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Wildness Study in Wales

Final Report

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1 Introduction

In the last few years there has been a growing ecological, political and social interest in “wilderness”, “wild land” and “wildness”. The meanings are wide ranging and cover scales from large to small (Fisher et al., 2010). By comparing the different definitions it can be seen, that all have the following criteria in common: more or less human impact, low density of population, remoteness and inaccessibility, size, ruggedness, challenge and opportunity for physical recreation. Europe is currently developing strategies and guidelines for wilderness, wild land and non-intervention management that will ultimately influence the policies and thinking of Natural Resources Wales and the Welsh Government (European Commission, 2013).

The Welsh landscape is exceptionally varied with a diverse geography based on the complex interplay between geology, topography, location and biodiversity overlaid with the associated human veneer of land use, social and cultural histories. Central to Wales' nature conservation policies are its wilder areas represented within the remote and least modified corners of the Welsh countryside. Much research on wild land mapping has been done to date in Scotland. The Scottish National Parks have developed a strategy for mapping wildness using GIS and high resolution spatial data which has been extended and rolled out across the whole country. This has proved pivotal in informing the Scottish Government's thinking on wild land and the threats and opportunities acting on it. Such a mapping programme could provide similar benefits for Wales both environmentally, socially and economically. A Welsh wildness map has been developed here using the same methods and similar datasets (and so aid compatibility and reduce development times/costs) and is used to identify core areas for consideration within landscape and nature conservation policies.

1.1 A GIS-based approach

A GIS-based approach is developed here to identify the geographical extent and intensity of wildness in Wales. This is based on previous work on wild land quality mapping utilising GIS-based multi-criteria evaluation (MCE) and fuzzy mapping methods (Carver et al., 2012).

Established methodologies for the assessment and mapping of wilderness tend to focus on four basic criteria: “Perceived naturalness of land cover“, “Absence of modern human artefacts”, “Rugged and challenging nature” and “Remoteness from mechanised access”. The total value of wilderness was calculated by the equally weighted intersection of the above criteria. Because of the lack of a wild land policy in Wales, these and other physical attributes used in the identification of wild land are taken directly from Scottish Natural Heritage policy on wild land (SNH, 2002) and are expanded on in Table 2.1.

Table 1.1 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. 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.	Distance is not an absolute guide on its own, but most of the wild land 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.

The datasets and methods that are used to map these four attributes are described in detail in section 2 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, 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.

1.2 Developing a wildness model

Maps of the four attributes of wildness, as defined by SNH (2002), can be combined to produce a series of wildness maps for Wales 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, Carver et al., 2012). 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 1.1.

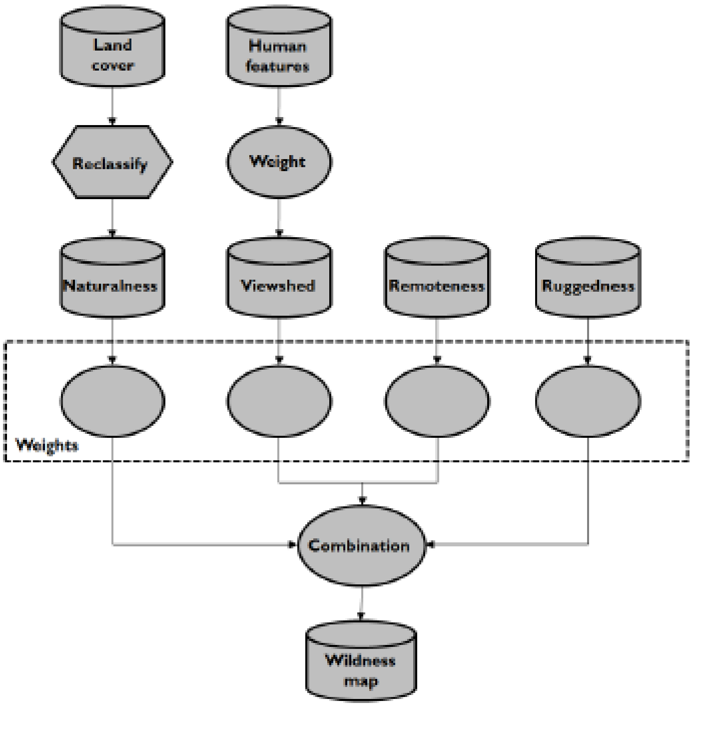


Figure 1.1 Flow chart showing how the data are parameterised by weights and combined to generate a wildness map.

1.3 GIS-based MCE model

The following GIS-based MCE model has been developed for mapping the wildness in the Scottish Cairngorm National park and for the whole of Scotland, respectively. This methodology was adapted to identify wildness areas in Wales. As a consequence of this, the Welsh mapping attributes are based on the public perception survey in Scotland as well as the SHN policy. The model illustrated in Figure 1.1 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 in Scotland.

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 1.2.

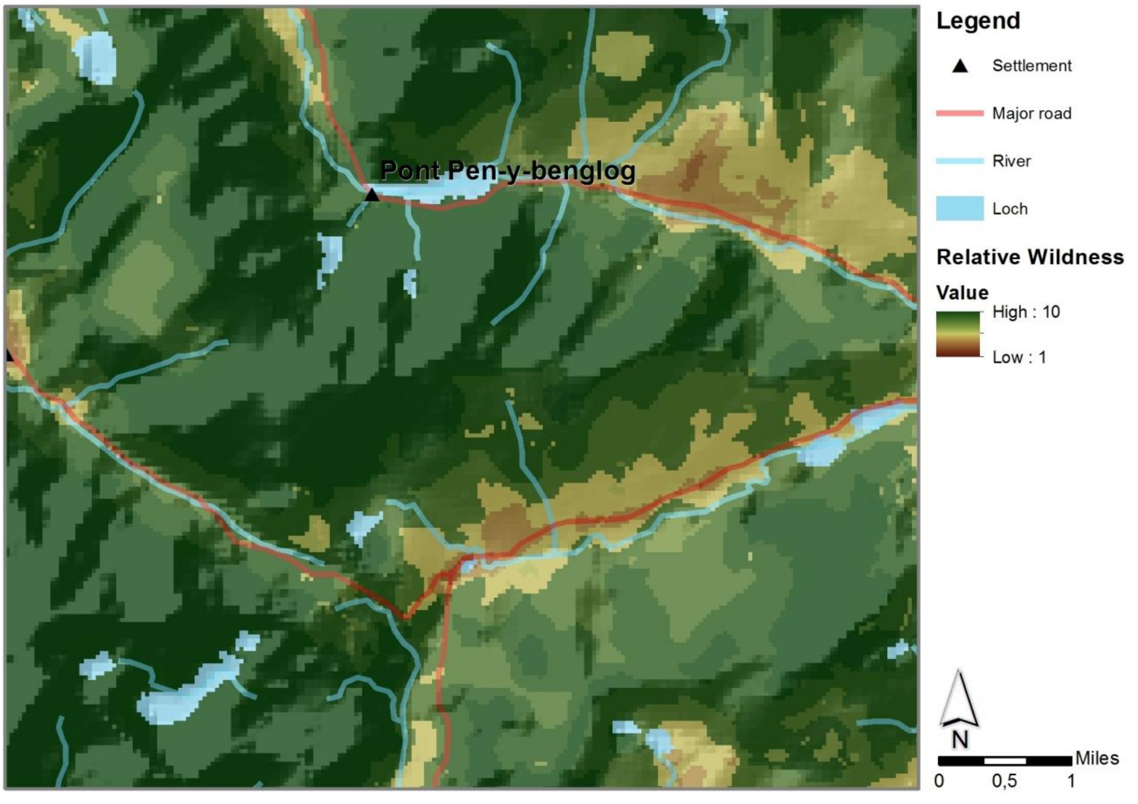


Figure 1.2 Example wildness map for Wales

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 3.1).

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. 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).

1.3.1 Derivation of model weights

It was noted, that the map attributes that were used in this approach were based on the perception study in Scotland (Appendix 1). Equal to this, the derived model weights for a variation of wildness map in Wales were also adapted from the Scottish wildness mapping project.

1.3.2 Equal weightings strategy

The weightings option was to weight all of the components of wildness equally. There are a number of reasons for doing this. 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. 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.

2 Attribute mapping

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 Wales plus a buffer zone of 30 km. 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 country boundary. These are described in turn, together with the data used, method of mapping and associated caveats/assumptions used.

2.1 Perceived naturalness of land cover

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 Wales. These include the Land Cover Map 2007 (LCM2007) as well as the Welsh data of the National Forest Inventory 2013 (NFI) combined with the data of the Ancient Woodland Inventory 2011 (AWI).

2.1.1 Data sources

Aspects of land management are identifiable from national land cover datasets such as the Land Cover Map 2007. These datasets are available from the Centre for Ecology and Hydrology (CEH). 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 (see Table 2.1). 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).

