Wildness Study in the Cairngorms National Park

Final Report

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Executive summary

Background

The uplands are highly valued hallmarks of Scotland, often combining spectacular landscapes with wildlife of high conservation importance, and providing a major focus for outdoor recreation. The distinctive aesthetic qualities of the Scottish hills are particularly strongly expressed in certain areas that are dominated by natural or near-natural vegetation, lack of obvious human intrusion from built structures and the rugged, challenging and remote nature of the terrain. These are now widely referred to as 'wild land'. The total Scottish wild land resource has been subject to steady attrition due to various types of development, including renewable energy schemes, afforestation and the construction of bulldozed hill tracks. Wild land is increasingly reflected in land use and planning policy in Scotland. National Planning Policy Guideline (NPPG) 14, published in 1999, highlights the value of wild land, indicating that local authority development plans should identify and protect such areas. In order to support this initiative, SNH recently produced a Policy Statement on Wildness in Scotland's Countryside (SNH, 2002). The commissioning brief for the current work outlined proposals for three linked pieces of work:

- a public survey investigating peoples' perceptions of wildness and wild land in Scotland;

- a method for a Geographic Information System (GIS) based analysis of wildness; and

- a GIS analysis of wildness to identify the geographical extent and intensity to which different wildness qualities or attributes can be experienced across the Cairngorms National Park.

This report describes work completed on the latter two using the Cairngorms National Park and its immediate environs as an example. The first piece of work was subject to a different contract and reported separately (Market Research Partners, Edinburgh 2007).

Work undertaken

A GIS-based approach is developed here to identify the geographical extent and intensity of wildness in the Cairngorms National Park (CNP). This is based on previous work on wild land quality mapping utilising GIS-based multi-criteria evaluation (MCE) and fuzzy mapping methods. These methods are used together with results from the perception study to develop map datasets describing the four principal attributes that contribute to perceptions

of wildness in the CNP; namely perceived naturalness of land cover, absence of modern human artefacts, rugged and challenging nature of the terrain, and remoteness. The four attribute maps are combined into a single wildness map using MCE/fuzzy methods allowing the relative priorities derived from the perception study to be reflected in the wildness map without the need for deterministic criteria or sharp boundaries defining what is considered wild and that which is not. The method is implemented across the whole of the CNP and surrounding areas to produce a map that quantifies and spatially delimits perceptions of wildness across the park that can be used for planning and other decision support purposes. A wildness mapping tool suitable for implementation in ArcGIS software suite is developed and provided for use by CNP officers along with a novel rapid viewshed assessment tool.

Main findings

The work described in this report delivers the following outputs:

- A GIS-based methodology for mapping wildness attributes and combining these using different weighting schemes to draw wildness maps.

- A step-by-step guide to the use of the methodology to allow CNPA officers to replicate the study and keep attribute maps up to date.

- An ArcGIS9.2 compatible tool for creating wildness maps from attribute layers and training for CNPA staff in use of this tool.

- A series of output datasets and maps of individual wildness attributes and combined wildness maps.

- A lifecycle of output datasets consisting of accurate metadata and lineage based on the CNPA metadata schema and including descriptions of attribute fields and values.

- A detailed interpretation of the results including an analysis of dataset accuracy and sensitivity of the results to different weighting schemes.

- A retrospective analysis of the study to identify lessons learnt and possible next steps.

The maps contained in the report show a high degree of complexity and variability within the components of wildness across the CNP and its immediate environs. The spatial pattern in wild land attributes is sensitive to the methods, assumptions and the data used. This results in local differences between the different ways of mapping each of the attributes. This sensitivity notwithstanding, the same basic overall pattern of wild land attributes can be observed across all the attribute maps, irrespective of the methods used, in that the wilder areas of the CNP are in the main confined to the large roadless areas of the mountain core and their associated glens. These include, but are not limited to:

- the Cairngorm plateau and mountain coires east and west of the Lairig Ghru;
- the high moorland plateau of Mòine Mhòr;
- the peaks and coires of Bein A' Bhuird and Ben Avon;
- Lochnagar and the White Mounth;
- the remote headwaters of Glen Feshie; and
- the head of Glen Banchor adjacent to the Monadhliath in the north.

At the other end of the wildness spectrum, the least wild areas are strongly controlled by the straths and glens that dissect the park, including Strath Spay, Strath Avon, Strath Don, Braemar and Deeside, Glen Clova and Glen Truim, together with their associated roads, settlements, infrastructure and agricultural land use patterns. Plantation forestry also has a marked effect in reducing wildness in key localities such as Glenmore/Rothiemurchus, Strath Avon/Tomintoul and Abernethy, while local ski developments have a marked local effect through their concentration of access roads, maintenance tracks, ski lifts and buildings. These include the Cairngorm, Lecht and Glenshee ski areas, although the effect of the latter is less pronounced by virtue of its location on the park boundary.

Combining the attribute maps using the MCE/fuzzy methods and different weighting schemes and inputs developed in the main body of the report generates a range of overall wildness maps. Using an equally weighted map as the baseline for comparative purposes, it can be seen that whilst there are local differences in either the intensity or pattern of the relative wildness values, there is a strong agreement between all the maps as to the overall pattern of wildness that corresponds to those wild areas listed. This is indicative of a high degree of robustness and associated confidence in both the methods/data used and the maps produced.

All attribute maps and composite wildness maps are reproduced throughout the report as well as in larger A3 format in Appendix 7.

Contents

1. Introduction

(1.1)   A GIS-based methodology is developed to map wildness attributes in the Cairngorms National Park (CNP). This is based on previous work by the team members on wild land quality mapping utilising GIS-based multi-criteria evaluation (MCE) and fuzzy mapping methods (see Carver et al., 2002 and Fritz et al., 2000). Existing digital map datasets are used wherever possible supplied under licence from Cairngorms National Park Authority (CNPA), Scottish Natural Heritage (SNH) and other organisations as appropriate. These are used to develop map datasets describing the four principal attributes that contribute to wildness in the CNP, namely perceived naturalness of land cover, absence of modern artefacts, rugged and physically challenging terrain, and remoteness. The attribute maps are combined into wildness maps for the CNP area using MCE/fuzzy mapping methods. This has allowed the relative priorities derived from the perception study to be reflected in the wildness map without the need for deterministic criteria or sharp boundaries defining that which is considered wild and that which is not. The method has been implemented across the whole of the CNP at a high resolution and the lifecycle of each dataset established to allow for ease of maintenance and future updates by CNPA and SNH staff. A wildness mapping tool suitable for implementation in ArcGIS 9+ has been developed and provided for use by the CNPA along with a novel rapid viewshed assessment tool. The steps in the development of this wildness assessment method, its application and the outputs generated are outlined in detail later in this report.

2. Background

*"**Wild, lonely, isolated country is a thing of very high value to men. It is a value that has been greatly underestimated by all but a very few of our planners... The remnants... will become a priceless asset, if we resolve now to keep them.**"*
W.H.Murray (1968)

(2.1)   There has been a great deal of debate in recent years over the definition and applicability of wild land in the UK. Perhaps the most progress has been in Scotland, where some of the nation's wildest landscapes can be found. Here, several organisations, taking their lead from National Planning Policy Guideline 14 (NPPG14) on Natural Heritage, have developed their own wild land definitions. These include Scottish Natural Heritage (SNH), the National Trust for Scotland (NTS) and the John Muir Trust (JMT). NPPG14 defines wild land as "*Uninhabited and often relatively inaccessible countryside where the influence of human activity on the character and quality of the environment has been minimal*" (NPPG14, 1998). The SNH definition, published in 2002 refers to the "*parts of Scotland where the wild character of the landscape, its related recreational value and potential for nature are such that these areas should be safeguarded against inappropriate development or land-use change*" (SNH, July 2002, p.8). The NTS further define wild land as "*relatively remote and inaccessible, not noticeably affected by contemporary human activity, and offers high-quality opportunities to escape from the pressures of everyday living and find physical and spiritual refreshment.*" (NTS, January 2002, p.4). This has been the subject of a long running informal debate and a number of publications and discussion documents[1].

(2.2)   An important aspect of the wild land concept is its subjectivity and the often shifting nature of the goal posts. This is characteristic of the very nature of peoples' differing perceptions of the concept of wildness and is captured nicely in the two quotes by Roderic Nash from his book *Wilderness and the American Mind*. Here Nash states "*Wilderness is what men think it is*" and "*One man's wilderness is another's roadside picnic ground*" (Nash, 1982, p.1). This begets an interesting problem that in order to manage a landscape value such as wild land quality, we first need to be able to define it sufficiently rigorously that we can actually map it. For the purposes of this report, wild land quality is assumed to be an index derived by combining attribute maps describing the constituent parts or components of wildness and weighted according to their order of priority, such that the relative value of wildness can be mapped for any area. Based on the definition of wildness developed by SNH these attributes include the perceived naturalness of land cover, absence of modern human artefacts, the rugged and challenging nature of the terrain, and remoteness from mechanised access. The method of combining these attribute maps used in this report and elsewhere is based on adaptations of work by the Australian Heritage Commission on the Australian

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[1] See for example, the ongoing discussion in the pages of ECOS (e.g. Fenton, 1996) and Peter Taylor's book 'Beyond Conservation' (2005).

National Wilderness Inventory (Lesslie and Maslen, 1993) and work by the contractors for the UK (Carver, 1996; Fritz et al., 2000; Carver et al., 2002; Carver, 2005).

(2.3)   Established methodologies for the assessment and mapping of wilderness tend to focus on four basic criteria: remoteness from human habitation, remoteness from mechanised access, apparent naturalness or absence of human artefacts, and biophysical or ecological naturalness (Lesslie, 1993; Carver, 1996). However, there are no true (i.e. pristine) wilderness areas in Scotland or the CNP study area. In Scotland the emphasis is more on 'wild land' as those areas where the qualities of wildness as perceived by humans can best be experienced. This is distinct from more ecological definitions of naturalness or ''wild nature' which focus on the undisturbed nature of functioning ecosystems (Fenton, 1996). Developing policy on wild land in Scotland has tended to emphasise those elements of the landscape that make it appear wild to the visitor as defined in NPPG 14. Both SNH and the NTS consider the main attributes affecting peoples' perceptions of wildness to be:

a. Perceived naturalness in the setting, vegetation cover, wildlife and processes operating with little evidence of contemporary human land use;

b. Lack of modern artefacts or structures;

c. Landscapes that are rugged or otherwise physically challenging; and

d. Remoteness and/or inaccessibility.

The John Muir Trust (JMT) also include 'grand in scale' indicating that a sense of scale is also important, though it could be argued that this is geographically a component of the rugged/physically challenging and remoteness attributes. These and other physical attributes used in the identification of wild land are taken directly from SNH policy on wild land and are expanded on in Table 2.1.

Table 2.1 Physical attributes in the identification of wild land (After SNH, 2002)

Attributes	Main criteria	Further detail
Perceived naturalness	Vegetation cover primarily composed of functioning, natural habitats. Catchment systems largely unmodified, and other geomorphological processes unaffected by land management.	Habitat may often not be in best condition or at optimum ecological status. But there will normally be potential for recovery, and the vegetation cover should be composed of natural components. Some small plantations may be tolerated especially at the edge of an area, if they are the only detracting feature and of limited effect on wildness.
Lack of constructions or other artefacts	No contemporary or recent, built or engineering works within the area. Little impact from outwith the area on wild qualities from built development, power lines, or masts or other intensive land uses (say forestry), or from noise or light pollution. Limited effects on the wild qualities of the area from older artefacts.	Older features (fences, bridges, stalking tracks, or small buildings)may be present, if not intrusive overall. Archaeological features (normally a light imprint on the land) will contribute to visitors' appreciation of the continuity of human use of these areas. Some intrusive features (say vehicular tracks which partly penetrate into an area) may be tolerated, where their effects are limited, and where excluding such land would reject an area of high intrinsic quality.
Little evidence of contemporary land uses	Extensive range-grazing and field sports (as economic uses of the land) will often be present, as well as public recreation. Land uses of an intensive nature should not be present.	The cumulative effects of the economic uses of the land should not be intrusive. Evidence of muirburn or over-grazing, habitat management, footpath deterioration and erosion, or the effects of the use of offroad vehicles may be visible. But the effects of any one of these activities, or their cumulative expression should not be of a scale or intensity so as to significantly devalue visitors' perceptual experience.
Rugged or otherwise challenging terrain	Striking topographic features, or land having extensive rough terrain or extensive boglands, difficult to traverse. Natural settings for recreational activities requiring hard physical exercise or providing challenge.	Different kinds of terrain can offer an inspiring or challenging experience for people but, in the main, it is those landscapes which are of arresting character (by virtue of the scale and form of the terrain) which are most valued for their wildness.
Remoteness and inaccessibility	Distance from settlements or modern communications.	Distance is not an absolute guide on its own, but most of the wild land

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	Limited accessibility, either by scale of the area, difficulty in passage, or the lack of easy access, say by vehicular tracks, bridges, or by boat.	resource will lie in the remaining remote areas, as defined by distance from private and public roads and other artefacts.
Extent of area	An area of land sufficient to engender a sense of remoteness; to provide those who visit them with physical challenge; and to allow for separation from more intensive human activities.	Smaller areas of land of high intrinsic merit or inaccessibility can hold the qualities which underpin a sense of wildness, say an inaccessible rocky gorge, and the same applies to some small uninhabited islands, or stretches of isolated coast.

(2.4)   The datasets and methods that are used to map these four attributes are described in detail in section 4 of this report, but briefly these are defined here as:

- Perceived naturalness of land cover – the extent to which land management, or lack of, creates a pattern of vegetation and land cover which *appears* natural to the casual observer.

- Absence of modern human artefacts – the lack of obvious artificial forms or structures within the visible landscape, including roads, railways, pylons, hard-edged plantation forestry, buildings and other built structures.

- Rugged and challenging nature of the terrain – the physical characteristics of the landscape including effects of steep and rough terrain and harsh weather conditions often found at higher altitudes.

- Remoteness – the remoteness of inaccessibility of the landscape based on time taken to walk from the nearest point of mechanised access.

3. Developing a wildness model

(3.1)   Maps of the four attributes of wildness, as defined by SNH (2002), can be combined to produce a series of wildness maps for the CNP using the MCE and fuzzy methods developed and used in previous studies (e.g. Carver, 1991; Carver, 1996; Fritz et al., 2000; Carver et al., 2002; Carver, 2005; Carver, 2007). MCE methods allow the combination of predefined and standardised attribute layers (criteria) describing the relative merits of a particular solution or location using a set of user-defined weights to describe the relative importance or priorities assigned to each input layer. This process is illustrated as a flow chart in Figure 3.1.
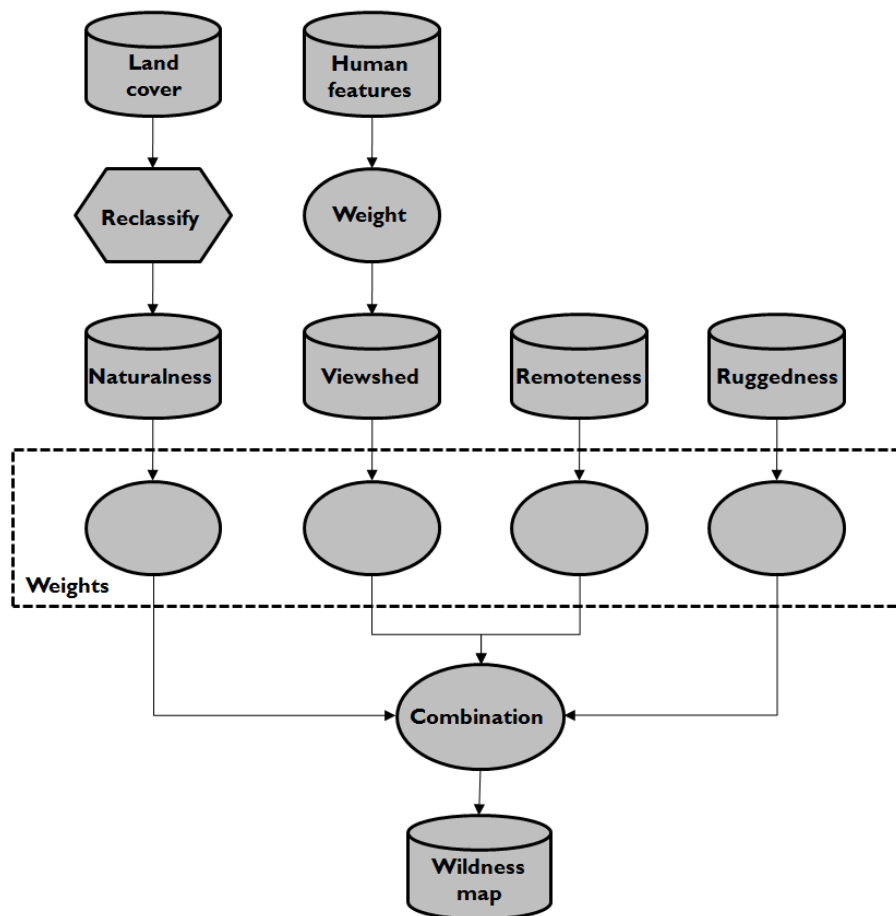

Figure 3.1 Flow chart showing how the data are parameterised by weights and combined to generate a wildness map

3.1 GIS-based MCE model

(3.2)   The model illustrated in Figure 3.1 needs to be populated by attribute maps derived from raw data and a set of weights reflecting the relative importance of the attributes in defining the overall wildness map. The attribute maps are prepared from the interpretation

of raw spatial data such that they represent the components of wildness derived from SNH policy with some additional inputs from the public perception survey. These are described in detail in section 4. Attribute weights can be defined either numerically (e.g. Carver et al., 2002) or using fuzzy methods (e.g. Fritz et al., 2000). The weights allocated to each of the attribute maps are defined in consultation with the Steering Group and from selected tables from the perception survey. Several different wildness maps are produced as part of this study using MCE and fuzzy methods to reflect the different viewpoints shown in the results of the perception study and discussions within the steering group. A wildness map that combines each of the four attribute maps using equal weights is produced and used as a benchmark. These wildness maps indicate the perceived wildness using a continuous scale rather than discrete areas. An example is shown in Figure 3.2.
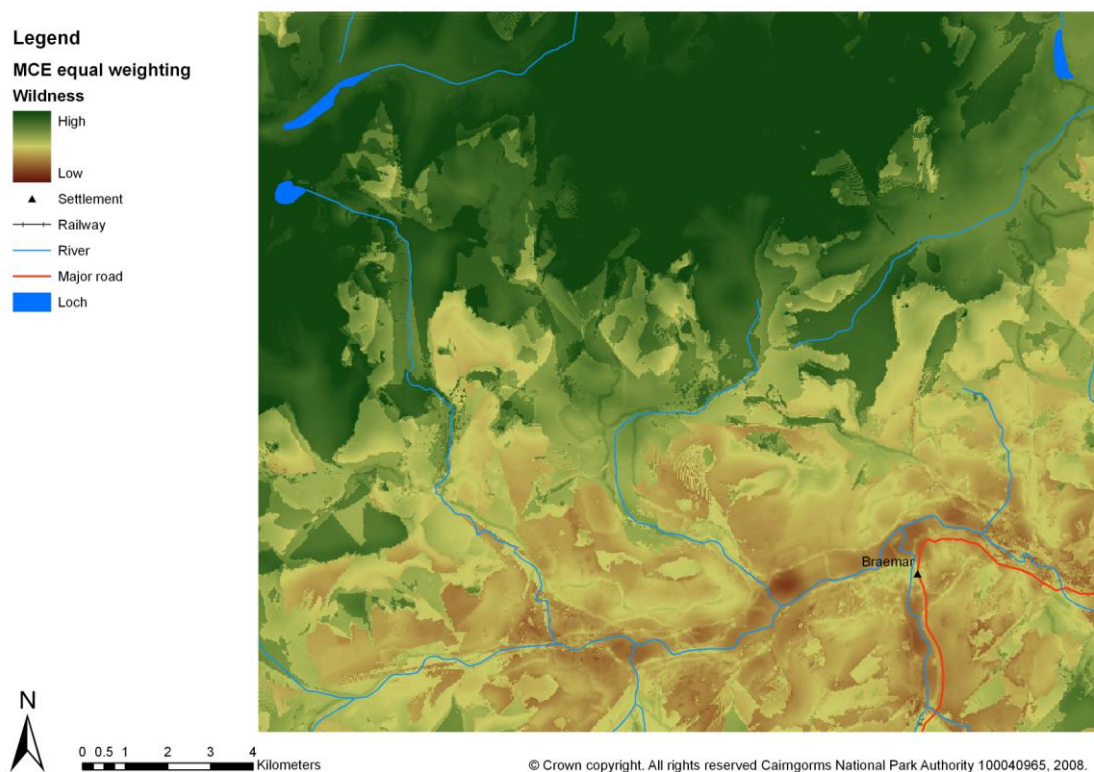
Figure 3.2 Example wildness map for the Cairngorms National Park

(3.3)   Care needs to be taken during this process to ensure that the input attribute maps do not exhibit a high degree of spatial correlation such that one particular theme does not dominate the results. For example, it is conceivable that the remoteness and ruggedness might be closely correlated in the core mountain areas away from the main valley routes. Statistical checks are performed to make sure attribute maps are not correlated and to flag up any possible problem areas where spatial correlations are found to exist (see section 4.5).

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(3.5)   All map layers need to be standardised (normalised) onto a common relative scale to enable cross comparison. For example, remoteness and perceived naturalness are measured using time (seconds) and nominal naturalness class, and so cannot be directly compared[2]. In addition, the 'polarity' of individual map layers needs to be maintained such that higher values in the standardised maps are deemed to be 'better' (i.e. indicative of greater wildness) and lower values are 'worse' (i.e. indicative of lower wildness). The weights applied to the map layers are defined on the basis of discussions with members of the project Steering Group and from interpretation of selected tables from the perception survey. These are then applied within a simple Weighted Linear Combination[3] MCE model within the GIS. Alternative wildness maps are created to demonstrate the influence of different weighting schemes on the results. These alternative weighting schemes and resulting wildness maps are described in section 5.

3.2 Derivation of model weights

(3.6)   The results from GIS-based MCE models are highly sensitive to the weights applied to the input attribute maps, so care needs to be taken in the definition of appropriate weighting schemes. Work by Comber has shown that different approaches to combining evidence from perception surveys will result in different outputs, in this case represented within the attribute maps (Comber et al., 2004, 2006, 2007). This work has also shown that the different approaches for evidence combination such as fuzzy set theory, Dempster-Shafer, Bayesian probability and endorsement theory are underpinned by different assumptions (see section 6.4). As different approaches result in different mapped outputs, which may themselves be used as the basis for further decision making, the maps need to be defensible despite their highly relative (as opposed to absolute) nature. Therefore, the work described here seeks to match the priorities of the CNPA with appropriate evidence combination methods. However, MCE methods are used throughout the main body of the report since these are the established method of choice when combining wildness attribute maps with weights describing their relative importance in the manner described (Lesslie, 1993; Carver, 1996; Fritz et al., 2000; Carver et al., 2002; Sanderson et al., 2002). In this work three sets of weightings were used to generate overall measures of wildness in order to capture some of this variation as described below.

3.2.1 The perception survey

(3.7)   The perception survey carried out on behalf of SNH surveyed a representative sample of just over 1300 Scottish residents using face-to-face interview techniques. Of this

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[2] Standardisation of the attribute maps is achieved here using a linear re-scaling of the input values onto a 1-256 scale on an equal interval basis.

[3] Weighted Linear Combination is simply based on the sum of the weighted standardised map layers as follows: $S_{ij} = \sum_{ij}^{i=n} \left(W_{ij} X_{ij} \right)$ where S = suitability of the choice alternative (site or grid cell), W = criterion weights, X = standardised criterion score, i = i[th] choice alternative, j = j[th] criteria.

sample, 300 people were residents of the CNP, while another 1,004 people were interviewed across the rest of Scotland. The interviews lasted around 18 minutes and covered topics investigating people's participation in outdoor activities, perceptions of wild places, knowledge of wild areas in Scotland and wild areas in the CNP in particular, and implications for and threats to wild places. The results from the survey were divided into Scottish and CNP residents and analysed separately. In general, the two groups showed similar responses, with a strong support for the conservation of wild land in Scotland. Other key findings include:

- The perception that wild places are an important part of Scotland's culture and heritage and important for tourism;

- Around one in two residents thought that wild places were under threat from development, with around 3 out of five people thinking that action is required to preserve wild areas through, for example, more stringent planning controls;

- Most people have a well established notion of what constitutes wildness with over 75% of respondents mentioning features which can be attributed to naturalness of land cover, although this is not limited to one particular landscape type with woodland, forest, mountains, hills, lochs and moorland all featuring highly as wild places;

- Key threats and detractors mentioned include modern human artefacts such as buildings, masts and turbines, with fewer people mentioning plantation forestry, old buildings and footpaths as being significant;

- A wide selection of areas are perceived as being wild by respondents, with many people referring to the Highlands, the Western Isles and Northern Isles; and

- Most people perceived the CNP as wild, with emphasis on mountain tops and moorland as the wildest areas of the park.

