A GIS model for mapping spatial patterns and distribution of wild land in Scotland

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Abstract

This paper presents a robust and repeatable method for mapping wildness in support of decisions about planning, policy and management in protected landscapes. This is based around the application of high resolution data and GIS models to map four attributes of wildness: perceived naturalness of land cover, absence of modern human artefacts in the landscape, rugged and challenging nature of the terrain, and remoteness from mechanised access. These are combined using multi-criteria evaluation and fuzzy methods to determine spatial patterns and variability in wild land character. The approach is demonstrated and tested for two national parks in Scotland: the Cairngorms National Park and the Loch Lomond and The Trossachs National Park. This is presented within a wider debate on the ability of such models to accurately depict and spatially define the concept of wildness within both the Scottish setting and the wider global context. Conclusions are drawn as to scalability and transferability, together with potential future applications including local and national level mapping, and support for landscape character assessment, planning policy and development control. Maps of the wild land core, buffer and periphery areas of the two parks are presented.

Keywords:

Geographical Information Systems (GIS), wildness, protected areas, landscape character, Scotland

1. Introduction

Mountains, lochs and rugged coastlines are valued hallmarks of Scotland's landscape, providing a major focus for outdoor recreation and wildlife conservation. These distinctive qualities of the Scottish landscape are strongly expressed areas dominated by natural or near-natural vegetation, lack of human intrusion from built structures and the rugged and remote nature of the terrain. They are not wilderness in the true sense, but they do posses certain attributes of wildness and so are widely referred to as 'wild land' (Aitken 1977; Aitken et al., 1992; SNH, 2002). These iconic landscapes are fundamentally linked to Scotland's national identity and represent a key draw for visitors (Harris Interactive, 2008). However, despite recognition of their value, Scotland's wild land areas face a growing array of threats including renewable energy, overgrazing and bulldozed hill tracks (McMorran et al., 2008). Previous studies have shown these factors can impact significantly on an area's wildness and result in a gradual attrition of the wild land resource (Carver and Wrightham, 2003).

The importance and value of wild land is increasingly reflected in planning policy in Scotland. National Planning Policy Guideline (NPPG 14, 1999), states that local authority development plans should identify and protect wild land. In order to support this initiative, Scottish Natural Heritage (SNH) produced a Policy Statement on *Wildness in Scotland's Countryside* (SNH, 2002). NPPG 14 was superseded by the Scottish Planning Policy document, wherein the need to safeguard areas of wild land character from development is highlighted: "*Areas of wild land character in some of Scotland's remoter upland, mountain and coastal areas are very sensitive to any form of development or intrusive human activity and planning authorities should* *safeguard the character of these areas in the development plan*" (Scottish Government, 2010, p26). This has been given extra credence by the Scottish Government with the commissioning of a report on "*A Review of the Status and Conservation of Wild Land in Europe*" (Fisher et al., 2010) which itself arises out of recommendations from the European Parliament's resolution on wilderness for:

1. better definition of wilderness including ecosystem services and conservation value;
2. a programme of mapping aimed at identifying Europe's last wilderness areas, the current distribution, level of biodiversity and existent of untouched areas where human activities are minimal; and
3. greater attention to providing effective protection from threats to wilderness areas.

(European Parliament, 2009)

In 2007, SNH and the Cairngorms National Park Authority (CNPA) commissioned research that linked three pieces of work:

1. a perception survey of wildness in Scotland;
2. development of a Geographic Information System (GIS) based analysis of wildness; and
3. its application to identify the geographical extent and intensity of wildness across the Cairngorms National Park.

Wild land is a qualitative concept and numerous definitions exist within the Scottish context (SNH, 2002; NTS, 2002) (see Table 1). To support management and planning policy methods for mapping wildness in a robust and repeatable manner need to be developed. The aim of this paper is to: 1) review previous work on wilderness mapping, 2) describe work carried out on behalf of Scotland's national park authorities and SNH to map and model wildness in both the Cairngorms National Park and the Loch Lomond and The Trossachs National Park, and 3) explore the utility of the resulting maps for further developing wild land policy and support of landscape character assessments.

[Table 1 near here]

2. Defining and mapping wilderness: scalability and relativity

Geographically speaking, wilderness is a term that is more commonly associated with other parts of the world and is not readily applied to Scotland. At a global scale, the distribution of wilderness areas is relatively well mapped based on the impact of human activity (e.g. Sanderson et al., 2002). GIS approaches for mapping wilderness have been developed (e.g. Kliskey and Kearsley, 1993; Lesslie et al. 1993; Aplet et al., 2000; Carver et al., 2002) which adopt a spatial definition of wilderness based on the continuum concept outlined by Nash (1993) whereby wilderness is regarded as one extreme on a scale of environmental modification from the "paved to the primeval" (Figure 1). Various methods and criteria have been used to describe this continuum, but invariably focus on mapping and classifying landscapes according to measures of remoteness and naturalness, with landscapes exhibiting a greater tendency towards a wilderness condition if they are both remote from human influence and more natural in terms of their ecosystem form and function.

[Figure 1 near here]

The continuum concept gives rise to an interesting philosophical debate in our deliberation about the point along the continuum at which wilderness can be said to exist (Lesslie and Taylor 1985; Dawson and Hendee, 2009; Nash, 1993; Carver, 1996). Nash (1993, p.1) maintains that "one man's wilderness is another's roadside picnic ground" indicating that individual experience and background is important in what might be considered wild and what isn't. Nash neatly side-steps the need for a formal definition by suggesting that "wilderness is what men think it is" and that wilderness should be self-defining (Nash, 1993, p.1). The imprecise definitions of wildness point to fuzzy approaches for spatially delimiting wildness for policy and management purposes: applications of the continuum concept demonstrate that wildness is both relative and scalable and can be defined using continuous geographical variables to identify both the wildest and least wild locations and all points in between (e.g. Carver, 1996; Lesslie and Maslen, 1995). Researchers have selected and/or weighted different criteria to explore how individual perceptions shape spatial patterns of wilderness quality (Carver et al., 2002), attempting to address Nash's original and careful ambiguity by generating fuzzy membership sets for 'wildness' (Fritz et al., 2000; Carver et al., 2002, Comber et al., 2010) and thereby demonstrating the scalability and relativity of the wilderness concept. This approach has been used to map relative wildness across a range of spatial scales and regions from continental to local scales (e.g. Carver, 2010; Aplet et al., 2000; Carver and Wrightham, 2003).

The definition of wild land from Scottish Natural Heritage (SNH) provides some basis for the geographical analysis of wild land in Scotland. It characterises wild land by a lack of human habitation and influence, remoteness and inaccessibility, size, ruggedness, challenge and opportunity for physical recreation. These characteristics of wildness can be mapped, either directly or using proxy indicators. SNH identify four basic attributes of wildness; naturalness, human impact, ruggedness and remoteness as shown in Table 2 with associated criteria. These provide the basis for the data inputs described in section 4.

[Table 2 near here]

3. Study area

This work analysed wildness in two national park areas in the Cairngorm and Trossach mountains in Scotland, an autonomous region within the UK. The Cairngorm National Park in the North East of Scotland has an area of 4,528km^2 making it Britain's largest national park and is centred on an area of high mountain plateau deeply dissected by glaciers. It contains 5 of the country's 6 highest mountains and the largest area of the UK above the 4,000 foot contour. It includes the largest area of arctic montane habitat in the British Isles and has a unique collection of habitats and wildlife including 25% of threatened and significant remnants of ancient Caledonian pine forest. The park has a population of 17,000 people mainly engaged in tourism, agriculture and forestry. Around 30% of the local economy is based on tourism with over 1 million visitors to the park every year (Cairngorms National Park, 2006). The Loch Lomond and The Trossachs National Park in the West of Scotland is much smaller with an area of 1,865km^2 and encompasses a varied landscape of high mountains, lochs, rivers, forests, woodlands and lowlands. It contains 20 mountains above 3,000 feet and 22 large lochs including Loch Lomond, the largest freshwater body in Britain. The park is home to a rich collection of wildlife including otter, capercaillie and osprey. Over 15,000 people live within the park, but more significantly around 50% of Scotland's population live with only an hour's drive of the park, making it very accessible for recreation and tourism.

