New GIS Approaches to Wild Land Mapping in Europe

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Abstract—This paper outlines modifications and new approaches to wild land mapping developed specifically for the United Kingdom and European areas. In particular, national level reconnaissance and local level mapping of wild land in the UK and Scotland are presented. A national level study for the UK is undertaken, and a local study focuses on the Cairngorm Mountains in Scotland. 'Remoteness from mechanized access' is mapped on a local scale, using Naismith's Rule in combination with Djikstra's algorithm. 'Apparent naturalness' is mapped by using an Internet questionnaire in order to collect perceptual information on how different human-made features affect an individual's overall perception of wild land. A fuzzy logic modelling framework is proposed to translate the findings from the questionnaire into the spatial domain.

The use of Geographical Information Systems (GIS) for wilderness mapping is a recent development, though several attempts to map wilderness using this technology have already been made that cover a range of different areas across the globe (for example, Lesslie and others 1988; Lesslie and Maslen 1995; Henry and Husby 1994; Kliskey and Kearsley 1993; Kilskey 1994; Carver 1996). Methodologies range from the mechanistic and rigorous approach adopted by the Australian Heritage Commission (Lesslie 1988) to the more subjective approach of Kliskey and Kearsley (1993) using Stankey's wilderness purism scale (Stankey 1977). None of these methodologies are directly applicable to Europe and Britain in particular, where the term 'wild land' or 'secondary wilderness' is proposed as a better representation of a landscape that has been dramatically altered due to its long history of settlement and rural land use (Aitken 1977). At present, with the exception of some Arctic districts and a few mountainous areas, the whole of Europe has been severely affected by dense population, intensive industrialization and agriculture (Pyle 1970; Dorst 1982; Zunino 1995).

In terms of biophysical naturalness, 'wilderness' has ceased to exist in nearly all parts of Europe. However, people still value the land according to factors such as solitude, remoteness and the absence of human artifacts, and therefore perceive it as wild. However, not all factors can be measured easily in a quantitative sense (for example, solitude is highly dependent on experiential value).

This paper is divided in two parts. The first focuses on mapping wild land in Britain carried out as part of a national study. The techniques developed are generic and can be potentially applied to other areas of Europe, as long as the particular data limitations of individual regions are taken into account. A national UK level study was undertaken based on similar factors as in the Australian study carried out by the Australian Heritage Commission, but adding another dimension to it within a multi-criteria evaluation (MCE) framework.

The second part focuses on a local study in the Cairngorm area in Scotland. This study quantified two main factors having a strong influence on wild land perception in Scotland a. One factor is closely linked to the idea of the 'long walk in' and termed here as 'remoteness from mechanized access.' It can be measured as the minimum time it takes a walker to reach a particular destination from any origin (usually a road or car park). A second factor strongly influencing wild land perception is the impact of certain human-made features such as roads, hill roads, pylons and hydro-electric power plants. The presence of such features can significantly detract from a 'wild land experience,' particularly when the features are highly visible. This factor is termed here 'apparent naturalness.' The Cairngorm study describes an approach to building a spatial mapping tool for wild land areas that captures qualitative perceptions of the factors affecting wild land quality. The methodology uses an Internet questionnaire designed specifically to collect softer, perceptual information such as naturalness (forest and land cover) and artifactualism (absence of human impacts) that are important wild land indicators. This information is then translated to the spatial domain within a fuzzy modeling framework.

Defining Wilderness and Wild Land

Several authors (for example, Lesslie 1985; Hendee 1990; Countryside Commission, 1994; Carver 1996) agree that there is no generally accepted definition of wilderness or wild land. Ecological and sociological definitions are differentiated. Due to the dramatic alteration of the landscape in most parts of Europe, a sociological definition seems to be more appropriate. A perceptual or sociological definition of wilderness can be found in Roderick Nash's book 'Wilderness and the American Mind' (1982). He defines wilderness from the perspective of the people and notes:

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> There is no specific material thing that is wilderness. The term designates a quality that produces a certain mood or feeling in a given individual and, as a consequence, may be assigned by the person to a specific place. Wilderness, in short, is so heavily freighted with meaning of a personal, symbolic, and changing kind as to resist easy definition.

