a standardised value at the sensor (digital number to radiance conversion),
- Correction of the effect of the sun angle (conversion to top of atmosphere reflectance),
- Placement of the imagery in the correct position on the earth surface (ortho-rectification),
- Correction of atmospheric effects due to dust and air pollution (atmospheric correction),
- Correction of the effect of topographical slopes causing shade (topographic correction)

Further to these stages a process of linear spectral unmixing was undertaken. In a multi-spectral image, where individual pixels cover homogeneous areas, the spectrum measured for the pixel can be considered as a “pure” example of the cover type. For example a large ploughed field, considerably larger than the sensor resolution, will provide numerous pure bare earth pixels. However, pixels will rarely consist of just one component. Typically pixels will contain a mixture of cover types, each with a distinctive spectrum. In this case the spectrum recorded for the pixel will be a mixture of each component cover spectrum.

Linear spectral unmixing (also referred to as spectral mixture analysis) is a method for estimating the proportion of each pixel that is covered by known cover types. It involves collecting endmembers, which are pure examples of each known cover type. In this case the following three end-member classes were identified:

- Non-photosynthetic vegetation (NPV) that is where dead material of plant origin is the dominant signal in the image.
- Photosynthetic vegetation (PV), where the dominant signal is highly productive photosynthetic vegetation.
- Shade, where the shading from within the vegetation community is very high.

Using these endmember spectra, a linear unmixing statistical model is applied, such as the Horwitz linear mixture model (Horwitz et al 1971), to estimate the fractional cover of each end member within each pixel. In this project ENVI was used to select end members and run the unmixing model to produce three images showing the fractional cover for each endmember.

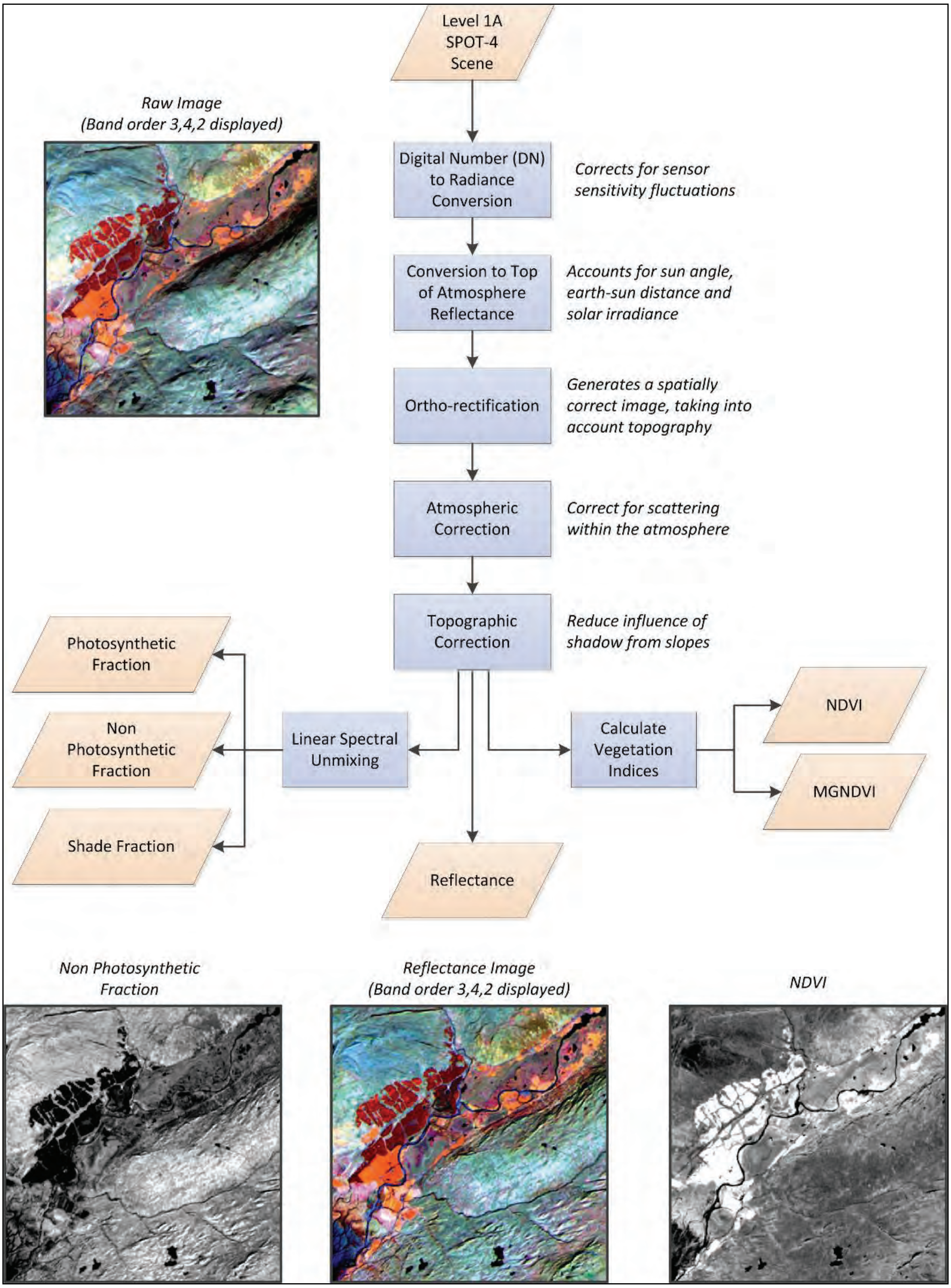


Figure 5 - Stages of image processing

2.2.2 Segmentation

One of the features noted by the field team was the poor presentation of the alpine classes as the objects originally identified did not sufficiently follow the ridge line landforms where the exposure to the westerly winds are expected to provide conditions suitable for the creation of alpine classes. The segmentation was re-worked in three stages to take account of this and this is shown in Figure 6, which uses the image processing outputs identified in Figure 5.

The three levels of segmentation that were instigated:

- Mask level; where previously identified features were segmented out, such as roads, rivers and forestry.
- Landscape level; here the ridgelines and alpine areas were separated from the remaining landform
- Ecological level; the communities occurring in each part of the landform were identified spectrally.

2.2.3 Classification

The new revised classification was built up using analytical rules developed by comparing existing ecological understanding and knowledge passed on by the field team, in terms of vegetation community distributions within the landscape combined with the information content from the remote sensing data. Single thresholds, Boolean (logical) operations were developed using spectral features, within the eCognition GUI environment. In general, rules were developed to find a spectral value where the habitat showed a high value and then one where the spectral values were low. Mosaics of different habitats are a known constituent of many of the large upland Special Areas of Conservation. Fuzzy mapping is a remote sensing technique that can significantly improve the understanding of mosaics. This allows habitats with a 'membership' to the spectral and landscape properties identified by the class to be mapped in terms of how closely they match the class membership. Fuzzy rules were developed for some habitats present as mosaics within the study area, to demonstrate the ecotone features that can be identified in this way.

The rules were designed to consider ecological biophysical characteristics e.g. reflectance of different species and growth stages, photosynthetic activity, proportion of dead material, moisture content, roughness, slope, altitude and exposure.

Rules were developed and tested on sample subset B of the imagery, and the distribution of mapped classes was compared with those observed in the aerial photography and the classes identified in the original NVC survey. Once the values assigned to the rules were giving a good 'fit' to the existing 'training' data they were run over the whole study area. The accuracy of the results was then tested against the field data collection sample subset A.

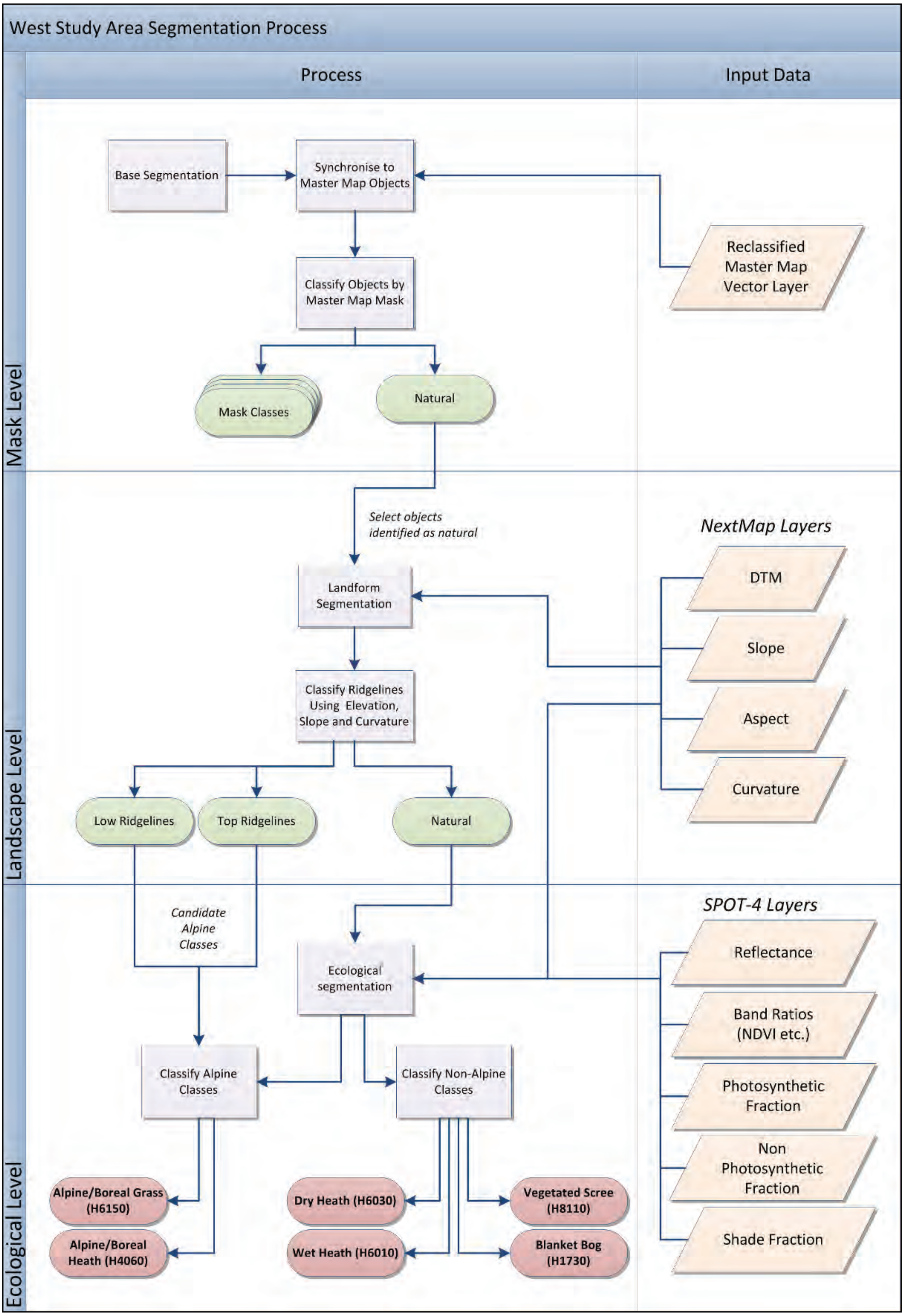


Figure 6 - Revised segmentation process

3. RESULTS

3.1 Imagery

The imagery was re-worked to give full correction including topographic correction. Topographic correction works to even out the signal from the north and south facing slopes. In a mountainous country such as Scotland, the south facing slopes can return an over bright signal, whilst the north facing slope returns a reduced signal due to shadow.