4. Materials and methods

The approach used is to create spatial data layers to represent the attributes in Table 2 which are then combined to create an overall index of wildness (Carver, 1996; Fritz et al., 2000). This is illustrated in Figure 2. The results describe a continuum of the degree of human modification of the landscape and the physical nature of the terrain itself. This assumes that where all attributes have a high value, then a location can be described as wild. If one or more are in some way compromised, then the area might slip down the scale away from "wild" and towards "not wild". If all of the attributes are modified or compromised to a high degree, for example through intensive farming, urbanisation or energy developments, then an area would be described as not wild. The attributes used to describe wildness in both national parks are defined as follows.

[insert Figure 2 near here]

4.1 Perceived naturalness of land cover

Perceived naturalness of land cover is 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. This is in part related to evidence of land management activities such as fencing, plantation forestry and stocking rates, as well as presence of natural or semi-natural vegetation patterns (SNH, 2002). Datasets used include the Land Cover Map 2000 (LCM2000), Land Cover of Scotland 1988

(LCS88) and Highland Birchwoods Woodland Inventory (MacKenzie, 2000). These are combined to create a composite land cover map at a resolution of 25m which is reclassified into the 5 naturalness classes shown in Table 3. While the LCS88 data is more than twenty years old, it is useful in helping determine levels of management of moorland landscapes, for example by muirburn. The resulting maps are visually checked against aerial photography and local knowledge to identify any inconsistencies. To account for the influence that the pattern of land cover immediately adjacent to the observer has upon perceived naturalness, the average naturalness score of all cells within 250m of the target cell is calculated. The figure of 250m was decided upon through discussion with the project Steering Group and taken to represent the neighbourhood in which an individual might reasonably experience their immediate landscape.

[Table 3 near here]

4.2 Absence of modern human artefacts

Absence of modern human artefacts refers to the lack of artificial structures or forms within the visible landscape, including roads, vehicle tracks, railways, pylons, hard-edged plantation forestry, buildings and other built structures. The choice of which human features to include is based on SNH wild land policy (SNH, 2002) and relevant sections of a perception survey (Market Research Partners, 2008). Previous work on the effects of human artefacts on perceptions of wildness has tended to focus on photographic preference surveys (Habron, 1998) or simple distance measures (Lesslie, 1993; Carver, 1996; Sanderson et al., 2002). Recent work has used measures of visibility of human artefacts described using digital terrain models and land cover datasets with viewshed algorithms to calculate the area from which a given artefact can be seen and its visual impact based on its relative size due to distance decay effects (Fritz et al., 2000; Carver and Wrightham, 2003; Ode et al., 2009; Ólafsdóttir and Runnström, 2011). Visibility analyses calculate 'line-of-sight' from one point on a terrain surface to another, the accuracy of which is strongly dependent on the accuracy of the terrain model used and the inclusion of intervening features (buildings, woodland, etc.) in the analyses (Fisher, 1993). The NextMap™ 5m resolution digital surface model (DSM) with vertical accuracies to within ±1m provides surface height, including the height of buildings, woodland, hedges, etc., thus providing a terrain surface that is ideal for high accuracy viewshed analyses.

The location of human artefacts are extracted from the OS Mastermap™ baseline digital map data and divided into a number of discrete classes representing the main groups of human features as drawn from Scotland's wild land policy (SNH, 2002) as follows:

- Linear features (railway lines, roads and tracks)
- Non-natural vegetation (plantation forests)
- Built features (buildings and structures)
- Engineering structures (pylons and hydro-electric / reservoir draw down lines)
- Novel and 'alien' features (wind turbines)

A cumulative visibility surface is calculated based on the vertical area of each artefact visible in a full 360° arc around the target location taking the effect of distance decay on relative size into account. The different viewsheds are combined with equal weights applied to each artefact type as it was not possible to confidently derive individual weights for each feature type from the perception survey results. Bishop's (2002) work on the determination of thresholds of visual impact, and the SNH report on “Visual Assessment of Windfarms: Best Practice” (SNH, 2002), are used to define the limits of viewsheds and the distance decay function used, with maximum view distances of 30km for wind turbines and 15km for all other features. An inverse square distance function is used in calculating the significance of visible cells providing the relative vertical area in the viewer's field of view.

4.3 Rugged and physically challenging nature of the terrain

Rugged and physically challenging terrain is taken to refer to a combination of both the physical characteristics of the landscape including effects of steep and rough terrain and the harsh weather conditions often found at higher altitudes. A 10m digital elevation model (DEM) is used to derive indices of terrain complexity that take gradient, aspect and relative relief into account. The ruggedness index is defined as the standard deviation (SD) of terrain curvature within a 250m radius of the observer. As with perceived naturalness, a 250m radius was chosen to represent the neighbourhood in which an individual might reasonably experience their immediate landscape. Climate records from the UK Meteorological Office are used to derive a simple relationship between altitude and temperature and wind speed. Higher elevations show a significant increase in wind speed and drop in temperature compared to conditions at lower elevations. To account for this the altitude data from the DEM is combined with the standard deviation of terrain curvature layer by linear summation to give the overall attribute map.

4.4 Remoteness from mechanised access

Given the varied nature of the terrain found within the Scottish national parks it is essential to include terrain as a principal variable governing remoteness from mechanised access rather than linear distance. Remoteness is mapped in using a GIS implementation of Naismith's Rule (Naismith, 1892) with detailed terrain and land cover information to estimate the time required to walk from the nearest road or track taking the effects of distance, relative gradient, ground cover and barrier features, such as open water and very steep ground, into account. Work by Carver and Fritz (1999) has developed anisotropic measures of remoteness based on a GIS implementation of Naismith's Rule incorporating corrections which under certain assumptions, account for downhill routes: a person can walk at a speed of 5km/hr over flat terrain, adding a time penalty of 30mins for every 300m of ascent and 10mins for every 300m of descent for slopes greater than 12°. When descending slopes between 5° and 12° a time bonus of 10mins is subtracted for every 300metres of descent. Slopes between 0° and 5° are assumed to be flat. The angle at which the terrain is crossed (i.e. the horizontal and vertical relative moving angles) is used to determine the relative slope and height lost/gained. The road network, both within and outside the study areas, is used as the access points from which to calculate remoteness of off-road areas and so avoid any edge effects. A full description of this model is described in Carver and Fritz (1999) and its application here is summarised in Table 4. In locations where water craft are commonly used a variant of Naismith's model is used to include different cost surfaces, representing the different speeds of different craft, an ingress/egress rule for launching/landing personal watercraft, shoreline barriers, speed restrictions, water bylaws and ferry and water taxi routes. The maps for both walking and water-based remoteness were then combined using map overlay to determine the minimum access time possible using any combination of walking and water transport. While it is unlikely that most people would use such optimum combinations, this provides a conservative view of remoteness.

[Table 4 near here]

4.5 GIS-MCE wildness model

GIS-based Multi-Criteria Evaluation (MCE) methods are used to weight and combine the four attribute layers weighted by their relative importance. Attribute weights were defined in consultation with the Steering Group and from the 2007 perception survey (Market Research Partners, 2008), as shown in Table 5 and used to derive different wildness maps indicating variations in wildness that reflect the different viewpoints shown in the results of the perception study. A wildness map that combines each of the four attribute maps using equal weights is used as a benchmark.