Table 2.1 Defining naturalness class

LCM-Class	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 LCM2006 are so are excluded. This has been split into Ancient Semi Natural Woodland (1.1a), Restored Ancient Woodland Site (1.1b) and Plantation on Ancient Woodland Site (1.1c) using the National Forestry Inventory data.	1	5 4 3
Coniferous woodland	All coniferous woodland. Generally planted in larger blocks and so are better defined. This has been split into Ancient Semi Natural Woodland (2.1a), Restored Ancient Woodland Site (2.1b) and Plantation on Ancient Woodland Site (2.1c) using the National Forestry Inventory data.	2	5 4 3
Arable and horticultural	All cropped lands including cereal crops, vegetables, ley pasture, and set-aside.	3	2
Improved grass	Any grassland that has continuous attempts at improvement including drainage, ploughing, reseeding, fertiliser application, etc.	4	2
Rough grassland	Contains low productivity „Improved Grassland" and acid, neutral and calcareous grassland, which could not be assigned with confidence to specific grassland Broad Habitats.	5	3
Neutral grass	Any semi-natural grassland on neutral soils/rocks. Some improvement may be present.	6	3
Calcareous grass	Any semi-natural grassland on calcareous soils/rocks. Some improvement may be present.	7	3
Acid grass	Any semi-natural grassland on acid soils/rocks. Generally not improved.	8	4
Fen, Marsh and Swamp	Areas characterised by vegetation types found on permanently, seasonally or periodically waterlogged soils.	9	4
Heather, Heather grassland	Vegetation dominated by dwarf shrubs (heather, bilberry, gorse, etc.). Two level 2 classes are distinguished: dense (10) and open (11) but both are considered of equal naturalness.	10,11	4
Bog	Areas of heath or moor vegetation with peat depth greater than 0.5m as defined by BGS.	12	5
Montane Habitats	All vegetated areas at altitudes greater than 600m	13	5
Inland Rock	Natural exposed rock surfaces such as inland cliffs, caves, screes and limestone pavements	14	5
Despoiled land	Artificial exposed rock surfaces various forms of excavations and waste tips such as quarries and quarry waste.	14	1
Saltwater	Saltwater is mapped to a limited extent around the coastline of the UK.	15	5
Freshwater	Water bodies > 0.5 ha are readily mapped, as are very wide rivers (>50 m).	16	5
Supra-littoral Rock	Features that may be present in this coastal class include vertical rock, boulders, gullies, ledges and pools.	17	5
Supra-littoral Sediment	Includes sand-dunes, which are reliably mapped in this class.	18	5
Littoral Rock	These classes are those in the maritime mask zone on a rocky coastline. They are generally more extensive than supra-littoral rock and thus more readily mappable from satellite images.	19	5
Littoral Sediment	is mapped spectrally, although there may be some confusion with the 'Supra-littoral sediment' class	20	5
Saltmarsh	Saltmarsh is a Priority Habitat and of sufficient extent and spectral distinction to be mapped consistently.	21	5
Urban	Includes dense urban, such as town and city centres, where there is typically little vegetation. 'Urban' also includes areas such as dock sides, car parks and industrial estates.	22	1
Suburban	'Suburban' includes suburban areas where the spectral signature is a mix of urban and vegetation signatures.	23	1

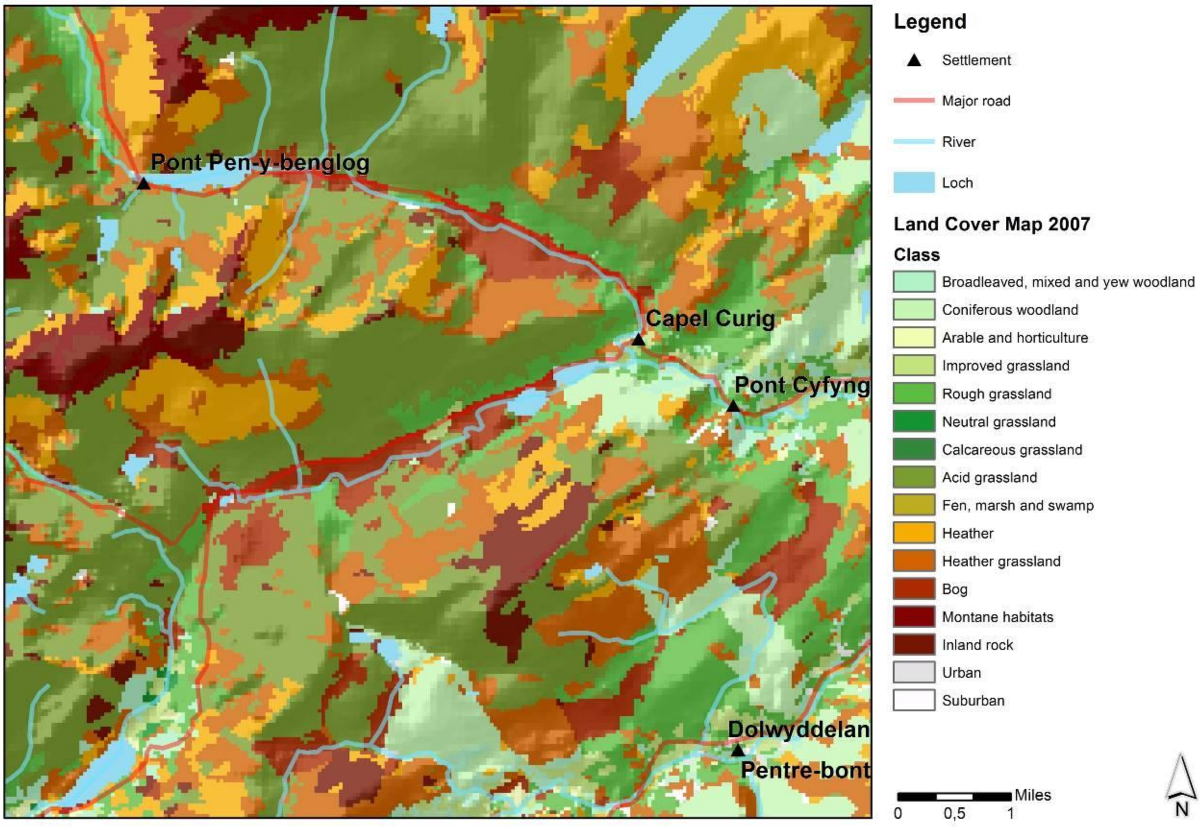
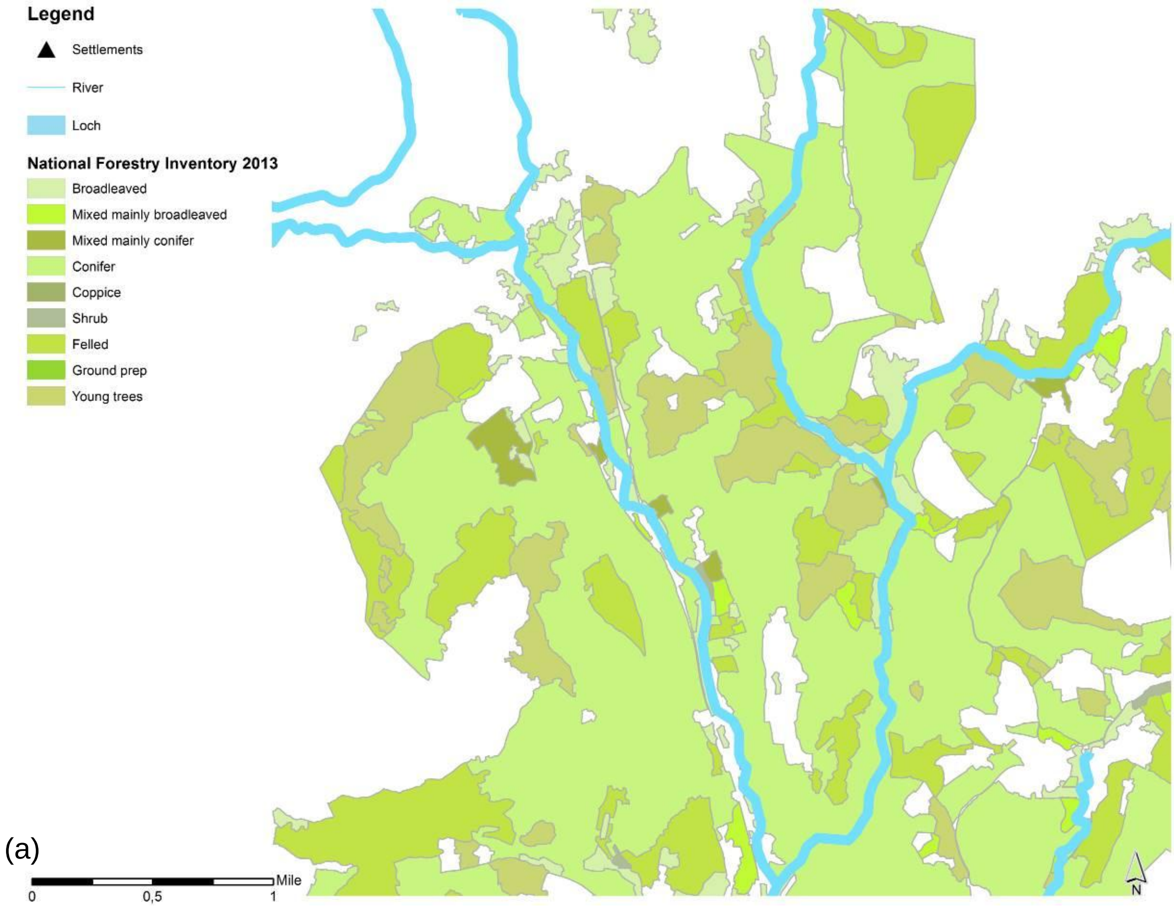


Figure 2.1 Example land cover dataset

The woodland data of the National Forestry Inventory is an alternative to using the woodland data of the LCM2007. It has the advantage of including all areas of woodland over 0.5ha and open areas over 0.5 ha, that are completely surrounded by woodland. The result is a more detailed classification of woodland, as shown in Figure 2.2. Furthermore the integration of the Ancient Woodland Inventory (AWI) allows a distinction between "Ancient Semi Natural Woodland", "Restored Ancient Woodland Site" and "Plantation on Ancient Woodland Site" (Figure 2.3). From both datasets (NFI and AWI) it is possible to derive the naturalness values of woodlands which were substituted the naturalness values of the LCM woodland classes "Broadleaved, mixed and yew woodland" and "Coniferous woodland", respectively.