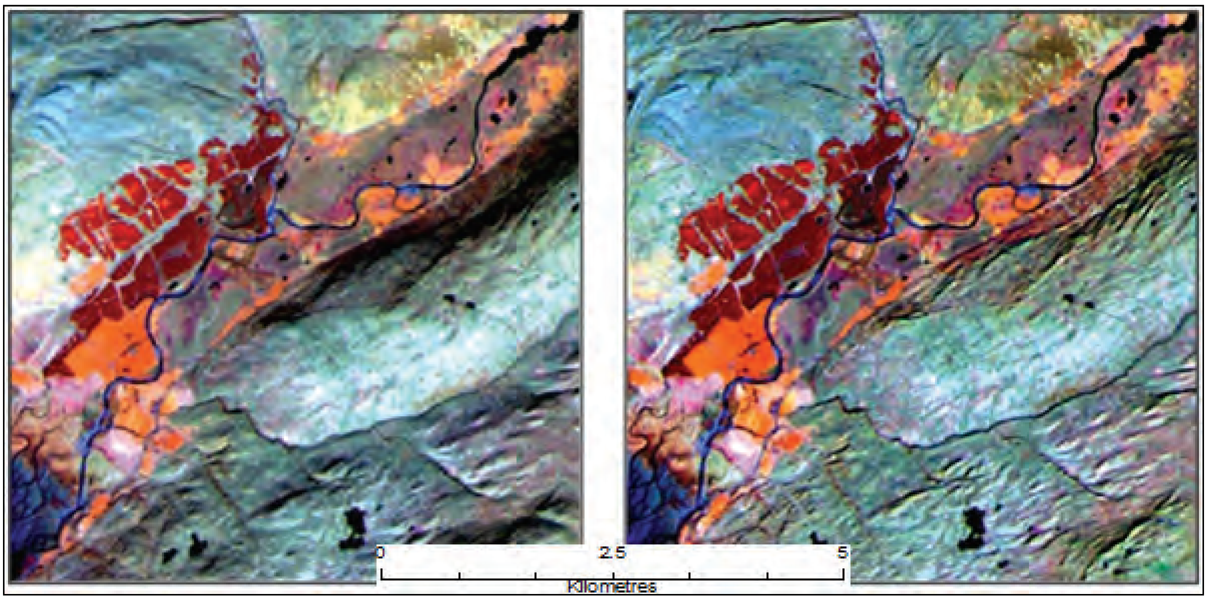


Figure 7 - Comparison between raw reflectance image (left) and topographically corrected image (right)

Figure 7 shows a comparison between the raw reflectance and topographically corrected images for the same area. Note that in the topographically corrected image (right) there is negligible difference in reflectance between north and south facing slopes, unlike the raw image. This allows for improved definition of vegetation spectra on shaded slopes and allows rules to be developed largely independently of sun angle. However, the simple method employed in this demonstration (C-Correction) does tend to over correct on ridge tops due to the difference between DTM and SPOT-4 image resolutions (5m vs. 20m pixel sizes) and residual errors in SPOT-4 orthorectification. This tends to lead to overly high reflectance values along ridge lines. Employing more sophisticated topographic correction models, such as ATCOR-3, together with investing time on improving the alignment between SPOT image and DTM would go a long way towards eliminating these artefacts in an operational project.

3.2 Accuracy of the segmentation

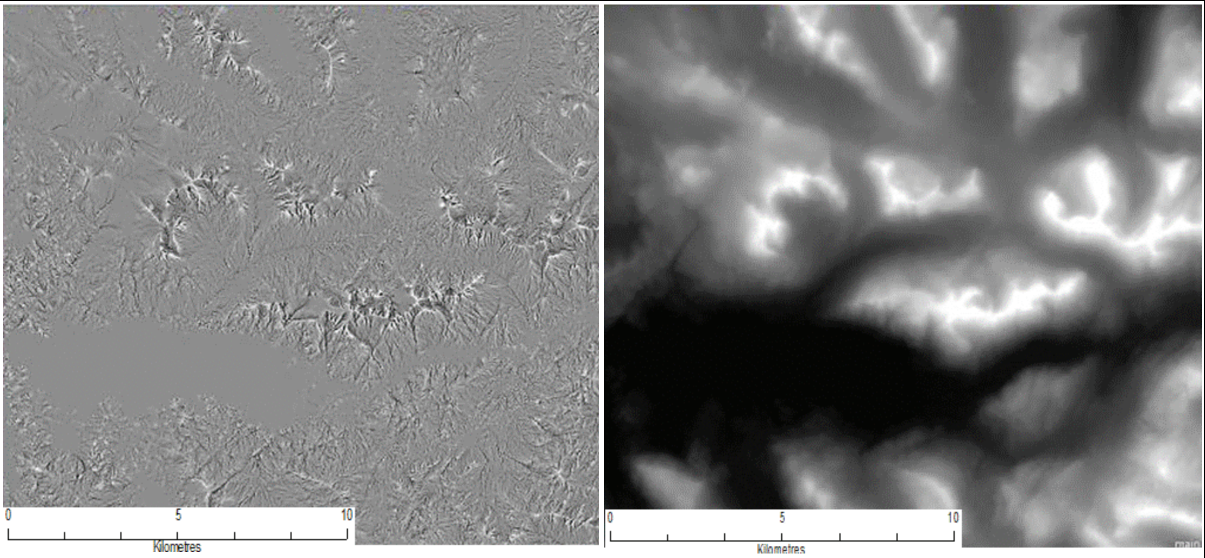
The field work found that the polygons provided by The GeoInformation Group's original classification with the greatest accuracy were as follows:

- waterbodies, small lochs in particular are mostly clearly defined.
- areas of open rock and scree – generally appearing as blue on the satellite image.
- roads and tracks, including the ski runs at Glenshee
- burns and the shadows of burn gorges
- areas of deep shadow

The original segmentation gave polygon boundaries which were largely unrepresentative of habitat features on the ground despite the field team finding half of the vegetation boundaries on the ground being clearly visible on the satellite imagery.

Because of the issues with the first segmentation identified within the field work a new segmentation was developed in the west. This was based around existing expertise and knowledge gained from the field staff. The new segmentation was based on the following features:

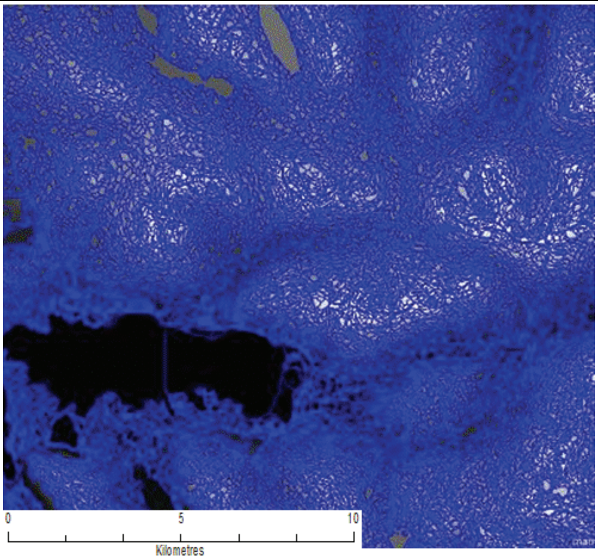
- Alpine and boreal grassland habitats were found to occur on exposed ridges, as well as on the summits of the mountains. The exposure of an area was considered a more significant factor to the development of heathland vegetation, than a simple altitude value, an exposed ridge top at 450m may well have an alpine type community, whilst a sheltered slope at 450m will not. In order to identify such exposed ridge lines, the first segmentation developed was a landform segmentation based on both the convexity of the ridge lines and their height. The lower ridge lines had a very fine potential class just on the most exposed areas, the higher ridges included the mountain top areas. This is shown in Figures 8 and 9:



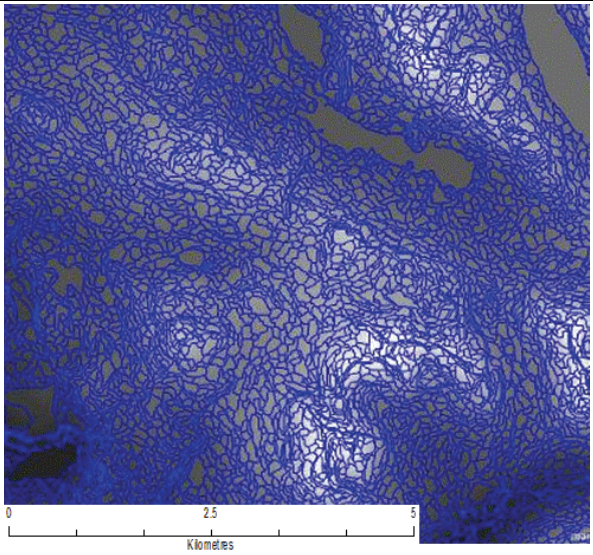
(a) Screen shot showing the curvature of the landscape with bright areas show the ridge lines pulled out by the first stage of the new segmentation.

(b) Screen shot showing the digital terrain model of the landform with brighter areas as the highest land.