To create the wildness maps, all map layers are normalised onto a common relative scale (0 to 255, 'low' and 'high' in subsequent figures) to enable cross comparison and the 'polarity' of individual map layers maintained such that higher values are deemed to be indicative of greater wildness and lower values are indicative of lower wildness. All attribute layers are mapped to an extent outside of the park boundary so as to avoid edge effects. The various sets of weights are applied within a simple Weighted Linear Combination MCE model as follows:

$$S_i = \sum_{j=1}^{n} W_{ij} X_{ij} \qquad \text{Eq.1}$$

where *n* = the number of attributes, S_i = the overall wildness score of the i^{th} alternative (i^{th} cell or pixel), W = criterion weights, X = normalised criterion score.

Alternative wildness maps are created to demonstrate the influence of different weighting schemes on the results. These are found to be highly sensitive to the weights applied to the input attribute maps, so care needs to be taken in the definition of appropriate weighting schemes. Work by Comber et al. (2010) shows that different approaches to combining evidence using the same weights results in different outputs as different approaches for evidence combination such as fuzzy set theory, Dempster-Shafer, Bayesian probability and endorsement theory are underpinned by different assumptions (Comber et al., 2004). The work described here seeks to match the priorities of the CNP and LLTNP with appropriate evidence weighting. In this work layer weights for 'Scottish' residents (Table 5) are used to generate overall measures of wildness and compared with equal weights. The perception survey interviewed just over 1,300 Scottish residents using a doorstep survey - 300 residents of the Cairngorm National Park and 1,004 people from the rest of Scotland (Market Research Partners, 2008). In general, the two groups show similar responses, with a strong support for the conservation of wild land in Scotland. Other key findings include:

- 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; and

- 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.

In this way the perception survey captures useful information on the relative importance of the 4 components of wildness. Table 5 shows the weights for two groups of respondents, Scottish and CNP residents, as described in Carver et al., (2008). Despite general support for the notion of wild land as shown by the main survey, there are some significant differences between the two groups in regard wildness attributes with Scottish residents placing greater emphasis on naturalness as opposed to CNP residents who, while recognising naturalness, placed more emphasis on absence of human artefacts. These differences most likely arise from greater knowledge and experience of Highland landscapes by CNP residents and their acknowledgment that they are not ecologically wild but can feel wild in the absence of human intrusion. This has implication for subsequent wild land zoning, but because this work analyses wildness in two areas, the CNP resident weights cannot be not used for the LLTNP, as this would not be consistent with local knowledge and perceptions in this park.

[Table 5 near here]

Work by Comber et al. (2010) shows how fuzzy modelling techniques can be used to generate planning zones and indicates the opportunities for a wild land typology as described by McMorran et al. (2008). Here an example 3-class typology of wildness are created for both national parks to inform local planning processes. Three zones, ‘Core’ (most wild), ‘Periphery’ (least wild) and ‘Buffer’ (in between) are defined using the thresholds described in Table 6 to create monotonically increasing and decreasing semantic import models for application to the original data layers (ie before normalisation to the 0-255 scale). Core and Periphery values for each pixel are defined by the project team. Buffer areas are defined as (1 – Core – Periphery). This allows the fuzzy membership continuum to be reclassified into three wild land zones; core, buffer and periphery, based on the fuzzy membership functions shown in Figure 3 and the thresholds defining core and periphery areas (using an example Layer Value scale of 0-255 rather than the actual scales in Table 6).

[Table 6 near here]

[Figure 3 near here]

5. Results

Results for each of the attribute layers are shown in Figures 4-7. The normalisation process applied to the attribute layers uses the full range of the combined raw data values for both the national parks in order to allow for direct comparison. These are presented on a common scale from low wildness (0) to high wildness (255) value.

The perceived naturalness model shows a strong spatial pattern that effectively distinguishes between vegetation patterns and land use associated with three principal zones within the two national parks; 1) high mountain or plateau, 2) moorland and valleys, and 3) glens/straths/lowland. This is consistent with the landscape character assessments carried out in both national parks (CNP, 2009; LLTNP, 2009). The mountain and plateau areas are dominated by arctic/alpine vegetation, rock and scree with little or no evidence of human modification either through forestry or grazing of domestic livestock. The moorland and valley areas are dominated by heather moorland that is largely managed for grouse and red deer (e.g. through burning and drainage) with rough grazing for sheep and forestry found on the valley sides. The lowland straths and larger glens are a mixture of human modified land including improved grassland, plantation forestry and settlement/infrastructure. Lochs, where they occur, are classified as natural, modified or impounded such that the model is able to distinguish between artificial impounded waters (reservoirs) and natural water features. These patterns are clearly shown in Figure 4 for both parks.

[Figure 4 near here]

The absence of modern human artefacts layer is closely controlled by the location of human features relative to terrain and distance as shown in Figure 5. The closer a location is to concentrations of human features, many of which are located in valleys and lowland areas, the more likely it is that one or more human features are visible. Topographic and vegetative screening can have a marked effect on this attribute and there are locations in both parks where it is not possible to see any obvious human features. There is an obvious contrast between the two parks here in that the topographic arrangement and geomorphology of the CNP, with its extensive core area of highly dissected mountain plateaus, exhibiting more extensive areas of visually unaffected landscape. The mountains of LLTNP on the other hand are more alpine in nature which tends toward greater visibility in all except a few small enclosed corries and valley heads.

[Figure 5 near here]

Ruggedness is controlled solely by variability in terrain and this is reflected in the maps shown in Figure 6. The addition of an altitude factor to account for the likelihood of encountering challenging weather conditions at higher elevations means that even the relatively flat plateau areas of the central Cairngorms receive a high score although the highest values are found in the steepest, high elevation terrain.

[Figure 6 near here]

Remoteness in the two parks is also strongly controlled by terrain, but in several ways. The access roads within and surrounding the parks from which remoteness is calculated naturally tend to follow the valleys where most of the settlement and agricultural/forest lands are located. Meanwhile, barrier features which impede progress such as large rivers and lochs are also located in the valleys or along valley sides such as cliffs and other steep terrain. Whereas traditional remoteness maps focus on horizontal distances, the off-road access times calculated using Naismith's Rule are driven as much by vertical distances (uphill, downhill) as they are horizontal distance, and so the remoteness maps shown here in Figure 7 tend to resemble the terrain surface, but with subtle nuances dictated by the location of access roads, barrier features and vegetation.

[Figure 7 near here]

Results from the application of the wildness model using both equal weights and Scottish Residents' weights for both national parks are shown in Figures 8 and 9. These maps reveal intricate patterns in the variation of wildness across the two parks that are not easily discernable through scrutiny of the attribute maps alone. While the general patterns of wildness shown are hardly surprising, with the main core wild land areas focusing on the higher elevations and remote/enclosed valleys within, they are more revealing in their detail, especially when comparing wildness maps based on different weighting schemes as shown in Figures 8 and 9. Here subtle differences in the detailed pattern can be seen between Scottish residents and the equally weighted maps, although the general pattern remains constant.

[Figure 8 near here]

[Figure 9 near here]

The results of applying fuzzy methods to the wildness continuum layers are shown in Figure 10 where the equally weighted wildness maps shown in Figure 8 are reclassified into three wild land zones; core, buffer and periphery, based on the fuzzy membership functions shown in Figure 3 and the thresholds defining core and periphery in Table 6.