The analysis of Scottish versus CNP residents revealed some interesting differences between the two groups. In particular the report notes that of the perceived threats to wild land in Scotland, masts and wind turbines were more of an issue to CNP residents. CNP residents also have a much tighter definition of wild areas than Scottish residents and are clearly much more aware of the status of the CNP as containing important areas of wild land.

(3.8)   Despite much of the positive evidence about perceptions and attitudes toward wild land contained in the perception survey report, much of the specific data in the survey results was found to be of little practical use to the project though it does clearly constitute an important source of background information on public perception of wildness in the Scottish countryside. Specifically:

- many of the questions were poorly specified in relation to the spatial aspects of the current project;

- the images used for ratings of wild images (section 3.2.3) in the perception survey heavily steered the respondent with the presence of livestock and people, ignoring established methods for statistically analysing public perceptions of landscapes (for example see Habron, 1998 as an approach for quantifying responses to the content recorded in images);

- the questions used to parameterise public rating of the impact of features on wild places were poorly constructed. For example the questions used to parameterise public rating of the impact of features on wild places (section 3.2.5) e.g. "What impact do the features have on a wild area?"

(3.9)   As a consequence many of the results of the perception survey were contradictory, making it difficult to identify a consistent voice. Notably, some results indicated that certain features were important contributors to wildness, whilst others did not and emphasised different landscape features as being important. As an example of this confusion compare the results as presented in Table 7 and Table 9 of the perception survey. Whilst not intended, few of the results were in a format that would support their direct incorporation into established wildness mapping methods as developed by Lesslie (1993) and Carver (1996). For example, the survey did not collect scores of the attributes of wildness (such as the components of naturalness) in a way that reflected their relative importance in determining whether an area is wild or not. Because of these issues it was decided explore different weightings to re-interpret the data in the perception survey in order to generate example weights for the model based on three sources as follows:

- the perception survey commissioned by SNH;
- an alternative analysis of this data by the contractors; and
- the perceptions of key staff at the CNP and SNH.

(3.10)   The perception survey did capture information on the relative importance of the 4 components of wildness. Table 3.1 shows the results for the two groups of respondents. Interestingly, both groups have weighted the components similarly with Naturalness having a much higher score (although this could be related to respondents having greater familiarity and understanding of the term).

Table 3.1 The different scored used as weightings for the data contributing to wildness - Table 8 from the Perception Survey "Categorisation of features or characteristics which make an area wild? (%)"

	Scotland	CNP
Naturalness	75	75
Remoteness	32	36
Lack of Modern Artefacts	16	16
Ruggedness	5	5
Base	806	222

3.2.2 Contractor derived weights

(3.10)   The perception survey did not present clear information on the relative importance of manmade structures in the landscape that have a negative impact on wildness as input parameters for the visual impact analysis in order to generate the lack of modern human artefacts layer. The contractors interpreted these from the information described in Figure 10 in the perception survey (What features or characteristics reduce the wildness of an area (total, after prompting)? Base: all respondents (1004 / 300) p16). These were used to weight features in the visual impact analysis in order to generate the lack of modern human artefacts data layer, specifically to identify the weights for buildings, roads and tracks, pylons and turbines in the calculation of this layer and are shown in Table 3.2. Upper and lower bounds were identified from the categories in Figure 10 of the perception survey: for buildings these were "Modern Buildings" and "Lots of Buildings" and for roads and tracks these were "Roads" and "Footpaths". The upper and lower bounds provide an indication of the reliability and confidences: the closer they are the greater the certainty and belief in either figure.

Table 3.2 Weights for the different visible landscape features used in calculating the lack of modern human artefacts data layer derived from Figure 10 in the Perception Survey

	Scotland Upper (Lower)	CNP Upper (Lower)
Buildings	71 (65)	80 (73)
Roads / Tracks	61 (14)	69 (19)
Pylons	34	50
Turbines	31	44

(3.11)   The contractors were concerned that the perception survey did not summarise the different features that contributed to each of the components (or dimensions) of wildness. Therefore they interpreted the features identified in Table 7 of the perception survey for the question "In your opinion, what features or characteristics make an area wild?" for each of the wildness components. Table 3.3 shows the relationship between different landscape features and the four dimensions of wildness for the 2 groups. These were then used to provide relative weights for the different layers.

Table 3.3 The components of wildness supported by the unprompted descriptions in the perception survey Table 7 "In your opinion, what features or characteristics make an area wild?"

	Scotland	CNP	Naturalness	Visibility	Remoteness	Ruggedness
Wildlife	31	27	X			
Forests / woods / trees	28	19	X			
Hills / mountains / glens	24	31				X
Open space	18	13		X		
Few people / lack of human interference	16	26		X		
Grassland / greenery / moorland	12	6	X			
Untouched / unspoiled	11	13	X	X		
Fauna / flora	10	10	X			
Lochs	8	8	X			
Scenery / natural beauty	7	15	X	X		
Remote area	7	10			X	
No buildings / urbanisation	7	7		X		
Countryside	6	5				
Rivers / waterfalls	5	7	X			
No traffic	4	1		X		
No roads	4	3		X		
Quiet	3	2		X		
Sea / coastline	3	2				X
Fresh air	1	1				
No footpaths	1	1			X	

3.2.3 Equal weightings strategy

(3.12)   The third weightings option was to weight all of the components of wildness equally. There are a number of reasons for doing this. Firstly, under the assumption of equal salience, where all four components are deemed to be equally as important as each other, it provides an objective unbiased approach. Secondly, the data from the perception survey had to be interpreted in order to be used: even the nominally straightforward results shown in Table 3.1 show cognition bias where unfamiliar terms are less well supported than familiar ones by the respondents. Using equal weights avoids the issue of the survey providing answers to different question to those required by this work. It also avoids the problems surrounding contractor interpretation of the survey results, such as being able to test whether contractor assumptions and interpretations are correct. Hence the Steering Group opted for equal weighting for the overall wildness map as reliable evidence to underpin a different weighting scheme was not available. These also provide a set of baseline weightings for considering different evidence combination methods.

3.2.4 Summary

(3.13)   The perception survey provided overall weights for the 4 components of wildness: perceived naturalness of land cover, remoteness, lack of modern human artefacts and rugged and challenging nature of the terrain. The contractors interpreted the perception survey data in order to provide weights for the features modelled in the Lack of Modern Artefacts layer. The contractors also derived weights for all layers based on their understanding of the problem from a single table in the perception survey.

3.3 Wildness modelling tools

(3.14)   A number of tools are provided along with the final attribute maps and results of the wildness analyses. These include:

- a normalisation tool for adjusting the values in the attribute maps onto a common scale;
- a weighted linear summation model; and
- an ordered weighted averaging model.

These are described in detail below.

3.3.1 Normalisation tool

(3.15)   This tool allows the user to adjust the values of any given attribute map. In the attribute maps used here it is assumed that for some of them there is a linear increase of

values. Such a linear behaviour might be appropriate and perceived as one possible way of creating a normalised attribute map for use in the MCE-based wildness model. However, some people might perceive that, at a certain point, wildness values will increase very little or there is a certain threshold above which wildness values do not change at all. For example, when looking at the remoteness attribute map, there might be a certain walking time threshold beyond which people perceive that they are in a wild land setting and walking any further away beyond this time threshold will have little or no influence on their perception of wildness. Alternatively, if it is assumed that the relationship between walking time and remoteness is linear, then a doubling of the walking time means doubling of remoteness and hence a similar doubling of this attributes influence on the overall wild land values. However, having for example walked away from a car park more than three versus six hours might not have the same relative impact as having walked away from this car park for one versus two hours. As there are exponential decay functions applied in the visibility analysis a similar behaviour might exists for remoteness (see section 4.2).

(3.16)   Normalisation tools are therefore provided (see Figure 3.3) which allow certain adjustments to the attribute maps to be made using a suite of functions. In particular, the logarithmic functions allow you to adjust a linear attribute map to an attribute map where, for example, the increase is initially quasi linear and then flattens out (see Figure 3.4). Moreover, the normalisation tool allows users to define a threshold at which the maximum value has been reached. This possibility enables the definition of a wildness topology to be integrated at a later stage (see section 6.2). With the normalisation tools applied, the current attribute maps can be used in the MCE wildness tools and further refinements and adjustments can be made. The normalisation tool is shown in Figure 3.3. The threshold value indicated in the tool is optional and does not have to be defined.
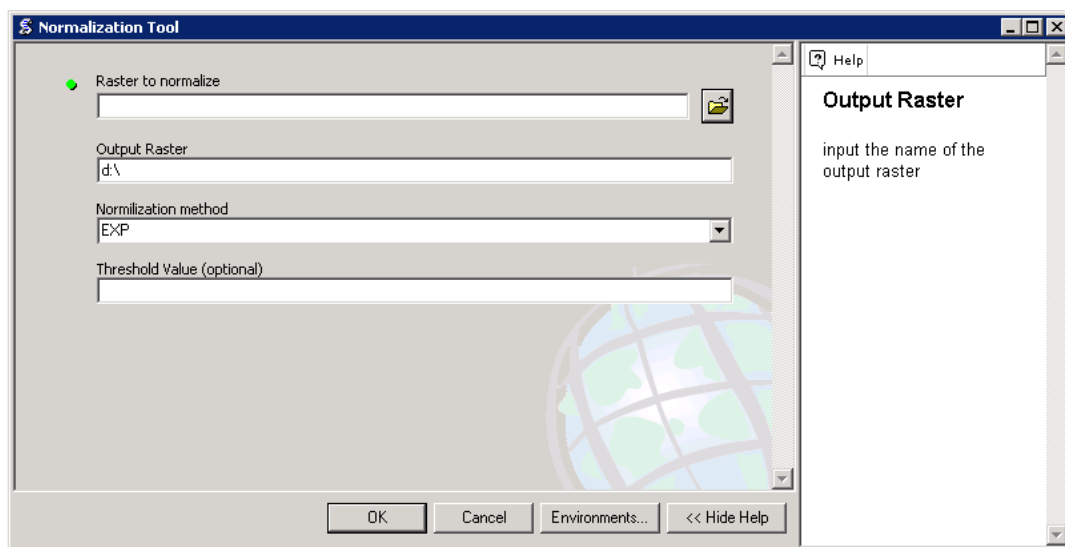

Figure 3.3 The normalisation tool interface
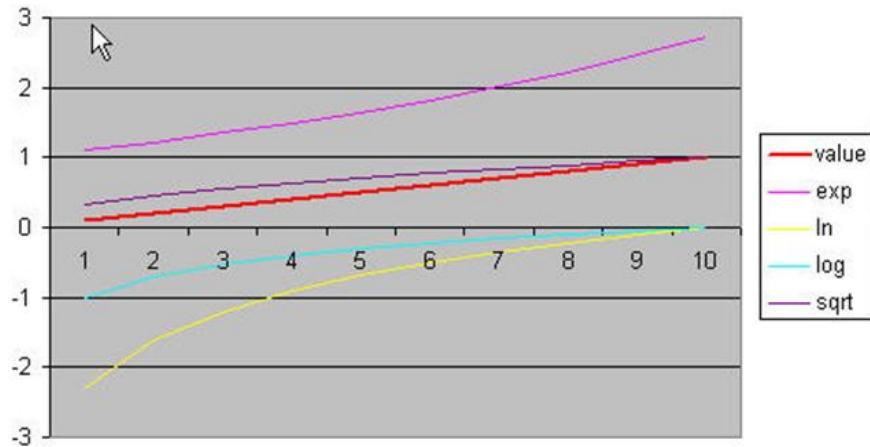
Figure 3.4 Example normalisation functions
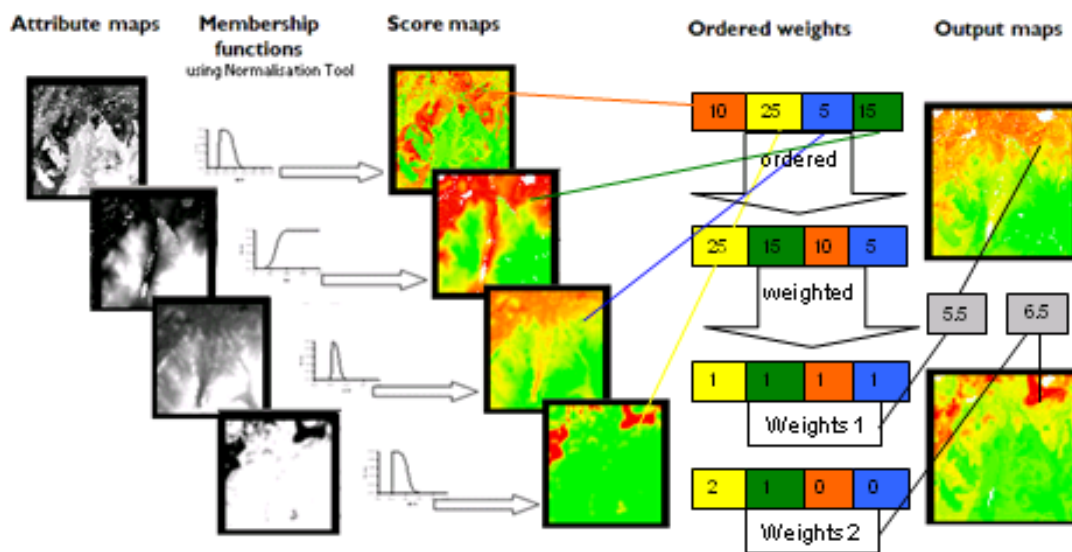
3.3.2 Linear Summation model

(3.17)   This tool allows for the weighting of the different attribute maps in order to be able to give those maps a higher weight which are perceived to have a stronger impact on the overall wildness quality. Since it is up to the individual to decide which attribute for them is most important, a wide range of different wild land maps can be created. The four attributes of remoteness, apparent naturalness, ruggedness and the map of absence of modern artefacts can be weighted according to one's individual perception. Figure 3.5 shows the weighted linear summation interface.
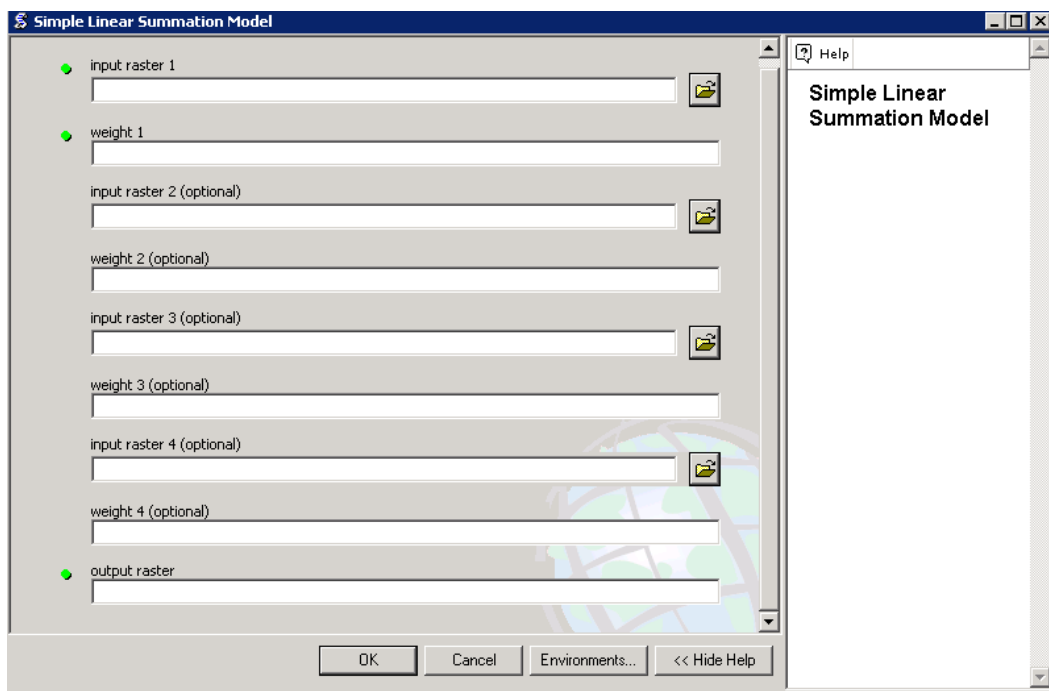
Figure 3.5 Weighted linear summation interface

3.3.3 Ordered weighted average (Fuzzy operator)

(3.18)   This tool is an extension of the linear summation model and adds an additional component. Since the linear summation model assumes that attribute maps should be combined in a linear way this tool allows for the combination of AND and ORNESS of different attributes. Just ORNESS would use the OR operator and combine the wild land maps in such a way that only the pixel value of the map which has the strongest impact is used. In contrast the AND operator uses all attributes and gives them equal weights. In some circumstances for example the OR operator can be more appropriate. Take the example of a major development in a very remote area which is natural as well as rugged. Having a wind farm at the top of the Cairngorm plateau might be perceived as having such a strong impact on the overall wild land quality that it cannot be compensated by the high remoteness, ruggedness and perceived naturalness values regardless of its location. The tool allows users to take such a potential perception into account. The way the tool works is illustrated in Figure 3.6.

Figure 3.6 Illustration of the Fuzzy Ordered Weighted Average Operator

(3.19)   Weights given (see Figure 3.7) determine the degree of AND and ORNESS. The weights in contrary to the linear summation model do not relate to the factor maps but are applied according to the rules determined by ordered weighted average operator. Further information on the installation and operation of these tools is given in Appendix 1.
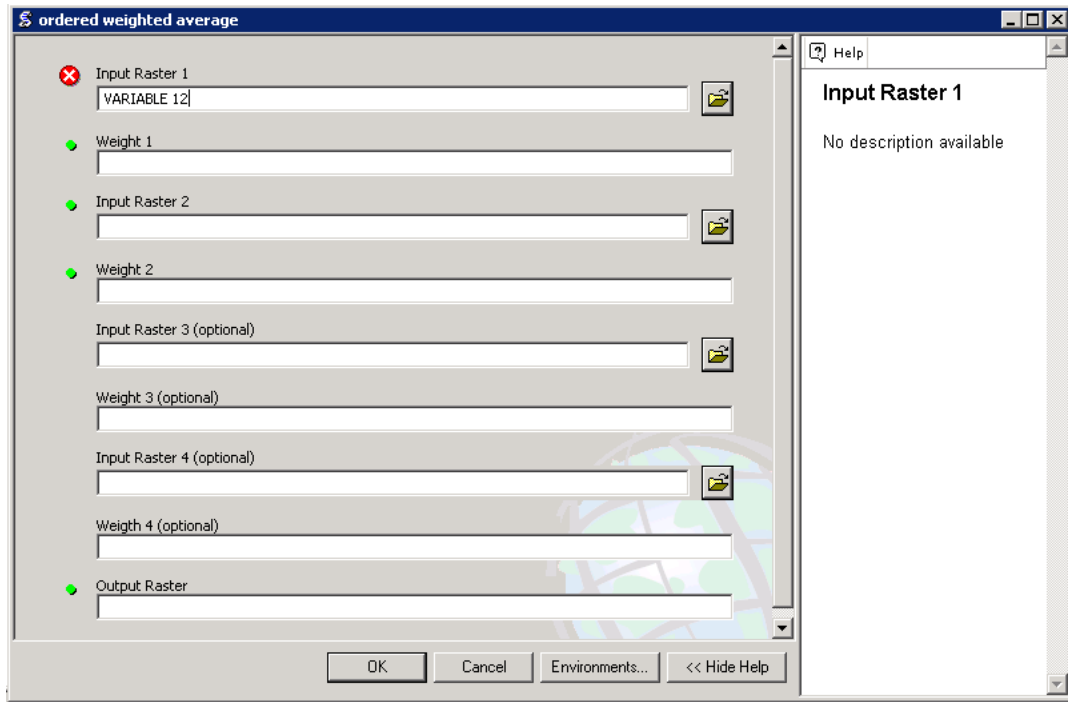
Figure 3.7 Ordered weighted average interface

4. Attribute maps

(4.1)   The four attributes of wildness as defined by SNH (2002) are mapped using a combination of readily available datasets and the latest GIS-based techniques. These attribute maps are produced for the CNP area and a buffer zone of 15km. This buffer zone is required to ensure that there are no edge effects arising from visible human features and points of access immediately outside the park boundary. These are described in turn, together with the data used, method of mapping and associated caveats/assumptions used.

4.1 Perceived naturalness of land cover

(4.2)   Perceived naturalness of land cover is described here as the extent to which land management, or lack of it, creates a pattern of vegetation and land cover which appears natural to the casual observer. Perceptions of wildness are in part related to evidence of land management activities such as fencing, plantation forestry and stocking rates, as well as presence of natural or near-natural vegetation patterns. Here a combination of datasets are brought together to best describe perceived naturalness in the CNP. These include the Land Cover Map 2000 (LCM2000), Land Cover of Scotland 1988 (LCS88) and Highland Birchwoods Woodland Inventory (1999).

4.1.1 Data sources

(4.3)   Aspects of land management are identifiable from national land cover datasets such as the Land Cover Map 2000 (LCM2000) and Land Cover of Scotland 1988 (LCS88). These datasets are available from the Centre for Ecology and Hydrology (CEH) and Macaulay Institute, respectively. While neither dataset directly captures the exact land features needed by this study (i.e. those that relate and contribute specifically to wildness such as naturalness) the distribution, presence and absence of features related to wildness can often be inferred from their classes when the datasets are combined. In areas where there is high internal variation within land cover classes then other thematic datasets may be used to provide more detailed information (e.g. woodland and forestry).