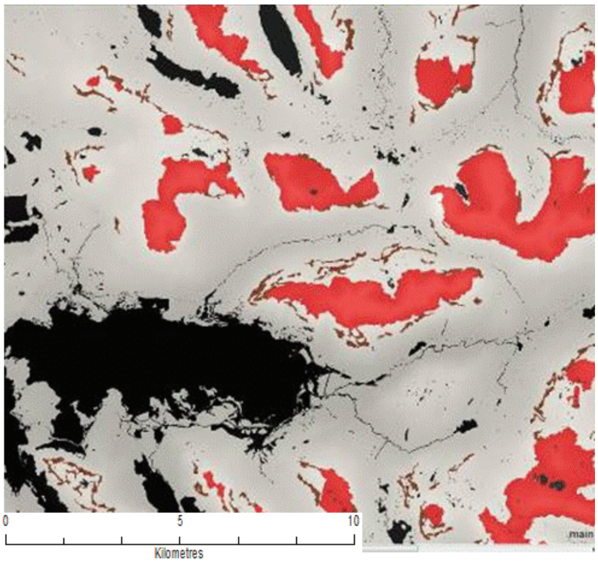
Figure 8 - Showing features used to build the new segmentation



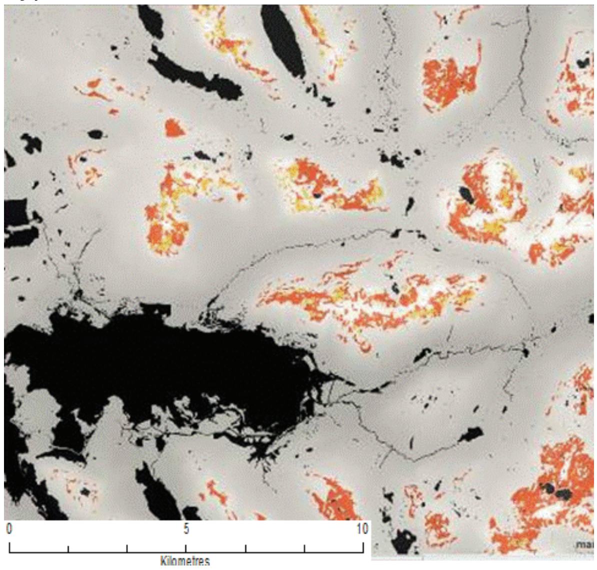
(a) Segmentation; the ridge lines have a much thinner and finer polygon size than the rest of the landscape



(b) This close up image shows the finer scaled polygons formed on the top of the ridge lines by the segmentation allowing more precision to be given to the identification of the alpine habitat types



(c) Ridge lines and alpine areas identified ready for classification by spectral means.



(d) The ridge lines classified into the two Annex I alpine classes. The remaining areas are bare rock.

Figure 9 - showing the stages of segmentation and classification for the alpine classes

- Areas that were not likely to be habitat were removed from the classification as a first stage segmentation. This included the roads, rivers and lochs from OS MasterMap as well as the improved grass fields, coniferous forests and urban areas.

- Habitats which were widespread over large areas such as H4010 - Wet heath and H4030 - Dry heath were segmented at a larger size than the finer scaled habitats as Figure10 illustrates.

- The wet heath showed two different manifestations, one with boulders which contained a much higher red signal than areas of wet heath without boulders. Because of the quite different spectral manifestation of this habitat, two classes had to be created and then later combined to form the Annex I habitat.

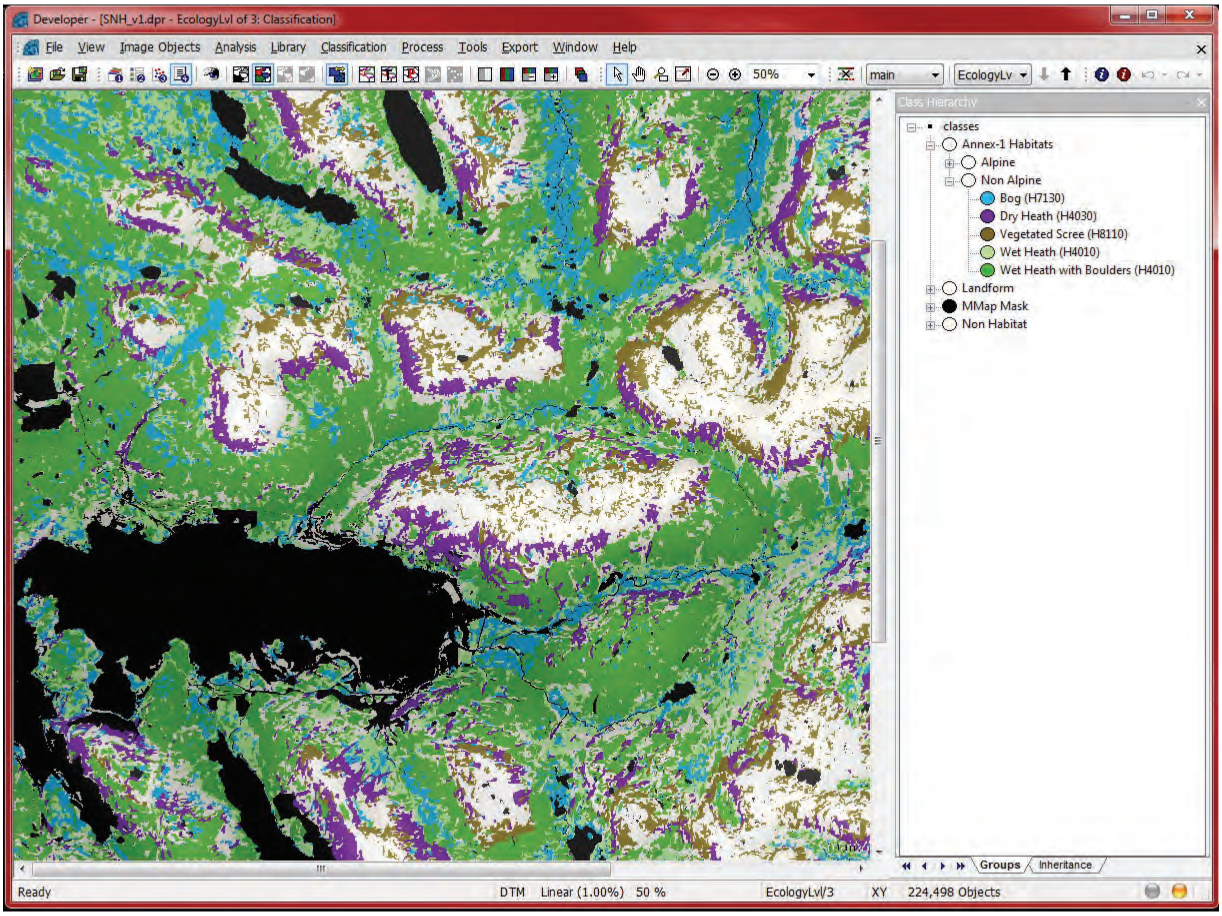


Figure 10 - Screen shot showing the classification of the non-alpine areas of the western imagery

3.3 Field data results and final accuracy assessment

The results of the field validation of the original segmentation results from the initial rule based pilot are shown in Table 1 below, using the headings from the field form in Annex 1.

Table 1 - Field validation results of polygon shape for the original segmentation

Polygon characteristic	% of polygons characterised correctly
Polygon correct size and shape	13.6
Actual habitat area is bigger	1.0
Actual habitat area smaller	2.4
Fuzzy boundary / partially correct shape	27.2
Mosaic; not visible as a discrete area	55.6

Many of the features were not clearly picked up from the original segmentation. Therefore the project was re-segmented as described in section 3.2. However, because the initial segmentation, and therefore classification, was not very well defined, several features became problematic when using the data for further rule development:

- Field work points marking the centres of the polygons were taken as representative of the habitats being described and these where used as training points – showing the spectral characteristics of the habitats for the new classification.

- The habitat was taken as the Annex I habitat and NVC class recorded at the centroid, for the majority of the mosaic habitats both the first and second habitat classes were considered.

- The points considered were derived from the initial classification which, as described above, was not very well defined. The more widespread habitats were over-represented and the rarer habitats were under-represented. Although this is indicative of the distribution and frequency of the habitats in general, it did not contain the desired representative sample of 50 of each habitat type as given in the original sampling design. Therefore, some of the rarer habitats had very few data points and were less statistically robust in their analysis. These are shown in Table 2 in pale blue.

- A visual analysis was undertaken for the new classification as the testing data was not statistically robust for the rarer habitats. These are presented in section 3.5 below.

3.4 Revised classification accuracy

The purpose of the accuracy assessment is to establish whether the representation of habitats given by the remote sensing agrees with the data collected by the ecological field work experts. The sources of error in remote sensing maps are different in nature to those found in field maps. Remote sensing map errors can include factors due to quality of the imagery and its processing as well as the accuracy of the habitat classification. For example, areas in shadow in the imagery have a lesser chance of being correctly identified as there is less spectral information present. Also the more distinct a habitat is in terms of its dominant species and biophysical characteristics such as dead material and wetness the easier it is to get a good rule to describe it with a high accuracy. Where habitats are more complex with many different species or similar species but distinguished from surrounding habitat by small herbs or soil changes they are much harder to describe accurately on a map using a rule base, as they can be described by much less distinct features. Therefore complex mosaics of wet heath and blanket bog lenses are harder to map distinctly than patches of, for example dry heath on steep slopes, which are dominated by *Calluna*. For an area with complex mosaics an accuracy of between 75% and 85% can be considered a reasonable description.

Both a qualitative (visual) accuracy assessment, described in section 3.5 and a quantitative (statistical) accuracy assessment, have been carried out as part of this study. The revised quantitative classification for the western area is shown in Tables 2 and 3 below. The overall accuracy for the revised classification, which takes into account all the habitat classes, those which were more successful and those which were less successful, was **80.87%**.

The accuracy of the revised classification was tested. Dataset 'A' field polygon results were used as a comparator against the new maps produced (as described in section 2.1). As the original field polygons were generally not a good descriptive unit, the centroids of these polygons were used as a point dataset representative of the habitats present at that location. Many of the polygons surveyed in the field work and the NVC survey comprised mosaics. It was not therefore possible to say for certain which habitat occurred at the point of the polygon centroid. In order to address this issue the first two classes of any mosaic found in the field work were used in the comparison to evaluate the accuracy. An error matrix (Table 2) was constructed using the values from these field work points and the mapped classification. In Table 2, the entries on the diagonal (highlighted in dark blue) show correct habitat classification, whereas the entries on the off-diagonal indicate an incorrect classification. The user-producer errors were also calculated for this matrix (Table 3), showing the habitats that the rule base classify well and those that are wrongly classified.