[Figure 10 near here]

6. Discussion

6.1 Emerging patterns

Visual comparison of the patterns in each of the attribute maps reveals spatial differences both within and between the two parks. The maps show a high degree of spatial complexity and variability within the components of wildness across the two parks and their immediate environs. The spatial patterns are sensitive to the methods, assumptions and the data used which results in local differences between each version of the attribute maps. This sensitivity notwithstanding, the same basic overall pattern of wild land attributes can be observed across all the attribute maps, irrespective of the methods used, in that the wilder areas of the parks are in the main confined to the roadless areas of the mountain core and their associated glens and corries. The principal core wild land areas are listed in Table 7. At the other end of the wildness spectrum, the least wild areas are strongly controlled by the straths and glens together with their associated settlement, farmland, forestry, infrastructure and transport routes that dissect both parks together with the agricultural and more densely populated areas south of the Highland Boundary Fault in LLTNP and towards Aberdeen along the eastern edges of the CNP. In the CNP, ski areas are observed to have marked impact with many overlooking areas experiencing a reduction in wildness quality due to their visual influence. In the LLTNP, plantation forestry and associated network of access tracks has a marked effect in reducing wildness across the park, while hydro/water supply schemes have a marked local effect through their concentration of access roads, structures, buildings, power lines and reservoir draw-down lines. Within the LLTNP there are also marked effects from major towns such as Helensburgh, Alexandria/Balloch and Dunoon that lie off the edge or just outside the park boundary. These are listed in Table 8.

[Table 7 near here]

[Table 8 near here]

6.2 Differences between the parks

Using an equally weighted map as the baseline for comparative purposes, it can be seen that, while there are local differences in either the intensity or pattern of the relative wildness values, there is a strong agreement between all the maps as to the overall pattern of wildness that corresponds to those wild areas listed. This is indicative of a high degree of robustness and associated confidence in both the methods/data used and the maps produced.

Overall, there are several key differences between the parks. These differences are partly due to scale differences, but are mainly due to differences in topography and levels of human impact. As Britain's largest national park, the CNP contains greater expanses of remote wild land with minimal influence from human land use and artefacts. These are mainly located within the Cairngorm plateau, high corries and remote glens because they are both remote and shielded from visual intrusion by the topography. This provides a more or less unbroken swathe of core wild land through the centre of the park. By comparison, the LLTNP is smaller and more heavily influenced by settlement, plantation forestry, agriculture and hydro schemes. As such the pattern of wild land in the park is more fragmented and tightly constrained to a few higher mountain peaks and corries, particularly those associated with the core mountain groups and the hills along the northern boundary of the park. These differences are largely down to size and the topographic differences between the two parks as well as the closer proximity of the park to the city of Glasgow and its outlying conurbations.

6.3 Applications and zoning

There are numerous applications for the wildness maps developed here. These include informing emerging planning policy on wild land in the national parks and Scotland at large, managing development within the park, guiding recreation and tourism plans, and targeting ecological restoration. The method and the maps generated can also be used to support and enhance landscape character assessments in the parks. Here, the consistency of the wild and non-wild areas provides a defensible model for current decision making in relation to, for example, consideration of landscape character within planning applications. The variation in the definition of the buffer provides some room for future adjustments to any zonation.

The homogeneity between the core wild and non-wild areas, generated from either equal weights or those generated from the 2007 perception survey as shown in Figures 8 and 9, and the heterogeneity in between these extremes, raises a number of issues related to the defensibility of the approach and the resultant maps. Very wild and very non-wild areas are easily defined by either high or low values in each of the attribute layers. However, there is much less certainty about how to allocate areas where combinations of high and low attribute values are present. The 5-class typology developed by McMorran et al (2008) includes 5 wildness classes whose definitions are overlapping. Future work will develop typologies to overcome this definitional uncertainty that can be readily applied to attribute layers. It is feasible to design different versions of this approach to defining different typologies or management/planning zones for a variety of end-uses. The basic set of zones shown in Figure 10 could be modified with suitable stakeholder input to represent a series of zones to assist in developing plans for development control, recreational opportunity/use and to help target areas for ecological restoration. For example, the weights in Table 5 indicate relative large differences between local population and national populations reflecting local nuances and issues. Yet for the results in different regions to be comparable, similar weights have to be used in different areas. Local weightings will result in different zonations.

At present, relatively little of either park is influenced by the visibility of wind turbines or other modern high impact developments. Several wind farm developments have been proposed to the north and east of the CNP, with some exhibiting potential to seriously impact on core wild land areas by visual intrusion and so impact landscape character and wild land values. Meanwhile in LLTNP a proposal to re-open an abandoned mine is likely to have a severe impact on local landscape and wildness values if given the go-ahead. In both cases the work described here could have a significant role to play in evaluating these plans.

Both parks are the focus of a well-developed tourism industry based largely on the natural qualities of the landscape and the opportunities for outdoor recreation that it presents. Sight-seeing is an important aspect of this industry and is dependent on the attractive landscape setting. Many outdoor activities such as walking and mountaineering take place in the parks, and many of these exhibit a high degree of wilderness dependency or at least benefit considerably from taking place within a wild setting. The approach developed here could be used to map the recreational opportunity spectrum (ROS) for the area (Clarke and Stankey, 1979; Joyce and Sutton, 2009) and could then be used to manage for and highlight the opportunity for a wilderness experience in certain types of activities such as backcountry skiing, mountaineering, walking and wild camping.

A further potential application is in targeting ecological restoration with the parks. This might include woodland regeneration projects, red deer reduction, designing habitat networks, and general re-wilding through the removal of human infrastructure such as deer fences, hill tracks, shelters, signage, etc. The work described here spatially describes a human perception of wildness from a landscape character perspective. It is not an ecological definition of wildness as it does not take into account the degree of modification of natural systems by human activity although it may be argued there is a strong correlation. Ecological definitions of wilderness tend to stress the biophysical realities of wildness wherein complete, fully functioning natural ecosystems are required before true wilderness conditions are said to exist. Further development of the wilderness continuum model developed here could re-focus the model on ecological wildness through the use of indicator species data, vegetation mapping and habitat patch/network models. The method described here could be used to highlight potential habitats and target areas and corridors for restoration for example through modifying the attribute layers before action on the ground is taken to demonstrate the likely benefits of such schemes and enable better targeting of limited resources.

7. Conclusions

This paper presents a rigorous and robust approach to the difficult task of mapping wildness in Scotland using the two new national parks of the Cairngorms and the Loch Lomond and The Trossachs as examples. The paper demonstrates that existing data can be used to develop suitable spatial proxies for SNH defined attributes of wildness. Combining attribute maps using MCE and survey derived weights is an effective way of mapping variations in wildness across a given landscape, while fuzzy classification methods can be used to develop management zones from the resulting surfaces.

The approach is transferable between study areas through having a common core model consisting of attribute layer inputs, an MCE model and fuzzy reclassification. It recognises that no two areas are the same and will have different mapping requirements so as to take local differences and variability into account. This is demonstrated here for the two national parks in regard to the variations in the remoteness model used to handle water features and water-born access.

The model is also scalable and can be applied to a range of spatial scales from local, to national depending on data requirements and available computing resources. The model developed and tested here is being applied by SNH at a national level using 50m resolution data and similar attribute definitions. This new national map will be validated using the work described here and used to further inform developing national wild land policy in Scotland. While other authors have developed similar approaches at broader spatial scales from the global (e.g. Sanderson et al., 2002) to the regional (e.g. Carver, 2010) and national (e.g. Aplet et al., 2000) these have all relied on making very broad generalisations away from the true definitions of wilderness attributes such as using simple linear distance from the nearest road as a proxy for human intrusion within the landscape. As a result these maps are very generalised and miss the critical patterns and variability that restrict their use as planning and management tools. The work described here has shown that local level knowledge coupled with careful application of local level datasets within bespoke GIS models can be a powerful tool in helping develop detailed planning policies and actions for wild land conservation and management. It is suggested the approach described here could be utilised in any geographical region or landscape from a national level down over and so could be rolled out across a region by a team of dedicated national wild land mapping champions. This would provide the detailed level of information required by local and national governments in responding to calls for regional wilderness registers such as in the 2009 European Parliament Resolution on Wilderness.