(4.4)   Previous work by Carver (2005, 2007) has based naturalness of land cover on a reclassification of the LCM2000, and the earlier LCM1990 product, into a smaller number of naturalness classes (see Appendix 5). Supplementary information derived from other sources such as the Highland Birchwoods Woodland Inventory and Ordnance Survey (OS) map products has been used to refine these naturalness classes as required (e.g. by distinguishing between planted and semi-natural woodland or natural and artificially impounded water, respectively). These classes were reviewed and agreed by the Steering Group using the relevant sections of the perception survey as a guide. The naturalness classes used here are shown in table 4.1 and examples of the raw land cover data are shown in Figure 4.1 with alternatives used in Figure 4.4 given in brackets.
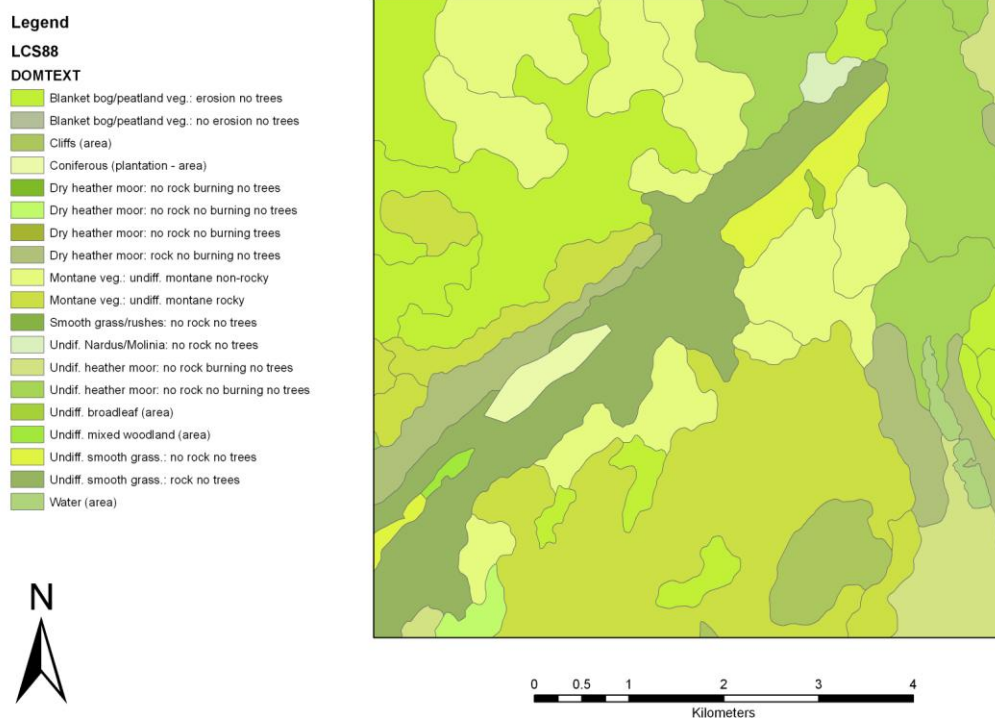
Table 4.1 Defining naturalness class

Broad Habitat	Description	Mapped value	Level 2 code	Naturalness class
Broad-leaved woodland	All broad-leaved woodland including mixed and yew woodland. Many woodlands are below the 0.5ha minimum mappable unit of the LCM2000 are so are excluded. This has been split into semi-natural (1.1a), mixed semi-natural/planted (1.1b) and planted woodland (1.1c) using the Highland Birchwood inventory data.	3000 / 2000 / 1000	1.1a / 1.1b / 1.1c	5 / 4 / 3
Coniferous woodland	All coniferous woodland. Generally planted in larger blocks and so are better defined. This has been split into semi-natural (2.1a) and plantation forest using the SSNW and Highland Birchwood data (2.1b)	3000 / 1000	2.1a / 2.1b	5 / 3
Arable and horticultural	All cropped lands including cereal crops, vegetables, ley pasture, and set-aside.	41, 42, 43	4.1 4.2 4.3	2
Improved grass	Any grassland that has continuous attempts at improvement including drainage, ploughing, reseeding, fertiliser application, etc.	51	5.1	2
Neutral grass	Any semi-natural grassland on neutral soils/rocks. Some improvement may be present.	61	6.1	3
Calcareous grass	Any semi-natural grassland on calcareous soils/rocks. Some improvement may be present.	71	7.1	3
Acid grass	Any semi-natural grassland on acid soils/rocks. Generally not improved.	81	8.1	4
Bracken	Areas recorded as bracken.	91	9.1	4
Dwarf shrub heath	Vegetation dominated by dwarf shrubs (heather, bilberry, gorse, etc.). Two level 2 classes are distinguished: dense (10.1a) and open (10.2a) but both are considered of equal naturalness.	101 / 102	10.1a / 10.2a	4 (5) / 4 (5)
Fen, marsh and swamp	Areas characterised by vegetation types found on permanently, seasonally or periodically waterlogged soils.	111	11.1	4
Bog	Areas of heath or moor vegetation with peat depth greater than 0.5m as defined by BGS.	121	12.1	5
Standing water/canals	Includes all areas of inland water greater than 0.5ha minimum mappable unit. This has been split here into natural waters (rivers, lakes, streams) (13.1a) and artificially impounded waters (reservoirs) (13.1b) using OS MasterMap data.	131	13.1a / 13.1b	5 / 3
Montane Habitats	All vegetated areas at altitudes greater than 600m	151	15.1	5
Inland rock	Includes mainly semi-natural bare rock surfaces, but also 'despoiled' areas such as quarries.	161	16.1	5
Built up areas and gardens	Buildings and open spaces in the built landscape greater than 0.5ha.	171 / 172	17.1 / 17.2	1 / 1

The naturalness classes given in brackets are higher alternatives used in the exploration of the effects of alternative classifications of habitat types shown in Figure 4.4
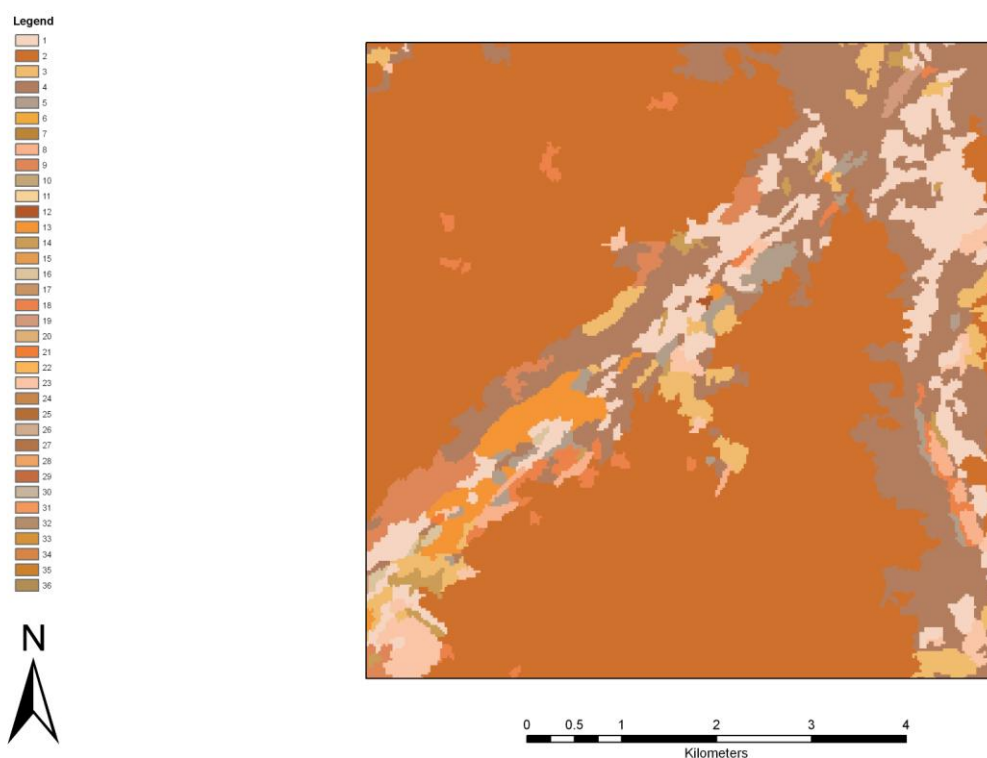
(4.5) LCS88 dataset is an alternative to using the LCM2000 and supplementary datasets. It has the advantage of being based on air photo interpretation at a scale of 1:25,000 to derive 126 land cover classes (as opposed to the 27 level 2 or 72 level 3 classes in the LCM2000 data) which are customised for the Scottish landscape and provide better resolution and a wider range of sub-classes in upland areas. The LCS88 is, however, nearly 20 years old and

so needs updating. Whereas it might be assumed that the land cover in many of the core wilder areas of the CNP will have changed little over the last two decades, there will have been significant changes around the edges due to land management. For example, changes will have occurred through forestry activities (planting and felling), agriculture, urbanisation and development of infrastructure. Land use management of upland areas (e.g. through muirburn and construction of hill tracks) and impacts on natural processes (e.g. woodland decline/regeneration or floodplain migration) will also have resulted in noticeable changes that will depart from the LCS88. The LCS88 therefore needs to be used with care. This is backed up through comparison with recent aerial imagery and base maps that shows some areas of significant departure from contemporary land use patterns. Of particular concern to the current work is the ability to distinguish between managed and non-managed heather moorland. Areas differentiated as containing "burning" or "no burning" for land management purposes appear to depart significantly from the pattern of muirburn as seen from aerial imagery. This is likely to be both a function of the age of the LCS88 data and they way it was interpreted from aerial photographs and the impossibility of including every patch of muirburn in the resulting polygon net. An example is shown in Figure 4.2. For this reason no differentiation is made in the analysis of perceived naturalness between "burned" and "non-burned" as the data from the LCS88 is considered too old to be reliable enough. For this reason, all areas of heather moorland from the LCM2000 are placed into naturalness class 4 as it is safest to assume that some level of management either through burning or drainage may be present or have been carried out in the past. Further research needs to be carried out into ways in which muirburn can be incorporated into the perceived naturalness attribute map (see section 6.1).

(4.6)   A similar difficulty occurs with distinguishing degrees of management in the improved grassland classes represented in the LCM2000 data. Classes 6.1 and 7.1 in the LCM2000 data mostly refer to improved grassland in the straths, but also appear as small enclaves of improved grassland in the hills such as in the Lairig Ghru and elsewhere. Classifying improved grassland with a naturalness of 3 is an accurate representation of its naturalness in the straths but is perhaps not the best description to grassland in the hills. Again, further research needs to be undertaken into how levels of grassland management can be incorporated into the perceived naturalness map.

Legend

LCS88

DOMTEXT

- Blanket bog/peatland veg.: erosion no trees
- Blanket bog/peatland veg.: no erosion no trees
- Cliffs (area)
- Coniferous (plantation - area)
- Dry heather moor: no rock burning no trees
- Dry heather moor: no rock no burning no trees
- Dry heather moor: no rock no burning trees
- Dry heather moor: rock no burning no trees
- Montane veg.: undiff. montane non-rocky
- Montane veg.: undiff. montane rocky
- Smooth grass/rushes: no rock no trees
- Undif. Nardus/Molinia: no rock no trees
- Undif. heather moor: no rock burning no trees
- Undif. heather moor: no rock no burning no trees
- Undiff. broadleaf (area)
- Undiff. mixed woodland (area)
- Undiff. smooth grass.: no rock no trees
- Undiff. smooth grass.: rock no trees
- Water (area)

N

(a)

Legend

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

N

(b)

Figure 4.1 Example land cover datasets
(a) Land Cover of Scotland 88 and (b) Land Cover Map 2000
Copyright Macaulay Institute and Centre for Ecology and Hydrology

27

Legend

- LCS88 sub-dominant no burning
- LCS88 dominant no burning
- LCS88 dominant with burning
- LCS88 sub-dominant with burning
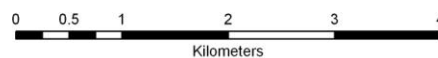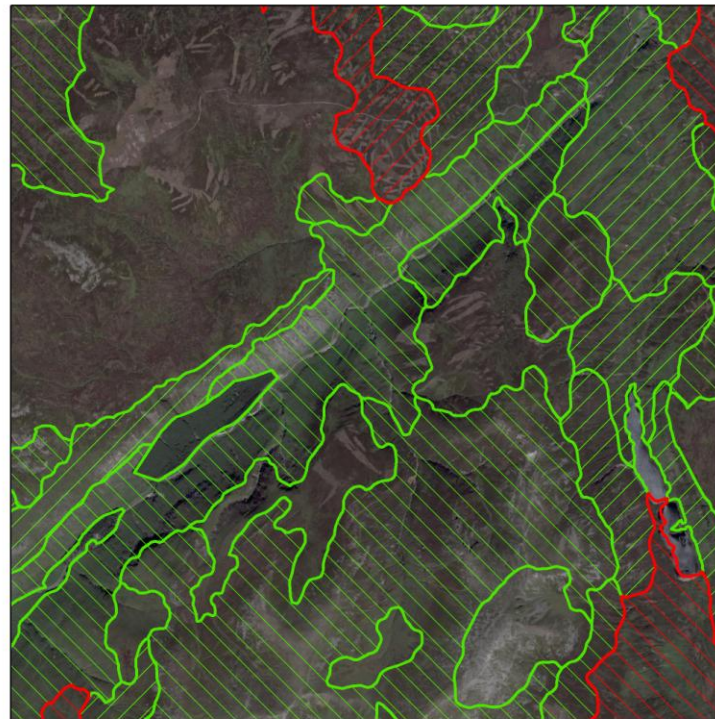
**Figure 4.2** Problems in extracting muirburn from land cover data
Copyright Macaulay Institute

4.1.2 Method

(4.7)   A combination of the LCM2000, LCS88 and Highlands Birchwoods Woodland Inventory data is used to create a composite land cover map at a nominal resolution of 25m which is then reclassified into 5 naturalness classes shown in Table 4.1. To account for the influence that the pattern of land cover in the area immediately adjacent to the target location has upon perceived naturalness of a certain grid cell the following method was applied to each location using a 250m radius neighbourhood filter:

> A separate map layer is created for each the five naturalness classes shown in Table 4.1 where a value of 1 is given to cells containing land cover of that naturalness score and a zero for the rest of the cells. These five layers are then used to calculate the percentage area each naturalness class occupies with a 250m radius of the target cell. These percentage areas are then multiplied by their naturalness score and summed. This value is then assigned to the target cell to represent the overall naturalness score for that location. Edge effects are avoided by calculating perceived naturalness up to 15km outside the CNP boundary and clipping the resulting data using the park boundary for use in subsequent analysis.

The resulting attribute map is shown in Figure 4.3 below.
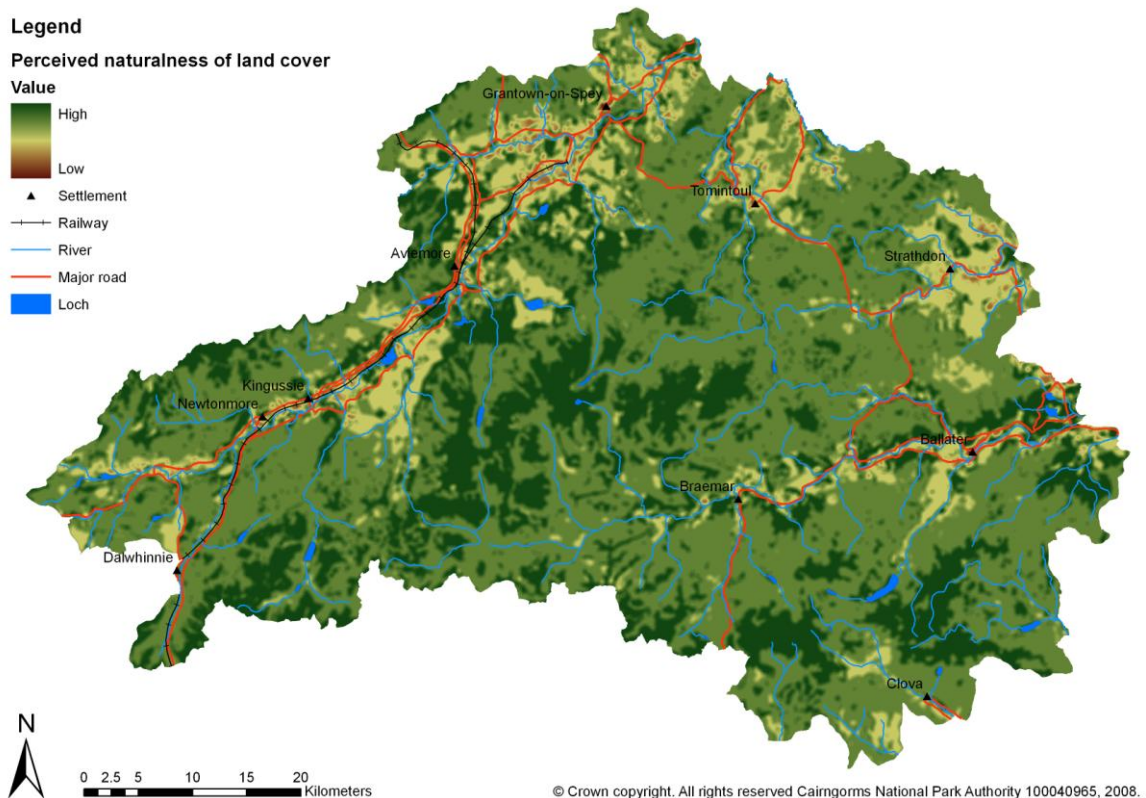
Figure 4.3 Perceived naturalness of land cover

4.1.3 Caveats and assumptions

(4.8)   The LCM2000 data is known to suffer from misclassification errors at a local scale on a cell-by-cell basis. This is described by Fuller et al. (2002). However, the dataset is considered here to be the best available basis for developing indicators of naturalness for landscape scale studies. The reclassification of the LCM2000 level 2 classes into 5 naturalness classes from natural/semi-natural to urban is based on the subjective reading of the class descriptions given by the CEH (Fuller et al., 2002). There will be differing levels of naturalness within LCM2000 land cover classes due to differing levels of management (e.g. presence of muirburn on heather moorland as described above in section 4.1.1) or topological relationships with other land classes (e.g. small patches of natural/semi-natural vegetation surrounded by intensively managed land) that are not accounted for within the data descriptions. These are incorporated within the perceived naturalness map through the inclusion of additional information from the LCS88 and Highland Birchwoods Woodland Inventory wherever possible as described in Table 4.1. The perceived naturalness map used here is quite generalised and contains various anomalies, but is felt to adequately represent this attribute at the landscape scale. An alternative interpretation is to consider that all areas

classified as heather moorland in the LCM2000 are perceived as natural by most casual observers and reclassify these with a naturalness class of 5. This is shown in Figure 4.4.
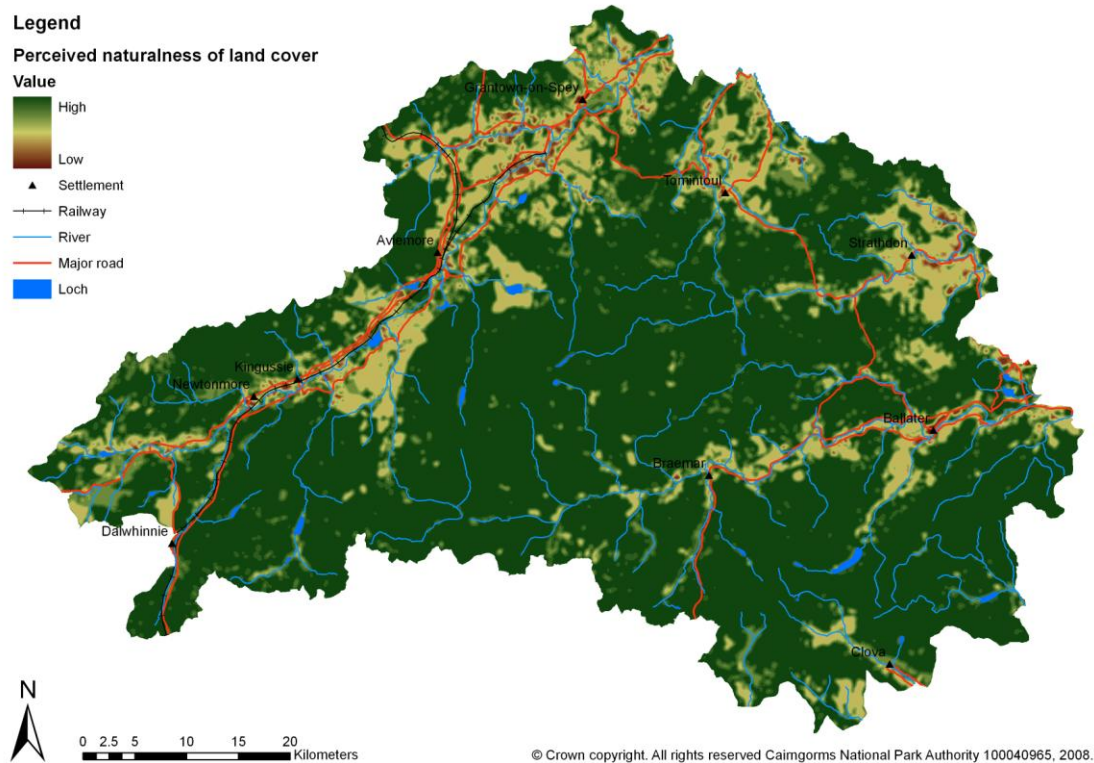
Figure 4.4 Alternative perceived naturalness (with heather moorland as class 5)

4.2 Absence of modern artefacts

(4.9)   Absence of modern human artefacts is considered here to refer to the lack of obvious artificial forms or structures within the visible landscape, including roads, vehicle tracks, railways, pylons, hard-edged plantation forestry, buildings and other built structures. The choice of which human features to include here is driven largely by what is understood to act as a wild land detractor based on SNH wild land policy (SNH, 2002), relevant sections of the perception survey and what data is available. Previous work on the effects of human artefacts on perceptions of wildness carried out at national to global scales has tended to focus on simple distance measures (Lesslie, 1993; Carver, 1996; Sanderson et al., 2002). More recent work has used measures of visibility of human artefacts in 3D landscapes described using digital terrain models (Fritz et al., 2000; Carver and Wrightham, 2003). This is feasible at the landscape scale utilising viewshed algorithms and land cover datasets to calculate the area from which a given artefact can be seen[4]. Work by Carver (2005 and

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[4] Viewshed algorithms are used to calculate where a particular feature, say building or mast, can be seen from by a person standing anywhere in the landscape using digital terrain models. These algorithms calculate line-of-

2007) for the North Pennine and Nidderdale AONBs has utilised cumulative and distance weighted viewshed algorithms to give a more accurate impression of the spatial pattern of the impacts of visible human artefacts on peoples' perceptions of wildness in guiding decisions about suitable areas for regeneration of native woodland. Terrain 'clutter' (i.e. intervening land cover that may shield artefacts from view) are included using terrain offsets calculated from a reclassification of the LCM2000 data into vertical heights which are then added to the terrain surface. A similar approach to that used for the North Pennine and Nidderdale AONBs is adopted here, based on inputs from the perception study about which artefacts are deemed to have an impact on wildness, together with more detailed terrain data and a digital surface model (DSM) from NextMap™ and a novel and rapid viewshed assessment method developed for the project.

4.2.1 Data sources

(4.10)   Visibility analysis and viewshed calculations rely on the ability to calculate 'line-of-sight' from one point on a terrain surface to another. It has been shown that the accuracy of viewsheds produced in GIS is strongly dependent on the accuracy of the terrain model used and the inclusion of intervening features (buildings, woodland, etc.) or 'terrain clutter' in the analysis (Fisher, 1993). The terrain data used here is the NextMap™ 5m resolution digital surface model (DSM) and derived digital elevation model (DEM). This data is derived from airborne RADAR imagery and is accurate to with ±1m. The DSM data provides the height of the surface detected, including the height of buildings, woodland, hedges, etc., thus providing a terrain surface that includes 'terrain clutter' and so is ideal for highly accurate viewshed analyses. Subtracting the DEM from the DSM layer provides an indication of where these differences lie. The orthorectified RADAR imagery (ORI) is also provided and is useful for visualisation purposes.
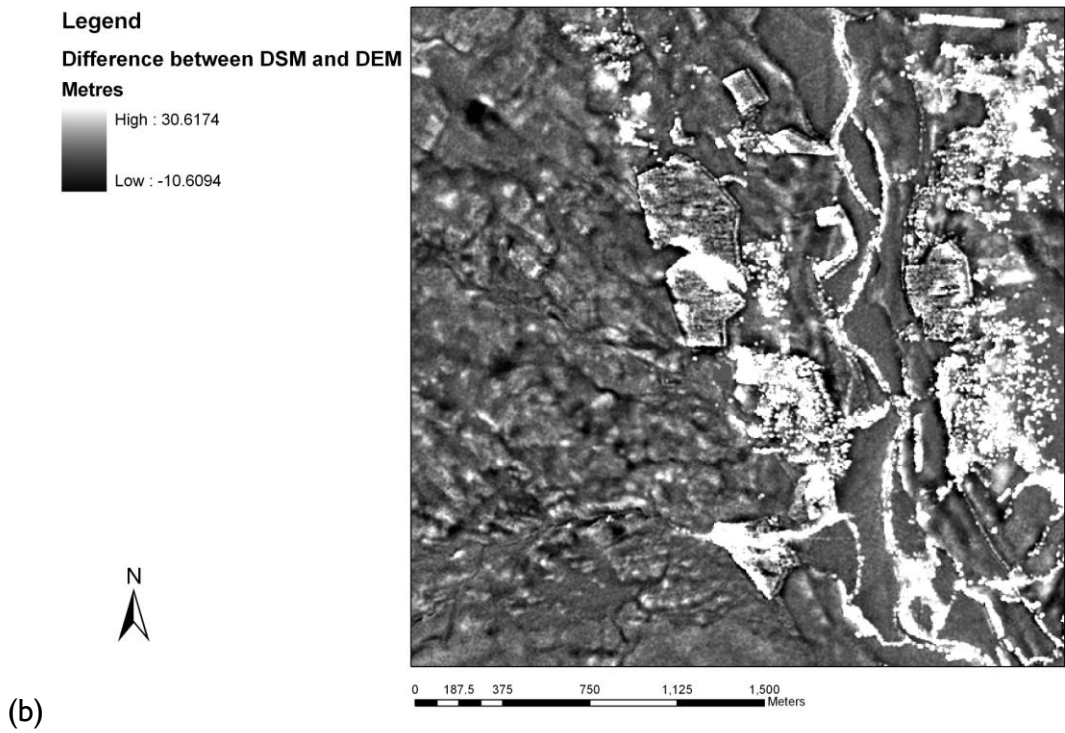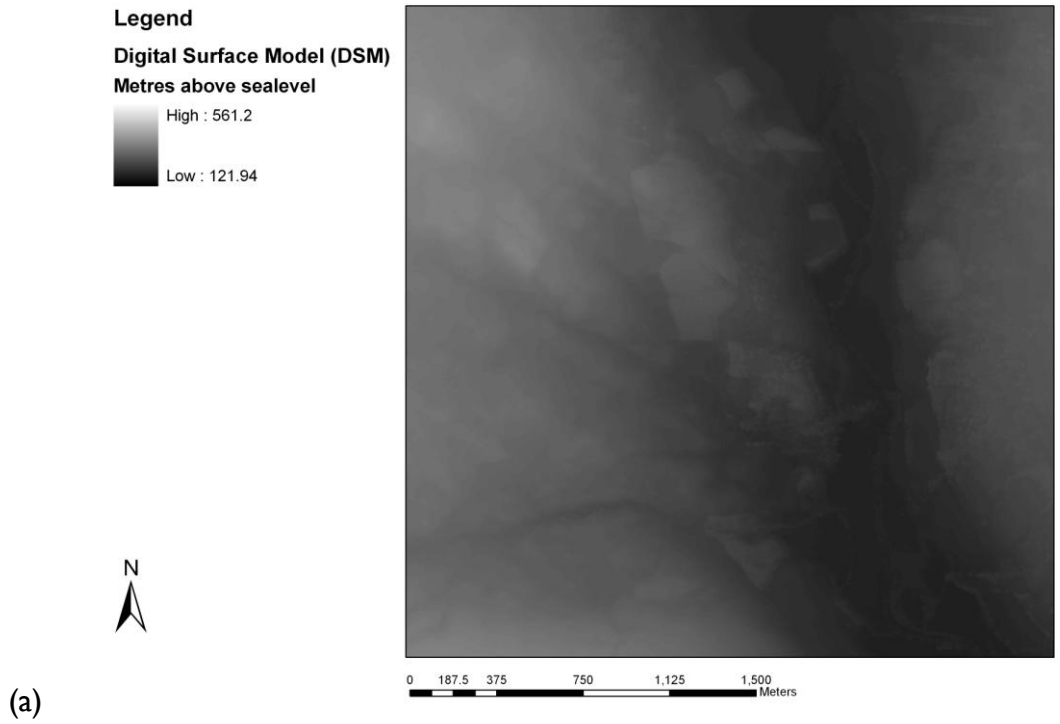
(4.11)   Modern human artefacts are extracted from the Ordnance Survey Mastermap™ baseline digital map data. These are divided into a number of discrete classes as follows:

- Railway lines, roads and tracks

- Buildings

- Pylons (including power line supports)

- Plantation forests

- Ski lifts

- Wind turbines

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sight between the viewer and the feature being observed, and in particular those areas where line-of-sight is interrupted by intervening higher ground.