Table 2 - Confusion matrix for revised segmentation based on field work data

		Predicted Class						
		H4010 Wet heath	H4030 Dry heath	H4060 Alpine and boreal heaths	H6150 Alpine and boreal grasslands	H7130 Blanket bog	H8110 Siliceous scree	Total
Observed Class	H4010	97			2	2	3	104
	H4030	1	33	1	2	1	7	45
	H4060	2		1	5	1	3	12
	H6150				7			7
	H7130					4	1	5
	H8110				4		6	10
	Total	100	33	2	20	8	20	183

Table 3 - Users and producers accuracy for revised segmentation based on field work data

	H4010 Wet heath	H4030 Dry heath	H4060 Alpine and boreal heaths	H6150 Alpine and boreal grasslands	H7130 Blanket bog	H8110 Siliceous scree
User's Accuracy	97.0%	100.0%	0.0%	35.0%	50.0%	30.0%
Producer's Accuracy	93.3%	73.3%	8.3%	100.0%	80.0%	60.0%

User's accuracy shows how many points on the map matched those on the ground, whilst the producer's accuracy show, of those expected on the ground, how many were correctly identified. Both the wet heath (97%) and dry heath (100%) are well described. The blanket bog and alpine classes are poorly supplied with field work points for checking. The accuracy of these is not statistically robust and the diagrams below show the visual comparison with the aerial photography which show a good visual match. The ecological manifestation of their classification is shown in Figure 11.

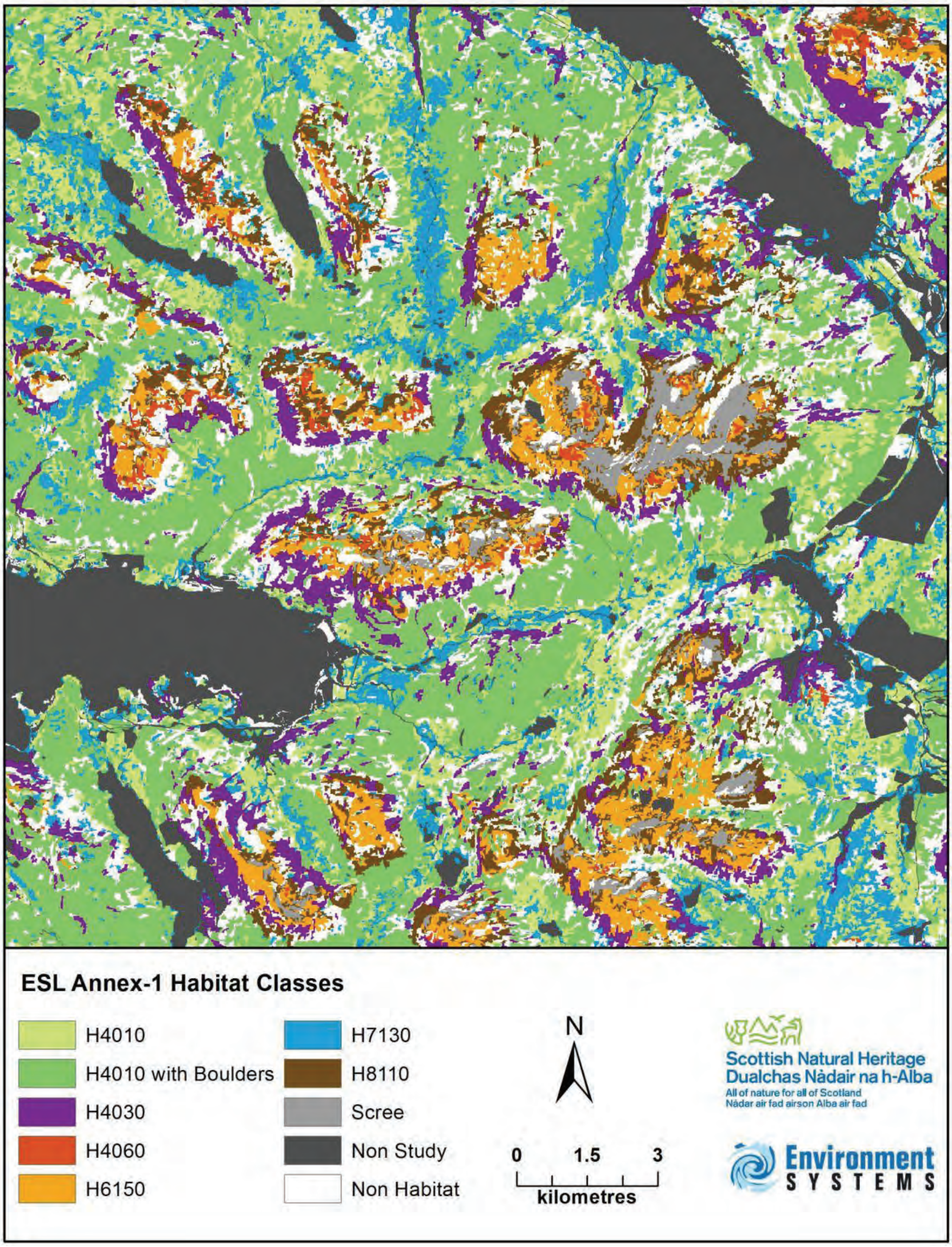


Figure 11 - Revised classification for the western area. (H4010 - Wet heath, H4030 - Dry Heath, H4060 - Alpine and Boreal heaths, H6150 - Alpine and boreal grasslands, H7130 - Blanket bog, H8110 - Siliceous scree)

3.5 Visual comparison of identified classes and class rule features

In this section excerpts of the classification for each habitat group are presented against colour infrared (CIR) photography to demonstrate the use of ecological theory underpinning the rule set. The appearance of vegetation assemblages is often referred to according to its productivity which is the degree of photosynthetic activity that occurs, with NDVI and the Photosynthetic Fraction layers typically providing the best analogues for vegetation productivity.

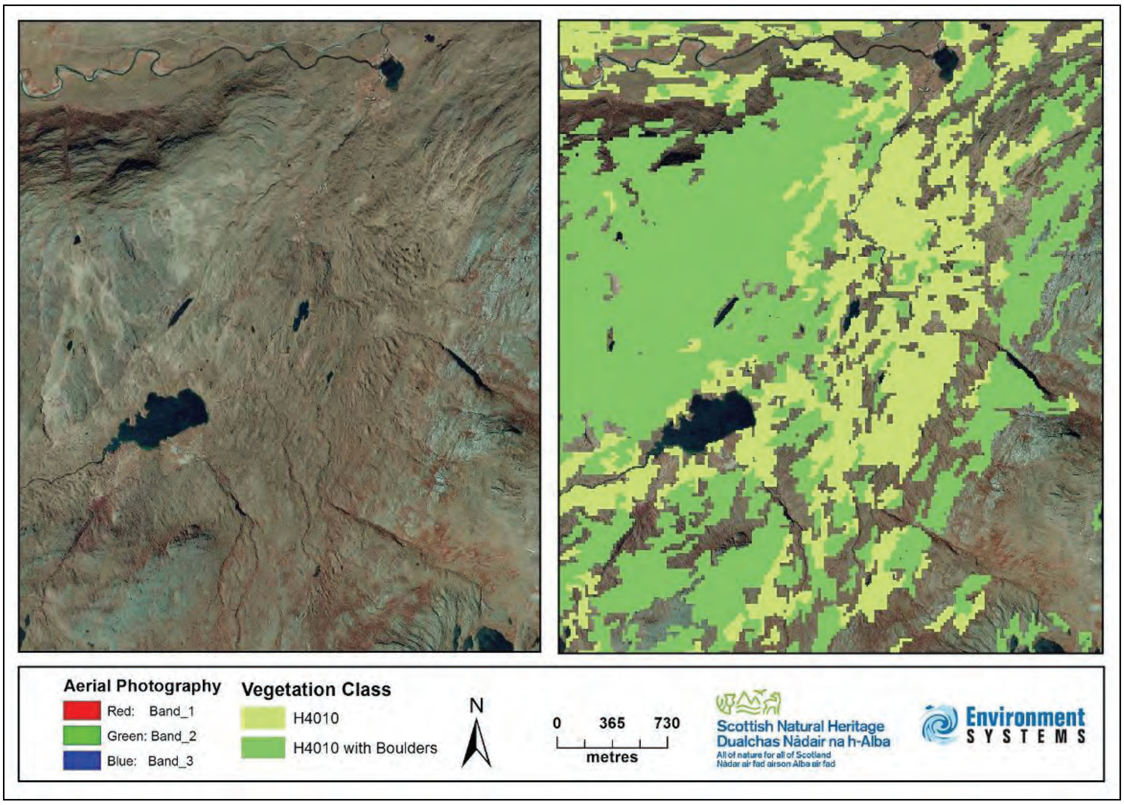


Figure 12 - Comparison between CIR aerial photo and distribution of H4010 - Wet heath

Figure 12 shows a typical example of wet heath for the western study area, with the wet heath found on both low lying valley floors and on low to moderate slopes. Looking at aerial photography and ground reference photos revealed that the wet heath on slopes tends to contain a high number of boulders, which are responsible for its bluer appearance in Figure 12 (left) indicating less productive vegetation cover. This variation is also observed in the SPOT imagery, with wet heath areas on slopes found to exhibit lower NDVI and photosynthetic fraction values than valley-floor wet heaths. Consequently two varieties of wet heath were identified; **H4010** - Wet heath and **H4010 with boulders** - Wet heath with boulders. This allowed slope, elevation and spectral rules, to be appropriately tuned for each variant.