Nash (1982) therefore defines wilderness as what people perceive it to be. Since wilderness in the true ecological sense is hardly considered to exist in Scotland, Huxley (1974) uses a similar definition:

> wilderness is where one feels oneself to be in a wild place, according to the sensibility of one's particular experience and knowledge on a global and local scale.

Due to the fact that the perception of wilderness quality of recreationists differs widely among individuals and is influenced by a variety of personal factors, the establishment of a wilderness or wild land threshold is arbitrary. Therefore, it is a definite advantage to identify wild areas in a relative way, either as a continuum or using fuzzy concepts.

It has been proposed by several authors (Aitken 1977; Aitken and others 1998) that even though there are hardly any wilderness areas left in Scotland, the wide-ranging vistas of heath-covered moorland and extensive glens provide the visitor with something approaching a true wilderness experience. Due, however, to the problematic use of the word wilderness ('some people refer to it as a wasteland'), the lobby for wild land conservation has tended to shift away from the use of 'wilderness' towards 'wild land' (Fenton 1996).

National Study: A Method of Mapping the Wilderness Continuum for the United Kingdom

Lesslie and others (1988) define wilderness as 'undeveloped land which is relatively remote, and relatively undisturbed by the process and influence of settled people,' and they map Australian wilderness areas based on this definition. A single wilderness quality indicator cannot assess remoteness and primitiveness. Remoteness can be described as a proximity function to settled land and settled people, whereas primitiveness also accounts for the lack of human artifacts and the naturalness of the ecosystem. These factors can be expressed in terms of the following four wilderness indicators (Lesslie and others 1988):

1) Remoteness from settlement: remoteness from points of permanent human occupation.
2) Remoteness from access: remoteness from constructed vehicular access routes (roads) and railway.
3) Apparent naturalness: the degree to which the landscape is free from the presence of the permanent structures of modern technological society.
4) Biophysical naturalness: the degree to which the natural environment is free of biophysical disturbances due to the influence of modern technological society.

By summing together the four wilderness indicator values assigned to each grid point, a simple estimation of wilderness quality can be obtained. However, the simple addition of indicators in this manner assumes that they contribute equally to total wilderness quality. The indicators are not necessarily comparable in a quantitative sense, and computerization of the method allows alterations to be made. One type of alteration would be to give different weights to the different wilderness indicators. Each of the wilderness indicators can be displayed individually and compared with the final wilderness map. This creates the opportunity to locate those features that influence wilderness quality (Lesslie and others 1988; Lesslie and Maslen, 1995). This method has been used to map Australia at the national level. However, it has been criticized for being too mechanistic and not taking into account the perceptual nature of wilderness (Bradbury 1996; Kliskey and Kearsley 1993). Nevertheless, it has been proved to be an effective and efficient way of deriving wilderness quality indices and is seen as particularly useful for environmental planning and legislation (Centre for International Economics, 1998).

Mapping the Wilderness Continuum for the United Kingdom

Wilderness, as defined by Lesslie and others (1988), can be mapped for the UK using similar criteria. However, in this case the more open-ended approach to wilderness definition advocated by Nash (1982) is adopted with a GIS-based MCE approach to mapping the wilderness. This is because, like the continuum concept itself, MCE methods are not restricted by the necessity to specify rigid thresholds or criteria in defining where an entity like wilderness begins and ends.