Examples of the NextMap™ DSM/DEM, difference map and ORI are shown in Figure 4.5, while example features extracted from the OS Mastermap™ data to show modern human artefacts are shown in Figure 4.6.
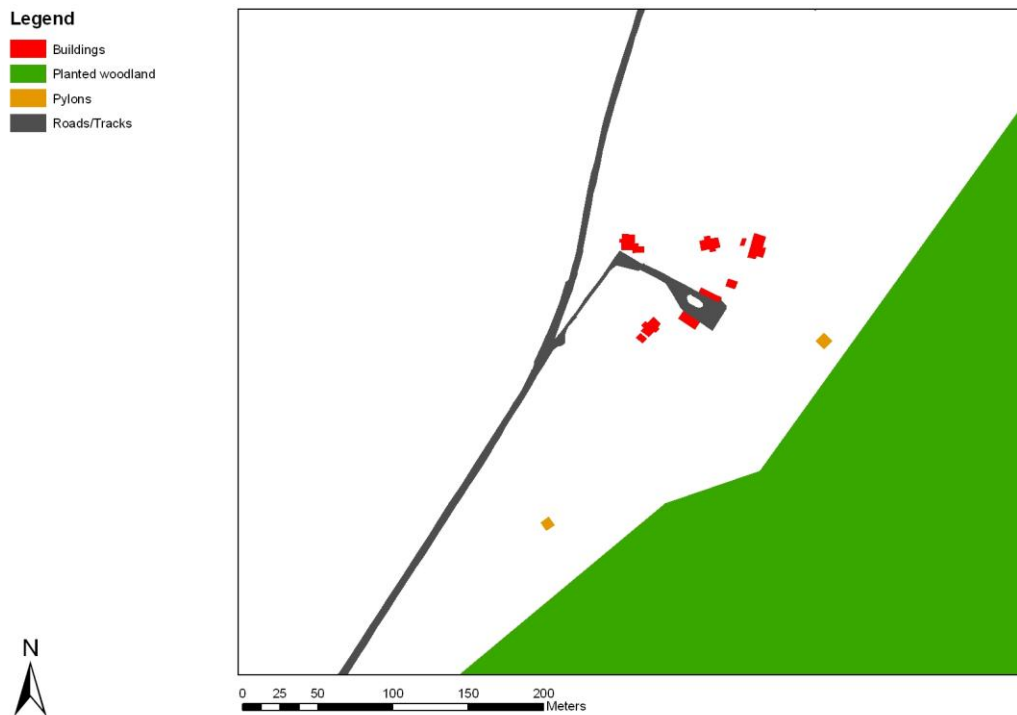

(a)

(b)

(c)
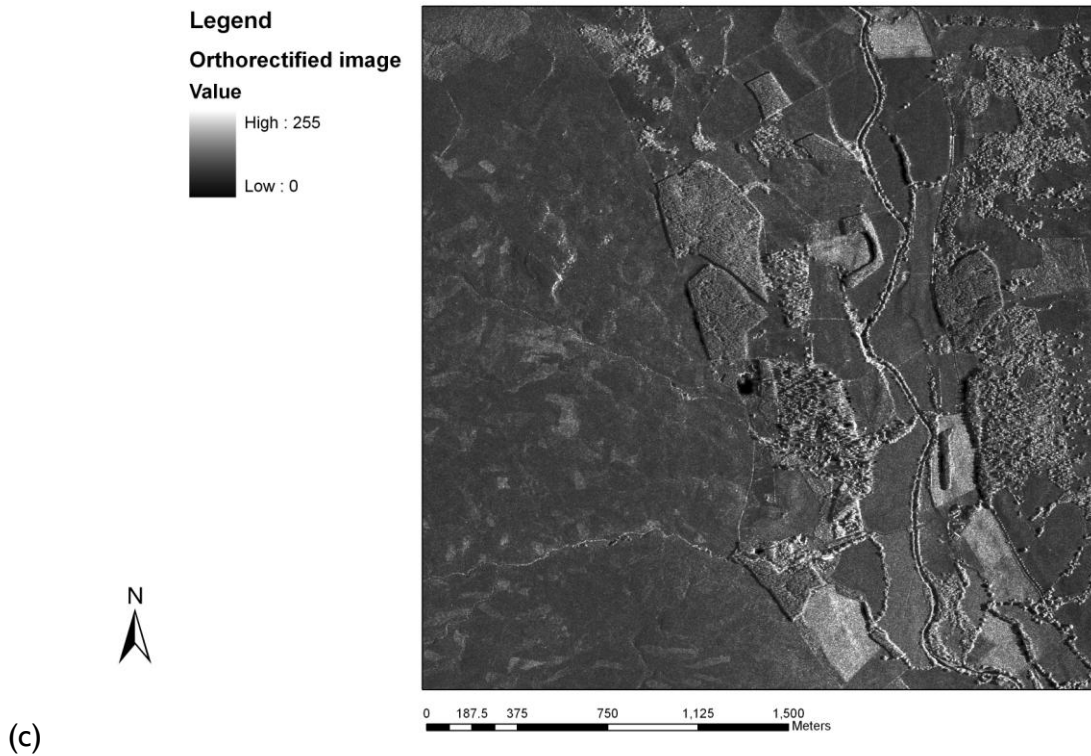
Figure 4.5 Example NextMap™ data

(a) DSM, (b) difference map, (c) Orthorectified image

Figure 4.6 Example modern human artefacts extracted from OS Mastermap™ data

4.2.2 Method

(4.13)   The use of visibility analyses in GIS that incorporate both a DSM and feature data showing the location and pattern of modern human artefacts allows the creation of cumulative viewsheds that can be weighted according to artefact type and distance. These can be combined and used to describe the attribute layer showing the relative effects associated with the presence and absence of human artefacts. Equal weights were applied for each artefact type based on discussions with the Steering Group. These are applied in the cumulative weighted viewshed methodology. Bishop's (2002) work on the determination of thresholds of visual impact, and the SNH report on "Visual Assessment of Windfarms: Best Practice" (SNH, 2002), were used to help define the limits of viewsheds and the distance decay function used.

(4.14)   Viewshed analyses such as these are extremely costly in terms of computer processing time. Detailed analyses can take weeks, months or even years to process depending on the number of human artefacts included in the database. It is usual to reduce processing times by generalising the artefact database by aggregating the number of human features in a cell of a given size. Work by Carver (2005 and 2007) used cell sizes of 500x500m and 250x250m, respectively. Recent work by Washtell (2007) has shown that it is possible to both dramatically decrease the processing times required for GIS-based viewshed analyses and improve their overall accuracy, through judicious use of a voxel-based landscape model and a highly optimised ray-casting algorithm.

(4.15)   While studies exist comparing the advantages of various optimised viewshed algorithms in their own right (Kaučič and Zalik, 2002) as of yet few of these seem to have percolated through into proprietary GIS packages. It is not clear whether the relative lack of sophistication of viewshed analyses sought within the Environmental Sciences (usually restricted to calculating the visibility of a handful of point features), owes itself to limitations in the pervading software, or whether the reverse is true. However, researchers in the domain have for some time been pushing the capabilities of the available tools - for example, by refining workflows for producing cumulative viewsheds (Wheatley, 1995).

(4.16)   The algorithm used herein, which is similar to those used in real-time rendering applications and in some computer games, was designed to perform hundreds of traditional point viewshed operations per second. By incorporating this into a custom-built software tool which has been designed to work directly with GIS data (see Figure 4.7), it is possible to estimate the visibility between every pair of cells in a high-resolution landscape model utilising only moderate computing resources. In this way, features of interest are no longer limited to a finite collection of points, but any set of features which can be described by a GIS data layer. This approach (called a 'viewshed transform') can be regarded as a maturation of traditional cumulative viewshed techniques. It was chosen for this project owing to the complexity of the surface and feature layers involved and the importance of applying methods that can realistically model the human perception of visual isolation in

complex terrain. Figure 4.7 shows the voxel viewshed transform software interface with both the feature layers loaded (Figure 4.7a) and with an example inverse square distance weighted viewshed for a single 10m high building (Figure 4.7b).

(4.17)   This approach is therefore adopted here utilising the NextMap™ DSM and feature data extracted from the OS Mastermap™ data. It is used here to:

- calculate a viewshed for every single human artefact;
- incorporate estimates of the proportional area of each artefact that is visible; and
- run separate viewshed calculations for each of the different categories of features listed above and weight these when combining them to create the absence of human artefacts attribute map.


(a)   (b)
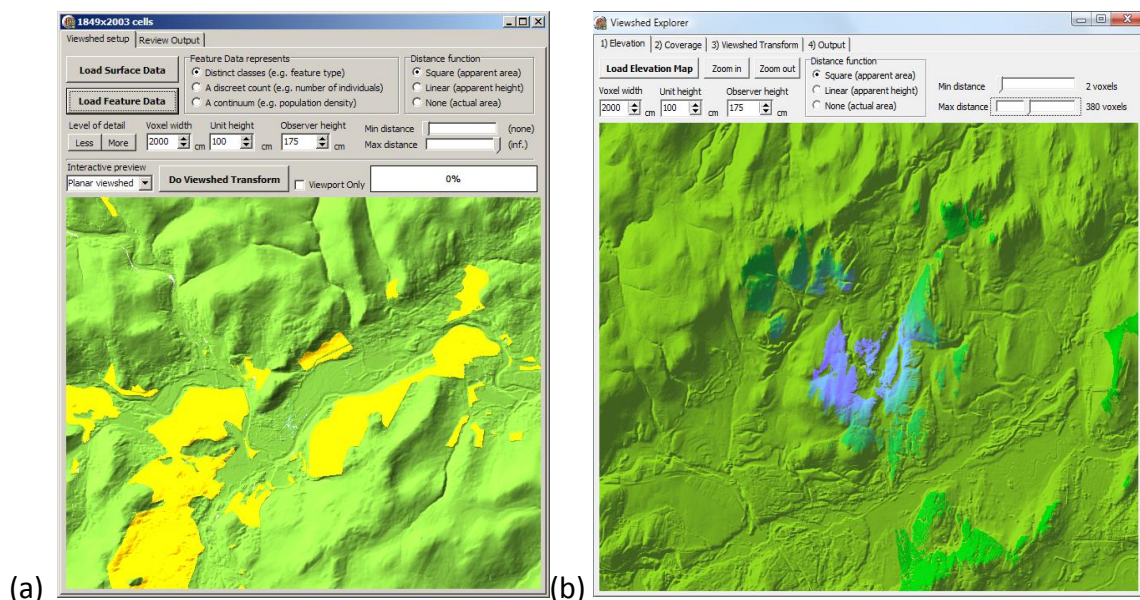
Figure 4.7 The Viewshed Tool interface, with (a) sample surface and plantation forest feature layer loaded (yellow), and (b) showing example inverse square distance weighting for a single 10m high building located in centre of map

(4.18)   An inverse square distance function is used in calculating the significance of visible cells. This function gives the relative area in the viewer's field of view that a cell or feature occupies; its relationship to perceived visual intrusion is borne out by the studies previously mentioned. This function is very sensitive to small changes in relative distance and in order that the results of these visibility calculations can be appreciated visually, a log scale is applied such that in the extreme case where a feature fills the observer's field of view, the maximum value is output, with each successive value thereafter representing an order of magnitude less visual intrusion. As even very small levels of visual intrusion are visible on such a scale, it also serves very well to highlight areas which are in total shadow from all visual features owing to the shape of the local landscape. Such areas of low or zero visual

intrusion from modern human artefacts comprise a significant portion of the core areas of the CNP. While occurring less frequently in the proximity of heavily modified areas (such as settlements and the straths), small pockets entirely bereft of visual intrusion can be found everywhere, owing to the general ruggedness of the terrain.

(4.19)   Example outputs from the voxel viewshed transform are given in Figure 4.8 and 4.9. The completed absence of modern human artefacts attribute map created from the combination of all output layers from the voxel viewshed transform is shown in Figure 4.10.

(a)

(b)
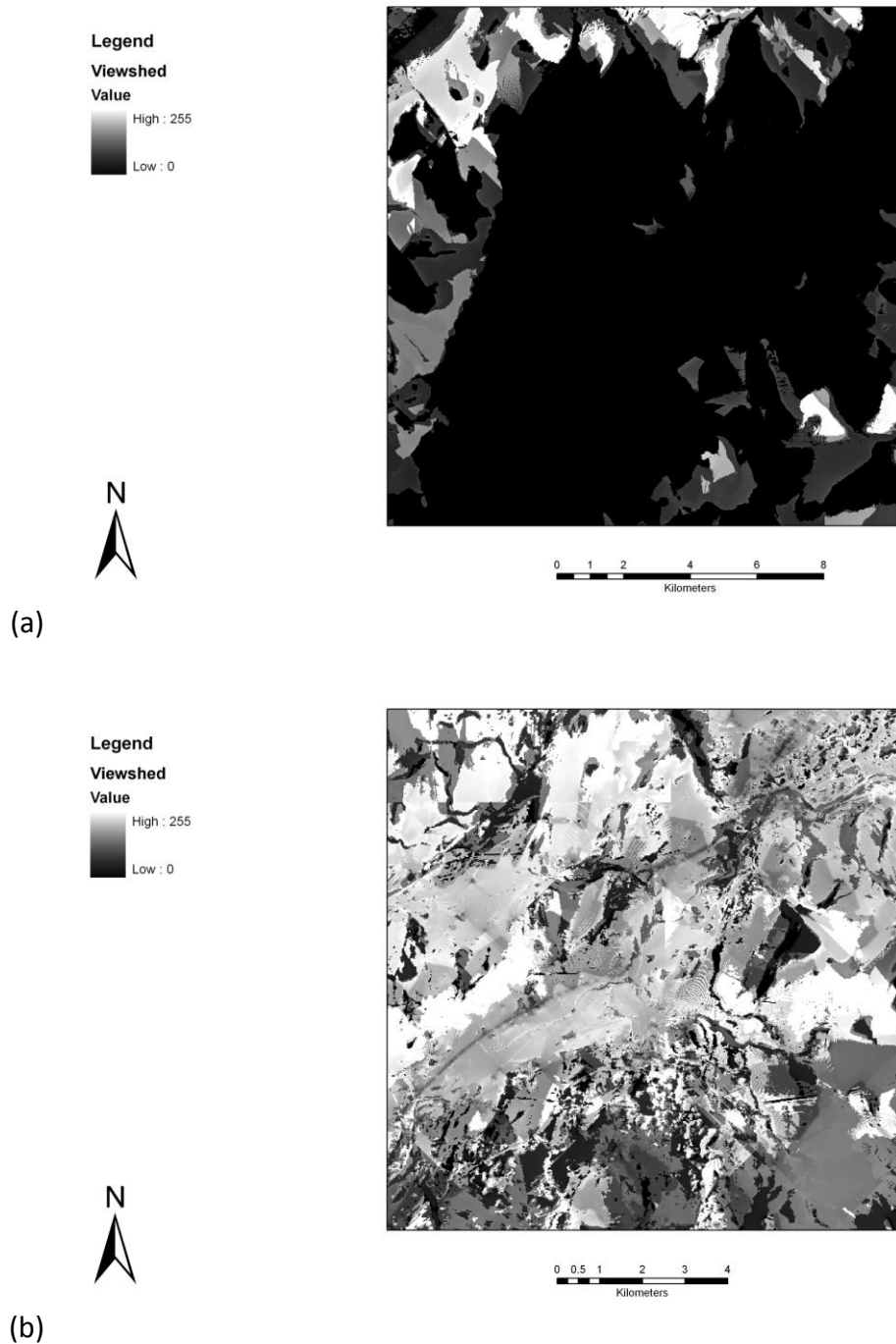
Figure 4.8 Example output showing detail in (a) core and (b) strath locations
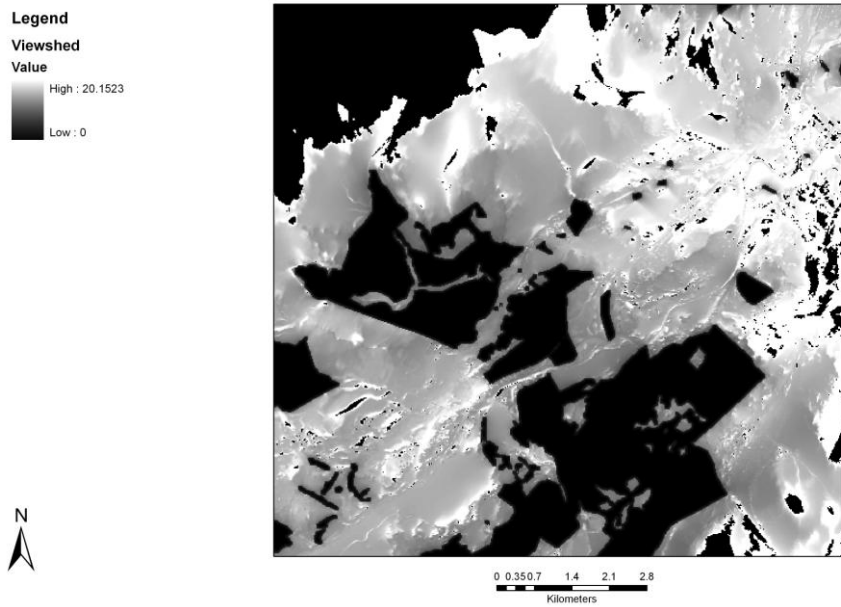
Figure 4.9 A completed viewshed analysis for a single tile of roads and tracks
(Greys indicate the varying magnitudes of visual intrusion while the features themselves appear in white and areas in black are totally shadowed from these features)
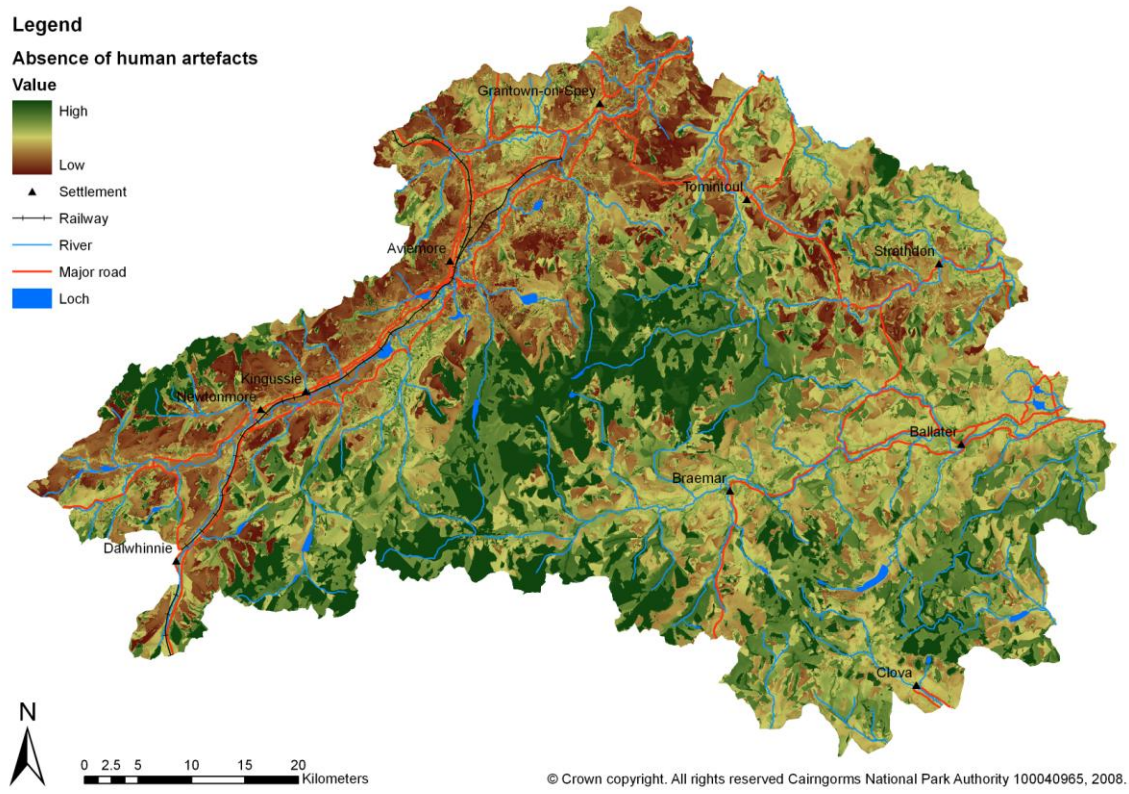
Figure 4.10 Absence of modern human artefacts

4.2.3 Caveats and assumptions

(4.20)   This is the first time this tool has been used on a project of this scale, and certain compromises and customisations are necessary in order to make the task manageable. These include:

- The cell resolution in this instance was limited to 20m;

- A "pessimistic" re-sampling was done to generate the 20m feature data in order to guarantee that features smaller than this area were included[5] with the result that the viewsheds produced may be viewed as a realistic representation of the visual impact of the artefacts present;

- The landscape was split into a number of overlapping tiles, such that they could be worked on in parallel by a cluster of desktop computers; and

- the maximum viewshed distance is 15km for all features except wind turbines, where this is increased to 35km in line with SNH guidelines.

An alternative attribute map for absence of modern human artefacts is shown in Figure 4.11 which also incorporates viewsheds from proposed as well as existing wind turbines. It is noted that the difference between this and the version in Figure 4.10 is only locally significant. These areas can be seen in the difference map shown in Figure 4.12.