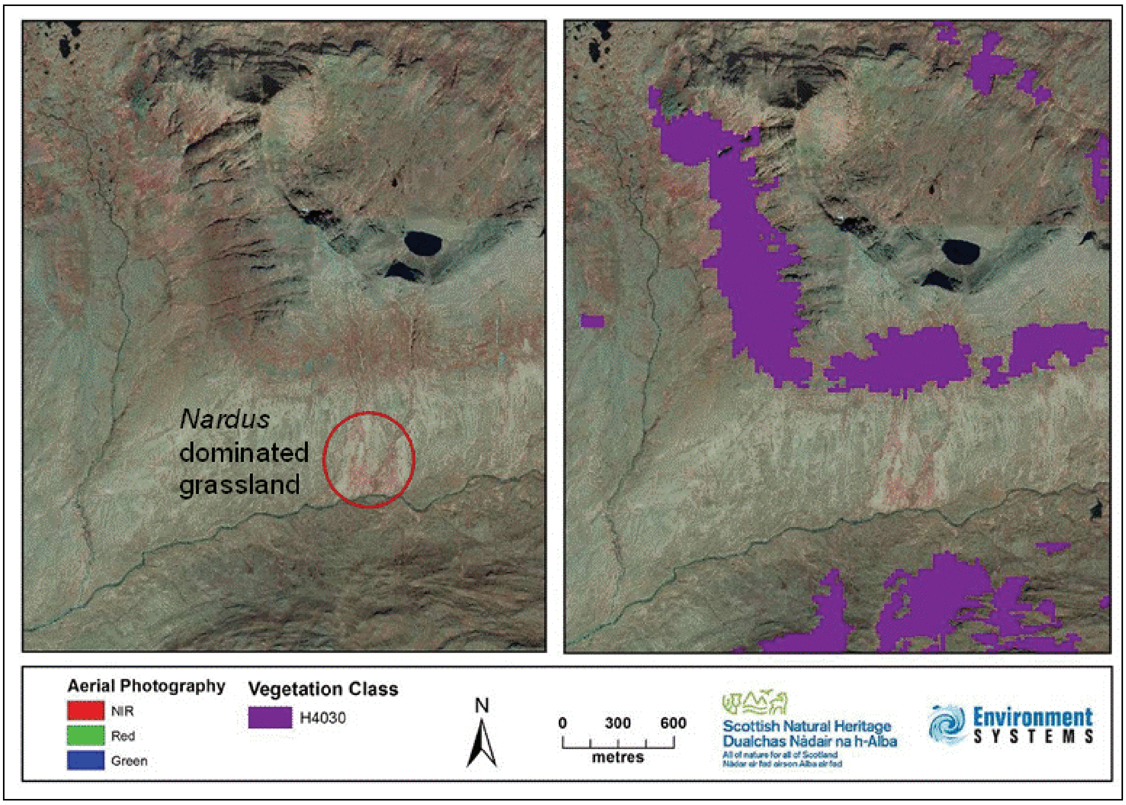


Figure 13 - Comparison between CIR aerial photo and distribution of H4030 - Dry heath

Dry heaths are typically observed as areas of relatively productive vegetation on slopes greater than 15 degrees. As Figure 13 demonstrates they often appear in the CIR imagery as dark red bands on slopes that are steep enough to prohibit wet heath dominance, yet not so exposed as to promote dominance of alpine vegetation. These topographic conditions are also often shared with *Nardus* dominated grassland which tend to be similarly productive (i.e. have similar NDVI) as the dry heath. However, the dry heath can be separated from grasslands using the green SPOT channel as dry heath is typically less reflective at green wavelengths than grassland.

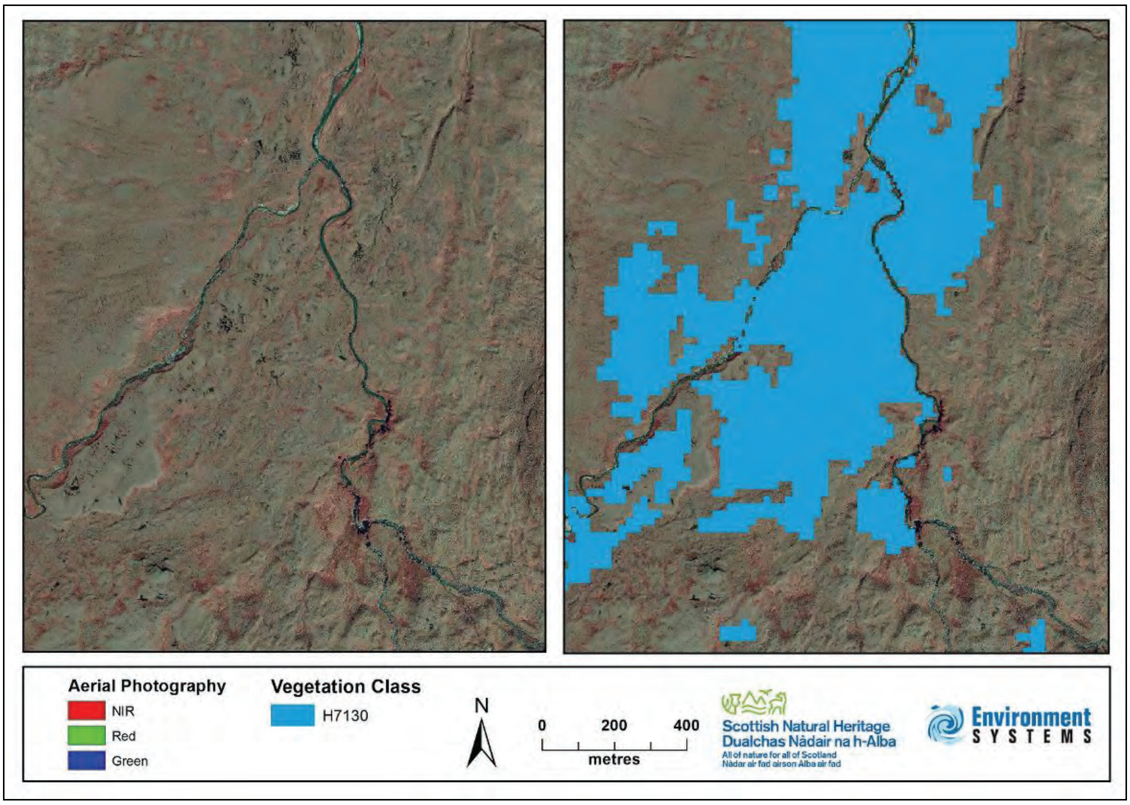


Figure 14 - Comparison between CIR aerial photo and distribution of H7130 - Blanket bog

Figure 14 shows bog as a mosaic of bare peat with shadow indicating the edge of the peat surface. This is surrounded by relatively low productivity vegetation which is very similar to valley bottom wet heath in CIR reflectance and topography. However, bog-dominated areas have a distinct signature in the SPOT-4 imagery as the coarser 20m pixel size averages together peat, peat/edge shadow and surrounding vegetation. This allows NDVI, wetness and slope rules to be applied that identify the bog dominated areas. It should be noted that as valley bottoms are a mosaic of wet heath and bogs it may be more appropriate to map bog and wet heath using a fuzzy classification so that objects can indicate joint membership to different classes.

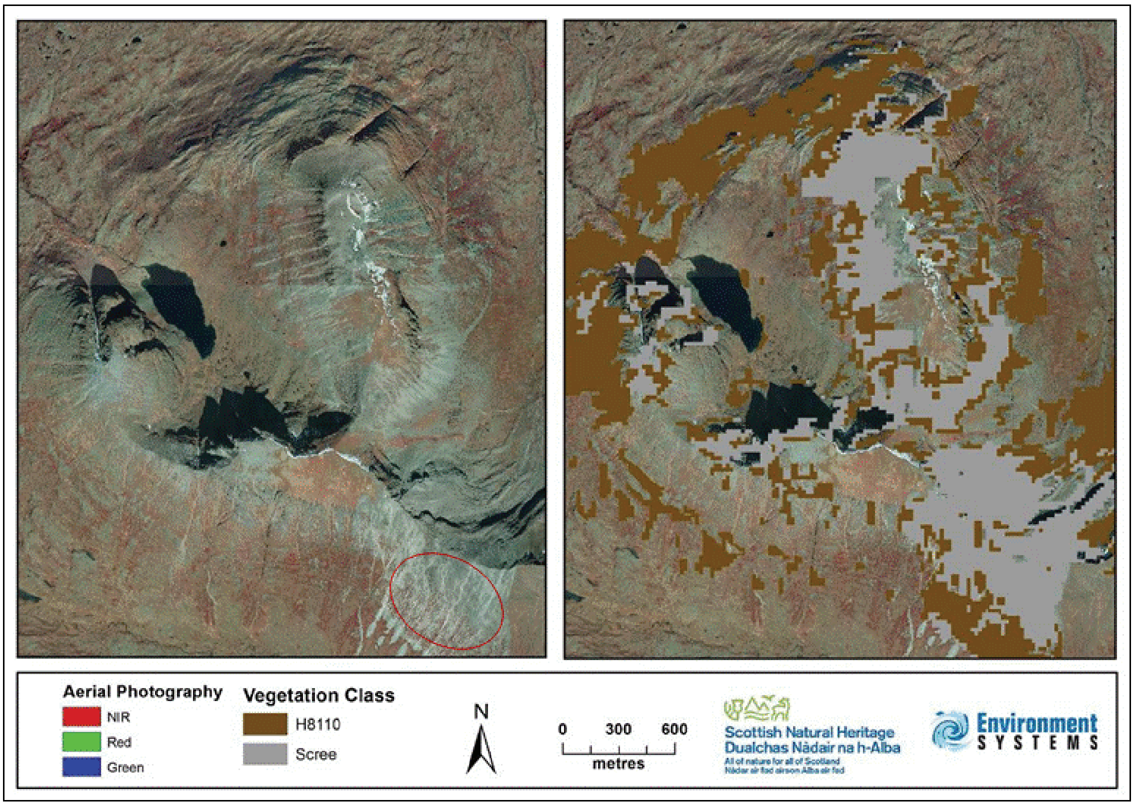


Figure 15 - Comparison between CIR aerial photo and distribution of H8110 - Siliceous scree. The area highlighted in red is likely to be a mosaic of bare earth and heath rather than scree

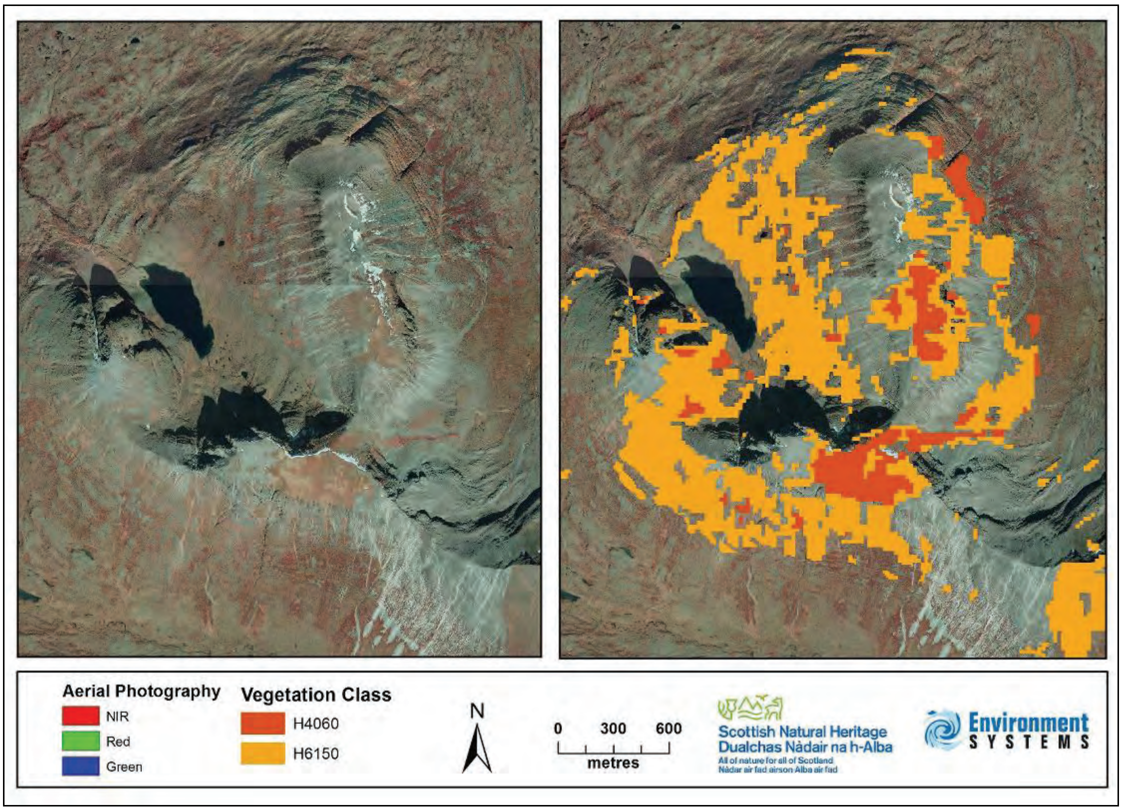


Figure 16 - Comparison between CIR aerial photo and distribution of alpine classes, Alpine and boreal heath - H4060 - and H6150 - Alpine and boreal grasslands