In highly populated areas such as Britain and most other places in Europe, a model that takes into account all features located within a certain radius is much more appropriate. This is different from the approach in Australia, which only takes into account the feature that affects wilderness quality the most. The approach for Britain has led to a map-based definition of wilderness using weighted distance decay models. This model is applied to remoteness and naturalness factors as follows:

1) *Remoteness from population.* Based on the 1991 UK Census of Population, a population-weighted exponential distance-decay model is applied at a 1 km grid resolution.
2) *Remoteness from access.* Remoteness from access is also based on a traffic- weighted exponential distance model, taking into account all forms of mechanized transport route (except air traffic) from the Bartholomew's 1:250,000 datasets.
3) *Apparent Naturalness*. Again, for mapping apparent naturalness, the above weighted distance-decay function is used by taking into account all highly visible non-natural features such as radio masts, railway lines, roads, industrial sites and urban areas.
4) *Biophysical Naturalness*. Landsat-based land classification data supplied by the Institute of Terrestrial Ecology are used to derive a map indicating the likelihood of finding natural or near-natural ecosystems from a weighted distribution of land cover types.

All the datasets were derived and analyzed using the GRID module in the ARC/INFO GIS.

In order to take the subjective nature of the wilderness concept into account, MCE techniques can be used to weight the wilderness indicators differently. This allows the wilderness continuum to be mapped for the whole study area, describing a continuous surface from the least to the most wild locations (Carver 1996). A simple weighted linear summation model is used here with the above datasets and a range of different weighting schemes to produce a variety of continuum maps for Britain. By using an MCE approach, datasets are not presumed to be of equal weight thereby allowing individual perspectives to shape the model outcome.

The wilderness continuum maps of Britain that stresses remoteness and naturalness factors, respectively, are shown in figure 1 by way of example. This approach can be useful as an initial attempt to get a first impression and to identify national patterns in the distribution of wild land. Furthermore, this approach can be applied to evaluate the wilderness quality of land that is formally protected and identify which parts might require further protection. This method can be potentially applied for the whole of Europe.

Methods of Wilderness Mapping on a Local Level—A Case Study on the Cairngorm Mountains in Scotland

The wilderness-continuum mapping described above works well as a national reconnaissance-level survey. Close examination of individual areas, however, reveals certain inconsistencies. A more detailed local level study can deliver more reliable data. In order to map wild land areas at a local level, other wilderness indicators need to be taken into account. Additional datasets can be considered (for example, footpath data and terrain models) while all factors having an influence on wild land perception can be mapped to a higher level of accuracy.

There are two main factors that have a strong influence on wild land perception in Scotland and can be quantified. One factor is closely linked to the idea of the 'long walk in' and termed here as 'remoteness from mechanized access.' It can be measured as the minimum time it takes a walker to reach a particular destination from any origin (usually a road or car park). A second factor is the effect that human artifacts in the landscape have on wild land perception.

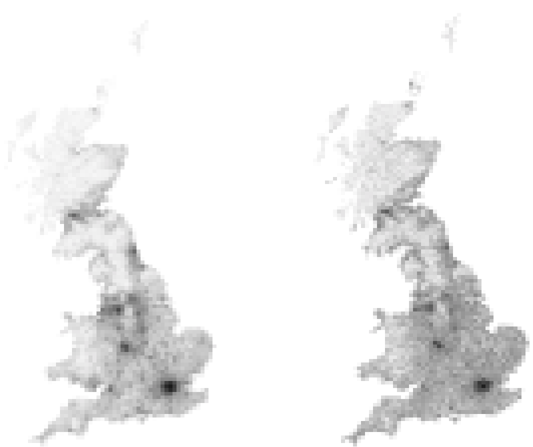

Figure 1—Wilderness continuum stressing remoteness (left) and naturalness factors (right).

Mapping Remoteness: The Impact of Terrain on Pedestrian Travel Times

Remoteness from mechanized access is not only described in terms of distance from roads, but also in terms of accessibility to a certain terrain structure. On a local level, it is possible to develop a model that takes into account the topography and isolation of the area, as perceived by a walker on the ground. A method of measuring accessibility is a time measure of walking distance. This can be achieved by integrating Naismith's Rule and a shortest-path algorithm.