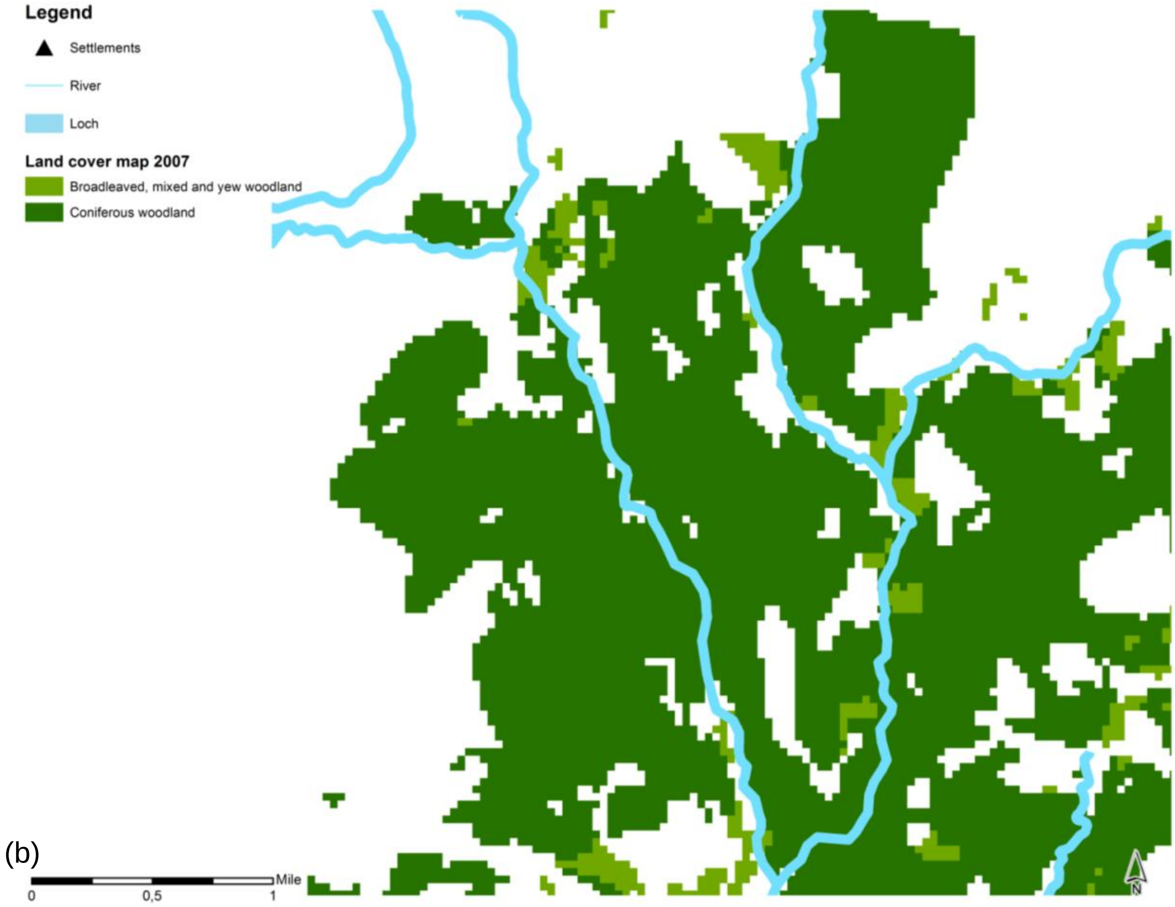


Figure 2.2 Comparison between (a) the data of the NFI and (b) the woodland data of the land cover dataset

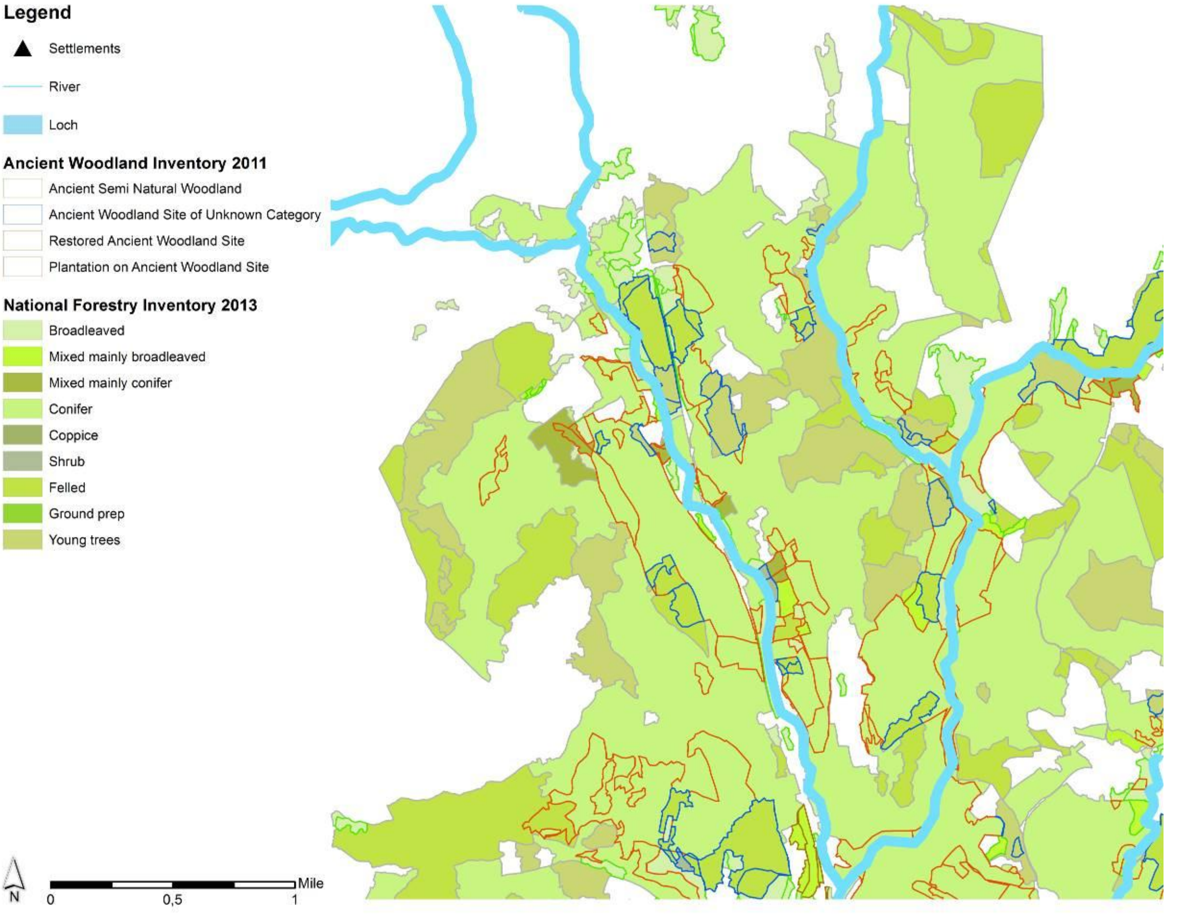


Figure 2.3 Example Ancient Woodland Inventory dataset

As well as the woodland data, the data on the water bodies can't easily be subdivided between "natural water bodies" or "modified water bodies." Therefore the more exact data of the Meridian 2 data would be used for a better classification of this land cover type.

2.1.2 Method

A combination of the LCM2007, National Forestry Inventory data, Ancient Woodland Inventory data and Meridian 2 data is used to create a composite land cover map at a nominal resolution of 50m which is then reclassified into 5 naturalness classes shown in Table 2.1. 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 2.1 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 30km outside the Welsh boundary and clipping the resulting data using the county boundary for use in subsequent analysis.

The resulting attribute map is shown in Figure 2.4 below.

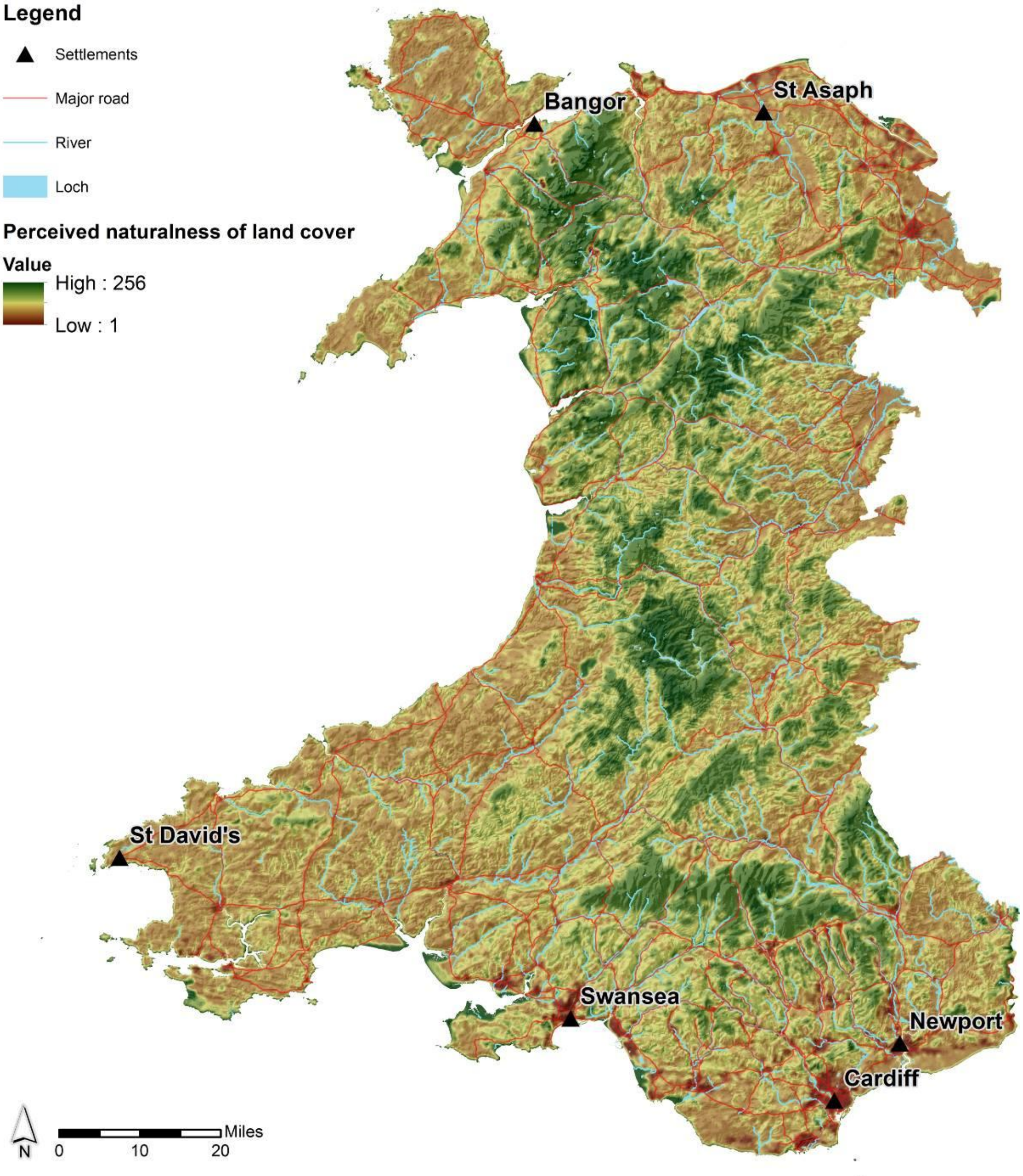


Figure 2.4 Perceived naturalness of land cover

2.1.3 Caveats and assumptions

The LCM2007 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 LCM2007 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 LCM2007 land cover classes due to differing levels of management 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 Meridian2, NFI, - and AWI data. In addition to it, the inclusion of more detailed dataset leads to a necessary assessment about the level of human impact in land types. For instance, the LCM 2007 data wouldn't show, either the conifer is plant or natural. Hence, through the combination of the AWI data and the NFI data it can be derived a natural score that is more accurate. Although it should be mentioned, that the intersection of the NFI and the AWI data is spatial limited, so 30% of the AWI data is matching the NFI data. Reasons for that could be the time difference of the survey as well as the fact that different classification methods are used between these dates.