Figures 15 and 16 show the alpine and scree classes identified for Beinn Eighe. The scree classes were identified using slope and productivity rules, with vegetated scree areas exhibiting both high slope angles and moderate productivity. However, the colour infrared imagery demonstrates that in these alpine and high slope environments:

- Vegetation is extremely heterogeneous. Figure 15 has an area highlighted in red that appears homogeneous in the SPOT imagery, yet is more likely to be a mosaic of bare rock and denser heath vegetation.

- Alpine habitat candidate locations narrowed down using landform rules to identify exposed ridge lines.

    - Within these candidate areas though the SPOT imagery is often too coarse resolution to provide an accurate indication of alpine habitat presence.

    - The one case where the imagery does work is the large patches of alpine heath on plateau areas which present clearly in the photosynthetic fraction. Because it is possible to identify these larger areas of alpine heath using remote sensing, it should be possible to devise a remote sensing classification method for smaller areas of this habitat using very high resolution data with for example a 1m pixel size, such as CIR aerial photography or IKONOS (or equivalent) imagery. With the higher spatial resolution it will be possible to separate out the bare rock patches from the alpine heath and grassland.

3.6 Mosaics and fuzzy mapping

The field work highlighted the importance of understanding the mix of species and their landscape component, and secondly the need to describe mosaics.

Many of the habitats contain the same constituent species, but in different proportions, mixes and growing upon different substrates. Because the spectral rules are based on dominant species it is important to understand the relationship between the species and their environment. During the fieldwork (as shown by the field form in Annex 2) up to three Annex I habitats and up to three NVC classes could be recorded for each field point. Table 4 shows the relationship between the primary Annex I code recorded and the primary NVC code recorded, in terms of number of sites. Table 4 highlights the similarity in make-up of these Annex I habitats, through comparison with the primary NVC classes identified during the field visit.

Table 4 - Annex I habitat classes and NVC communities identified during field work

NVC habitat code	H4010 Wet heath	H4030 Dry heath	H4060 Alpine and boreal heaths	H6150 Alpine and boreal grasslands	H7130 Blanket bog	H8110 Siliceous scree	H8220 Rocky slopes with chasmophytic vegetation	H91C0 Caledonian forest	Total
H10		8					1		9
H12		2							2
H13			1			2	2		5
H14			17			2	2		21
H15			9			8	8		25
H16			1				1		2
H17			1				1		2
H19			2						2

NVC habitat code	H4010 Wet heath	H4030 Dry heath	H4060 Alpine and boreal heaths	H6150 Alpine and boreal grasslands	H7130 Blanket bog	H8110 Siliceous scree	H8220 Rocky slopes with chasmophytic vegetation	H91C0 Caledonian forest	Total
H20			2			7			9
H21	1	8				5	3		17
H22		1	1						2
M14	1								1
M15	98				1	1	11		111
M17	1				32				34
M19					7				7
M23	1								1
M6	2								2
U10				12		8	4		24
U7			1	16		4	6		27
W18								2	2

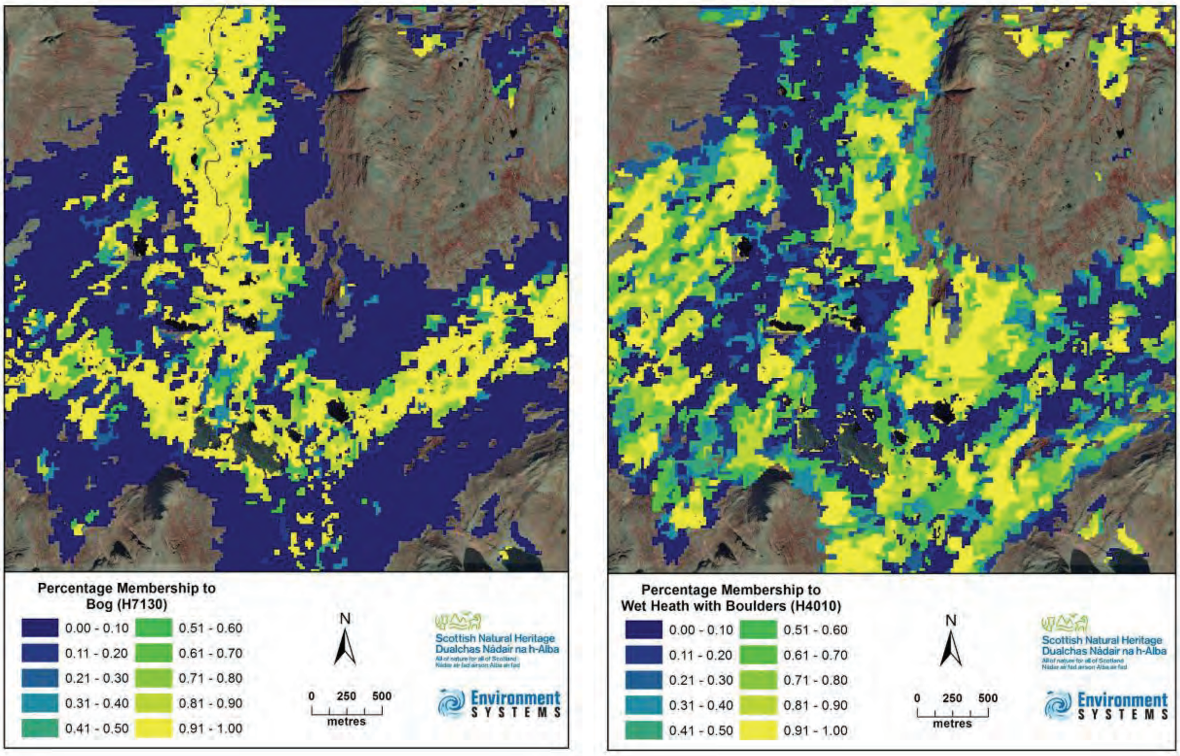
The similarity in NVC components in part explains some of the confusion with the alpine classes where both alpine and boreal grassland and alpine heath contain similar species and are often dominated by a bare rock component.

Table 5 shows the main cover forming species identified by the field team for each habitat type. It illustrates how similar some of the habitats are in their constituent species. In these instances understanding the manifestation of the habitat in its landscape ecology position can be key to correctly mapping it from remote sensing.

Table 5 - Dominant cover forming species for each community

Dominant species' cover	H4010 Wet heath	H4030 Dry heath	H4060 Alpine and boreal heaths	H6150 Alpine and boreal grasslands	H7130 Blanket bog	H8110 Siliceous scree	H8220 Rocky slopes with chasmophytic vegetation
Empetrum nigrum			1			7	
Eriophorum vaginatum					3		
Festuca ovina/vivipara							1
Juncus effusus							
Molinia caerulea	10				5		
Nardus stricta			3	10		2	8
Pinus sylvestris							
Racomitrium lanuginosum			1	13		10	6
Trichophorum cespitosum	39		7		22	2	14
Vaccinium myrtillus							1
Calluna vulgaris	11	19	19	2	9	14	14

Fuzzy mapping can describe the complex mix of habitats within a mosaic using a colour ramp to show how well each area conforms to the rules set to describe the habitat class, as membership values. Using this fuzzy technique, we can identify areas with high certainty, (membership value approaching 1), through to areas where these classes are less likely to occur, though they still may be present (membership approaching 0). This mapping technique is illustrated by Figure 17, and demonstrates the interrelationship between H7130 - Blanket bog and H4010 - wet heath. It can then be assessed as to where in the bog-heath continuum, a change in habitat takes place and by comparing different habitat certainty levels, habitat boundaries can be drawn.



(a) Fuzzy mapping showing the darker areas as having a higher degree of certainty of bog

(b) Fuzzy mapping showing the darker areas as having a higher degree of certainty of wet heath

Figure 17 - Examples of fuzzy mapping classes for bog and wet heath

4. DISCUSSION

Within this project a further phase of rule base development has been undertaken following a field based accuracy assessment of a previous project. This rule base development has allowed more ecological knowledge to be built into the system, demonstrating how to enhance accuracy.

The field work accuracy methodology used a stratified random sample of habitat classes identified by the study carried out by The GeoInformation Group. It had two main aims; the first was to test the accuracy of the original results and the second was to provide data to allow the rule base to be enhanced. The field based results showed good accuracy for man-made features such as roads, lochs and the most prevalent habitat, wet heath, although overall the accuracy was disappointing compared to other UK EO-based habitat mapping projects.

The original rule base had been developed as part of a larger project to look at different methods of remote sensing analysis and time did not permit for a very detailed trial. There were several stages of image preparation, that have been described in this report, not carried by The GeoInformation Group out that would considerably enhance the accuracy of any future project using satellite imagery. These additional image processing steps could then be incorporated in the new rule base. The use of atmospheric correction and exact georeferencing allowed more than one image to be included in the image stack, together with many other data layers such as OS MasterMap and landform data. These greatly enhance the range of features available for use within the rule base allowing greater separation of habitat and land cover types.

In particular topographic correction gives a greatly enhanced result, especially in a mountainous area such as Scotland. This has an effect of 'boosting' the signal in the north facing slopes, which are often in shadow and reduces the signal on the south facing slope which are often very bright, thus reducing the effect of slope differences. Where the shadows are so dense that no signal exists, habitats cannot be identified even with topographic correction, and so these areas were removed from the classification. Some habitats that have a different phenotypic manifestation on the north and south slopes of mountains and can require consideration of aspect built into the rules, however this was not undertaken during this study.