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[5] Re-sampling of feature layers in GIS is normally carried out on a "majority class" basis wherein the value of a grid cell takes on the value of the largest feature by area that it contains. Using this rule, a 5x5m building in a 20x20m grid cell that was otherwise not classified as an artefact, say heather moor, would not be recorded on re-sampling. The "pessimistic" re-sampling used here operates on a presence/absence basis such that any grid cell containing a human artefact will be classified as such even though the actually area or footprint of the artefact may not cover the majority of the grid cell.
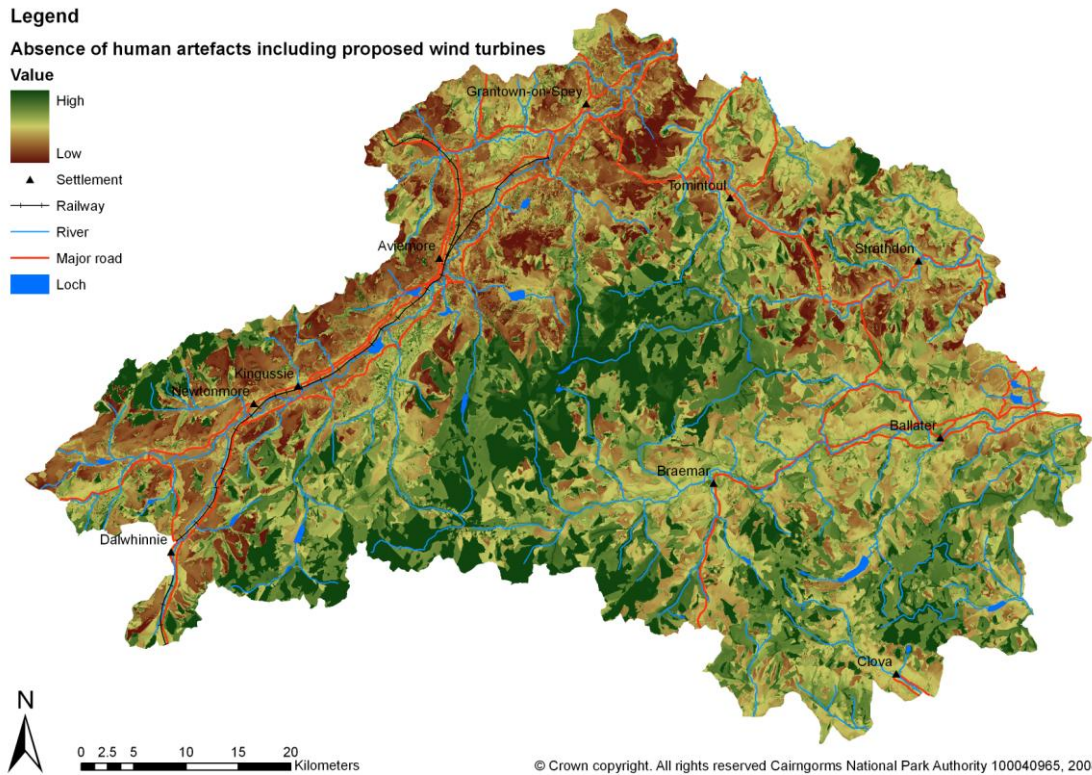
Figure 4.11 Absence of modern human artefacts including proposed wind turbines
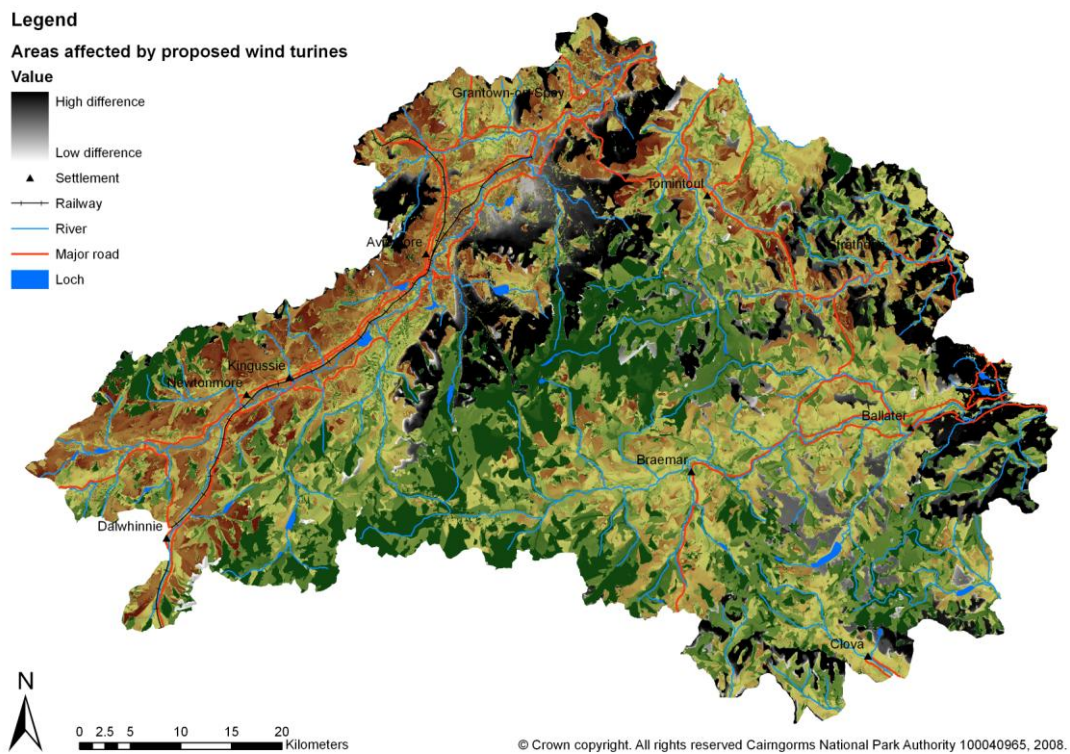
Figure 4.12 Areas affected by proposed wind turbines

4.3 Rugged and physically challenging nature of the terrain

(4.21)   The nature of the terrain within the CNP is varied and requires careful analysis to determine variations in its morphology (i.e. ruggedness) and challenging nature. Here, rugged and physically challenging terrain is taken to refer to the physical characteristics of the landscape including effects of steep and rough terrain and harsh weather conditions often found at higher altitudes. A digital terrain model is used to derive indices of terrain complexity that take slope (gradient), aspect and relative relief into account to create an attribute map describing the rugged and physically challenging nature of the terrain in the CNP. Weather also has an effect on perceptions of wildness, especially at higher altitudes where weather conditions can be extreme. For example, temperature, wind speed, precipitation and days with snow lying, all influence perceptions of wildness and tend to increase with altitude.

4.3.1 Data sources

(4.22)   The NextMap™ DEM is used here to represent the terrain surface of the CNP. Data from selected meteorological stations in the CNP area are used to incorporate a climatic element to the ruggedness/challenging terrain attribute map. Climate records from three weather stations; Braemar, Strathspey and Cairngorm summit are used to derive a simple relationship between altitude and temperature and wind speed.

4.3.2 Method

(4.23)   Ruggedness is calculated from the NextMap™ DEM as a simple index defined as the standard deviation (SD) of terrain curvature within a 250m radius of the target location. This is calculated as follows:

> Using the CURVATURE function in ArcGIS a grid is generated with values representing the amount of convex and/or concave curvature of the surface in both plan form and profile. Areas where curvature changes frequently are identified because they are deemed to represent rapidly changing terrain and hence ruggedness. This is achieved by applying a FOCALSTD function to the curvature surface to calculate the standard deviation of curvature values over a 250m radius circle.

(4.24)   The influence of climate on the physically challenging nature of an area is investigated by looking at temperature and wind speed data for various altitudes within the Cairngorm. Higher elevations show a significant increase in wind speed and drop in temperature compared to readings taken at lower elevations. To account for this the altitude data from the DEM is combined with the standard deviation of terrain curvature layer in the following linear sum:
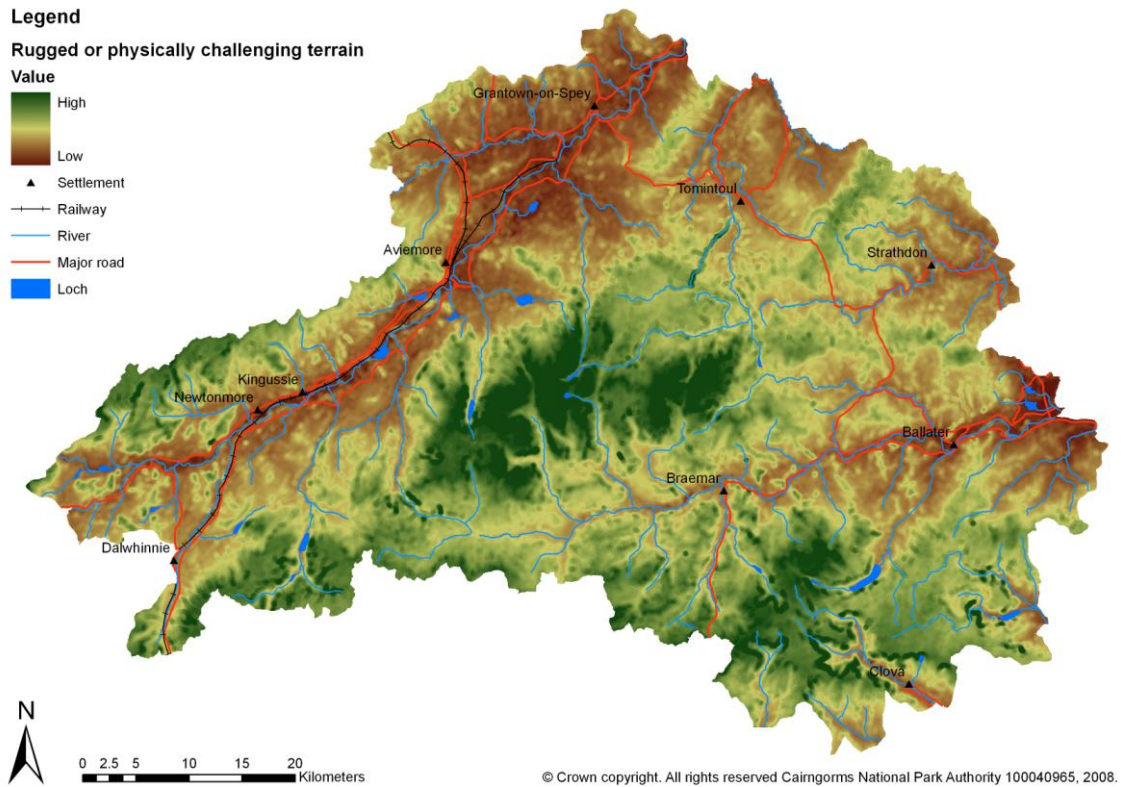
Rugged and challenging nature of the terrain = DEM + 2 (SD of curvature)

Figure 4.13 provides examples of how altitude and curvature vary within the CNP, while Figure 4.14 shows the completed ruggedness and challenging nature of the terrain attribute map.

(a)

(b)
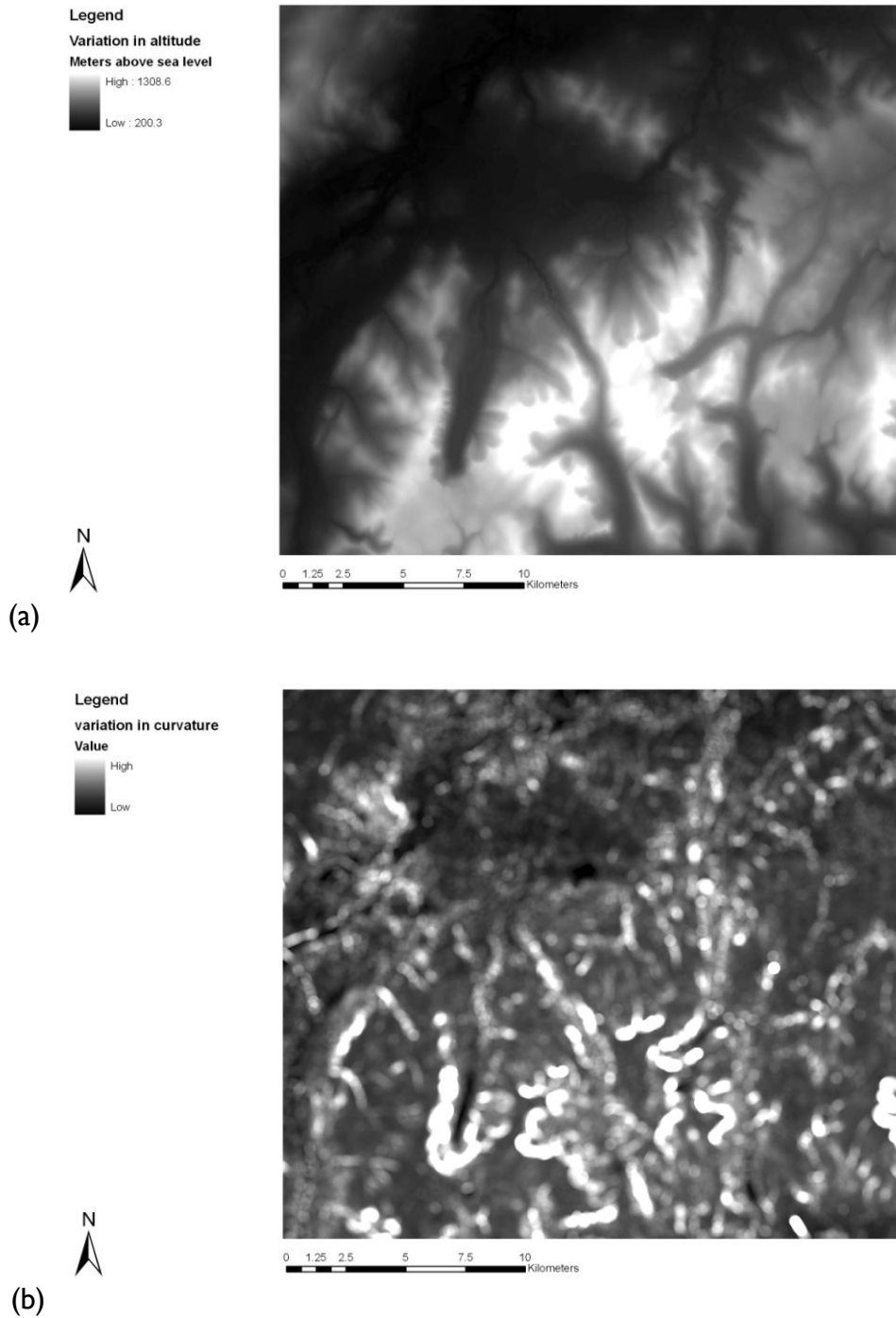
Figure 4.13 Variation in altitude (a) and curvature (b) in the central Cairngorms

Copyright Ordnance Survey

Figure 4.14 Rugged and challenging nature of the terrain

4.3.3 Caveats and assumptions

(4.25)   It is understood that there are many different ways of looking at and measuring ruggedness or roughness of a terrain surface. Other methods considered included fractal complexity[6], combinations of slope and aspect and statistical indices derived from these. As with the perceived naturalness map, a radius of 250m is used to estimate ruggedness within a fixed neighbourhood around the target location. This is used to spatially limit the ruggedness index to the immediate vicinity of the observer without taking into account what terrain is visible from a target location and how rugged it looks. This could be achieved using the voxel viewshed transform described in section 4.2.

(4.26)   With a limited number of climate stations available within the CNP area it is only possible to define a very simple, linear relationship between altitude and climatic conditions affecting the challenging nature of the terrain. With two climate stations at roughly the same low altitude (Braemar and Strathspey) and one at high altitude (Cairngorm summit) it is only possible to define a straight line relationship. This is applied at half the weight of the

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[6] Fractal complexity refers to the degree to which an object can be divided into separate objects each of which is similar to the original. For example, a tree can be split into a series of branches each of which may resemble the original tree. These branches can then be divided themselves into twigs, each of which again may resemble the original tree and its branches.

curvature index as shown above in section 4.3.2. This relationship could be improved with better climate data for the area.

4.4 Remoteness

"Distance, 10 miles; total climb, 6,300 feet; time, six and a half hours (including short halts). This tallies exactly with a simple formula, that may be found useful in estimating what time men in fair condition should allow for easy expeditions, namely, an hour for every three miles on the map, with an additional hour for every 2,000 feet of ascent." Naismith (1892)

(4.27)   Given the varied and challenging nature of the terrain found within the CNP it is essential to include terrain as a principal variable governing remoteness within the park. Remoteness is mapped in the CNP based on a GIS implementation of Naismith's Rule using detailed terrain and land cover information to estimate the time required to walk from the nearest road or track. Maps showing remoteness from public roads and hill tracks are included in the SNH policy document "Wildness in Scotland's Countryside" (SNH, 2002). These are based on linear distance from the nearest public road or hill track taking barrier features such as lochs and reservoirs into account. Work by Carver and Fritz (1999) has developed anisotropic measures of remoteness based on a GIS implementation of Naismith's Rule incorporating Langmuir's corrections. This model assumes a person can walk at a speed of 5km/hr over flat terrain and adds a time penalty of 30mins for every 300m of ascent and 10mins for every 300m of descent for slopes greater than 12 degrees. When descending slopes between 5 and 12 degrees a time bonus of 10mins is subtracted for every 300metres of descent. Slopes between 0 and 5 degrees are assumed to be flat. This has been subsequently applied in modelling the historic trends in wild lands in the central Highlands (Carver and Wrightham, 2003) and wild land quality in the North Pennines AONB (Carver, 2005). This anisotropic[7] approach to modelling remoteness is based on the relative time taken to walk into a roadless area from the nearest point of mechanised access taking the effects of distance, relative slope, ground cover and barrier features, such as open water and very steep ground, into account. This assumes remoteness to be directly proportional to the time taken to walk from A to B across varied terrain and is therefore analogous to the concept of "the long walk in" which is a long established principle in Scottish mountaineering. The implementation of this model of remoteness requires a detailed terrain model and ancillary data layers that are used to modify walking speeds according to ground cover (e.g. Naismith's 3 miles per hour on the map can be reduced to 2 miles per hour or less when walking across open heather moor), and include

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[7] Anisotropic models do not assume equal ease of travel/movement in all direction, rather movement is either aided or restricted by other factors such as steepness of slope and the presence of impassable barriers such as lochs such that the cost of movement is not-directly proportional to horizontal distance. Isotropic models are much less realistic because they do assume equal ease of movement in all directions and therefore oversimplify the concept of remoteness in this context.

barrier features as "null" values which force a detour[8]. Comparisons of the remoteness maps produced here with visitor usage data could provide useful information on opportunities for solitude within the CNP.

4.4.1 Data sources

(4.28)   Calculating remoteness based on Naismith's Rule requires a range of data including a detailed terrain model, land cover data and information on the location of rivers, open water, roads, tracks and other access features. These are all sourced from datasets described in the previous sections on naturalness, human artefacts and ruggedness. The NextMap™ data is used for the DEM, the LCM2000 for the land cover data, and OS Mastermap™ for the road, track, open water and river data. Foot bridges, which are important access features, were digitised from OS 1:25,000 maps via heads-up[9] digitising from raster maps.

4.4.2 Method

(4.29)   Remoteness is calculated here using a GIS implementation of Naismith's Rule incorporating Langmuir's Correction. A macro program is written that implements this using the PATHDISTANCE function in ArcGIS. This estimates walking speeds based on relative horizontal and vertical moving angles across the terrain surface together with appropriate cost or weight factors incurred by crossing different land cover types and the effects of barrier features such as lochs and very steep ground. The theory and practical application of this model is described by Carver and Fritz (1999). The model is applied using the following conditions:

- *Source grid:* This is taken to be the public road network that provides vehicular access via private car.

- *Cost surface:* This is assumed to be 5km/h for all land cover types except heather and forest which is 3km/hr and bog which is 2km/hr. Fords across rivers were deemed to take 10mins to cross per 5m of river which equates to approx 0.03km/h. The roads and tracks data from the OS Mastermap™ data is used to amend the cost surface as having the least resistance to movement with a speed of 15km/hr where it is possible to use a mountain bike to gain more rapid access to the core areas. When hill tracks exceed 20 degrees of slope the speed of movement in the cost surface is reduced to 5km/hr to reflect walking speed where cyclists are likely to have to dismount and push.

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[8] NoData or null values in a raster grid contain no data and so are disregarded in most calculations unless the model explicitly references these. NoData values are useful in building access models in that they can be used to describe the locations of barrier features that cannot be crossed.

[9] Digitising directly onto a map on the computer screen using the mouse cursor.

- *Barriers to movement:* These are taken to include rivers that appear as polygons (i.e. showing both left and right banks) in the OS Mastermap™ data, slopes that are greater than 45 degrees from the horizontal and open water/lochs. A distinction is made between normal (low flow) and spate (high flow) conditions in regard to the usability of crossing points marked on maps as fords. Rivers crossed by any means, including bridge and fords, are assumed to be crossable at low flow conditions where the roads, tracks or footpaths are shown to cross, whereas those rivers described in the OS Mastermap™ data as polygons are assumed to be barrier features (i.e. not fordable) except via road or foot bridges during spate conditions.

4.4.3 Caveats and assumptions

(4.30)   Naismith's Rule and the model used to implement it here assumes a fit and healthy individual, and does not make any allowance for load carried, weather conditions (such as poor visibility and strong head winds) and navigational skills. The model does, however, take barrier features and conditions underfoot into account. Lakes and reservoirs are considered to be impassable on foot and are included as barrier features by coding these as NoData (null values) in the model inputs. This forces the model to seek a solution that involves walking around the obstacle. The model also uses a cost or friction surface that controls the walking speed according to the land cover or conditions underfoot. A speed of 5km/hr (1.389m/s) is assumed for most land cover types, while speeds of 3km/hr (0.833m/s) and 2km/hr (0.555m/s) are assumed for the 'dense shrub heath'/'forest' and 'bog' categories, respectively[10]. The angle at which the terrain is crossed (i.e. the horizontal and vertical relative moving angles[11]) is used to determine the relative slope and height lost/gained. These values are input into the model using a simple look up table as shown in Table 4.2. The road network, both within and outside the CNP boundary, is used as the access points from which to calculate remoteness of off-road areas. Where the boundary of the CNP is not defined by a road, the road network outwith the CNP is used so as to avoid any possible edge effects in the remoteness calculations. In considering the effects of rivers as barrier features, these are assumed crossable only at those points where roads, tracks or footpaths cross and only where there is a bridge under spate conditions. In practice the mapping was found to be incomplete, with missing footbridges identified through local knowledge and examination of 1:10,000 maps.
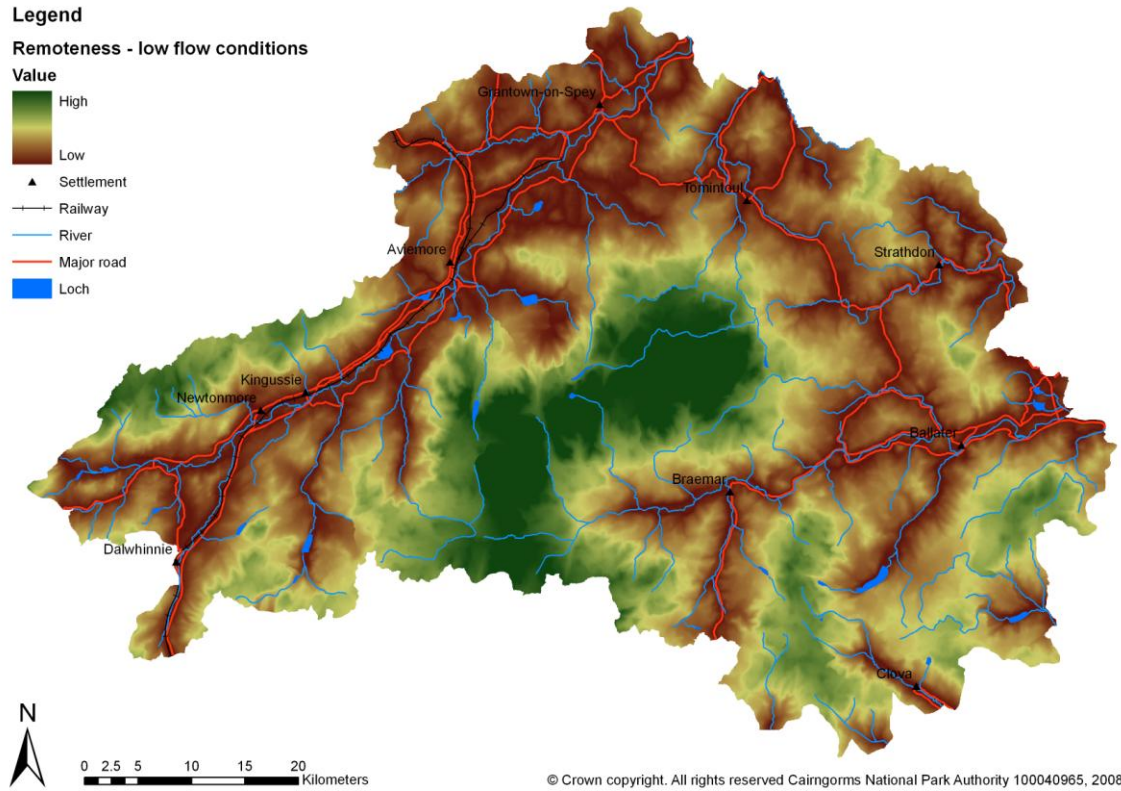
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[10] Lower walking speeds are included here based on discussion about the maximum likely speeds attainable across these two land cover types.