2.2 Absence of modern human artefacts

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, buildings and other built structures as wind turbines.

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. Work by Carver (2005 and 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 people 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 LCM2007 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 Scottish perception study about which artefacts are deemed to have an impact on wildness, together with the Ordnance Survey 1:50,000 50m Panorama terrain data and a novel and rapid viewshed assessment method developed for the project.

2.2.1 Data sources

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).

Modern human artefacts are extracted from the different data sources as shown in Table 2.2. These are divided into a number of discrete classes as follows:

- Railway lines, roads and tracks
- Buildings
- Wind turbines

The use of 50m Panorama DEM (Digital Evaluation Model) of the Ordnance Survey 1:50,000 data provides the height of the terrain. However, the viewshed calculations require information about the surface. Due to a missing digital surface model, which would include the height of human artefacts, the DEM has to be modified in advance by adding an average height of human artefacts, which is shown in Table 2.2:

Table 2.2 Additional height of the human artefacts

Human artefacts	**Data source**	**Added height to the DEM**
Buildings	LCM2007	
- Urban		20m
- Suburban		10m
Roads, tracks, railways	Open Street Map	3m
Wind turbine	POI - Ordnance Survey	individual

The visibility analysis for the wind turbines were processed separately as they require a higher maximum visibility distance. For that a 100m DEM of the Ordnance Survey was used with the added height of the single wind turbine.

2.2.2 Method

The use of visibility analyses in GIS that incorporates both a DEM 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. These are applied in the cumulative weighted viewshed methodology. 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.

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 2.3), 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 2.5 shows the voxel viewshed transform software interface the feature layers loaded.

This approach is therefore adopted here utilising the modified DTM and feature data extracted from the in Table 2.2 shown data sources. 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.

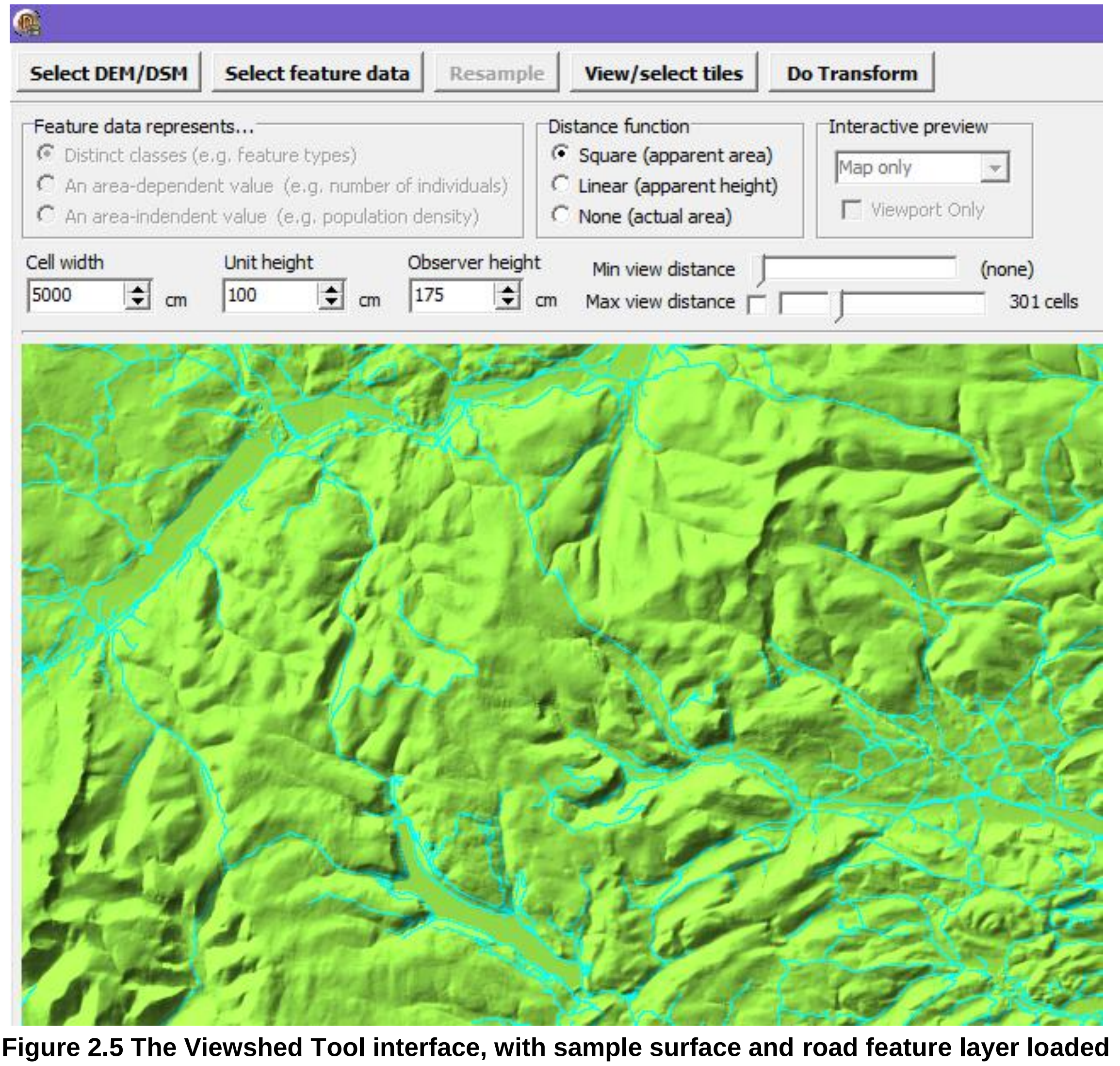
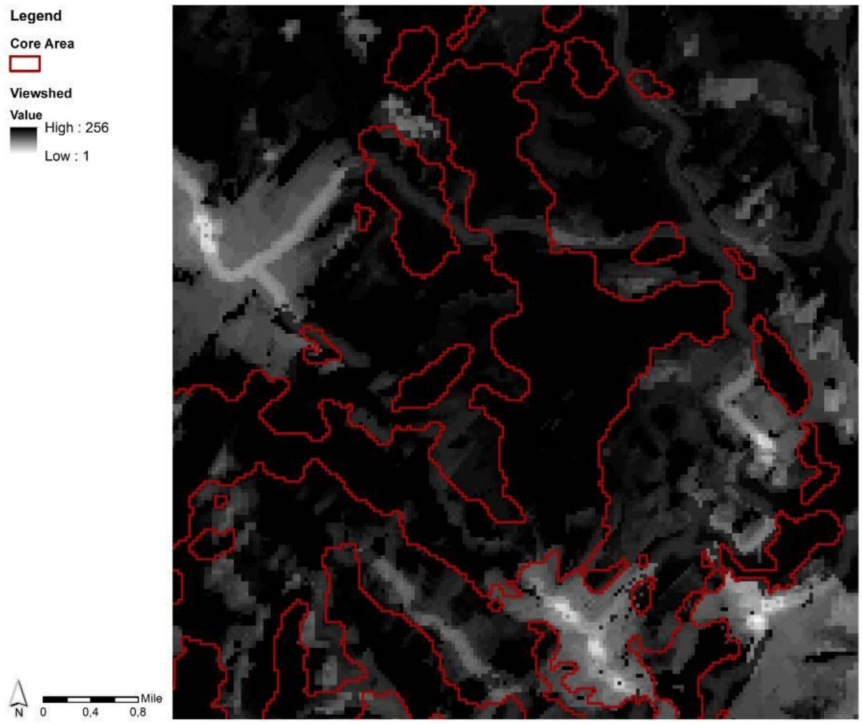


Figure 2.5 The Viewshed Tool interface, with sample surface and road feature layer loaded (blue lines)

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 Wales. 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.

Example outputs from the voxel viewshed transform are given in Figure 2.6. 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 2.7.