As well as the topographic correction, linear spectral unmixing was undertaken on the image to give the PV, NPV and shade fractions. The PV and NPV were particularly useful as many of the classes have a fairly high proportion of non-photosynthetic material and therefore are slightly brighter in this fraction. *Molinia careulea* in particular tends to have a large dead vegetation component and so NPV can be useful for identification of this species.

For the revised rule base a three stage segmentation was introduced. Stage one of the process included removal of features from OS MasterMap such as road, rivers, fields and forestry. Then in stage two the landform was evaluated to pull out high and low ridge lines to allow the alpine classes to be found. Following on from this, in stage three the non-alpine areas were segmented and classified. This process ensured that the physical manifestations such as shape and location of the communities (e.g. long thin strips of vegetation on the tops of ridges) could be considered as well as their spectral properties.

A habitat with distinct attributes, such as a dominant species with distinct spectral features, which occurs in a specific part of the landscape is more likely to be accurately described by remote sensing techniques than a indistinct habitat separated only by the presence of low frequency herbs or soil features. For example, a *Calluna* dominant dry heath is better identified in this study than blanket bog. This is because many small lenses of blanket bog identified by the field team have similar species to the wet heath, but are separated mostly by peat depth. Where blanket bogs cover wider areas and begin to show a distinct spectral signature due to the presence of *Eriophorium* spp. or bare peat, then the two habitats become easier to separate and hence the objects are more accurately classified on the map. In an area such as Torridon where the habitats occur in intricate complex mosaics and have similar species which occur in different proportions, accuracy of both remote sensing and field mapping will be different to a less intricate landscape where each species occupies a more defined zone. An accuracy of a map for an upland mosaic, complex landscape of around 80.87% is a good result. For example a brief comparison of the existing NVC classification and the field work results indicates a similar level of accuracy.

A visual comparison of the final habitat map, the aerial photography and existing NVC surveys shows a better match than the statistics suggest. This is due to the following three reasons:

- Firstly the field points were chosen based on the original classification, this original classification over emphasised common habitats at the expense of rarer ones and there were therefore few points that represented the rarer habitats. Ideally when undertaking accuracy assessment 50 points for each habitat are needed. In some instances there were less than 10 known locations available. This gave insufficient field points for rigorous statistical testing, skewing the results.

- Secondly many of the alpine Annex I habitats contain very similar species assemblages and a high percentage of bare rock, they are therefore very demanding to separate out spectrally. It is possible to determine it as alpine vegetation, but less possible to show whether it is alpine heath or grassland. A data set with a higher spatial scale, such as CIR aerial photography (from manned or unmanned aerial systems) with a pixel size of at least 1m, could provide an additional level of segmentation which would significantly enhance the separation of these habitats. This higher resolution data would only need to be included for the ridge top areas, keeping the size of data within the overall project within manageable levels.

- Most of the habitats within this area appear as mosaics, corroborated by the field work results. Mosaics make it hard to attribute a single class to any object because many of the objects are ecotones between two different habitat manifestations. In future operational projects, these mosaics can be described using a technique called fuzzy mapping which allows membership to each class in an ecotone to be shown on a map. This can present a useful way of describing such habitats.

Object orientated, rule-based techniques used for mapping habitats from EO provide a good approach for on-going mapping and monitoring. Once a successful rule base is established, it can be used as part of a wider monitoring programme where the rule base is run over several years of satellite data to look at changes in the vegetation patterns over time.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- The fieldwork campaign identified the need for more detailed ecological training within the initial rule base. The results produced by the developed rules support the use of Earth Observation techniques as a very useful method of classification of the widespread and distinct Annex I habitats in the uplands of Scotland, such as wet heath and blanket bog.

- A hierarchical classification is necessary, embedded with different levels of segmentation, to narrow in on candidate classes and reduce confusion with other similarly presenting habitats.

- The fieldwork information was of key importance to the project. Any EO-based project needs ground validation to fully understand the manifestation of the communities in each study area. This needs to occur in two phases:
  - Firstly a preliminary field campaign to annotate the imagery to understand how the habitat presents in the area of interest, which will help with designing rules. This can be relatively short, only a few days, and requires several areas of each habitat type under consideration to be visited.
  - Secondly a field campaign is required to QA the results and can be used to iteratively refine the rules. For a robust statistical validation of the classification at least 50 known sites of each habitat type must be visited. A less rigorous QA process can be undertaken, comprising enough field work to sense check the results which can also be valuable, especially if the findings are fed back into the rule base.

- EO data from satellites deliver wide area coverage at a relatively low resolution, this offers a base which can be used in conjunction with data from aerial and unmanned aerial systems to increase the spatial resolution and temporal coverage for areas which require additional information.

- Suitable data, comprehensive data processing steps and a high level of ecological understanding of plant community features and processes are all essential to develop a rule based approach.

- Thorough data preparation allows for a more accurate and transferable rule base, and would be essential for monitoring, where multiple date imagery would be compared. Topographic correction reduces confusion caused by shadows.

- Many of the upland communities comprise mosaics of different habitats and are better described using fuzzy membership mapping techniques. All forms of mapping have uncertainties associated with them, although uncertainties associated with EO mapping are different from those associated with field work. As with field work when describing complex landscapes, a judgement has to be taken as to where the boundary represents the division between the habitats. By using fuzzy mapping techniques this judgement is quantified by thresholds, when membership of several habitat features reaches these defined thresholds, boundaries can be drawn between habitat patches.

- The use of techniques such as rule base analysis and fuzzy mapping provides a powerful monitoring tool, where changes in the communities can be picked up by applying the rule bases over old and new satellite imagery. It is therefore possible to monitor backward in time as well as collect and analyse new data.

5.2 Recommendations

Imagery

- Continue to update and develop the database of imagery available for Scotland

- Maintain a catalogue of any available imagery, stored fully processed and ready for use

Further rule base testing and development

Using the examples of best practice established in this project it is recommended that further trial areas are investigated for priority habitats including:

- Expansion of the pilot area to determine how far spatially the rules developed in this project apply

- Other areas of upland habitat such as the eastern area defined by the initial work to understand how much variation there is and how much work is required to transfer the rules to other locations of Annex I alpine habitats. The eastern study area is an ideal first additional trial area as there is already field work data available to test against.

- Investigation of areas of lowland Annex I habitats and the inclusion of finer resolution imagery such as CIR photography, to investigate habitats which have a finer spatial scale

- Trial on the islands – to investigate marginal very specific habitats such as machair

Trials of using rule based mapping for non-priority habitats

- The separation of the landscape into heavily managed land and more natural areas forms the first step of most rule based approaches for looking at landcover. The identification of the semi-natural vegetated areas would allow for targeted areas of search for potential habitat and restoration work. It is recommended that this be tested within one of the less natural types of trial area to determine how useful the outputs are and how they can be used for resource efficiency.

Using rule based mapping for condition and change detection

- Trial of using EO to determine change in designated sites as an early warning system to target field survey.

- Trial of using EO to determine condition features of priority habitats.

Capacity building

- Increase the understanding and potential of EO within SNH. This could include other uses of segmentation products and data layers and fractions produced from the imagery (such as vegetation indices and photosynthetic or non-photosynthetic vegetation fractions) to aid feature identification in the field.

- Building the understanding of the manifestation of habitats in Scotland within satellite imagery. Annotation of satellite imagery by field teams during routine condition survey could feed into future EO pilots reducing the need for a specific field visit associated with the EO project, lessening the time and resource required.

6. REFERENCES

Brown, I., Gimona, A., Poggio, L., Castellazzi, M., Aitkenhead, M. & Brooker, R. 2011. Inventory of Upland BAP and Annex I habitats – Developing habitat inventories. *Scottish Natural Heritage Commissioned Report No. 494*

Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data, *Remote Sensing of Environment*, **37**, 35-46.

Congalton, R.G., and Green, K. 1999. Assessing the Accuracy of Remotely Sensed Data: Principles and Practices, *CRC Press,* Boca Raton, Florida

Horwitz, H. M., Nalepka, R. F., Hyde, P. D. and Morganstern, J. P. 1971, Estimating the proportion of objects within a single resolution element of a multispectral scanner. *In the 7th International Symposium on Remote Sensing of Environment,* Environmental Research Institute of Michigan

Lucas, R.M. 2010. Unpublished Lecture Notes, *University of Aberystwyth*

Lucas, R., Medcalf, K., Brown, A., Bunting, P., Breyer, P., Clewley, D., Keyworth, S., and Blackmore, P., 2011, Updating the Phase 1 habitat map of Wales, UK, using satellite sensor data, *ISPRS Journal of Photogrammetry and Remote Sensing*, **66**, 1, 81-102.

Medcalf K., Turton, N., Jarman, M. and Keyworth, S. 2011a. Inventory of terrestrial and freshwater BAP priority habitats and Annex I habitats*. Scottish Natural Heritage Commissioned Report No. 445.*