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List of Tables:

Table 1. Policy and other definitions of Scottish wildness

Organisation	***Definition***
National Planning Policy Guideline (Scottish Office Development Department, 1999)	"uninhabited and often relatively inaccessible countryside where the influence of human activity on the character and quality of the environment has been minimal"
Scottish Natural Heritage (2002) – Wildness in Scotland's countryside	"The term 'wild land' is…..best reserved for those limited core areas of mountain and moorland and remote coast, which mostly lie beyond contemporary human artefacts such as roads or other development"
National Trust for Scotland – Wild land Policy (2002)	'Wild land in Scotland is relatively remote and inaccessible, not noticeably affected by contemporary human activity, and offers high quality opportunities to escape from the pressures of everyday living and to find physical and spiritual refreshment.'
John Muir Trust – Wild land Policy (2004)	'Uninhabited land containing minimal evidence of human activity'

Table 2. Physical attributes in the identification of wild land (After SNH, 2002)

Attributes	***Components***	***Main Criteria***
Naturalness	Perceived naturalness	Functioning natural habitats Unmodified catchment systems
	Little evidence of contemporary land uses	Little indication of historic settlement Only extensive grazing and field sports
Human impact	Lack of constructions or other artefacts	No recent buildings/works Little impact from large structures outside area
Ruggedness	Rugged or otherwise challenging terrain	Striking topographic features and difficult terrain Natural settings for recreation providing hard physical exercise and challenge
Remoteness	Remoteness and inaccessibility	Distance from settlement and communications Limited access either by scale of area and/or lack of easy access
	Extent of area	Area sufficient to engender feeling of remoteness and solitude

Table 3. Naturalness classifications applied to land cover features

LCM class	*BHSUB*	*Broad NClass*	*Supplementary Data*	*Criteria*	*Refined NClass*
Broad-leaved woodland	1.1	5	Highlands Birchwoods	Semi-natural	5
				Mixed	4
				Planted	3
Coniferous woodland	2.1	3	Highlands Birchwoods	Semi-natural	5
				Mixed	4
				Planted	3
Arable & horticultural	4.1, 4.2, 4.3	2			
Improved grass	5.1, 5.2	2			
Neutral grass	6.1	3			
Calcareous grass	7.1	3			
Acid grass	8.1	4			
Bracken	9.1	4			
Dwarf shrub heath	10.1, 10.2	4	LCS 88		4
Bog	12.1	5			
Inland Water	13.1	0	OS MasterMap, OS 1:25,000	Natural	5
				Raised	4
				Impounded	3
Montane habitats	15.1	5			

Inland rock	16.1	5		
Built up areas	17.1, 17.2	0	Edited LCM built up areas, OS Meridian, OS MasterMap	1
Supra littoral rock	18.1	5		
Supra littoral sediment	19.1	5		
Littoral rock	20.1	5		
Littoral sediment	21.1	5		
Saltmarsh	21.2	4		
Sea / Estuary	22.1	5	NextMap DTM	5

Table 4. Conditions applied to the walking model

Item	*Rule*
Source grid	This is taken to be the public road network that provides vehicular access via private car.
Cost surface	Assumed to be 5km/h for all land cover types except heather and forest which is 3km/hr and bog which is 2km/hr. Fords across rivers were deemed to take 10mins to cross per 5m of river which equates to approx 0.03km/h. The roads and tracks data from the OS Mastermap™ data is used to amend the cost surface as having the least resistance to movement with a speed of 15km/hr where it is possible to use a mountain bike to gain more rapid access to the core areas. When hill tracks exceed 20 degrees of slope the speed of movement in the cost surface is reduced to 5km/hr to reflect walking speed where cyclists are likely to have to dismount and push.
Barriers to movement:	These are taken to include rivers that appear as polygons (i.e. showing both left and right banks) in the OS Mastermap™ data, slopes that are greater than 45 degrees from the horizontal and open water/lochs. A distinction is made between normal (low flow) and spate (high flow) conditions in regard to the usability of crossing points marked on maps as fords. Rivers crossed by any means, including bridge and fords, are assumed to be crossable at

	low flow conditions where the roads, tracks or footpaths are shown to cross, whereas those rivers described in the OS Mastermap™ data as polygons are assumed to be barrier features (i.e. not fordable) except via road or foot bridges during spate conditions.

Table 5. Layer weights from the Perception Survey

	Scotland	**CNP**
Naturalness	0.48	0.20
Remoteness	0.32	0.38
Lack of Modern Artefacts	0.16	0.29
Ruggedness	0.04	0.13
Total	1.00	1.00

Table 6. Semantic Import model raw data ranges showing the thresholds for no support ('0') and full support ('1') to the sets of 'Core' and 'Periphery'

Layer	**CNP data range**	**LLTNP data range**	**Core layer values (high)**	**Periphery layer values (low)**
Naturalness	100-500	100-500	0: 400 1: 450	1: 300 0: 350
Remoteness	0 - 330	0 - 235	0: 120 1: 180	1: 60 0: 90
Absence of Artefacts	0 - 23.072	0 - 23.649	0: 10 1: 13	1: 6 0: 8
Ruggedness	12 - 707	3 - 662	0: 180 1: 230	1: 100 0: 140

* These are raw data values (ie before normalisation)

Table 7. Principal core wild land areas in CNP and LLTNP

Cairgorms National Park	Loch Lomond and The Trossachs National Park
• the Cairngorm plateau and mountain coires east and west of the Lairig Ghru • the high moorland plateau of Mòine Mhòr • the peaks and coires of Bein A' Bhuird and Ben Avon • Lochnagar and the White Mounth • the remote headwaters of Glen Feshie and Glen Tarf • the head of Glen Banchor adjacent to the Monadhliath in the north	• the peaks of Ben Lomond, Ben Vorlich (Earn & Lomond) • The Breadalbane Hills (Ben Challum, Meall Glas, Beinn Bhreac) • the peaks of Ben Lui and Ben Oss • the "Arrochar Alps" • the Ben More massif and surrounding hills (Stob Binnein, Stob Garbh, Beinn a' Chroin)

Table 8. Principal non-wild/human impacted areas in CNP and LLTNP

Cairngorms National Park	Loch Lomond and The Trossachs National Park
• Strath Spey, Strath Avon, Strath Don, Braemar and Deeside, Glen Clova and Glen Truim • Glenmore/Rothiemurchus, Strath Avon/Tomintoul • the Cairngorm, Lecht and Glenshee ski areas	• Strath Fillan/Glen Dochart • Loch Lomond • Loch Long/Goil • Queen Elizabeth Forest Park (Loch Ard and Achray Forests) • Strathyre Forest • Glen Branter Forest • Loch Sloy, Loch Arklet, Loch Venachar and Glen Finglas reservoir • Proximity to Helensburgh, Alexandria/Balloch and Dunoon

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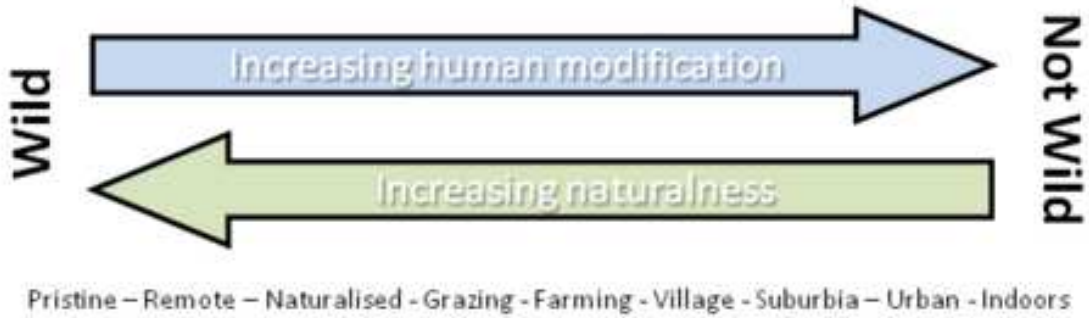