(a)



(b)

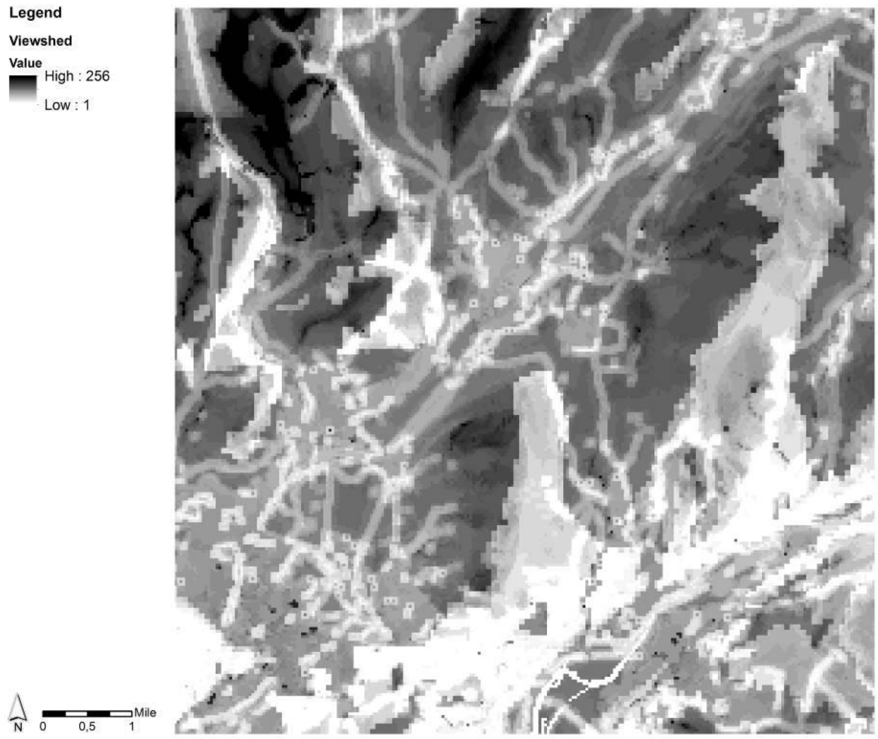


Figure 2.6 Example output showing detail in (a) core and (b) strath locations

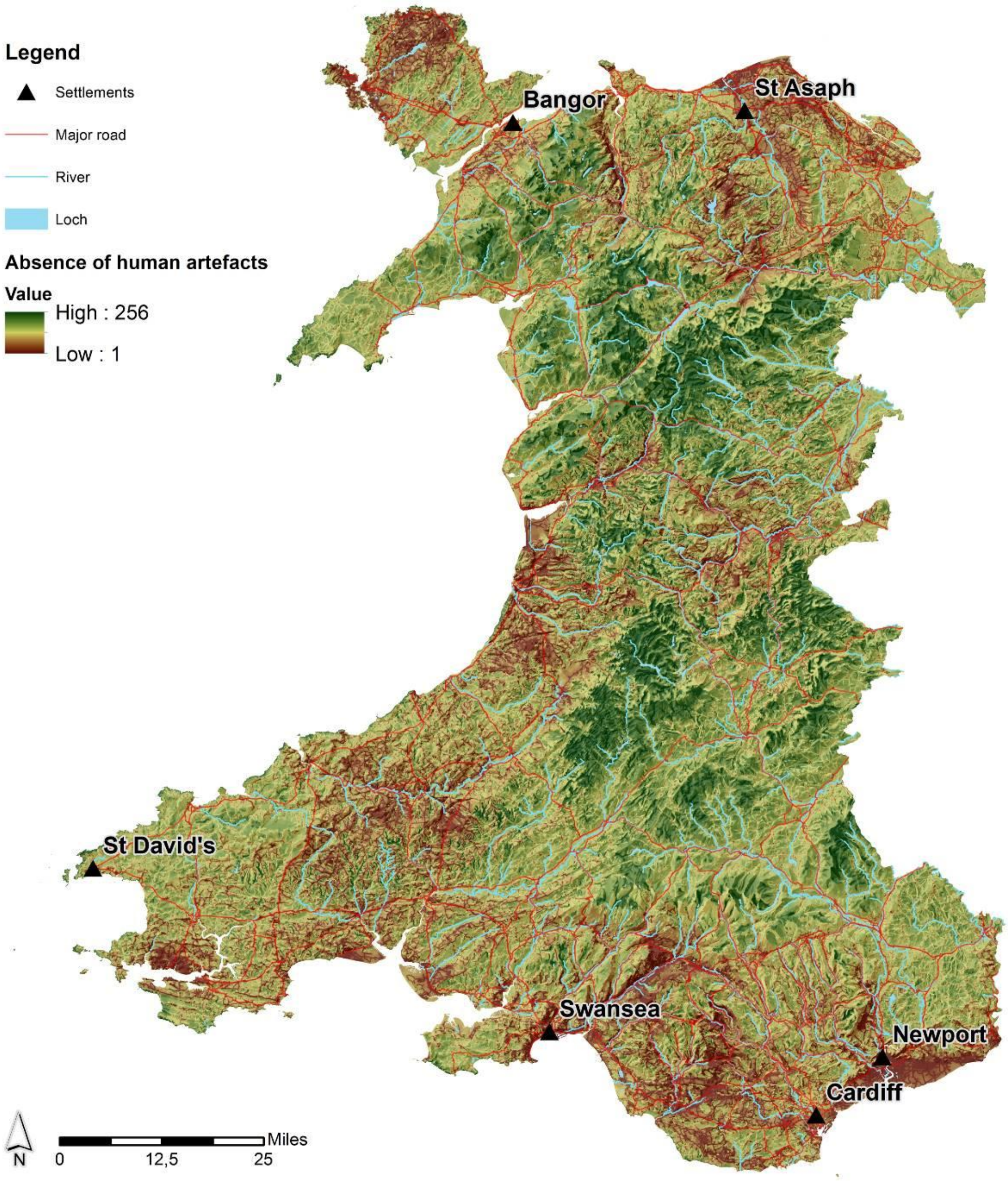


Figure 2.7 Absence of modern human artefacts

2.2.3 Caveats and assumptions

The main problem was caused by the incomplete base data and also by the lack of a digital surface model. Firstly, the data of the buildings were extracted of the LCM data, hence the building data is heavily generalised as well as the height of the buildings is an average value. Secondly the wind turbines dataset of the Ordnance Survey doesn't contain all wind turbines of Wales. By comparison between the UK Renewable data and the POI data, it can be seen, that several wind turbines farms are missing. Both facts encourage an optimistic result for the visibility analysis. Further compromises and customisations are necessary in order to make the task manageable. These include:

- The cell resolution in this instance was limited to 50m for buildings, roads tracks and railways; 100m for wind turbines;
- 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 30km for all features except wind turbines, where this is increased to 60km.

2.3 Ruggedness of the terrain

The nature of the terrain within Wales 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 Wales.

2.3.1 Data sources

The Ordnance Survey 50m Panorama DEM is used here to represent the terrain surface of Wales.

2.3.2 Method

Ruggedness is calculated from the Ordnance Survey 50m Panorama 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. This is hown in Figure 2.7.

2.3.3 Caveats and assumptions

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, 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 2.2.

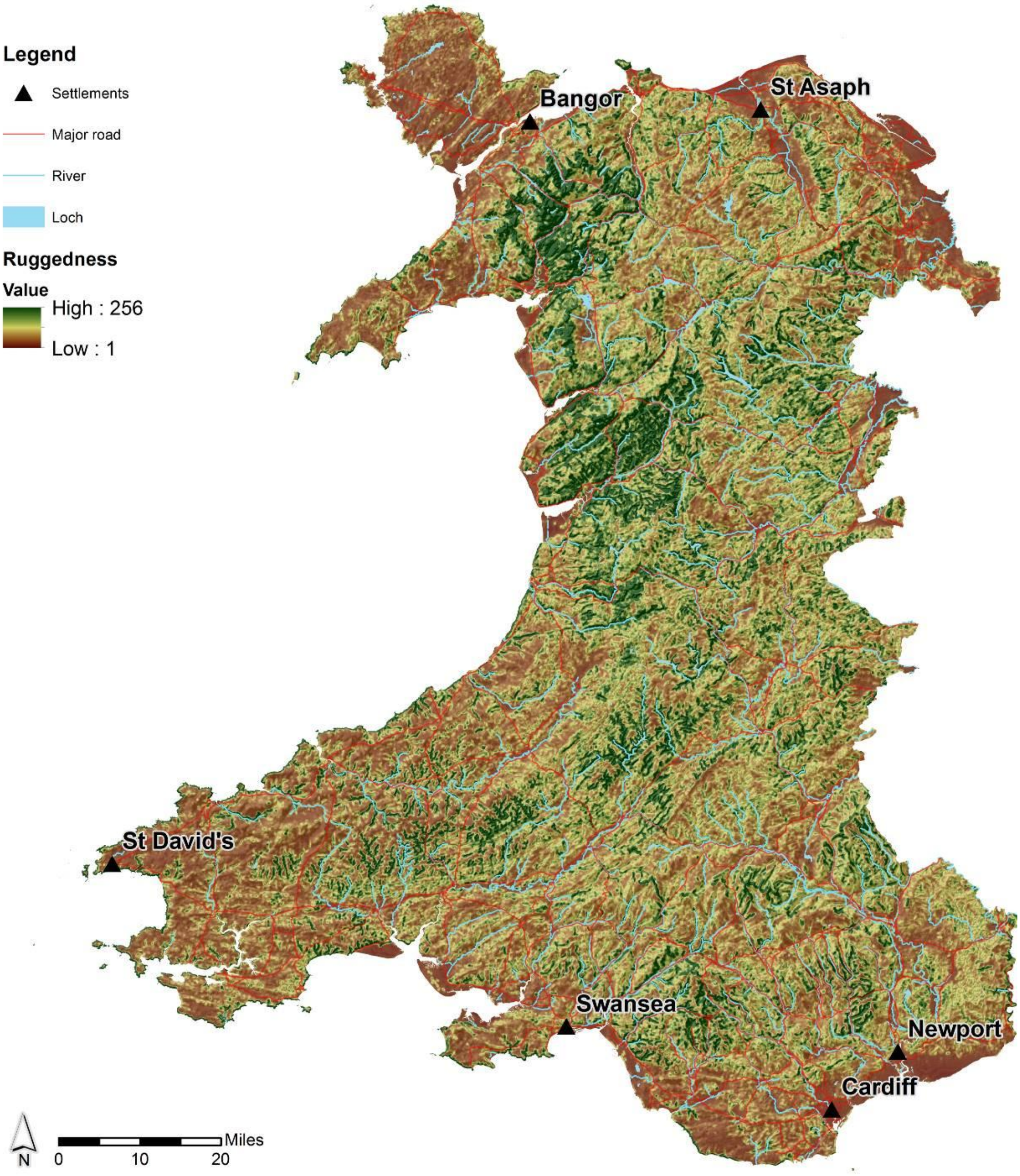


Figure 2.8 Ruggedness of the terrain

2.4 Remoteness

Given the varied and challenging nature of the terrain found within Wales it is essential to include terrain as a principal variable governing remoteness with in the county. Remoteness is mapped in Wales 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. 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 anisotropic 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 barrier features as "null" values which force a detour.