Although first written down in 1892, Naismith's Rule is still used to obtain a rough estimate of the time required for a given walk (Aitken 1977; Langmuir 1984). The basic rule states that a walker can maintain a speed of 5 km/h on level ground, but half an hour needs to be added for every 300 m of ascent. Several refinements have been made to Naismith's Rule. These range from Tranter's Correction, which takes an individual's fitness level and fatigue into account, to simple corrections that assume Naismith to be an optimist and so add 50% (Langmuir, 1984). Aitken (1977) made refinements according to ground conditions. This assumes that 5 km/h can be maintained on paths, tracks and roads, but is reduced to 4 km/h on all other terrain. Langmuir (1984) made the following further refinements: Naismith's Rule of 5 km/h plus 0.5 hour per 300 m of ascent, minus 10 minutes per 300 m descent for slopes between 5° and 12°, plus 10 minutes per 300 m descent for slopes greater than 12°. It is thought that the rule is generally applicable for reasonably fit hill walkers negotiating typical terrain under typical weather conditions. However, further corrections can be made to allow for variations in terrain and conditions under foot, prevailing weather, steep ascents/descents, fitness and load carried.

Using Naismith's Rule, it is possible to calculate the time taken to traverse a set of cells in a digital elevation model (DEM) by taking gradient and slope direction relative to direction of travel into account. A DEM is defined here as a digital model of height (elevation or altitude) represented as a regularly spaced grid of point height values. Values of slope (gradient) and slope direction (aspect) can be calculated from the DEM. Accessibility from different directions relative to the same point in the landscape should be considered and the shortest path taken into account. Using this approach, it is possible to design a model that calculates the time taken to walk from single or multiple origin points to any destination on the terrain surface. Because it is unknown which route a walker will take, the model only considers the quickest possible path.

The model described here integrates Naismith's Rule with Dijkstra's shortest path algorithm (Aho and others, 1974). Dijkstra's algorithm works by considering the relative costs of moving through each of the cells in a matrix. Costs are represented by impedance values in the cell matrix. In order to implement Naismith's Rule within Dijkstra's algorithm, four different matrices were used. These include a heights matrix, a distance matrix, a trace matrix, which marks all the cells that have been dealt with, and a results matrix, the values in which are changed during the analysis process. This process has been automated within the Arc/Info GRID module and custom C code. For a detailed description of the implementation of the algorithm, see Fritz and Carver (1998).

Using this approach, it is possible to define remoteness surfaces for any landscape. Figure 2 shows an example of remoteness surface based on the hybrid Naismith/Dijkstra's algorithm applied to a 50 meter resolution DEM of the Cairngorm Mountains, using all roads as access features. The model has been used by Scottish Natural Heritage (Carver and others, 1999).

Mapping Apparent Naturalness: The Impact of Land Use and Artifactualism

A second factor strongly influencing wild land perception is the impact of human-made features such as roads, hill roads, pylons and hydroelectric power plants. The presence of such features can detract from the 'wilderness' experience, particularly when the features are highly visible within the landscape.

Measuring People's Perceptions According to the Influence of Human-Made Features—Kliskey and Kearsley (1993) mapped different peoples' perceptions of wilderness based upon the concept of 'multiple perceptions of wilderness.' The method is an approach to wilderness mapping in which the concept of wilderness comes close to the definition of Nash (1982). Kliskey and Kearsley's paper concentrates on the management of a national park and maps of wilderness from the viewpoint of a backcountry user. One disadvantage of their approach is that it is area-specific: the wilderness mapping study, which was carried out in the Nelsons National Park in New Zealand, can only be applied locally since the questionnaire was specifically designed for that area. Kliskey and Kearsley (1993) also determined the spatial criteria for mapping the influences of human-made features on an arbitrary basis.