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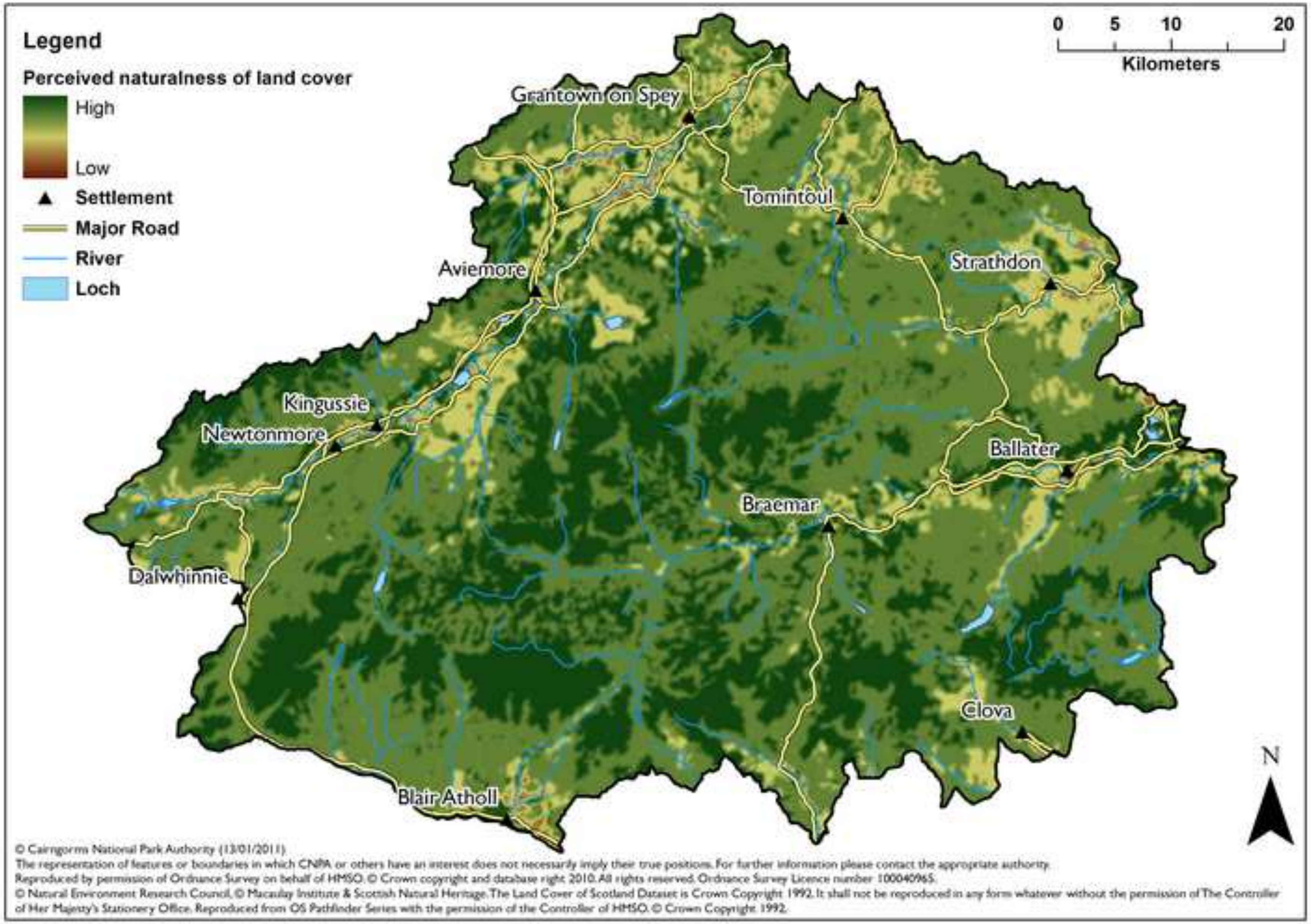

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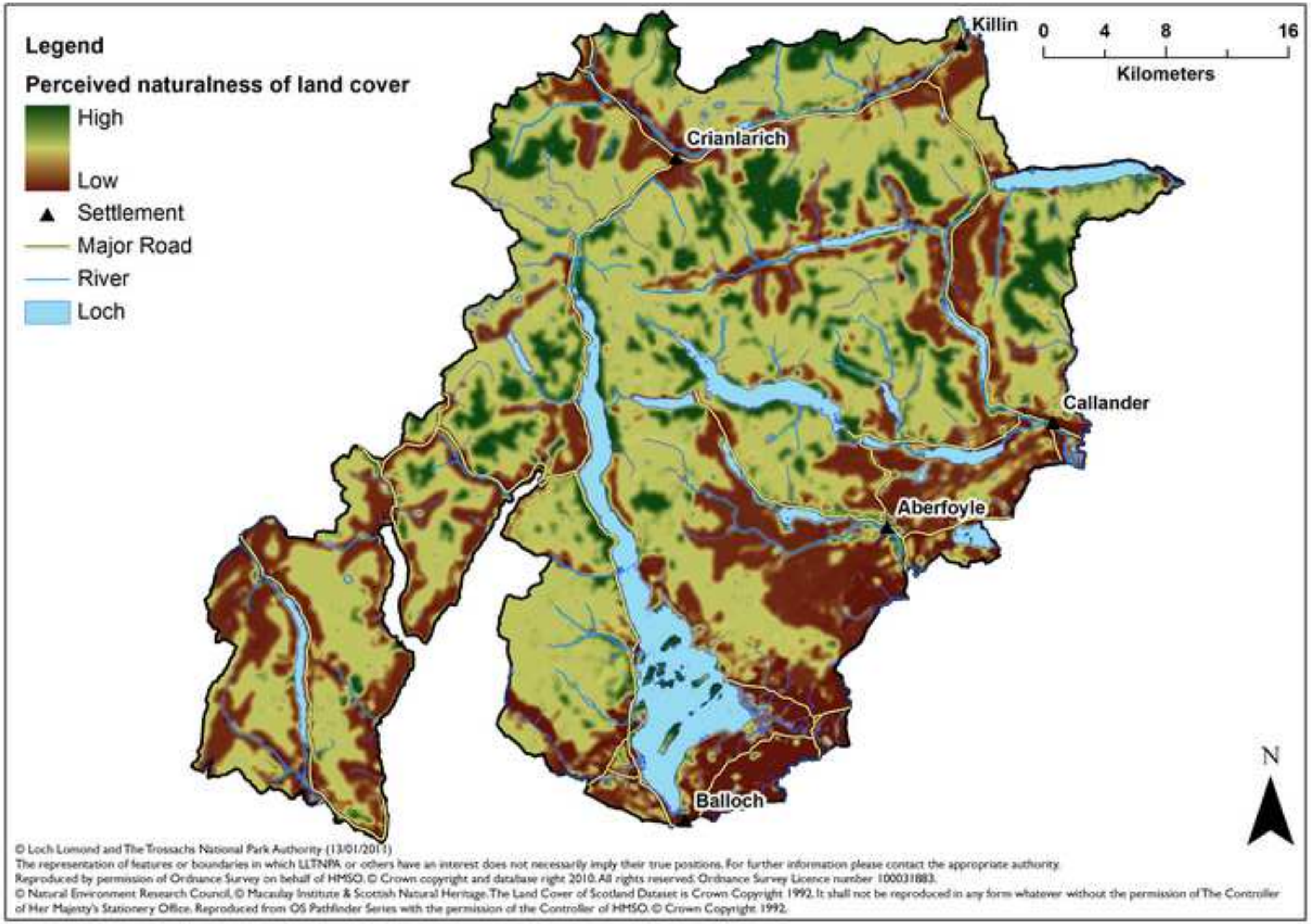