2.4.1 Data sources

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 Ordnance data is used for the DEM, the LCM2007 combined with the NFI data for the land cover data, and OSM for the road, track, foot bridges, open water and river data.

2.4.2 Method

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. The roads and tracks data from the OSM data is used to amend the cost surface as having the least resistance to movement with a speed of 10km/hr where it is possible to use a mountain bike to gain more rapid access to the core areas.
- *Barriers to movement:* These are taken to include rivers that appear as polygons (i.e. showing both left and right banks) in the OSM data, slopes that are greater than 45 degrees from the horizontal and open water/lochs.

2.4.3 Caveats and assumptions

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 (0.55m/s) are assumed for the “heather” “forest” and “bog” categories, respectively. The angle at which the terrain is crossed (i.e. the horizontal and vertical relative moving angles11) 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 2.3. The road network, both within and outside the boundary of Wales, is used as the access points from which to calculate remoteness of off-road areas. Where the boundary of Wales is not defined by a road, the road network out with 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 could be found to be incomplete, because the Open Street data is an open source with no guarantee that the used dataset are complete.

Due to the fact, that the resolution of the data was set to 50m, all polyline data had to be expanded by one pixel to guarantee a width of 50m per polyline feature. This caused a spatial overlapping between the barrier feature and the roads and footpath feature. Therefore it was decided to order the priority of the feature as following:

- Barrier crossing
- Barrier feature
- Cost Surface (including roads, railways, tracks, footpath)

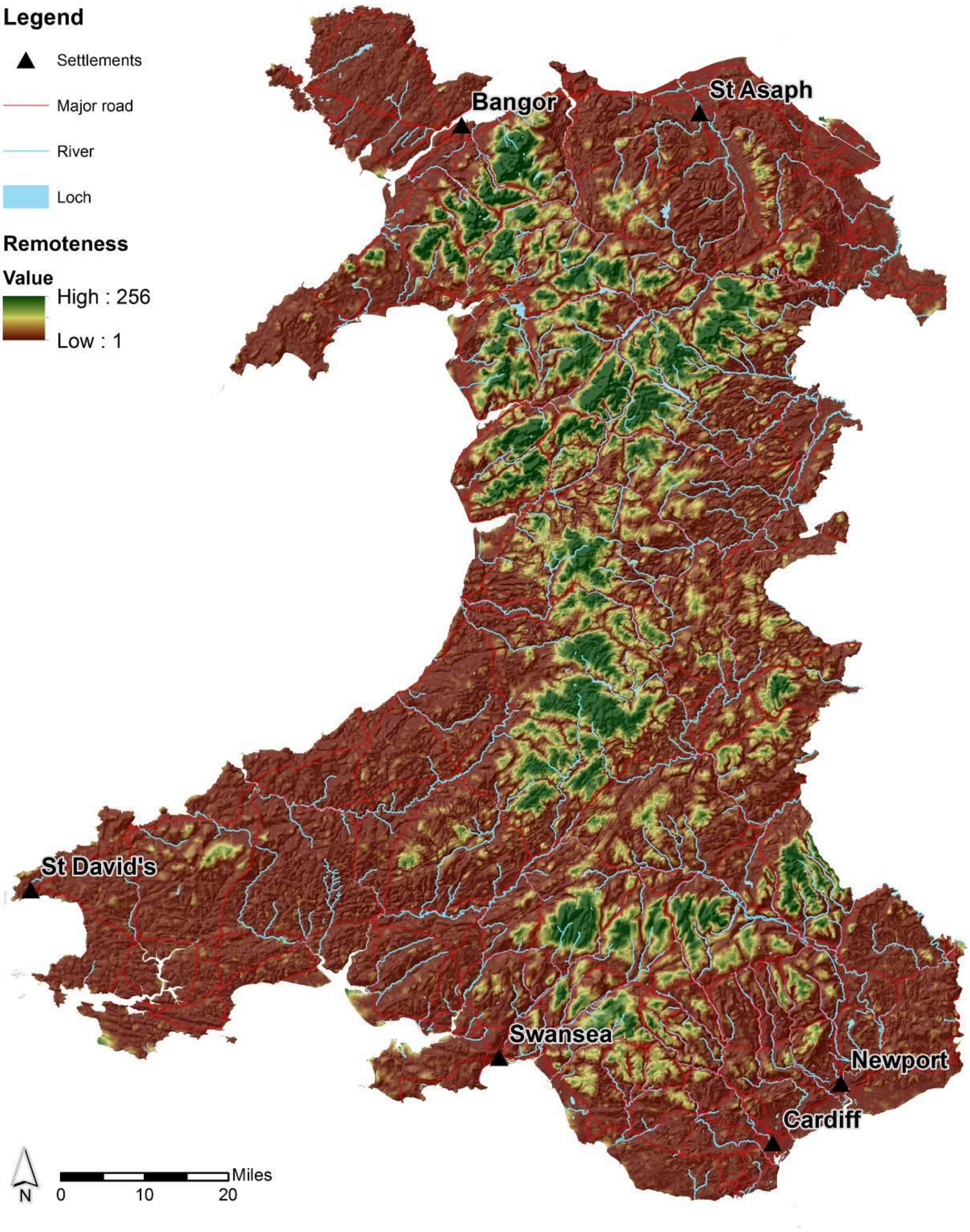


Figure 2.9 Remoteness

2.5 Checks for autocorrelation

In any MCE model it is preferable that the input map layers are not highly spatially autocorrelated. This is described in section 3. All input layers are cross correlated to check for similarity. The correlation matrix shown in Table 2.4 shows that there is only a very low correlation between any of the attribute maps used in this project. In section 1.3 it was predicted that the ruggedness and remoteness might show any real degree of autocorrelation. But in this case, the scores of the perceived naturalness and remoteness are highest correlated of the attributes. This could be a consequence of the Land Cover data 2007, which were used for both criteria. Even so, the degree of autocorrelation between perceived naturalness and remoteness is still only 0.61 and well within the limits normally required by MCE methods.

Table 2.4 Attribute map correlation matrix

Attribute	Perceived naturalness	Remoteness	Absence of human artefacts	Ruggedness
Perceived naturalness	-			
Remoteness	0,61876	-		
Absence of human artefacts	0,4055	0,37746	-	
Ruggedness	0,37879	0,24658	0,25666	-

3 Results: Wildness in Wales

The methodology described in section 2 is applied across the whole of Wales at a base resolution of 50m using the attribute maps described in section 2. 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.

The map in Figure 3.1 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 a perception survey run in Scotland are applied here to illustrate this point.

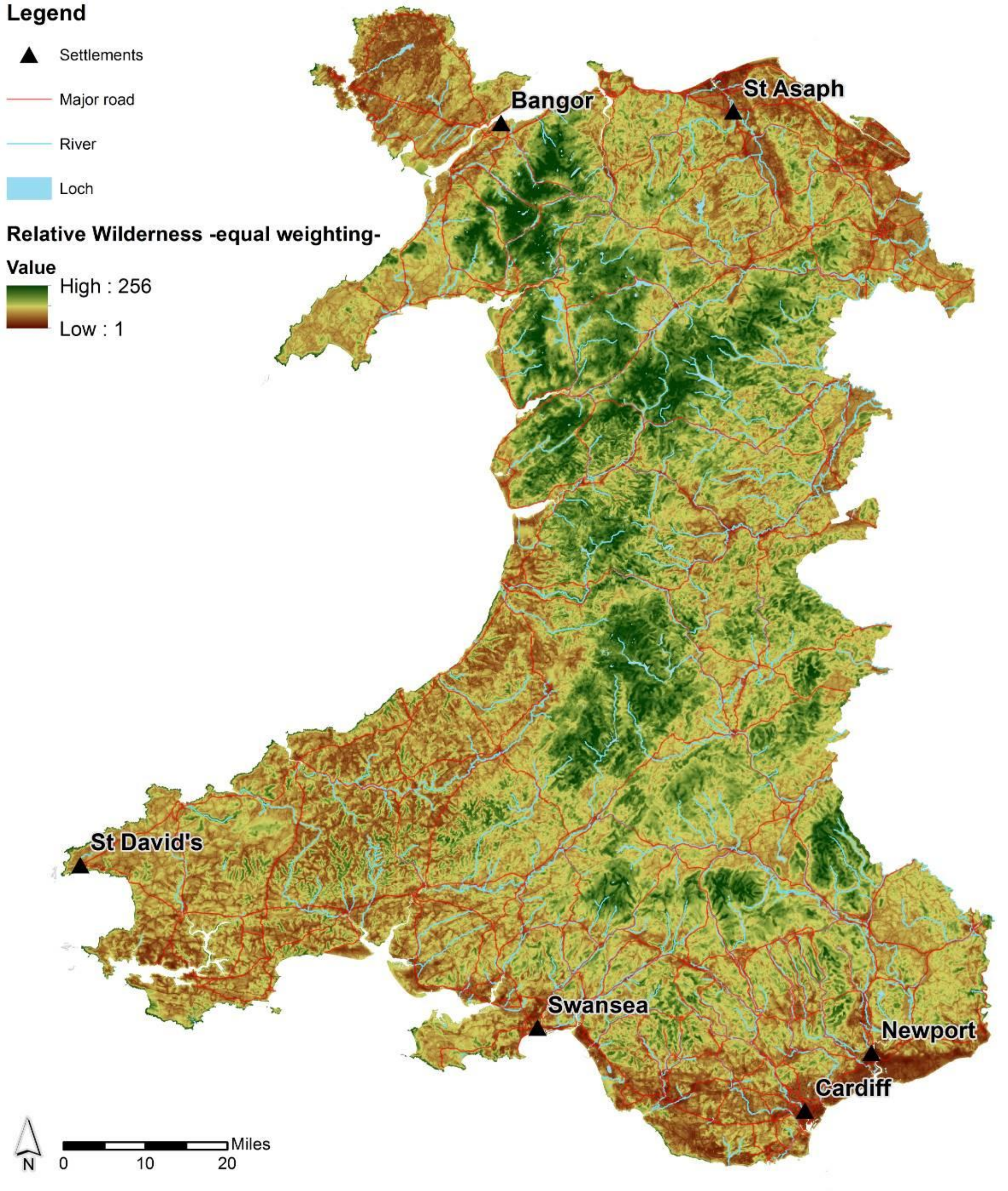


Figure 3.1 Equally weighted model

The maps shown in Figures 3.1 and 3.2 show the model results from applying two sets of weights derived from the Scottish perception survey as described in section 3.2 and Table 3.1