Kliskey and Kearsley's 'wilderness' perception survey looks at measuring four properties: artifactualism (absence of human impact); remoteness; naturalness (in relation to forest and vegetation); and solitude. Four backcountry user groups were categorized with the use of a wilderness purism scale. This scale has been used to provide a mechanism that accommodates the variation of user definitions of wilderness (Stankey, 1977). Backcountry users were asked for their views about desirability of various activities and experiential items in what they considered to be a wilderness setting. A value from 1 to 5 was assigned to each response (from strongly desirable to strongly undesirable), and each group of the wilderness purism scale had a range of scores (for example nonpurist 16-45). Contingency table analysis of purism groups and desirability of items in what is perceived as wilderness were used, supporting the use of these indicators for differentiating and determining variations in perception levels. The results were then translated into a spatial concept according to remoteness (such as roads), artifactualism (mines, lighthouses, etc.) solitude and naturalness. The maps produced reveal that differing user groups have entirely different perceptions of wilderness (Kliskey and Kearsley, 1993; Kliskey, 1994). The work can then be used in a management framework for the zoning of the 'wilderness resource.'

The following method captures the information in a similar way to Kliskey and Kearsley, but with an Internet questionnaire. The difference is that people are directly asked to evaluate the spatial impact of a human-made artifact and the impact of vegetation. In addition, they can differentiate between features which are visible and those which are not. Instead of using simple buffers around the features, factors influencing wild land are combined within a fuzzy framework, and people can establish their individual criteria to produce their own wild land map.

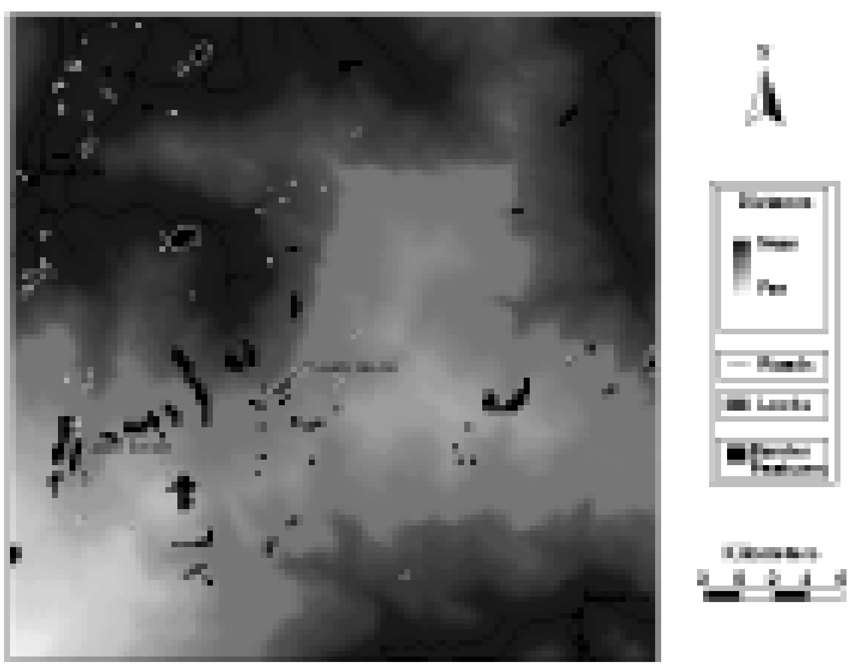

Figure 2—Remoteness surface for the Cairngorm Mountains.

1. What is the impact of a hill road on your perception of wild land when you are:

	near (visible)	medium (visible)	far (visible)	close (out of sight)	further away (out of sight)
very strong impact	❍	❍	❍	❍	❍
strong impact	¶	¶	¶	¶	¶
medium impact	¶	¶	¶	¶	¶
low impact	¶	¶	¶	¶	¶
very low impact	¶	¶	¶	¶	¶
no impact	¶	¶	¶	¶	¶

Figure 3—Questions about the impact of hill roads from Internet questionnaire.