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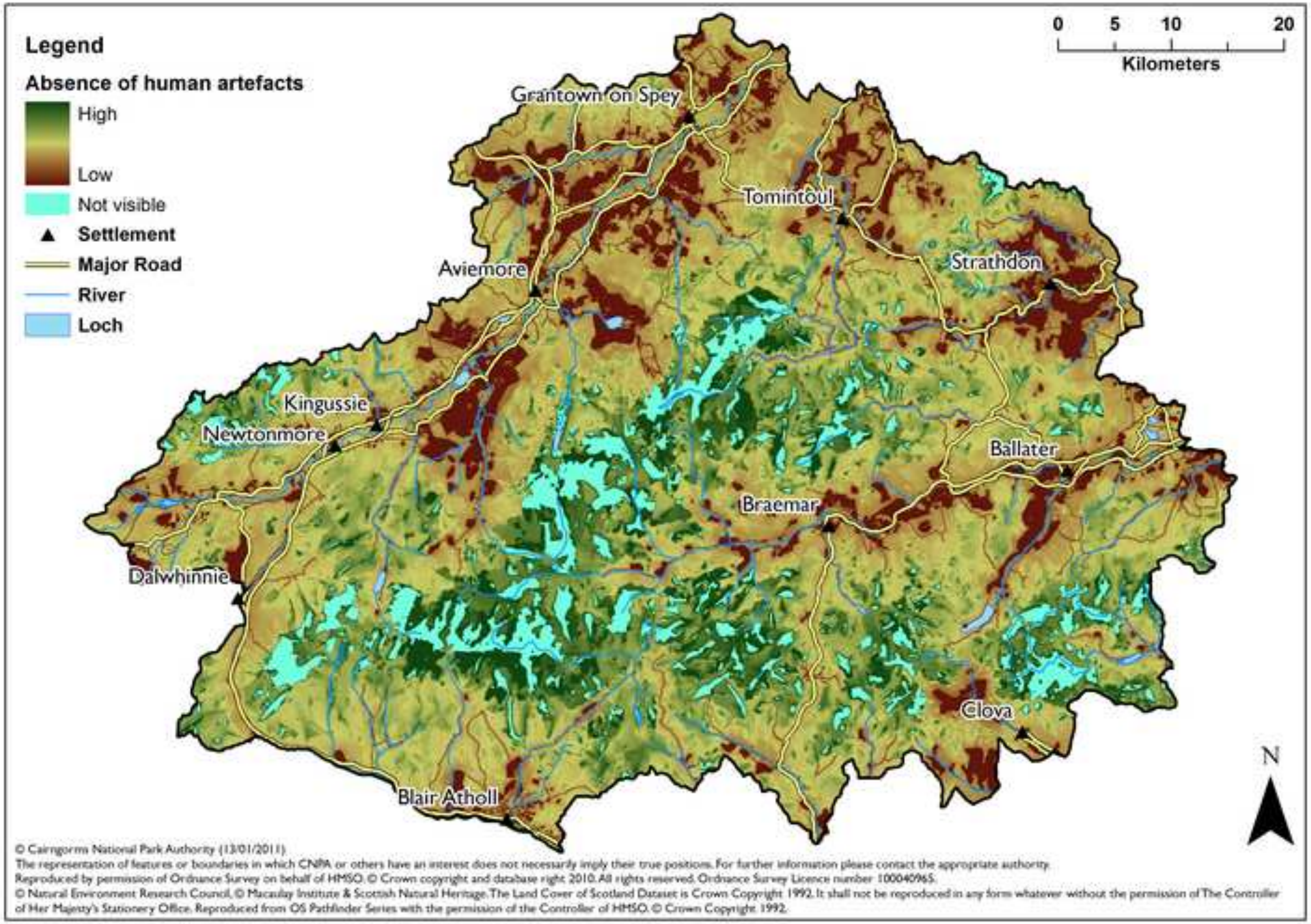

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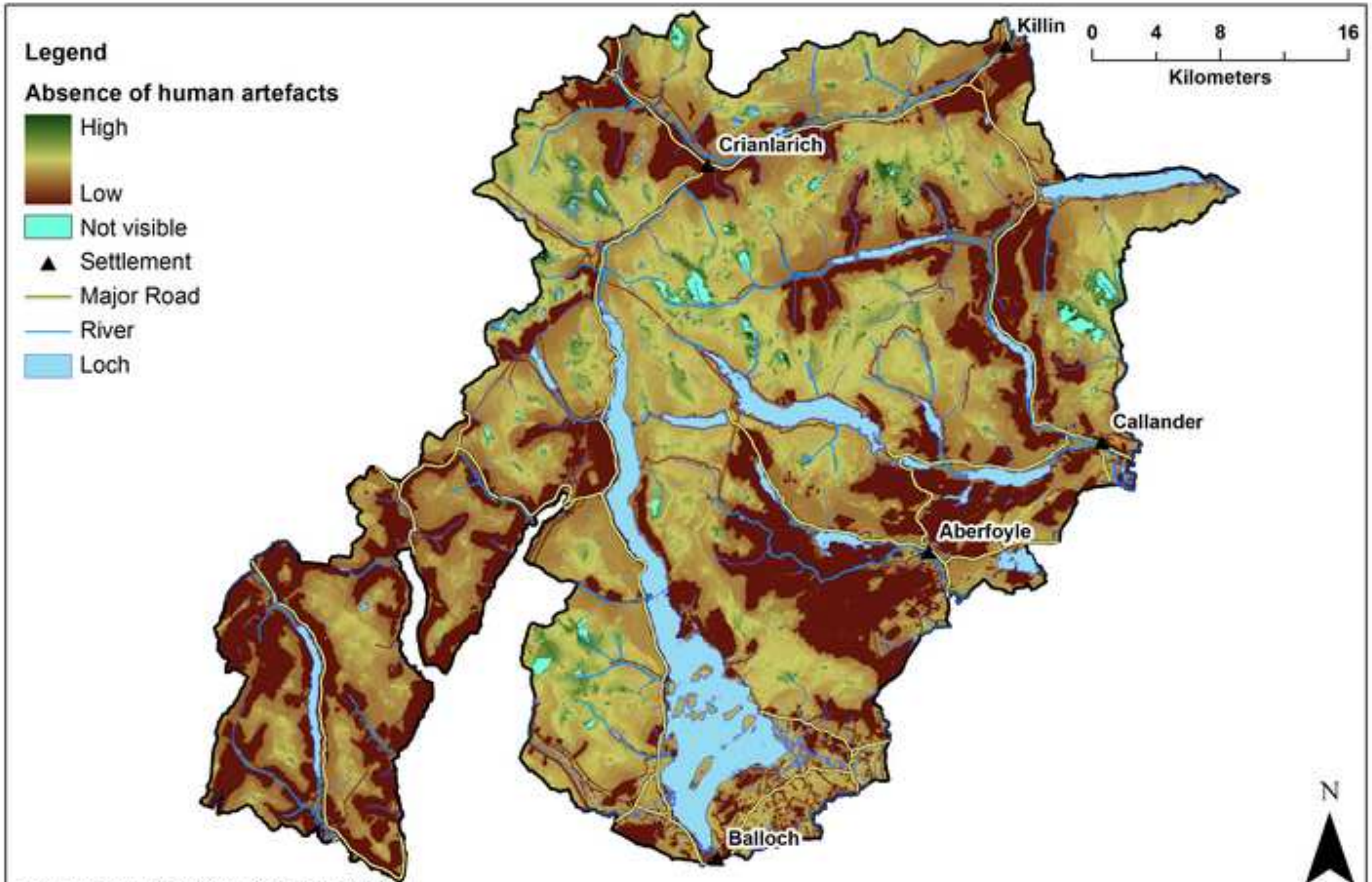