[11] Vertical and horizontal factors determine the difficulty of moving from one cell to another while accounting for the vertical or horizontal elements that may affect the movement, these include slope and aspect as they determine the relative angle of the slope in the direction it is crossed and hence the height gained or lost.
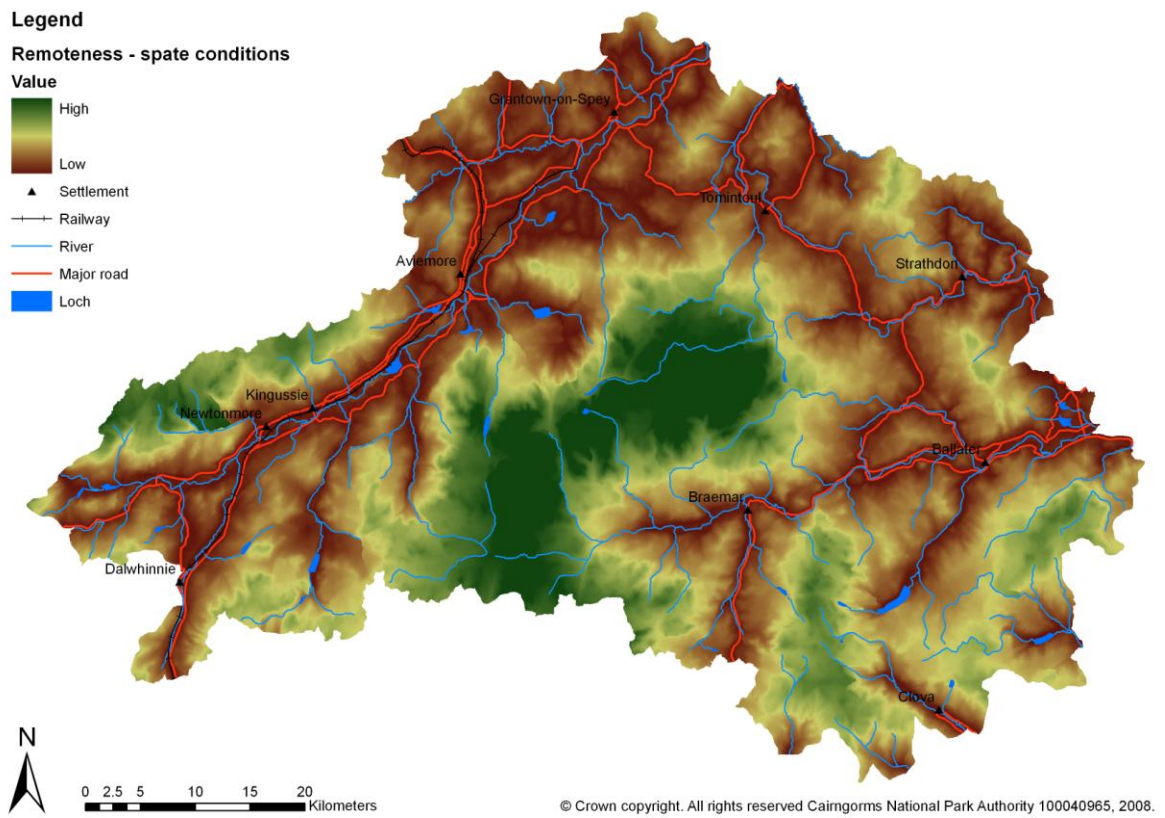
Table 4.2 Naismith's Rule expressed in the VRMA field

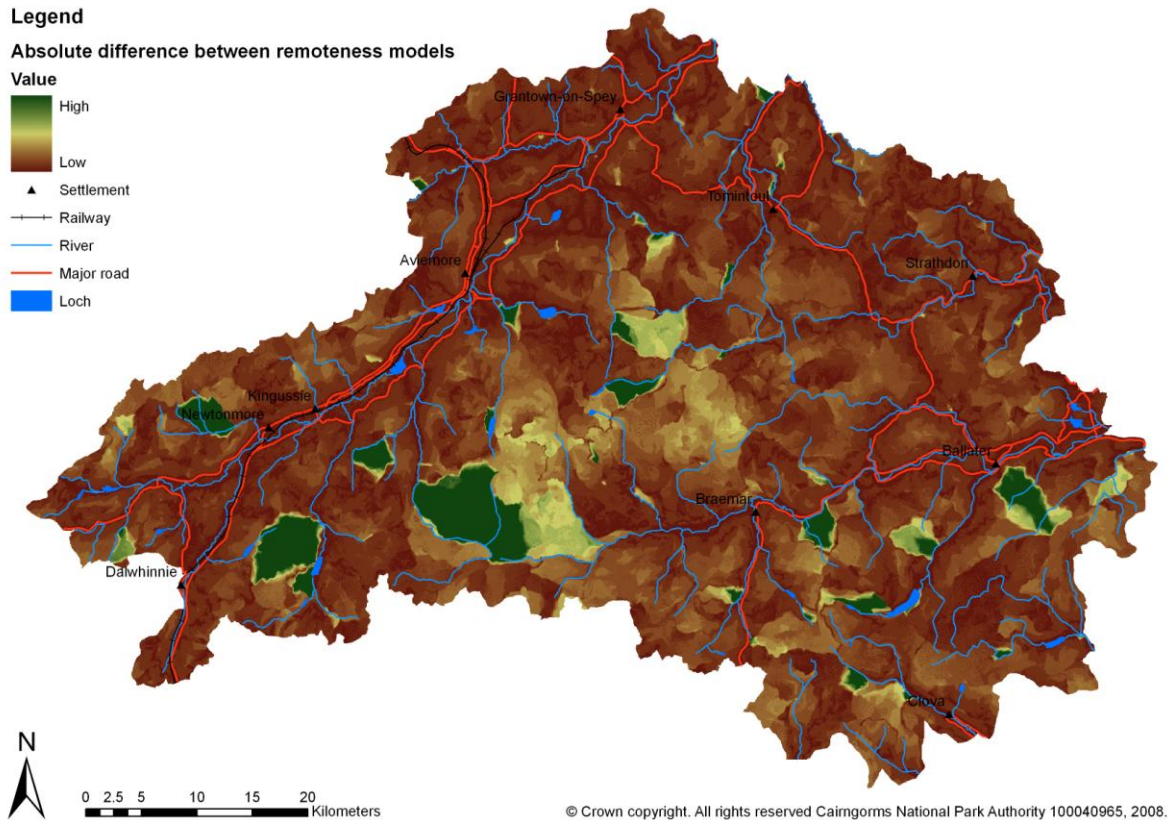| Vertical Relative Moving Angle (degrees)	Vertical Factor
-40	2.21
-30	1.83
-20	1.53
-12	0.69
-11	0.72
-10	0.75
-9	0.72
-8	0.8
-7	0.82
-6	0.85
-5	1.0
0	1.0
10	1.76
20	2.57
30	3.49
40	4.62

(4.31) Figure 4.15 shows remoteness in the CNP at low flow conditions, while Figure 4.16 shows remoteness in the CNP at high flow/spate conditions. Figure 4.17 is a simple residuals map showing the difference between Figures 4.15 and 4.16.

Legend

Remoteness - low flow conditions

Value
- High
- Low
- ▲ Settlement
- ┼─┼ Railway
- — River
- — Major road
- ▮ Loch

Grantown-on-Spey
Tomintoul
Aviemore
Strathdon
Kingussie
Newtonmore
Ballater
Braemar
Dalwhinnie
Clova

N

0 2.5 5   10   15   20
                              Kilometers

Figure 4.15 Remoteness under low flow conditions

Legend

Remoteness - spate conditions

Value
- High
- Low
- ▲ Settlement
- ┼─┼ Railway
- — River
- — Major road
- ▮ Loch

Grantown-on-Spey
Tomintoul
Aviemore
Strathdon
Kingussie
Newtonmore
Ballater
Braemar
Dalwhinnie
Clova

N

0 2.5 5   10   15   20
                              Kilometers

Figure 4.16 Remoteness under high flow conditions

Figure 4.17 Residuals map showing difference in remoteness between low and high flow conditions

4.5 Checks for autocorrelation

(4.32)   In any MCE model it is preferable that the input map layers are not highly spatially autocorrelated[12]. This is described in section 3. All input layers are cross correlated to check for similarity. The correlation matrix shown in Table 4.3 shows that there is only a very low correlation between any of the attribute maps used in this project.

(4.33)   As predicted in section 3, it is only the ruggedness and remoteness attributes which show any real degree of autocorrelation. This is to be expected as these attributes are both controlled by terrain variables. Even so, the degree of autocorrelation between ruggedness and remoteness is still only 0.73 and well within the limits normally required by MCE methods.

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[12] Spatial autocorrelation occurs when characteristics at a particular location or area appear to be correlated, either positively or negatively. This might result when whatever is causing the observation or value at one location also causes similar observations in nearby locations, or it might be the result of spatial causality where something at a given location directly influences it in nearby locations.

Table 4.3 Attribute map correlation matrix

|	Remoteness	Perceived naturalness	Ruggedness	Absence of artefacts
Remoteness	1	-	-	-
Perceived naturalness	0.4539	1	-	-
Ruggedness	0.7298	0.5323	1	-
Absence of artefacts	0.5063	0.3553	0.4787	1

4.6 Life cycle analysis

(4.34)   Future updates to a number of the data sources referenced in Appendix 6 will result in some of the attribute maps becoming out of date in due course. The LCM2000 is expected to be updated in the near future and as such changes will need to be made to the perceived naturalness attribute map. Updates to the OS Mastermap™ data are available from the OS on a regular basis and will include the addition or removal of buildings and the construction or remediation of vehicle tracks. These changes will need to be incorporated into the absence of modern human artefacts map using the voxel viewshed tool on a rolling basis, say every other year. Changes to access features within OS Mastermap™ data will also affect the remoteness attribute map requiring the remoteness model to be re-run as these changes occur. The rugged and physically challenging nature of the terrain attribute map is derived principally from the NextMap™ DEM data and so will not change over time meaning this attribute map will not require updating.

5. Results: Wildness in the Cairngorms National Park

(5.1)   The methodology described in section 3 is applied across the whole of the CNP at a base resolution of 25m using the attribute maps described in section 4. These are used together with weights derived from the perception study and in consultation with the Steering Group to produce wildness maps for the entire CNP area using the MCE/fuzzy methods described.

(5.2)   The map in Figure 5.1 shows the result from combining the four attribute maps using equal weights. This may be regarded as the baseline model against which alternatives may be compared. It is possible to argue that different people and/or stakeholder groups might wish to apply different weighting schemes that will affect the pattern of wildness shown in these maps. Example weighting schemes derived from the perception survey are applied here to illustrate this point.
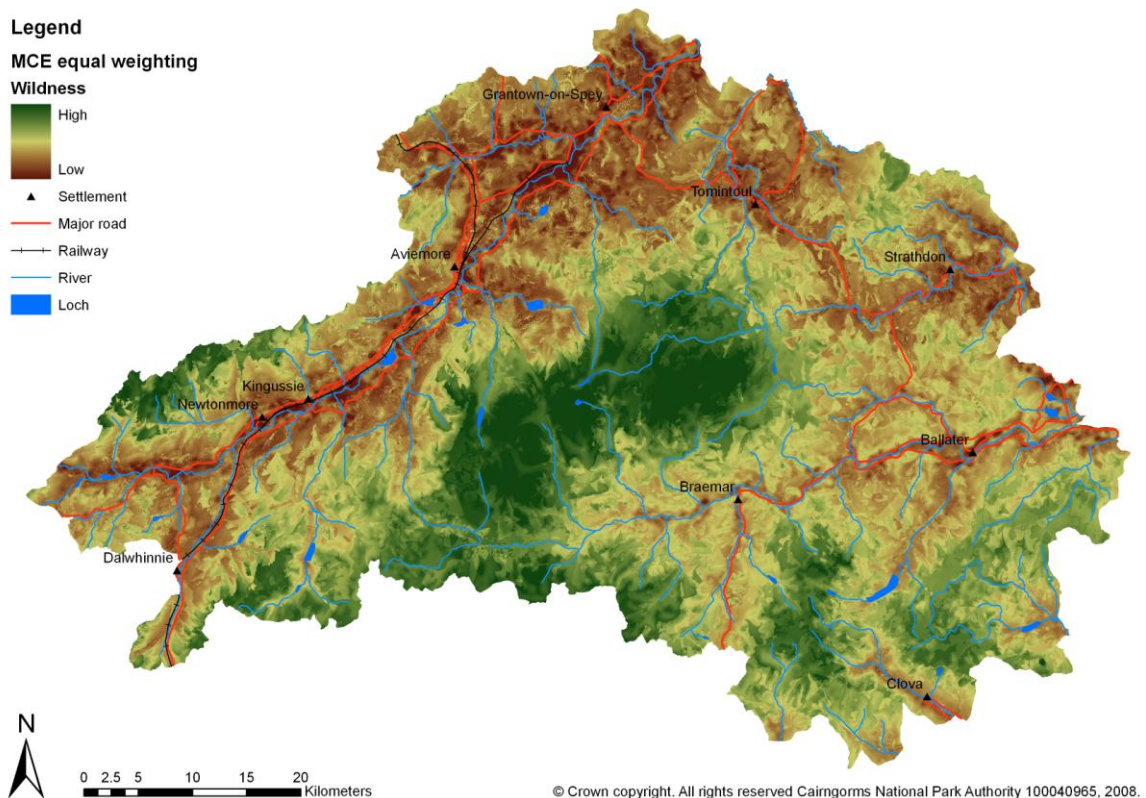
Figure 5.1 Equally weighted model

(5.3)   The maps shown in Figures 5.2 and 5.3 show the model results from applying two sets of weights derived from the perception survey as described in section 3.2 and Table

50

3.1. These two maps show the spatial pattern arising from subtle differences in the way that people living inside and outside the CNP perceive wildness. The weights used are as follows:

Table 5.1 Weights for the Scotland and CNP residents models

	Scottish residents	CNP residents
Perceived naturalness	0.48	0.20
Absence of artefacts	0.32	0.38
Remoteness	0.16	0.29
Ruggedness	0.04	0.13
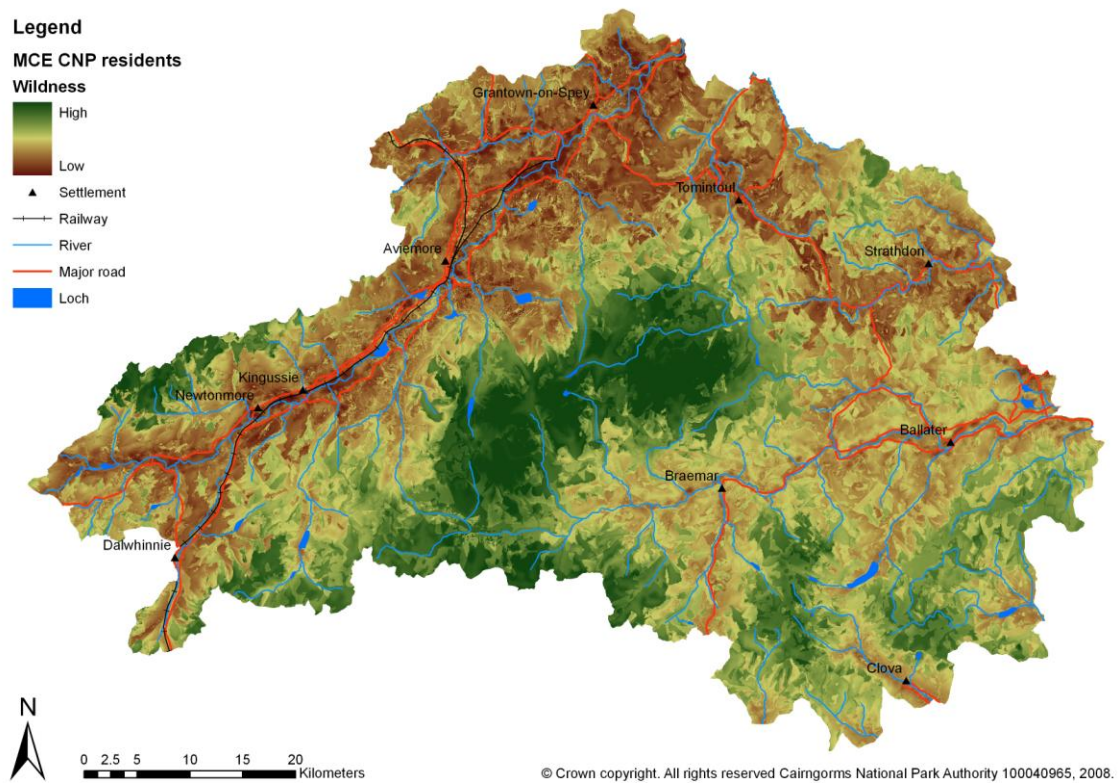
Figure 5.2 Weights from CNP residents group
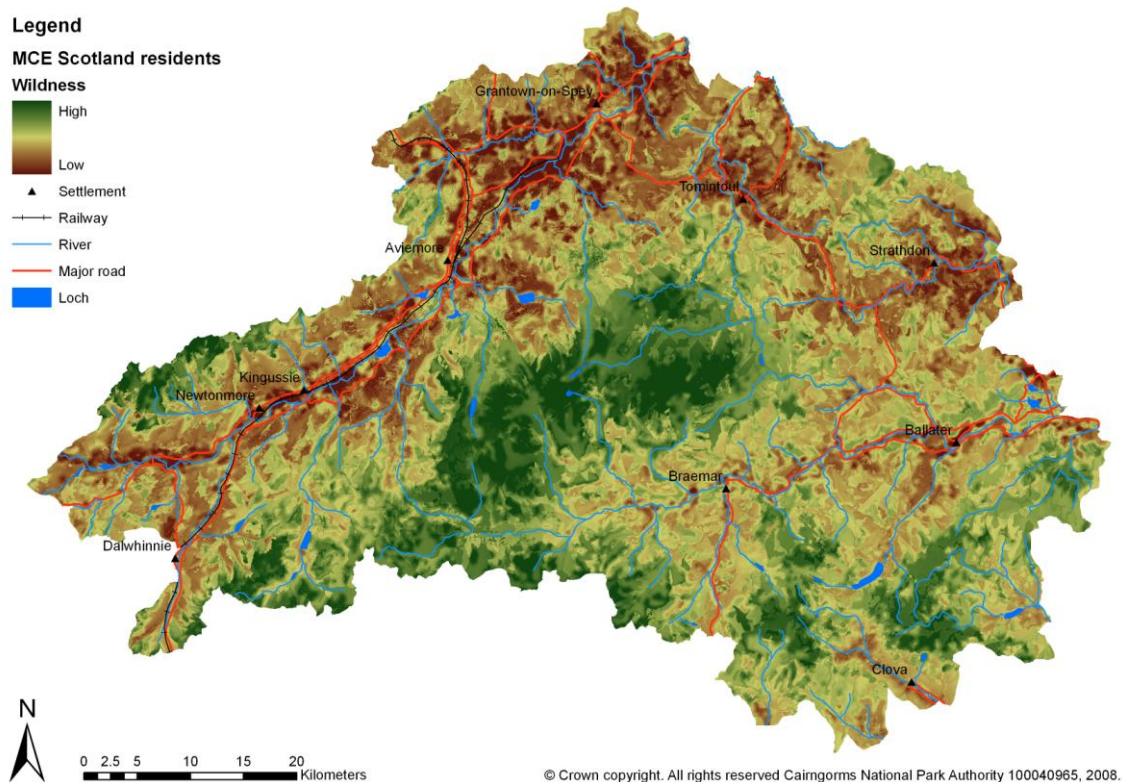
Figure 5.3 Weights from Scotland residents

(5.4)   The maps in Figures 5.4 and 5.5 show the results from applying alternative interpretations of the perceived naturalness and remoteness attribute maps. Figure 5.4 uses a perceived naturalness map that is based on the alternative assumption that all heather moorland is perceived as natural regardless of the possible presence of management practices such as muirburn and drainage (see section 4.1). Figure 5.5 uses an alternative remoteness map that assumes spate conditions with the resulting effect that the main rivers and streams are only crossable at bridges (see section 4.4). As with the different results shown in Figures 5.2 and 5.3 these alter the detail of the maps but it can be clearly seen that the overall pattern of wildness in the CNP remains largely the same. These can be compared with the initial equally weighted map in Figure 5.1.
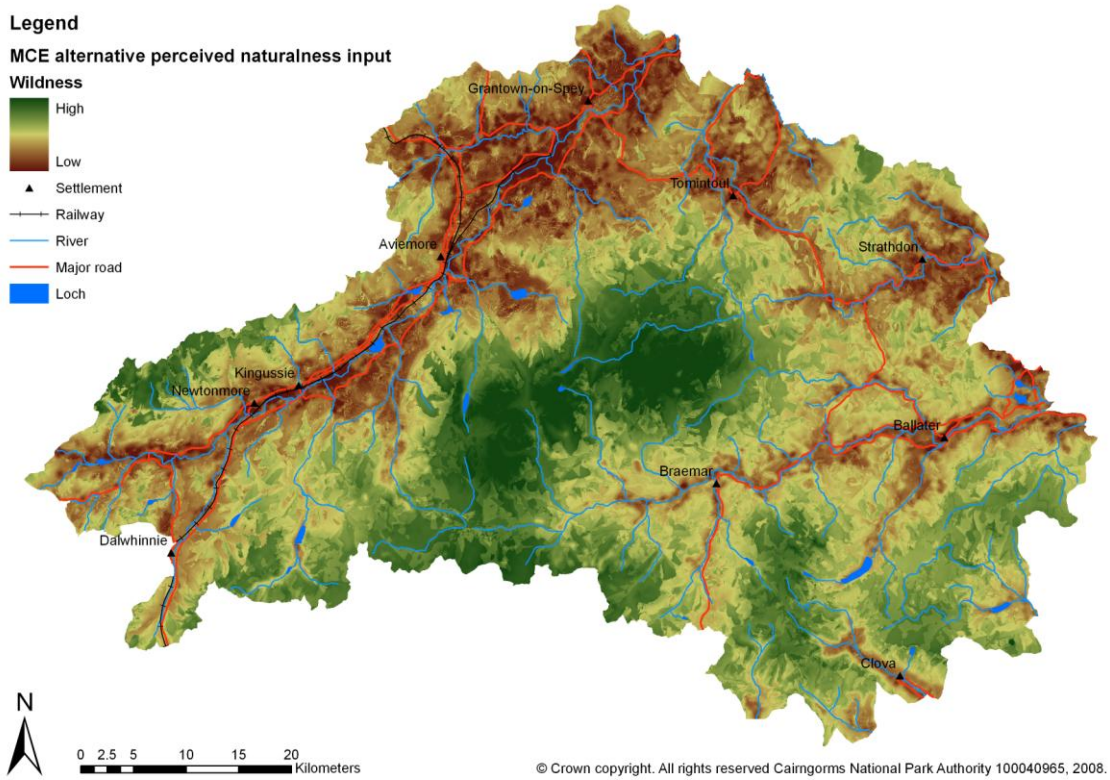
Figure 5.4 Equally weighted with alternative perceived naturalness map
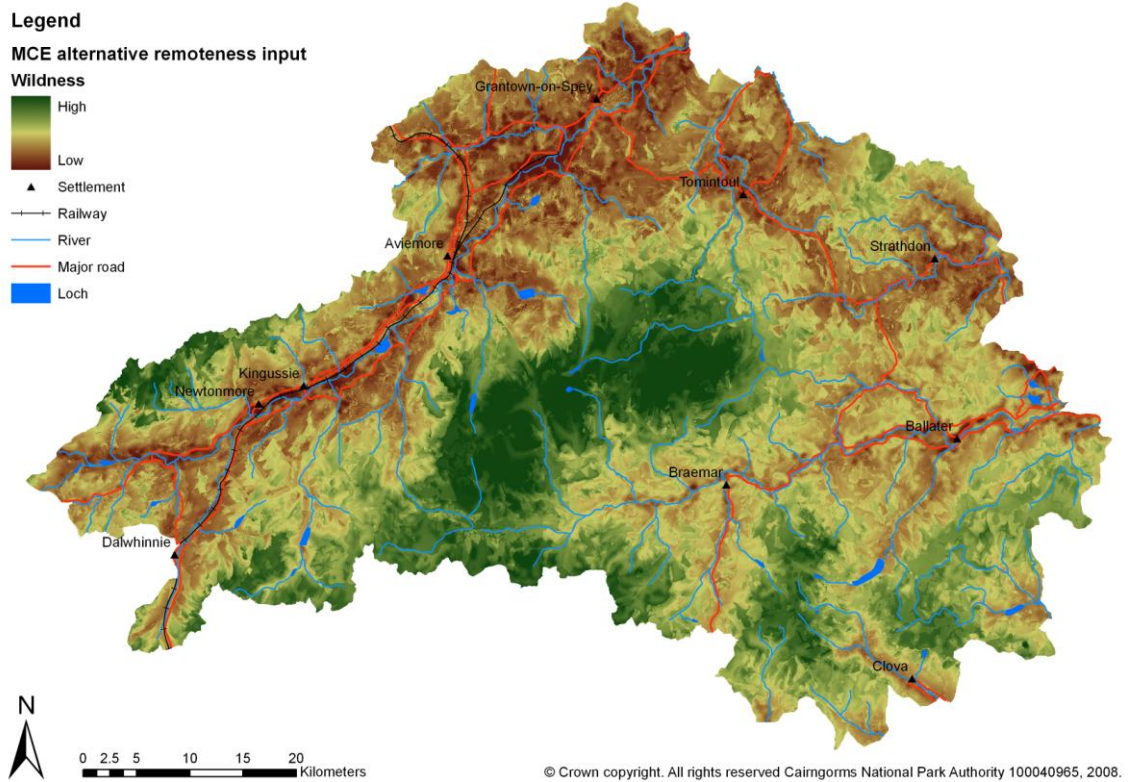
Figure 5.5 Equally weighted with spate conditions remoteness map

(5.5)   One of the principal developments affecting wildness within the CNP over the next few years is likely to the continued development of the renewable energy resource through the construction of large wild farms. A small number of wind farms already exist on the borders of the park and these have been included in the absence of modern human artefacts map shown in Figure 4.10. Information on proposed wind farm developments can be included in the viewshed analysis to estimate the impact of these further developments on wildness within the CNP. Figure 4.12 highlights the difference between the viewshed models in Figure 4.10 showing current conditions and that which includes additional visual impacts from proposed wind turbines.