The Internet Questionnaire—The questionnaire was specifically designed to gather information about the perceived impact of various factors on wild land quality. The questionnaire was posted on the Internet to promote wider accessibility. Participants will also be able to view composite maps based on a combination of all the participants' responses in a future version of the Web site. The Internet questionnaire consists of three parts. In part one, the user is asked to enter personal information, while part two asks some general questions about hiking in Scotland and the area covered by the questionnaire in particular. Information from these two parts will be used to classify the participants into different behavioral/recreational groups. Part three contains the main questions regarding the impact of certain features on the participant's perception of wild land. The respondents are first required to define a set of fuzzy spatial concepts in meters or miles. These include being near to, a moderate distance away from and far from visible features, as well as the concepts of close to and far away from features that are not visible but which can still have an impact on the perception of wild land. Eleven questions follow, all in the same style. The participant is required to think about what impact a particular type of artifact has in terms that range from 'no impact' to a 'very strong impact' . This is divided into two categories based on being near, a moderate distance away and far to a visible feature or close and farther away from features that are out of sight. Questions referring to the factor 'hill road' are provided in figure 3, and all the factors are displayed in table 1. The final question asks whether the participant thinks there are factors additional to the ones listed in the questions that may affect their perception of wild land and which can be used to improve the questionnaire in the future. The questionnaire can be found at the following address:

http://www.ccg.leeds.ac.uk/steffen/questionnaire1.html

A Fuzzy Logic Modeling Approach to Wild Land Mapping

Fuzzy logic is one of several new alternative approaches to modeling that has emerged from the fields of artificial intelligence and process-based engineering. Originally formulated by Zadeh (1965), fuzzy logic replaces crisp and arbitrary boundaries with a continuum, thereby allowing the uncertainty associated with human perception and individual-concept definition to be captured. For this reason, fuzzy logic is particularly well-suited to wild land mapping because it enables different factors influencing the perception of wild land to be integrated into a fuzzy wild land map, analogous to the way in which our brains might handle this information in a decision-making process. It also allows different degrees of wild land quality to be mapped, thereby eliminating the crisp boundary between wild and non-wild land. Moreover, this approach explicitly considers the spatial component by asking people to define their concept of distance and the subsequent impact of certain human-made features on their personal definition of wild land.

Visibility and Distance Analysis—A visibility map of the southwestern area in the Cairngorm Mountains in Scotland was produced using the Arc/Info GRID module at a 50m resolution for five factors on the Internet questionnaire, including paved roads, hill roads, built-up areas, isolated buildings and coniferous plantations. A visibility analysis of the DEM was undertaken for each individual human-made feature. The distance of the closest visible feature of each factor was recorded. These factors were extracted from the Land Cover of Scotland (LCS88) data supplied by the Macaulay Land Use Research Institute. In

Table 1—Factors affecting the perception of wild land embedded in the Internet questionnaire.

Factors/impacts on wild land
Surfaced road (paved)
Hill road (non-paved)
Built-up areas
Isolated building
Pylons
Grazing sheep or cattle
Arable land
Coniferous plantation
Hydroelectric power plant
Ski lifts
Shielings (derelict buildings)

addition, the closest Euclidean distance was calculated for each factor in order to acquire a data set for those areas where a feature is not visible, but which still has a potential influence on wild land perception. Figure 4 shows a map of the DEM, overlaid with the features used for this study. In the future, the remaining factors on the questionnaire will be taken into account, including hydroelectric power schemes, pylons, sheilings (old crofters' cottages), grazing (cattle and sheep), ski lifts and agricultural land.

A Fuzzy Logic Model for Mapping Wild Land—The distances specified by the respondent were used to construct fuzzy sets for defining the concepts near, medium and far for visible features and close and far away for nonvisible features. The user-defined distances were assumed to have membership values of 1.0 and were constructed to completely overlap neighboring sets. The output sets for wild land quality, which range from a very strong impact to no impact were evenly spread across a continuum of 0 to 1. Example fuzzy sets are provided in Figure 5 assuming values of 200m, 400m, 600m, 800m and 5km for the five distances.