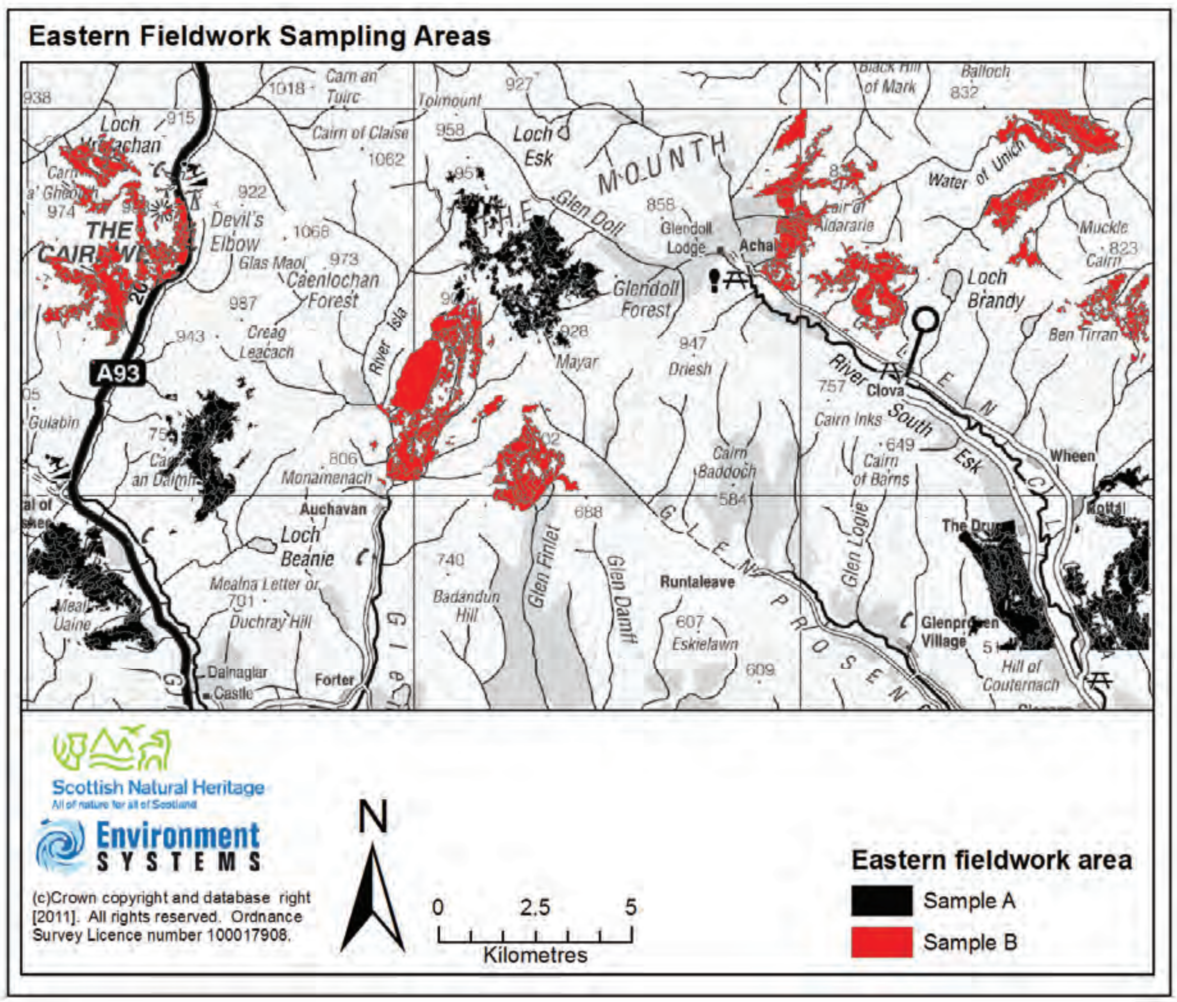
Medcalf K. A., Parker J.A., Turton, N., and Finch C. 2011b. Making Earth Observation Work for UK Biodiversity Conservation – Phase 1. PART B - Annexes and technical evidence. Report to the JNCC and Defra.

Radoux, J., Defourny, P. and Bogaert, P. 2006. Comparison of pixel- and object-based sampling strategies for thematic accuracy assessment, *International Conference GEOBIA 2008 Pixels Objects Intelligence GEOgraphic Object Based Image Analysis for the 21St Century.* The International Society for Photogrammetry and Remote Sensing.

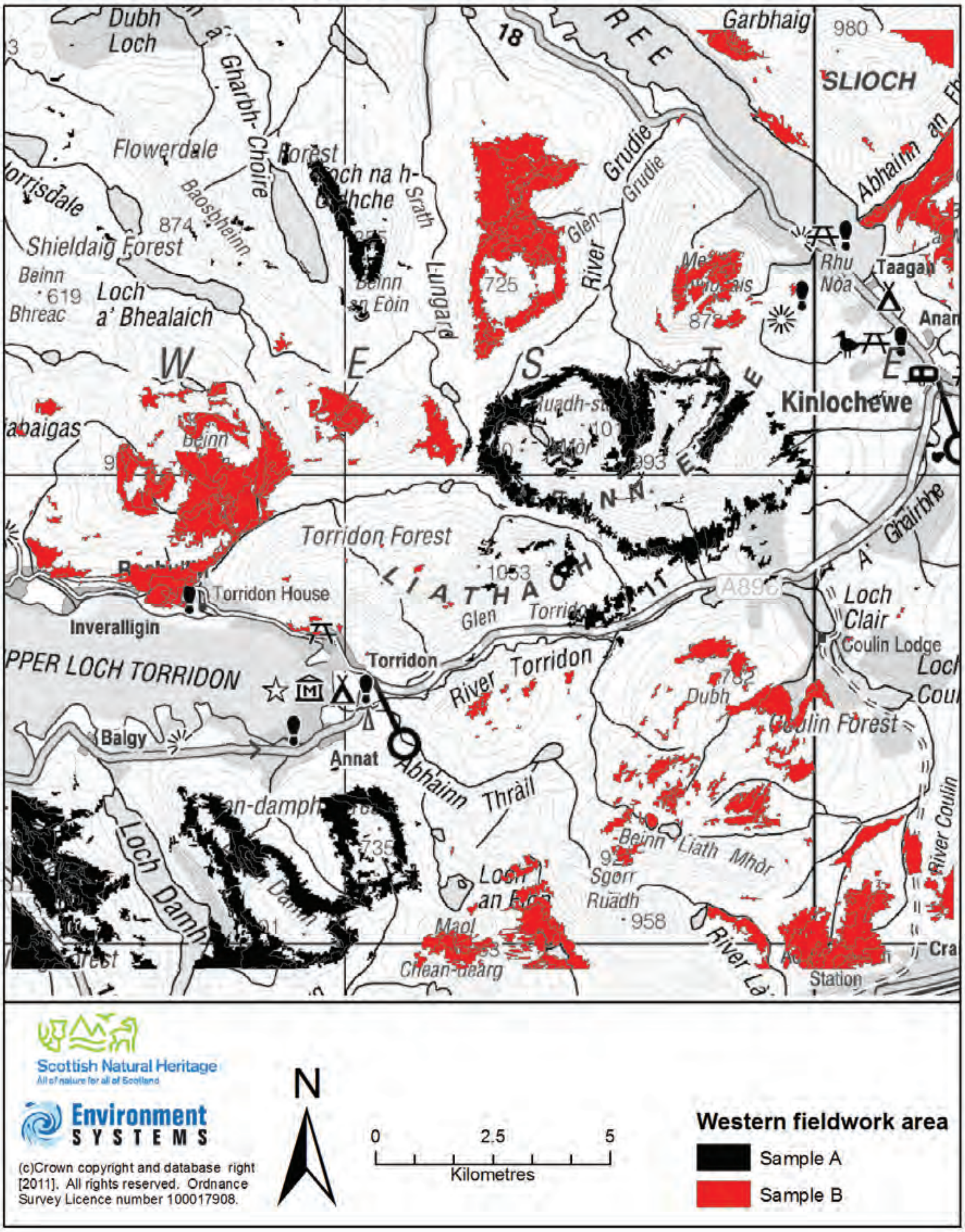
Swain, P.H., and Davis, S.M., (eds.). 1978. *Remote Sensing: The Quantitative Approach*, McGraw-Hill, New York

The GeoInformation Group. 2011. Inventory of upland BAP and Annex I habitats – Methodology for mapping upland habitats*. Scottish Natural Heritage Commissioned Report No. 495*

ANNEX 1: SAMPLING AREAS



Western Fieldwork Sampling Areas



ANNEX 2: FIELDWORK DATA CAPTURE FORM

This polygon has Reference Code: ....

1. **Do the boundaries of the mapped polygon match the features on the ground to within 50m?**

☐ Yes ☐ Bigger ☐ Smaller ☐ Fuzzy ☐ Partially correct *Please comment below* ☐ Not visible on ground *Please comment below*

Comments:...

2. **Is the classification correct/plausible?**

☐ Classic	☐ Plausible	☐ Mosaic *Please answer 2a*	☐ Different habitat *Please answer 2b,2c*	☐ Different habitat - mosaic *Please answer 2a,2b,2c*
Comments:...				

a. **List the individual components of the percentage cover of the three main habitats**

Annex I Habitat		Cover		
		Minor	Less than 25%	Dominant
1				
2				
3				

b. **Can you see the feature in the satellite image?** ☐ Yes ☐ No

c. **Is the polygon heavily shaded on the satellite image?** ☐ Yes ☐ No

3. **Are there also small, discrete features present?**

☐ N/A
☐ H3130| Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of *theIsoëto-Nanojuncetea*
☐H4080| Sub-Arctic Salix spp. scrub,
☐H6130| Calaminarian grasslands of the *Violetalia calaminariae*
☐H6230| Species-rich *Nardus* grassland on siliceous substrates in mountain areas
☐H6430| Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels
☐H7150| Depressions on peat substrates of the *Rhynchosporion*
☐H7220| Petrifying springs with tufa formation
☐H7230| Alkaline fens
☐H7240| Alpine pioneer formations of the *Caricion bicoloris-atrofuscae*
☐H8110| Siliceous scree of the montane to snow levels (*Androsacetalia alpinae* and *Galeopsietalia ladani*)
☐H8120| Calcareous and calcshist screes of the montane to alpine levels (*Thlaspietea rotundifolii*)
☐H8210| Calcareous rocky slopes with chasmophytic vegetation
☐H8220| Siliceous rocky slopes with chasmophytic vegetation
☐O1| Acid/Neutral Flush
☐O2| Spp. poor *Juncus* flush
☐B| Bare peat

☐ Other:...

4. **Do you think the dominant part of the polygon is a typical manifestation of the Annex I habitat?**
☐ Yes ☐ Close to, but lacking certain attributes ☐ Transitional
☐ No, a completely different habitat ☐ Not Annex I

5. **List the NVC types in this polygon and their percentage cover**

NVC Type Habitat		Cover		
		Minor	Less than 25%	Dominant
1				
2				
3				

6. **Is the soil type unusual or different to the surroundings, e.g., red sandstone, limestone derived, peat etc.?**
☐ No ☐ Red sandstone ☐ Limestone derived ☐ Peat

b. are there large boulders present? ☐ Yes ☐ No

7. **What are the three main cover-forming species in this polygon? Use full Latin names.**

1	
2	
3	

8. **Is there any evidence of recent management other than grazing?**

☐ None ☐Bracken clearing ☐ Burning	☐ Cutting ☐ Development ☐ Drainage	☐ Felling ☐Land improvement ☐ Recreation	☐ Renewables ☐ Scrub clearance ☐ Supplementary feeding ☐ Tree planting/natural regeneration

9. **Other comments**

10. **Picture IDs:..............................Picture Direction:..**

11. **Did you assess the polygon from within?** ☐ Yes ☐ No

12. **Is there any evidence of Phytophthora?** ☐ Present ☐Not present

www.snh.gov.uk

ISBN: 978-1-85397-868-5

Policy and Advice Directorate, Great Glen House,
Leachkin Road, Inverness IV3 8NW
T: 01463 725000

You can download a copy of this publication from the SNH website.

recycle

Scottish Natural Heritage
Dualchas Nàdair na h-Alba
All of nature for all of Scotland
Nàdar air fad airson Alba air fad