(5.6)   The wildness mapping methodology is provided as an ESRI ArcGIS 9.2 compatible tool. This will allow CNPA and SNH officers to evaluate the wildness of any location or region in the CNP, quantify it's attributes of wildness, and perform some basic 'what if?' type analyses such as "what if we removed this track or bridge or bothy?" and "what if a wind farm is built here or a hill track is constructed along here?" based on changes to the input attribute layers. This will allow the CNPA and SNH to better evaluate potential developments for their impact on wildness and evaluate the cost/benefits of landscape restoration projects such as track removal and native woodland regeneration.

(5.7)   To ensure complete transparency and longevity in the data preparation process, each dataset and attribute map is fully documented with appropriate metadata and lineage information (see section 4.6). This is used to provide dataset lifecycle information in a format suitable for use by the CNPA in both maintaining and updating the data as future land use, management and policy changes require, thereby "future proofing" both the data and the methodology/tools developed. Appropriate standards and formats for recording metadata and lineage are adapted from existing norms in consultation with the Steering Group. The tools provided for creating attribute and wildness maps will help the CNPA in this task by facilitating the easy maintenance, updating and recombination of attribute maps to create new wildness maps. Since there might be some expected changes in the future, the tools also incorporate a facility to allow different land management practices to be easily examined. In particular, the overall potential effect of land use or land management developments on wild land quality can be mapped and different outcomes can be investigated allowing for the comparison of the resulting wild land maps. The difference between the various wildness maps shown above is often slight and locally concentrated. These small differences are best shown as simple difference or residual maps. Figure 4.12 shows the difference generated by comparison of model outputs with and without the proposed wind turbines and in doing so better highlights the pattern of changes in both local and overall wildness in the park as a result of including proposed as well as existing wind turbines.

6. Further developments

(6.1)   The approach developed and described above could potentially benefit from a number of additional enhancements that address some of the caveats and assumptions described in section 4. These are summarised here.

6.1 Identification of muirburn and other land management practices

(6.2)   Difficulties in the accurate identification of managed heather moor through muirburn and drainage from the LCM2000 and LCS88 data, as described in section 4, mean that if the degree of land management is to feature in the perceived naturalness attribute map in future, then alternative methods need to be developed to capture this information. As the LCM2000 and the LCS88 data become increasingly outdated it should be possible to update these using contemporary satellite imagery and automatic change detection techniques developed for use in upland areas (Comber, 2002). This would involve the sourcing of suitable high resolution multi-spectral remote sensing imagery for the CNP area and their analysis using object classification techniques. Comber (2002) has developed a series of algorithmic 'experts' relating to the classification of different Scottish landscape features. These were generated through a knowledge acquisition exercise involving the 7 remaining photo-interpreters who constructed LCS88 and a wide ranging literature review. For example, the muirburn 'expert' was constructed using information from the remaining interpreters, Hester and Sydes (1992) and the *Muirburn Code* (Muirburn Working Party, 1977). It contained information formalised as 'rules' in an automated system relating to the spatial configuration of muirburn, its orientation relative to topography, its association with certain land covers, its periodicity and frequency, the variation in practice relating to environmental context (e.g. East vs. West Scotland), etc. It is understood that certain aspects of upland land management such as muirburn, drainage and the construction of bulldozed hill tracks have a significant impact on perceptions of wildness. In this case, the use of the automated change detection techniques could be successfully used to update these and other elements of both the LCM2000 and LCS88 data such as woodland regeneration, fencing and other land management practices.

6.2 Wild land typology

(6.3)   The approach developed in this report provides a method for drawing wildness maps using a wildness continuum concept. This generates maps of wildness interpreted from maps of the four attributes of wildness along a continuous, but relative numerical scale. It is suggested that this approach could be further developed by adapting the wildness mapping tool and its component attributes to generate a wild land typology map based on the concept developed by Mc Morran et al. (2007) in their review of the benefits and opportunities attributed to Scotland's landscapes of wild character. This would help place

the wildness maps developed above into the wider context of emerging SNH policy on wild land areas in Scotland and further facilitate the rolling out of the proposed methodology across the rest of Scotland. It is envisaged that this will make extensive use of the wildness attributes and develop a classification system for creating wild land typology areas from the wildness maps described above.

6.3 Participatory approaches

(6.4)   A further enhancement to the implementation of the main methodology would be to run the models live at meetings with representative groups of selected stakeholders. This would allow stakeholders to query the attribute maps, how they were derived and the weights used, and then derive a further set of wildness maps based on their own opinions/weights. This could be done as a facilitated participatory GIS exercise utilising video wall methods to project the GIS and datasets onto a large screen for group discussion and interaction. A further extension to this face-to-face approach of public participation would be to construct a simple online participatory GIS tool through which it would be possible to engage a much wider audience in commenting on the attribute and wildness maps produced. Previous work by Carver and Fritz (see Carver et al., 2001; Carver et al., 2002; Carver et al., 2005; Carver et al., in press) has successfully developed internet-based GIS approaches to soliciting public opinion on wild land and associated management issues. Existing tools from this work could be used to create an online participatory GIS for the current study which would solicit public opinion about the maps developed and/or allow respondents to develop their own wildness maps by weighting the attribute maps provided.

6.4 Further work on model weights

(6.5)   Further work on the effect of different weighting schemes is being carried out. The objective here is to consider how the weights identified from the three sources can be used to analyse different competing hypotheses:

1) that this pixel is wild
2) that this pixel is not wild
3) that the wildness of this pixel is uncertain

The weights and the data are used to generate beliefs in support of the hypotheses and these are then combined using different evidence combination methods. This results in alternative mappings describing areas that are 'wild', that are 'not wild' and that are uncertain and through analysis of the different evidence combination approaches (e.g. using Possibility, Dempster-Shafer and Bayesian theories) to identify core areas (i.e. those identified as being wild by all approaches). In this way the CNP can be provided with measures of confidence in areas identified as being wild.

7. Conclusions and recommendations

(7.1)   The methodology described in the report delivers a clear and robust approach to mapping wildness attributes and wildness maps within the CNP that could be used as is or adapted for use elsewhere across Scotland. The model is based on a common understanding and appreciation of the components of wildness and how they affect our experience of the Scottish landscape, and the Cairngorms in particular. The resulting attribute maps described in section 4 and the wildness maps described in section 5 demonstrate how a rigorous and repeatable GIS-based methodology can be applied to effectively map wildness over large areas of complex terrain taking multiple and often conflicting factors into account. The suggested additions to this methodology, outlined in section 6 could further enhance our ability to accurately map the extent and intensity to which wildness qualities and attributes vary across the landscape by offering improvements and efficiencies in the data used, how it is analysed and interpreted. This will provide both the CNPA and SNH with a framework for monitoring the change in wild land condition in the future and provide a mechanism by which planning applications and other developments affecting the landscape can be rigorously evaluated.

(7.2)   In particular the work described here delivers the following outputs:

- A GIS-based methodology for mapping wildness attributes and combining these using different weighting schemes to draw wildness maps.

- A step-by-step guide to the use of the methodology to allow CNPA officers to replicate the study and keep attribute maps up to date.

- An ArcGIS9.2 compatible tool for creating wildness maps from attribute layers and training for CNPA staff in use of this tool.

- A series of output datasets and maps of individual wildness attributes and combined wildness maps.

- A lifecycle of output datasets consisting of accurate metadata and lineage based on the CNPA metadata schema and including descriptions of attribute fields and values.

- A detailed interpretation of the results including an analysis of dataset accuracy and sensitivity of the results to different weighting schemes.

- A retrospective analysis of the study to identify lessons learnt and possible next steps.

(7.3)   The attribute maps for perceived naturalness of land cover, absence of modern human artefacts, remoteness and rugged and challenging terrain shown in section 4, together with the alternative interpretations of these, illustrate the complexity and

variability within the components of wildness across the CNP and its immediate environs. It is clear from earlier work on mapping wild land in Scotland (Fritz et al., 2000; Carver and Wrightham, 2003) that the spatial pattern in wild land attributes is sensitive to the methods, assumptions and the data used. This is reinforced by the work carried out here in relation to new methods and datasets tested on the CNP area. This sensitivity notwithstanding, the same basic overall pattern of wild land attributes can be observed across all the attribute maps in that the wilder areas of the CNP are largely confined to the large roadless areas of the mountain core including:

- the Cairngorm plateau;
- Mòine Mhòr;
- Bein A' Bhuird and Ben Avon;
- Lochnagar and the White Mounth;
- the head of Glen Feshie; and
- the head of Glen Banchor.

At the other end of the wildness spectrum, the least wild areas are strongly controlled by the straths, including Strath Spay, Strath Avon, Strah Don, Braemar and Deeside, Glen Clova and Glen Truim, and their associated roads, settlements, infrastructure and agricultural land use patterns. Plantation forestry also have a marked effect in reducing wildness in key localities such as Glenmore/Rothiemurchus, Strath Avon/Tomintoul and Abernethy. In addition, local ski developments have a marked local effect through their concentration of access roads, maintenance tracks, ski lifts and buildings. These include the Cairngorm ski area, the Lecht ski area and the Glenshee ski area, although the effect of the latter is less pronounced by virtue of its location on the park boundary.

(7.4)   Combining the attribute maps using the MCE/fuzzy methods and different weighting schemes and inputs described in sections 3 and 5, generates overall wildness maps shown in Figures 5.1 to 5.6. Using the equally weighted map in Figure 5.1 as the baseline for comparative purposes, it can be seen that whilst there are local differences in either the intensity or pattern of the relative wildness values shown in Figures 5.2 to 5.6, it is noted that there is a strong agreement between all the maps as to the overall pattern of wildness that corresponds to those areas listed above. This is indicative of a high degree of robustness and associated confidence in both the methods/data used and the maps produced.

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Appendix 1. Installation of Tools

Software Requirements:

All the tools described in this appendix require ArcGIS 2.4+ and an installed version of Python 2.4 and Pythonwin.

Installation instructions:

The software tools can be installed using the following instructions:

1. Unzip file tools.zip into directory

2. Go to ArcToolbox > right-click on Arctoolbox > choose add toolbox

3. Open + on wildness_tools to see (Normalisation Tool, order weighted average, Linear Summation model)

4. Right-click on Normalization Tool > Properties > Source > open folder icon > point to the python script (normalise_exp.py)

5. Right-click on ordered weighted average > Properties > Source > open folder icon > point to the python script (ordered_weighted_average.py)

6. Right-click on Simple Linear Summation Model > Properties > Source > open folder icon > point to the python script (Simple Linear Summation Model.py)

Currently the names for the factor maps are quite generic. Names for the factor maps can be changed by:

1. Right-click the python script (e.g. Simple Linear Summation Model) > properties > parameters (e.g. change name for input raster 1 to 'factor remoteness')

Running the Linear Summation tool:

The linear summation model is run as follows:

Load (or choose if you have the factor maps loaded already), see Figure A.1 below:
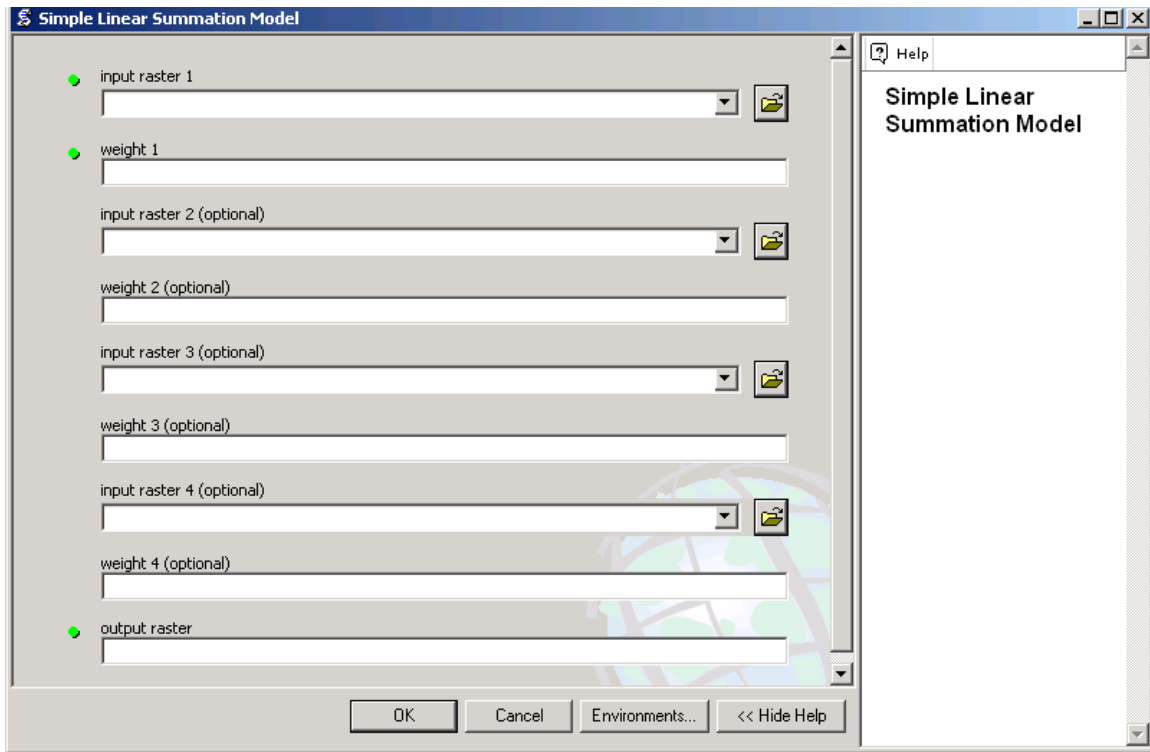
Figure A.1 Linear summation tool

1. Input rasters and weights (e.g. weights 1-10)
2. Under output raster window specify path with name of output raster (e.g. d:/cairngorm/lin_sum where path is d:/cairngorm/ name of output file lin_sum)

Equation for linear summation model:

$$\frac{\text{Factor1} * \text{Weight 1} + \text{Factor 2} * \text{Weight 2} + \text{Factor 3} * \text{Weight3} + \text{Factor 4} * \text{Weight 4}}{\text{Sum of Weights}}$$
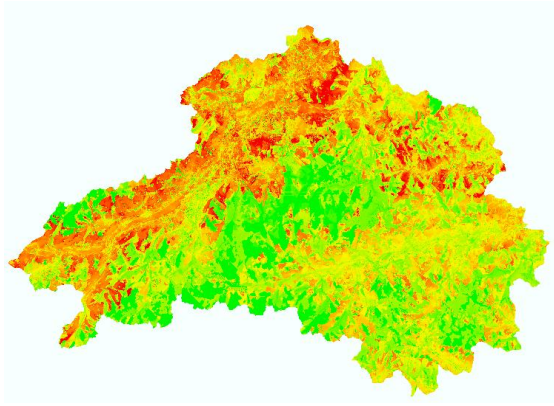
A $\dfrac{3 * 1 + 1 * 1 + 2 * 1 + 4 *1}{4} = \boxed{2.5}$

1	2.5
2.25	3.25

B $\dfrac{3 * 3 + 1 * 1 + 2 * 2 + 4 *4}{10} = \boxed{3}$

1	3
2.7	2

Figure A.2 Absence from Human Artefacts
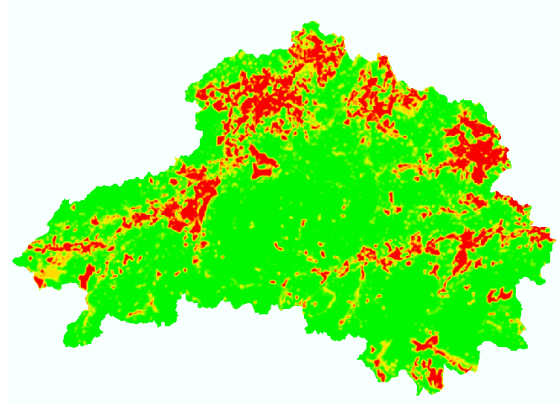
Figure A.3 Apparent Naturalness
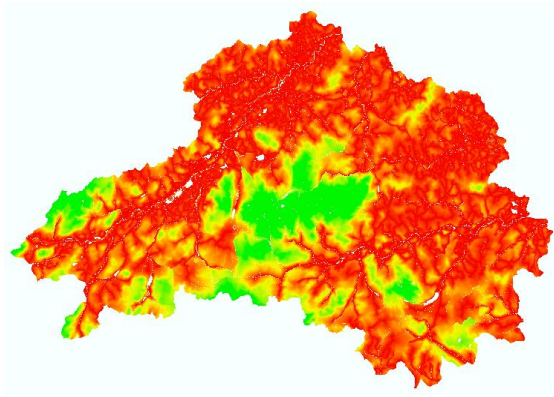
Figure A.4 Remoteness
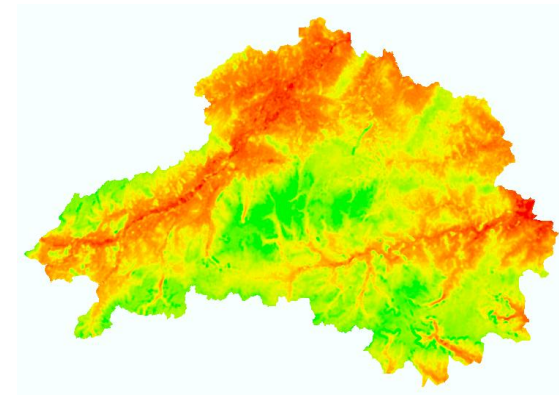
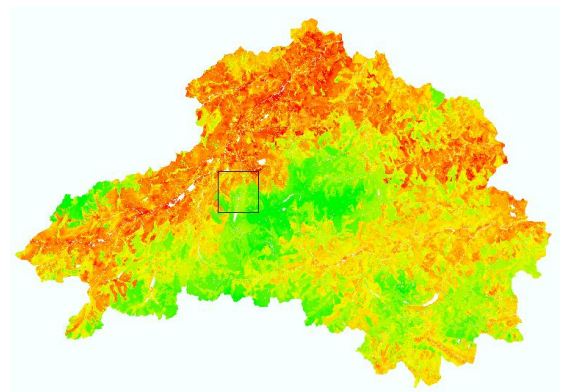**Figure A.5** Ruggedness
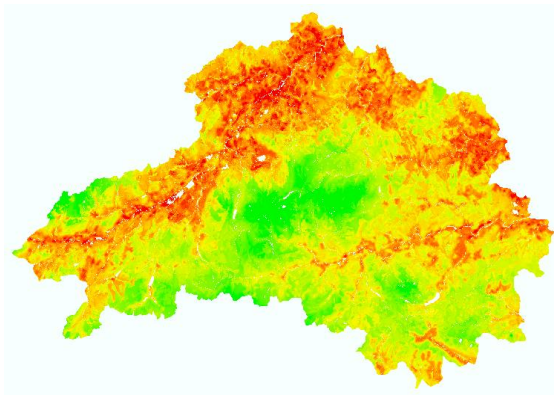
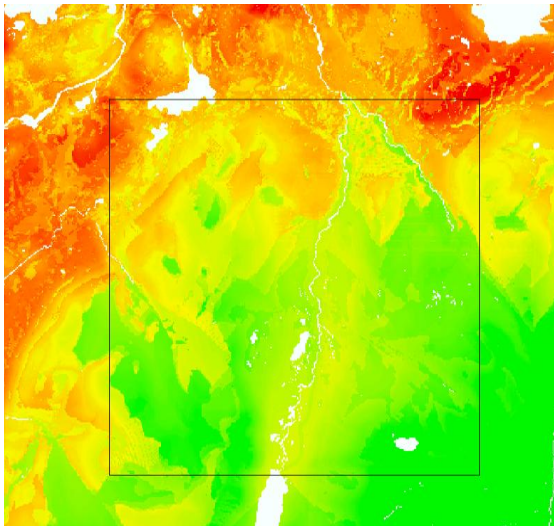**Figure A.6** Output with equal weights
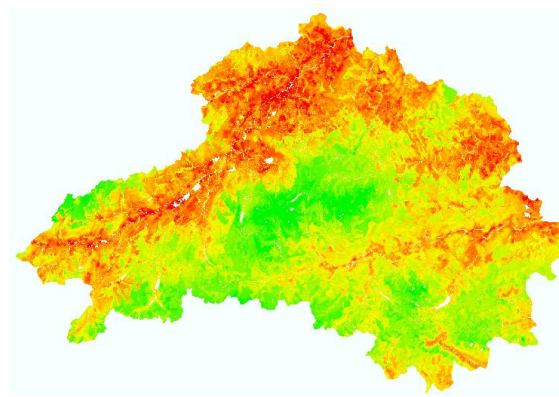
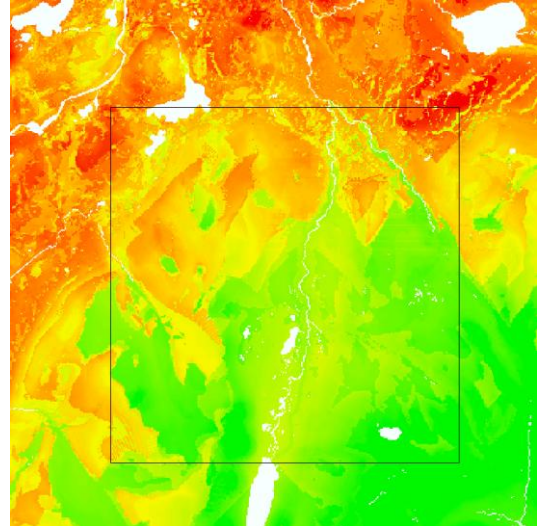**Figure A.7** Output weights as Example B
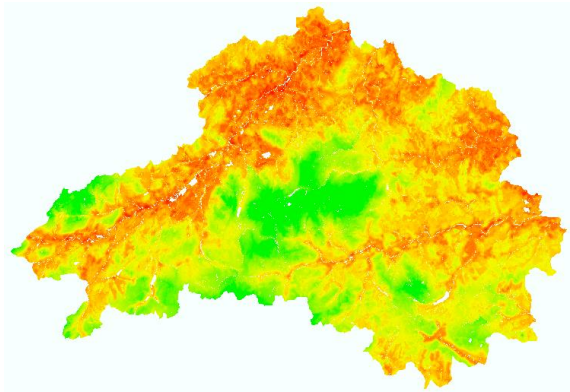
Figure A.7 Output stressing remoteness

Figure A.8 Output stressing absence of
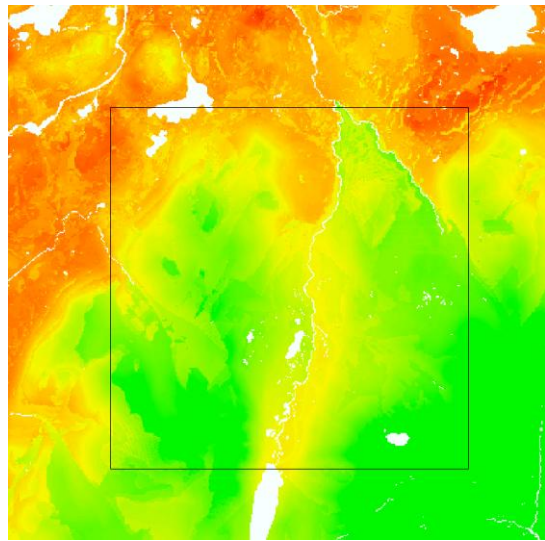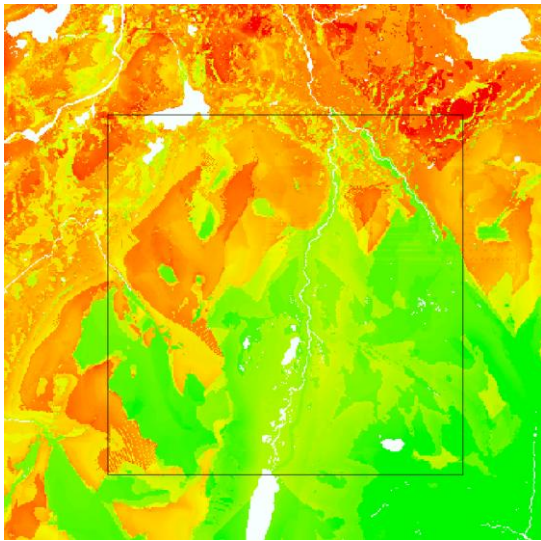
human artefacts (with zoom box)

Figure A.9 Equal weights

**Figure A.10** Same weights as example B

Figure A.11 Stressing absence of human artefact **Figure A.12** Stressing remoteness

Running the Ordered Weighted Average tool:

First it orders the different values of the factor maps according to the highest, the second highest etc. This makes the 4 layers of ordered values which are then multiplied: the highest value from the factor maps with the highest weight, the second highest value with the second highest weight, etc.
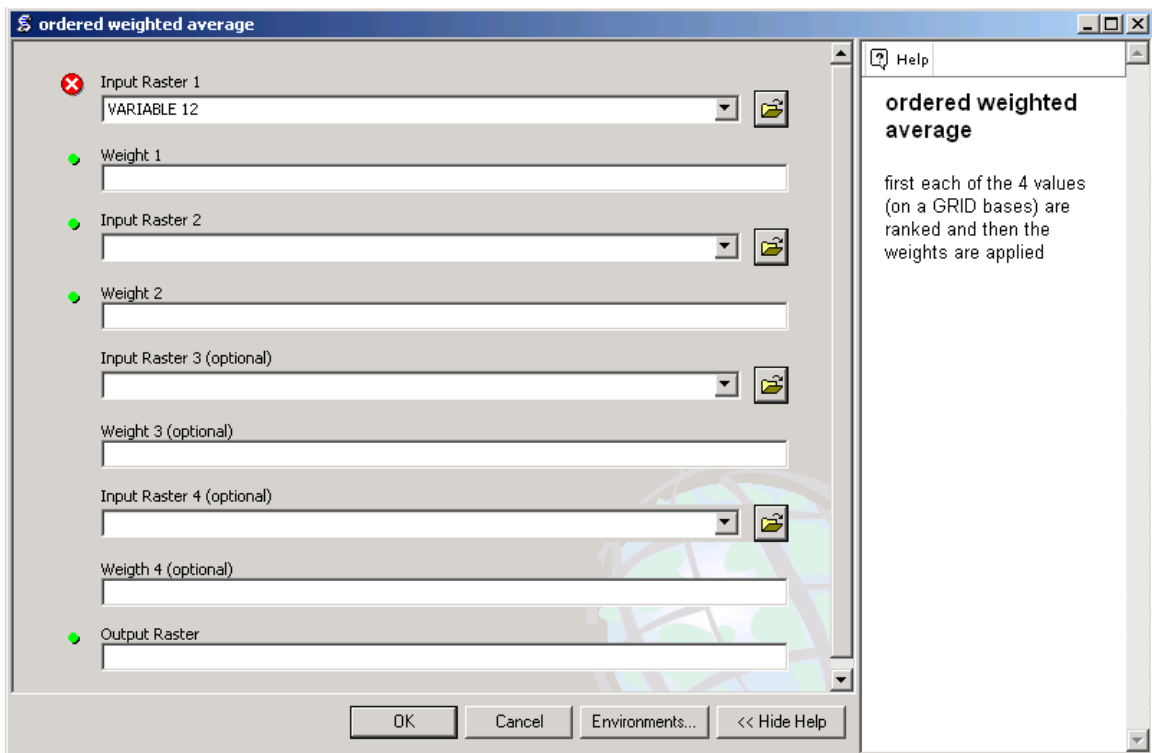
Figure A.13 Ordered Weighted Average tool

1. Input raster maps
2. Input weights in decreasing order: weight 1 highest weight, weight 2 second highest or equal weight1, weight 3 third highest or equal weight2, weight 4 lowest weight or equal weight 3) – e.g. (5,3,2,1) or (5,2,1,1)

Ordered Weighted Average

Factor 1: Absence of Human Artifacts
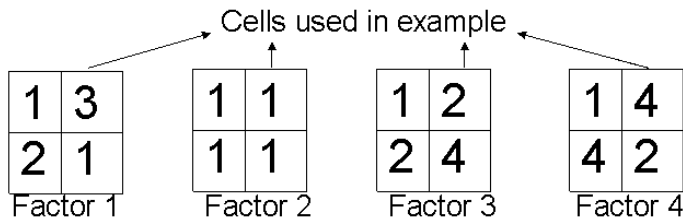Factor 2: Remoteness
Factor 3: Apparent Naturalness
Factor 4: Ruggedness

A Weights used 1 1 1 1
B Weights used 4 3 2 1
Note that Weights are not attributed to the factor maps

Cells used in example

1	3
2	1

Factor 1

1	1
1	1

Factor 2

1	2
2	4

Factor 3

1	4
4	2

Factor 4

1. Values of Factor Maps   3   1   2   4
2. Values in descending order   4   3   2   1

3. Multiply with weights retaining order (A:1,1,1,1) (B:4,3,2,1)

A $\dfrac{4 * 1 + 3 * 1 + 2 * 1 + 1 * 1}{4} = \boxed{2.5}$

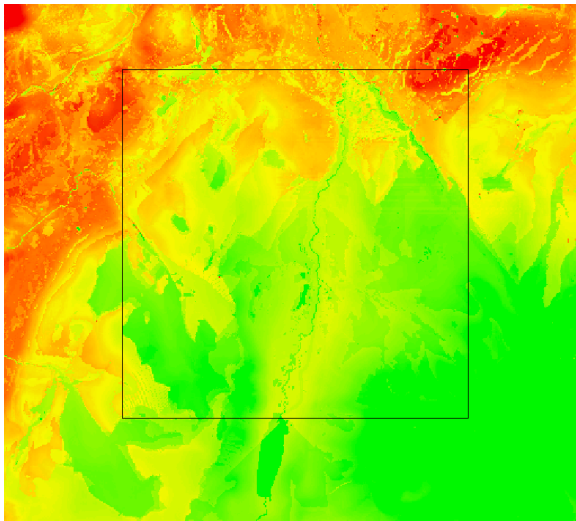| 1	2.5
2.25	3.25

(ANDNESS, same as Linear Summation Model with equal weights)
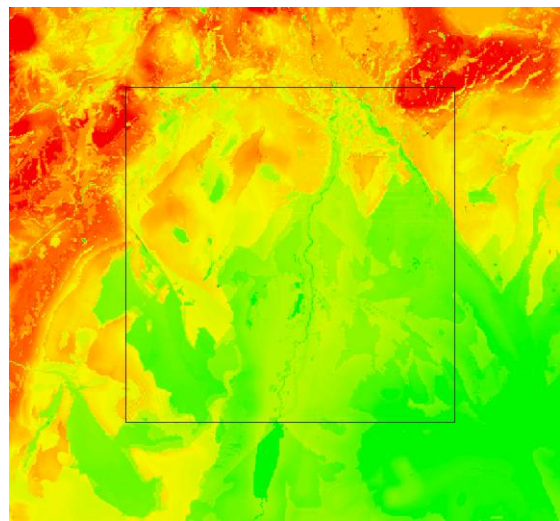
B $\dfrac{4 * 4 + 3 * 3 + 2 * 2 + 1 * 1}{10} = \boxed{3}$

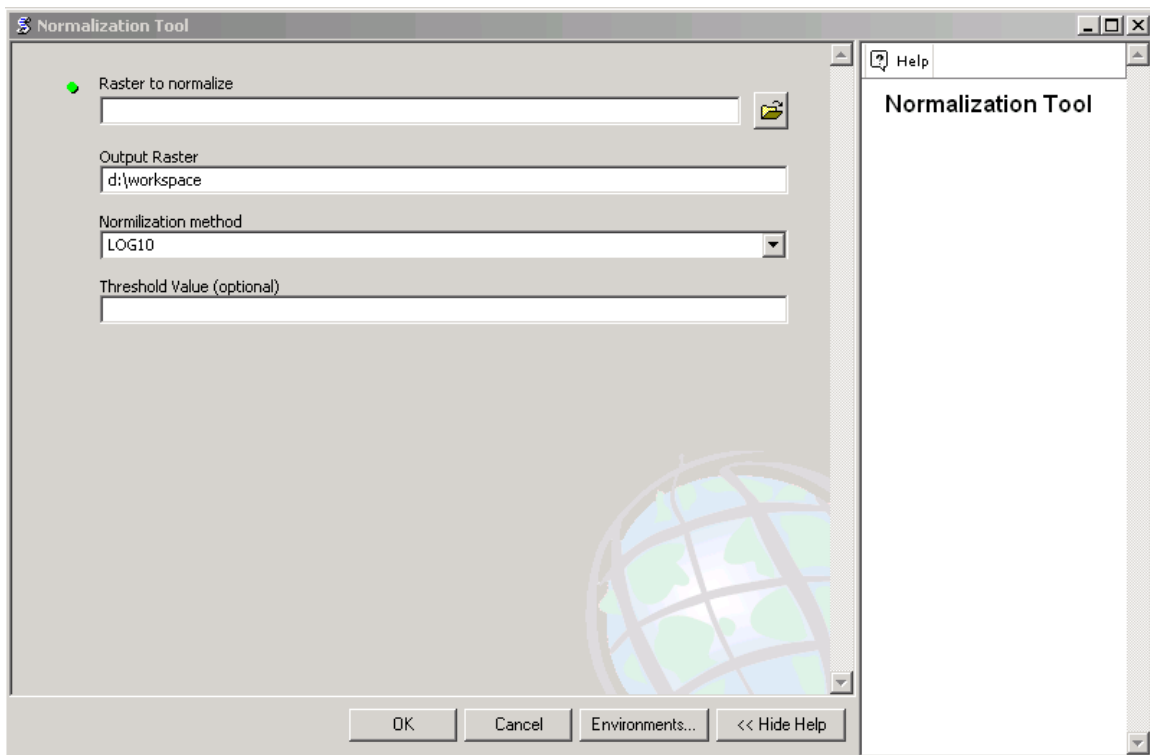| 1	3
2.7	2.5

(ANDNESS-ORNESS)

Figure A.14 Example A (weights 1,1,1,1)   **Figure A.15** Example B (weights 4,3,2,1)

## Running the Normalisation tool

Figure A.16 The Normalisation tool

The normalisation tool can be used to change a linear increase to a logarithmic one as well as it allows to define threshold. It normalises to to the range between 0-256.

1. Load raster file into window 'Raster to normalise'

2. Give path as well as name of normalised file in the Output raster window.

3. Choose Nortmlisation method

4. choose threshold values from which all values will be maximum (256) – if left bank no threshold value will be used
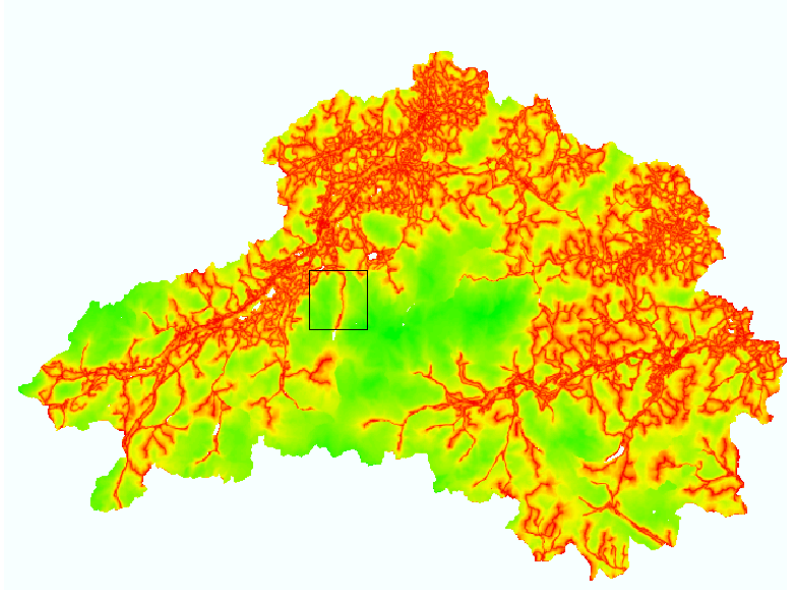
Figure A.17 Remotess map (normalised with LOG10)
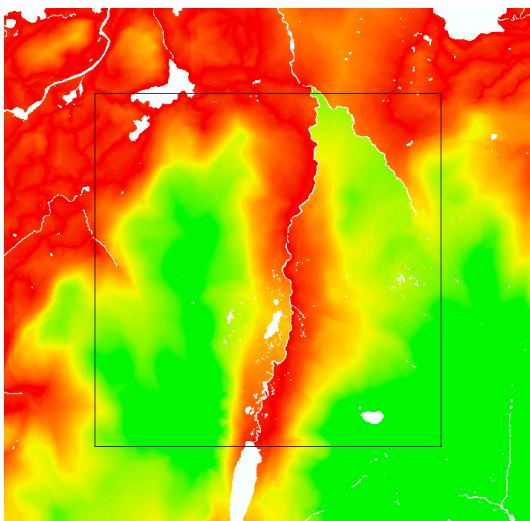
Figure A.18 Before normalisation

Figure A.19 After normalisation LOG10

Appendix 2. Using the Viewshed Explorer

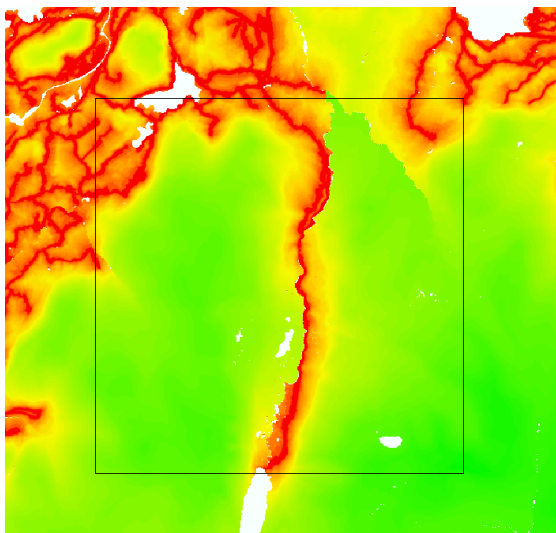**Using the Viewshed Explorer to perform interactive viewsheds:**

1. Prepare a floating point elevation model using ArcGIS and, optionally, the resample tool (see separate documentation in Appendix 3).

2. Click "Load elevation data" in the Viewshed Explorer, and select the .flt file which represents the prepared elevation model. After a few seconds, a relief shaded map showing the elevation data will be displayed in the main window. This is displayed at its native scale, where one pixel is equivalent to one data cell. You can navigate the map by dragging with the mouse on the display.

   If you receive an error message, or the relief map fails to appear, check the following, in this order:

   - That the .flt file has an accompanying .hdr (header) file with the same name and location, which specifies its dimensions in whole numbers.
   - That you selected the .flt file, and not the associated .hdr file.
   - That the dimensions of the .flt file (as specified in the .hdr file) are not too great for the memory capacity of the computer. If you received an out-of-memory error, take one of the following actions:
     - Ensure that no other software is running. Re-start the software and try again.
     - Run the software on a computer equipped with more RAM. As a very rough guideline, a computer with 1GB of RAM should be able to handle a landscape with around a million cells (e.g. 1000x1000 cells).
     - Try loading a smaller file (see separate documentation on ArcGIS and the resample tool in Appendix 3 for producing a file at a lower resolution, or points 4 and 6 below, and the ArcGIS documentation, for breaking the data into smaller chunks for separate processing).

3. Choose a preview mode from the drop-down list box. Some of these options may be disabled.

4. Move the pointer over the view area to see an interactive preview. TIP: You can still drag to scroll the view. In addition you can also adjust the "Observer height" parameter to witness its effect on the viewshed.

Using the Viewshed Explorer to perform a viewshed transform:

1. In addition to step 1 above, prepare an integer feature class file using ArcGIS and the resample tool (see separate documentation in Appendix 3).

2. Perform step 2 above to load the elevation data.

3. Click "Load feature data". After a moment, the relief shaded map will be updated with various colours representing the feature classes. IMPORTANT: The system is currently limited to five feature classes, including "NODATA". If you receive an error message, or the relief map fails to update, check the following, in this order:

    - That the .int (feature) file has an accompanying .hdr (header) file with the same name and location, containing dimensions specified in whole numbers that exactly match those contained in the .hdr file which accompanies the elevation data. TIP: If an accompanying .hdr file does not exist, you can duplicate the .hdr file that accompanies the elevation data loaded in step 2 above, renaming it so that it matches the name of the .int file.
    - That the actual dimensions of the .int (feature) file, match those of the .flt (elevation) file already loaded. The .int file should have exactly one quarter of the filesize of the .flt file. TIP: You can check this by right-clicking each file and looking at its properties. If there is a mismatch, these files have become corrupted or confused – revisit the documentation for ArcGIS and the resample tool.

4. Set the "Maximum view distance" slider to an appropriate number of cells (voxels). IMPORTANT: The viewshed transform will only be calculated for a region in the middle of the map which is surrounded on all sides by a buffer at least as large as the view distance which you specify. If you are performing the viewshed transform for one of a number of overlapping tiles which comprise a larger landscape (see point 6 below), it is important that this view distance does not exceed half the degree of overlap between these tiles.

5. Optionally, limit the viewshed transform output to the visible preview area, for test purposes, by specifying "Viewport Only". IMPORTANT: This is strongly recommended the first time you are performing a viewshed transform, to confirm that the output of the full viewshed transform (which can take a very long time to calculate), is going to be in line with your expectations. You can change the visible preview area by resizing the application window as well as scrolling the map.

6. Click "Do Viewshed Transform", and wait. Depending on the processing power of the computer, the number of cells which comprise the landscape, and the view distance, this process may range from a few minutes to a few days to complete. During this time, an estimation of the time to completion will be displayed in the title-bar, and the percentage complete will be displayed on the progress-bar in the main window. TIP: If you have a number of computers available, it may be advisable to exploit them simultaneously by breaking the data into a number of smaller overlapping chunks (see ArcGIS documentation)

Appendix 3. Using the Resample tool

Using the Resample Tool to resample surface model data:

1. Prepare a floating point elevation model using ArcGIS.

2. In the "source file" box on in the Resample Tool, enter the file path of the elevation file (.flt file). Alternatively, use the browse button to locate the file. Ensure that this location is write-enabled and has at least as much space free as the size of the file, for the resampled versions to be created.

3. In the "row cells" box, enter the width of the data in the file, in cells. TIP: This number can be found in the accompanying .hdr file, if you have one.

4. Ensure that the box which says "treat as discreet" is NOT checked.

5. Click "resample". A number of new files will be created, each with the same name as the original file, but with @*w* appended (where *w* is the new width, in cells). TIP: You will need to create .hdr files for each of these before they can be used by Viewshed Explorer. If the source .flt file has an accompanying .hdr file, you can make copies of this. Make sure that you edit each copy so that the filename and width information stored within the file reflect that of its associate .flt file.

Using the Resample Tool to prepare feature data:

1. Prepare the feature (land class) data using ArcGIS. The data must be exported as an .flt file, even though it only contains discreet classes. Viewshed Explorer cannot use this file directly – it must first be converted to a .int file…

2. In the "source file" box on in the Resample Tool, enter the file path of the feature (.flt) file. Alternatively, use the browse button to locate the file. Ensure that this location is write-enabled and has available space.

3. Click "discretize". A new file will be created, with the same name and location as the source file, except that it will have a .int extension, and will be one quarter of the size of the source file. This file can be used directly by Viewshed Explorer.

Using the Resample Tool to resample previously prepared feature data:

1. Prepare a feature (.int) file, as per the above instructions.

2. In the "source file" box in the Resample Tool, enter the file path of the prepared feature file (.int file) Alternatively, use the browse button to locate the file. Ensure that this location is write-enabled and has at least as much space free as the size of the file, for the resampled versions to be created.

3. Ensure that the box which says "treat as discreet" IS checked.

4. Check or uncheck the "pessimistic discreet resample" box as suits your application. TIP: Using pessimistic resample will guarantee that very small features will not be lost in the resampling process, but will bias the results of later viewshed analysis towards all features being slightly more visible than they are.

5. Click "resample". A number of new files will be created, each with the same name as the original file, but with @*w* appended (where *w* is the new width, in cells). TIP: You will need to create .hdr files for each of these before they can be used by Viewshed Explorer. If the source .flt file has an accompanying .hdr file, you can make copies of this. Make sure that you edit each copy so that the filename and width information stored within the file reflect that of its associate .flt file.

Appendix 4. Using the viewshed normalisation tool

Using the Resample Tool to normalize land class data transformed by the Viewshed Explorer (view classes):

1. Run a viewshed transform in Viewshed Explorer to generate a series of view class files (.flt files). TIP: There will be one of these for each land class.

2. Check or uncheck "logarithmic output" and "invert values" as suits your application. TIP: Logarithmic output compensates for the fact that the apparent visibility of features tends to drop off rapidly with distance. It therefore applies a logarithmic function so that low levels of visibility can be more clearly discerned when the data is rendered.

3. In the Viewshed Normalization tool, click "normalize a viewshed dataset" and, in the file browser, locate one of the view class files generated by Viewshed Explorer. TIP: Although you only need to select one of these files, the whole set will be normalized against each other. Make sure they are collected together in one location, and that there is sufficient free space in this location for a normalized copy of each file.

4. After a short delay, the files will be normalized. They are now ready for import into ArcGIS! It may be necessary to prepare .hdr files for them. You can do this by duplicating .hdr files from source data you loaded into Viewshed Explorer.

Appendix 5. Defining naturalness class from LCM2k level 2 classes

Broad Habitat	Description	Level 2 code	Naturalness class
Broad-leaved woodland	All broad-leaved woodland including mixed and yew woodland. Many woodlands are below the 0.5ha minimum mappable unit of the LCM2000 are so are excluded. This has been split into Ancient Semi Natural Woodland (ASNW) (1.1a) and non-ASNW using the ASNW inventory data (1.1b)	1.1a 1.1b	5 4
Coniferous woodland	All coniferous woodland. Generally planted in larger blocks and so are better defined. This has been split into Ancient Semi Natural Woodland (ASNW) (2.1a) and non-ASNW using the ASNW inventory data (2.1b)	2.1a 2.1b	5 3
Arable and horticultural	All cropped lands including cereal crops, vegetables, ley pasture, and set-aside.	4.1 4.2 4.3	2
Improved grass	Any grassland that has continuous attempts at improvement including drainage, ploughing, reseeding, fertiliser application, etc.	5.1	2
Neutral grass	Any semi-natural grassland on neutral soils/rocks. Some improvement may be present.	6.1	3
Calcareous grass	Any semi-natural grassland on calcareous soils/rocks. Some improvement may be present.	7.1	3
Acid grass	Any semi-natural grassland on acid soils/rocks. Generally not improved.	8.1	4
Bracken	Areas recorded as bracken.	9.1	4
Dwarf shrub heath	Vegetation dominated by dwarf shrubs (heather, bilberry, gorse, etc.). Two level 2 classes are distinguished: dense (10.1) and open (10.2).	10.1 10.2	4 4
Fen, marsh and swamp	Areas characterised by vegetation types found on permanently, seasonally or periodically waterlogged soils.	11.1	4
Bog	Areas of heath or moor vegetation with peat depth greater than 0.5m as defined by BGS.	12.1	5
Standing water/canals	Includes all areas of inland water greater than 0.5ha minimum mappable unit. This has been split here into natural waters (rivers, lakes, streams) (13.1a) and artificially impounded waters (reservoirs) (13.1b) using OS MasterMap data.	13.1a 13.1b	4 3
Montane Habitats	All vegetated areas at altitudes greater than 600m	15.1	5
Inland rock	Includes mainly semi-natural bare rock surfaces, but also 'despoiled' areas such as quarries.	16.1	4
Built up areas and gardens	Buildings and open spaces in the built landscape greater than 0.5ha.	17.1 17.2	1 1

Appendix 6. Data sources

All maps and datasets are provided on CD as ArcGIS9.2 Shape file (vector) and Grid (raster) format files accompanied by appropriate metadata description and legend files. In addition, the proposed wildness ArcGIS mapping tool is provided on the data CD together with an additional code as described in the main body of the report. All datasets are referenced to the British National Grid Horizontal datum and the Ordnance Datum Newlyn vertical datum. All datasets are topologically correct and contain full attribution according to CNPA standards.

Name	Origin	Resolution/ Scale	Description
CEH LCM2000	Centre for Ecology and Hydrology (www.ceh.ac.uk)	25m	A digital map of surface land cover based upon interpretation of spectral reflectances recorded by earth observation satellites.
Land cover of Scotland 1988	Macaulay Institute (www.macaulay.ac.uk)	1:25000	A digital map of surface land cover interpreted from air photography.
OS Mastermap topography	Ordnance Survey (www.ordnancesurvey. co.uk)	Urban 1:1250 Rural 1:2500	A vector dataset of multiple features such as buildings, roads and rivers.
Scottish semi-natural woodland inventory	Highland Birchwoods (for the Caledonian Partnership) (www.highlandbirchwo ods.co.uk)	1:25000	A vector dataset representing a comprehensive inventory of woodland in Scotland.
National Park Boundary	Scottish Natural Heritage (www.snh.gov.uk)	1:10000	The Cairngorms National Park boundary as a shapefile.
NextMap™ Digital Elevation Model	Intermap technologies (www.intermap.com)	5m	A digital map of elevation of the bare earth surface in meters above sea level
NextMap™ Digital Surface Model	Intermap technologies (www.intermap.com)	5m	A digital map of detected surface height in metres above sea level giving the height of buildings and forests etc.
Scottish Paths Record	Scottish Natural Heritage (www.snh.gov.uk)	1:10000	A vector dataset of paths in Scotland derived primarily from OS and OSCAR data.

Appendix 7. Maps