Each question regarding the impact of a single factor produces a set of fuzzy rules. Each rule, which might be one of several possible answers input by a respondent, takes the form:

If you are ***near*** to a surfaced road
Then this has a ***very strong impact*** on wild land quality.

Each question can yield a maximum of 12 rules that link a distance to one of six fuzzy sets for the impact on wild land quality; six of the rules correspond to visible features while the other six cover nonvisible features. Figure 6 provides a methodological outline of the procedure for processing the rules for each individual layer and then combining the layers to produce an integrated fuzzy wild land map shown in figure 7.

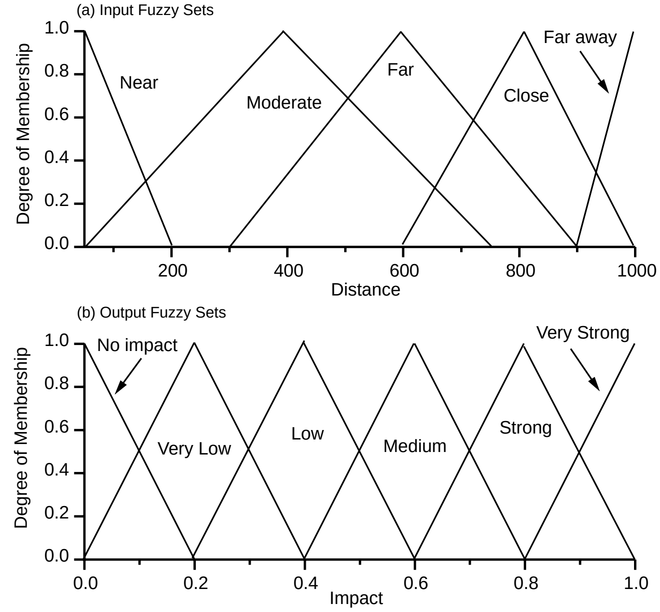

Figure 5—Example fuzzy sets for values of 200m, 400m, 600m, (visible); 800m and 5km (non-visible).

Conclusions

This paper has reviewed existing approaches to wilderness mapping and outlined modifications and new approaches developed specifically for UK and European areas. Particular emphasis is placed on the value of multi-scale approaches to national level reconnaissance and local level mapping of wild land in the UK and Scotland. Recent work on local level

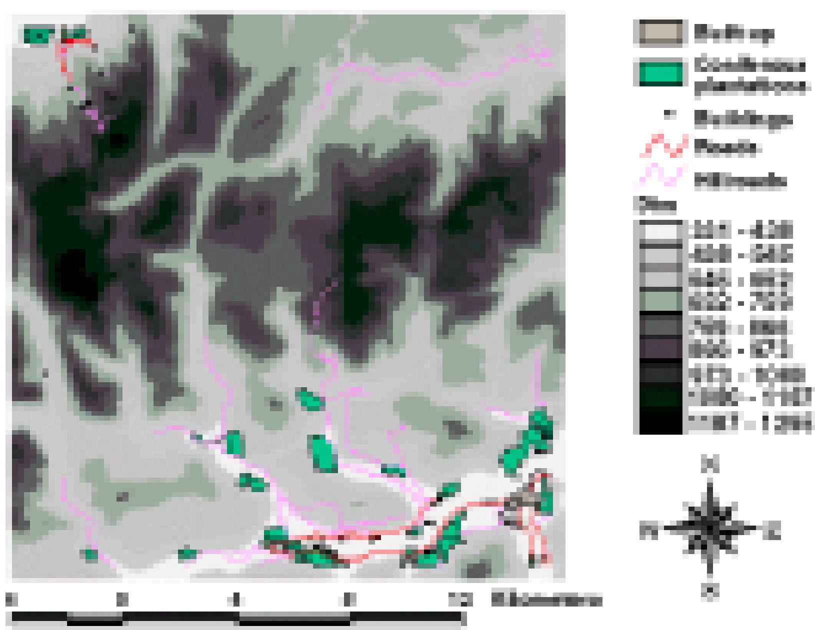

Figure 4—DEM and human artifacts for southwest Caringorms.