Although these data are derived from surveys of the Scottish population undertaken by SNH (SNH, 2008) there is no equivalent survey data for Wales at this time so the Scottish perception survey data are taken here as illustrative of likely differences between Welsh national residents and residents in the national parks (see Appendix 1). These two maps therefore show the likely spatial pattern arising from subtle differences in the way that people living inside and outside the Welsh national parks might perceive wildness. The Scottish survey derived weights used are as follows:

Table 3.1 Weights for the Scotland and the 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

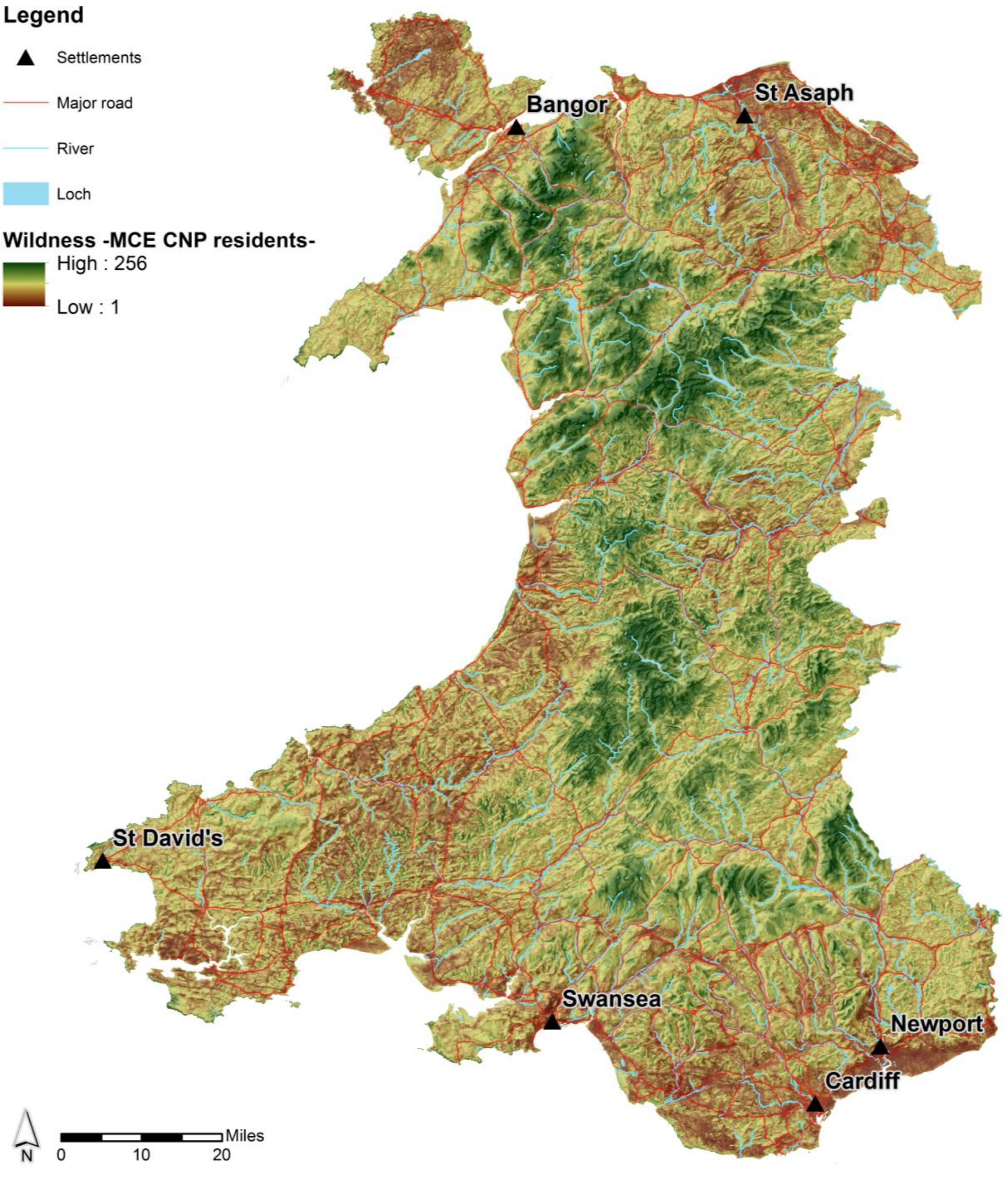


Figure 3.2 Weights from the CNP residents group

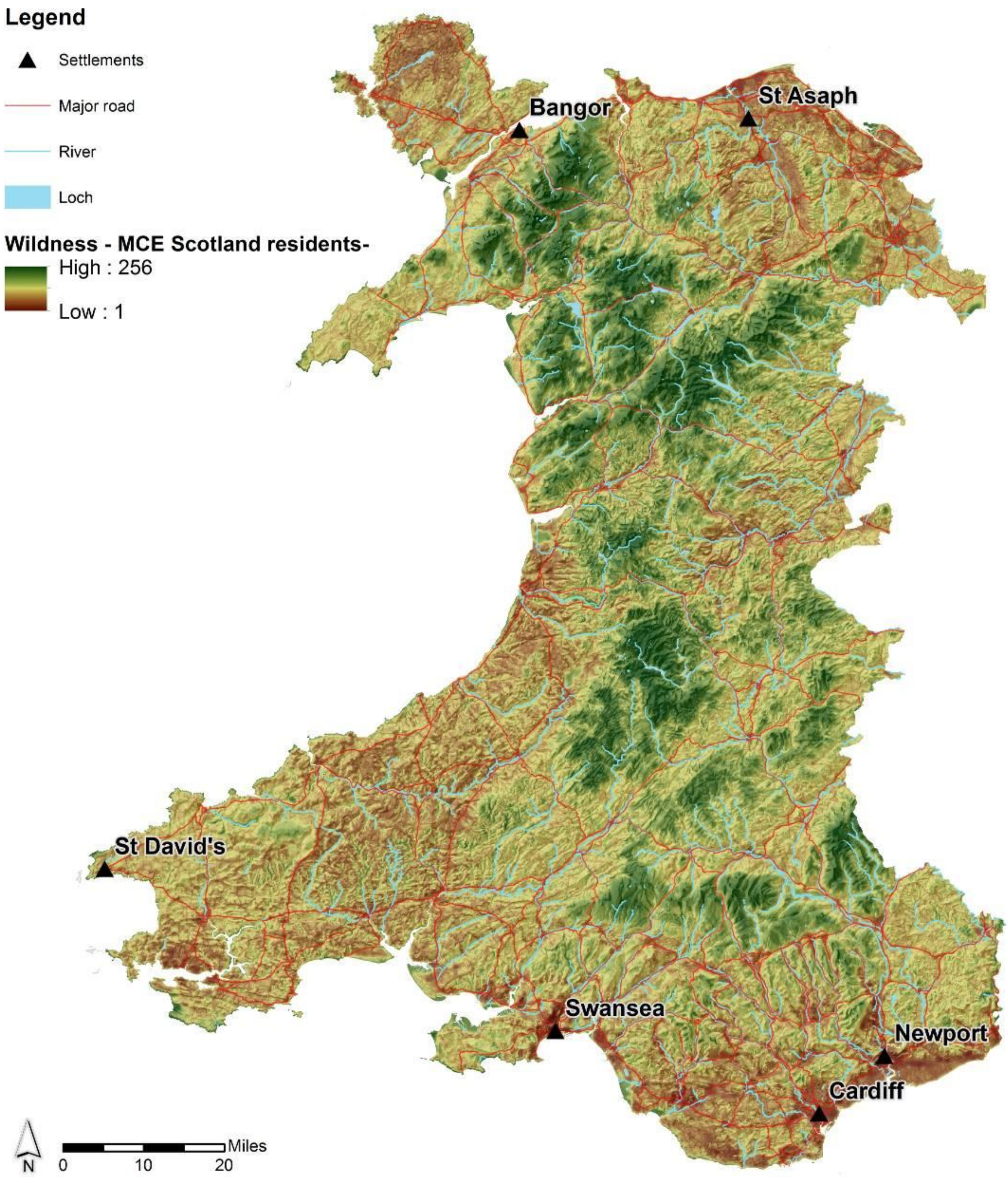


Figure 3.3 Weights from the Scotland residents

3.1 Comparison between Scotland and Wales

Combining the attribute maps using the MCE/fuzzy methods and different weighting schemes and inputs described in sections 2 and 3, generates overall wildness maps shown in Figures 3.1 to 3.3. Using the equally weighted map in Figure 3.1 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 3.2 and 3.3, 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. Nevertheless, there are still some interesting and relevant problems to be addressed.

In terms of switching the focus from a local to a regional scale the robustness and associated confidence of this method would be regarded as slightly lower. Because of adopting the Scottish wildness approach, it is interesting to compare both mapping results to look for any obvious differences in pattern and magnitude. In Figure 3.4 the Welsh and the Scottish map were merged together with the application of the same stretched output values to make them comparable.

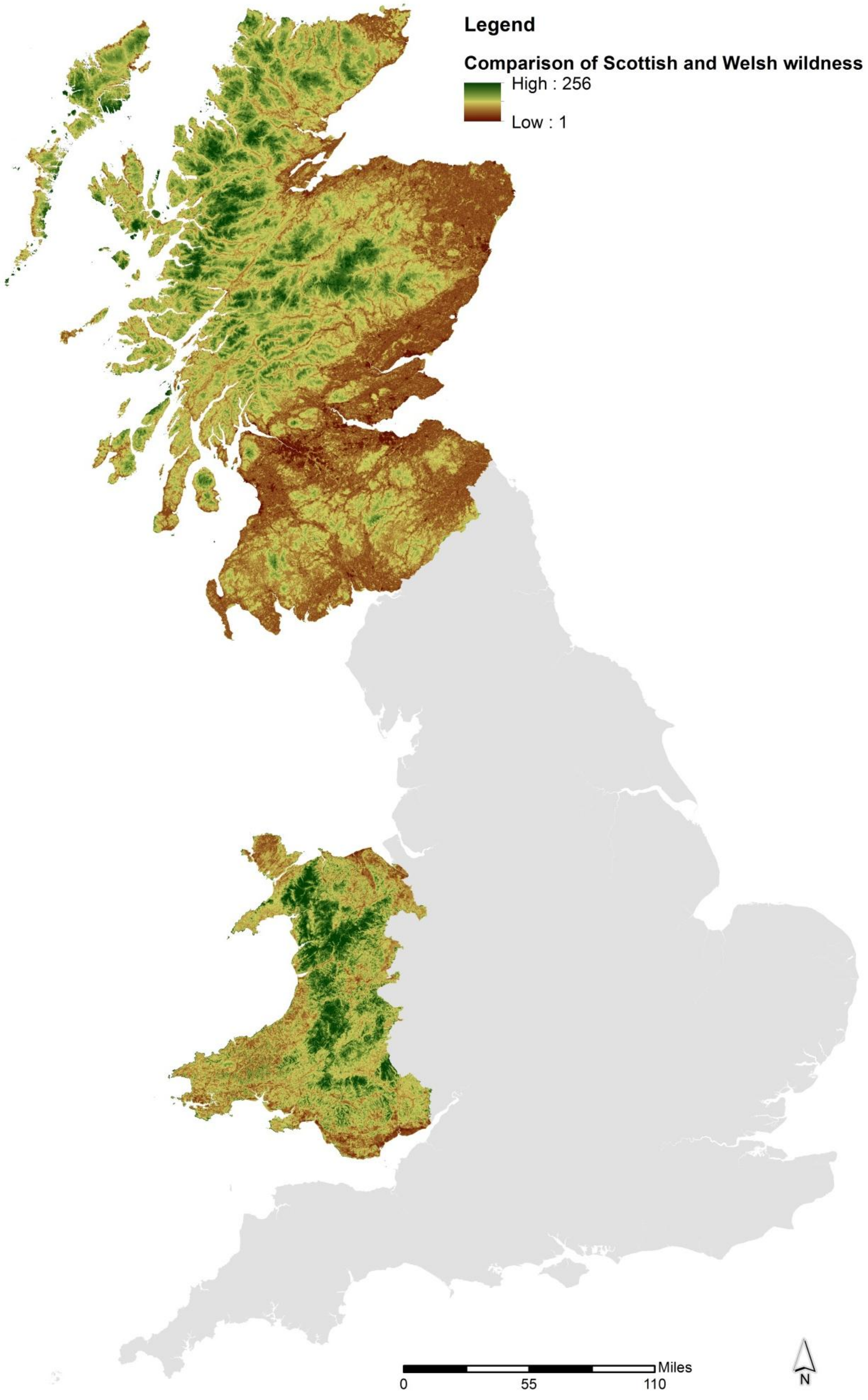


Figure 3.4 Comparison between the Scottish wild areas and the Welsh wild areas

Although it would be expected that Scotland shows a higher spatial distribution of wildness areas, but in this case Wales appears to have the higher results. This result emphasises some of the main problems in mapping wildness. Firstly a regional or global wildness mapping requires a standardised understanding of “What is wildness?” and “Which attributes could be used for mapping wildness?”. Secondly the base data has to possess the same level of quality as measured by resolution, accuracy and choice of datasets used. In contrast to the Scottish mapping this project was mainly based on open source data, so the quality of completeness and the accuracy were understandably lower. This is especially true of the visibility analysis which had to be performed with a incomplete wind turbine data as well as generalised building data. This has resulted in an over estimation of the wildness for Wales in terms of absence of modern human artefacts attribute. The last aspect is that wildness is also dependent on the prevailing climate, the occurring soil types, the land use etc., which is naturally different in every region. So to map wilderness in a comparable way, all of the above mentioned points have to be taken into account. Even if the same methods were used, there would be no guarantee for a high quality of cross-comparability and transnational differences.

3.2 Wild land typology

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 McMorran et al. (2008) in their review of the benefits and opportunities attributed to Wales‘s landscapes of wild character. This would help place the wildness maps developed above into the wider context of emerging Welsh policy on wild land areas in Wales. 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.

3.3 Further work on model weights

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) This pixel is wild
2) This pixel is not wild
3) 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) (Comber et al., 2010).

4 Conclusions and recommendations

As stated in section 3.1, this GIS-based methodology delivers a clear and robust approach to mapping wildness attributes and wildness maps within Wales. However, because the model is based on a common understanding and appreciation of the components of wildness of the Scottish landscape, and the Cairngorms in particular, this approach should be adapted according to the Welsh understanding of wildness if it is to be more widely used to support future decisions about the landscapes of Wales.

The resulting attribute maps described in section 2 and the wildness maps described in section 3 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 3.1-3.3 could further enhance the 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 how it is interpreted.

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

Recommendations

However, the data, analyses and maps presented here are, despite being useful drafts and indicators of general patterns, are not the final versions. It is recommended that the mapping be redone and enhanced using datasets that are more comparable to the work carried out by SNH in the Scottish mapping work. Several reasons for this are listed below:

1. Secure access to the more accurate MasterMap and NextMap data. The use of incomplete data within the work reported here and thus the potential sources of misclassified wildness areas could be reduced to a minimum by using the same data as used in the SNH mapping programme. This will ensure that the results of the wildness mapping in Wales could be better compared with the wild land areas in Scotland and formalised in Scottish Planning Policy.
2. A new wildness perception survey should be carried out for Wales to capture the distinctive local, regional and national identity associated with Wales' wilder landscapes. It is assumed that there will be subtle differences between the different areas within Wales and that the national pattern in perceptions regarding the attributes of wildness will vary from those identified in the Scottish surveys. This could follow the methodology developed by the Loch Lomond and The Trossachs National Park with MVA Consultants and/or use online surveys. One opportunity here would be to use Participatory GIS surveys to better elucidate the spatial and contextual patterns in people's perceptions of wildness and its attributes (for example using the Map-Me toolkit http://map-me.org).
3. New weights specific to Wales could be derived from the perception survey to identify acceptable and robust wild land areas utilising suitable classifications, either from the SNH Phase 2 methodology or fuzzy/Bayesian methods identified by Comber et al (2010). These could then take local and regional ideas of wildness into account (i.e. mapping the distinctive "Welshness" of wild land patterns). These could be compared against both random weights and those derived from the Scottish perceptions surveys to further elucidate the distinctiveness of Welsh wild landscapes.
4. Core area maps and associated attribute maps could be used to identify target areas for rewilding based on identifying those areas with attributes that fall short of being regarded as high wildness yet can easily be improved with local mitigation measures.

For example, an area might fall short of being classified as core wild land because of the effects of grazing pressure on the perceived naturalness attribute, whilst all other attributes are in the highest wildness class. Such an area could easily be rewilded by reducing grazing pressure or removing it entirely, thus bringing that area into the highest wildness class (see McMorran et al. 2008). This approach can be elaborated using those principles of spatial ecology concerning concepts of adjacency, expansion, infill, connectivity etc. thereby consolidating local and regional patterns of wild land at a landscape scale.

5. The wildness maps could be used as friction surfaces in wildlife connectivity modelling at landscapes scales to further develop and inform existing Forest Habitat Network plans. Such an approach can be used to better inform decision making about the design and development of green and blue corridors for existing indicator species and identify potential release sites for extinct keystone species (i.e. missing predators such as lynx) at some point in the future.
6. Take the opportunity to source data sets on water catchments and water quality/flow monitoring collected under the EU Water Framework Directive. This will provide a basis for future research projects on linking wildness to water quality, flow regimes and sediment yields using a watershed-based analysis of wildness. Such work will help provide the essential link between wilder landscapes and the provision of ecosystem services such as carbon storage and sequestration, flood water retention, water quality, nutrient balance, sediment stripping, provision of aquatic habitats and recreational environments.

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Appendix 1 *The perception survey* *(Source: Carver et al., 2008)*

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 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?‖

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.

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

Contractor derived weights

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

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	

Summary

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.

A newer perception survey is available that was developed with the Loch Lomond and The Trossachs National Park by MVA consultants in 2011. This provides additional evidence to suggest that there are similar differences between Scottish versus national park residents, which might equally apply to Welsh versus Welsh National Park residents in a similar fashion. The Loch Lomond perception survey is available online at: http://www.lochlomond-trossachs.org/looking-after/public-perception-survey-of-wildness-in-scotland-2012/menu-id-414.html

Appendix 2 Summary of the used data

Attributes	Main Criteria	Data Base	Source	Date
Perceived naturalness of land cover	Functioning natural habitats Unmodified catchment systems	Land Cover Map 2007	Centre of Hydrology and Ecology	2007
		National Forestry Inventory	Forestry Commission UK	2013
		Ancient Woodland Inventory	Forestry Commission UK	2011
		Meridian 2 National	Ordnance Survey	01/2014
		Strategi	Ordnance Survey	01/2014
Absence of modern human artefacts	No recent buildings/works Little impact from large structures outside area	Open Street Map Data	Open Street Map	November 2014
		Land Cover Map 2007	Centre of Hydrology and Ecology	2007
		Points of Interest – wind turbines	Ordnance Survey	March 2014
		Panorama Digital Elevation Model 50m	Ordnance Survey	July 2014
Rugged and challenging nature of the terrain	Striking topographic features and difficult terrain Natural settings for recreation providing hard physical exercise and challenge	Panorama Digital Elevation Model 50m	Ordnance Survey	July 2014
Remoteness from mechanised access	Distance from settlement and communications Limited access either by scale of area and/or lack of easy access	Open Street Map Data – road network, footbridges, tracks	Open Street Map	November 2014
		Land Cover Map 2007	Centre of Hydrology and Ecology	2007