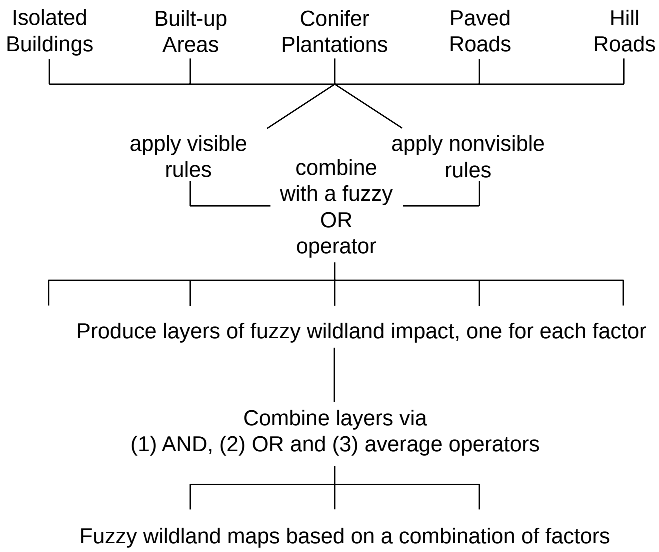

Figure 6—Methodological outline for processing fuzzy rules.

mapping of remoteness and artifactualism are described, using GIS-based models and fuzzy logic.

It has been shown that wild land is not easy to map, and it can only be done to a certain degree using measurable indicators. However, it is becoming increasingly important to try and quantify the less tangible resources such as wild land. For example, in a public inquiry, a stronger case may be made against the construction of a hydroelectric power scheme if quantitative data are available to demonstrate the more nonquantitative points of objection, such as the argument that the wild land character of a vast area may be spoilt. People arguing for a certain case feel much more confident when they can show a map of the size of the area that will be affected and to what degree it would influence people's 'wild land' perception. In addition, areas with wild land characteristics can only be objectively compared, when quantified. This approach allows the 'use' of an area in an optimal way and to provide an opportunity for satisfactory 'wild land experience' , while also maintaining the natural ecological processes in a relatively undisturbed state.

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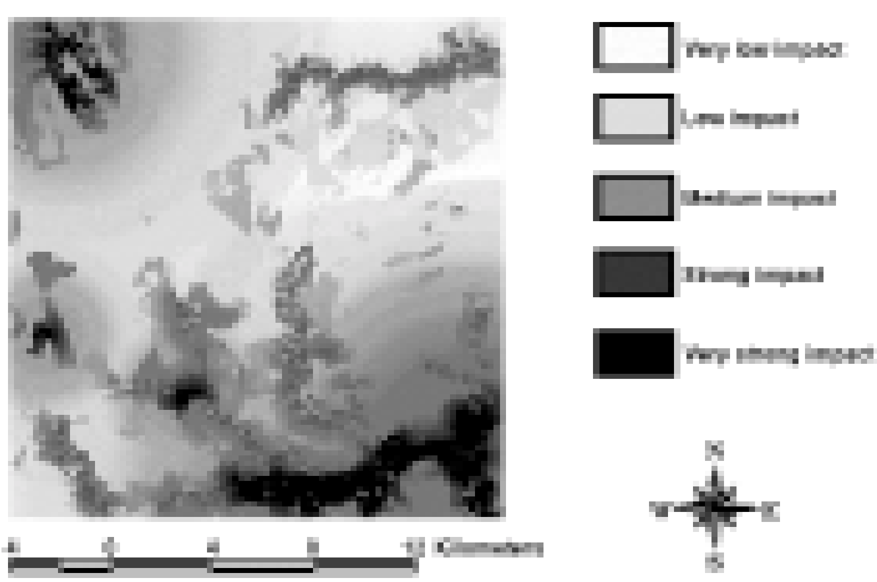

Figure 7—Fuzzy wild land map.

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