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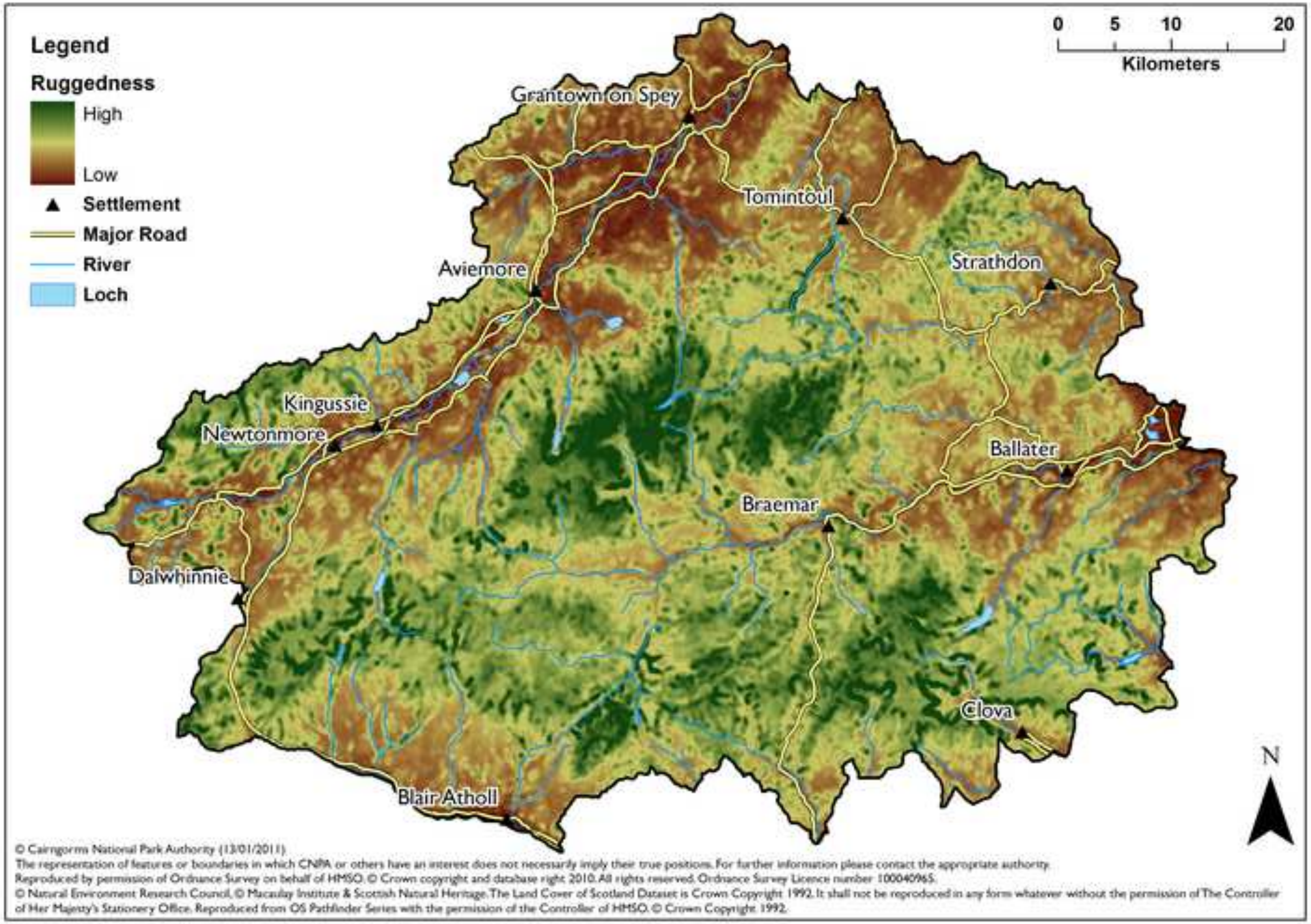

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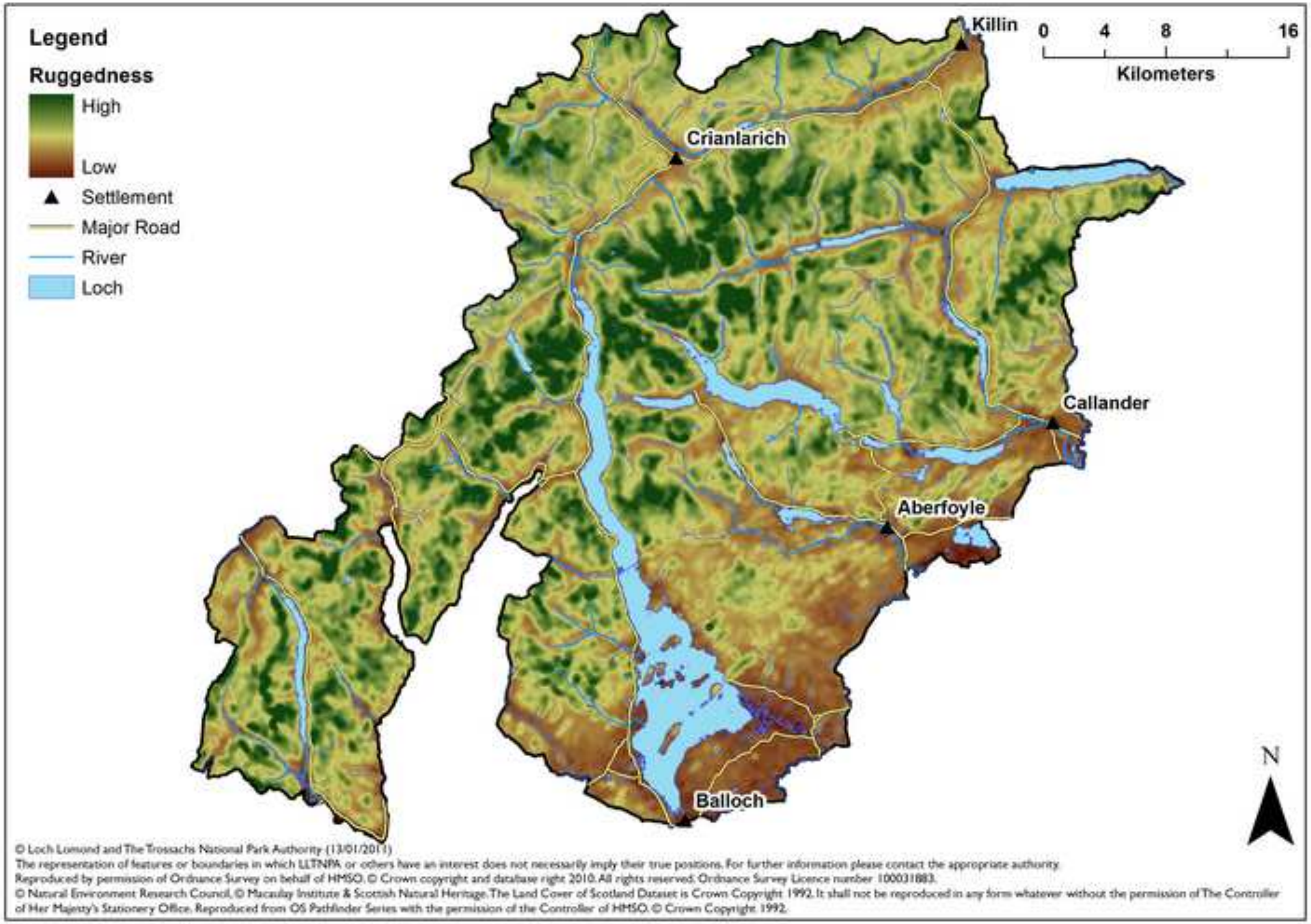

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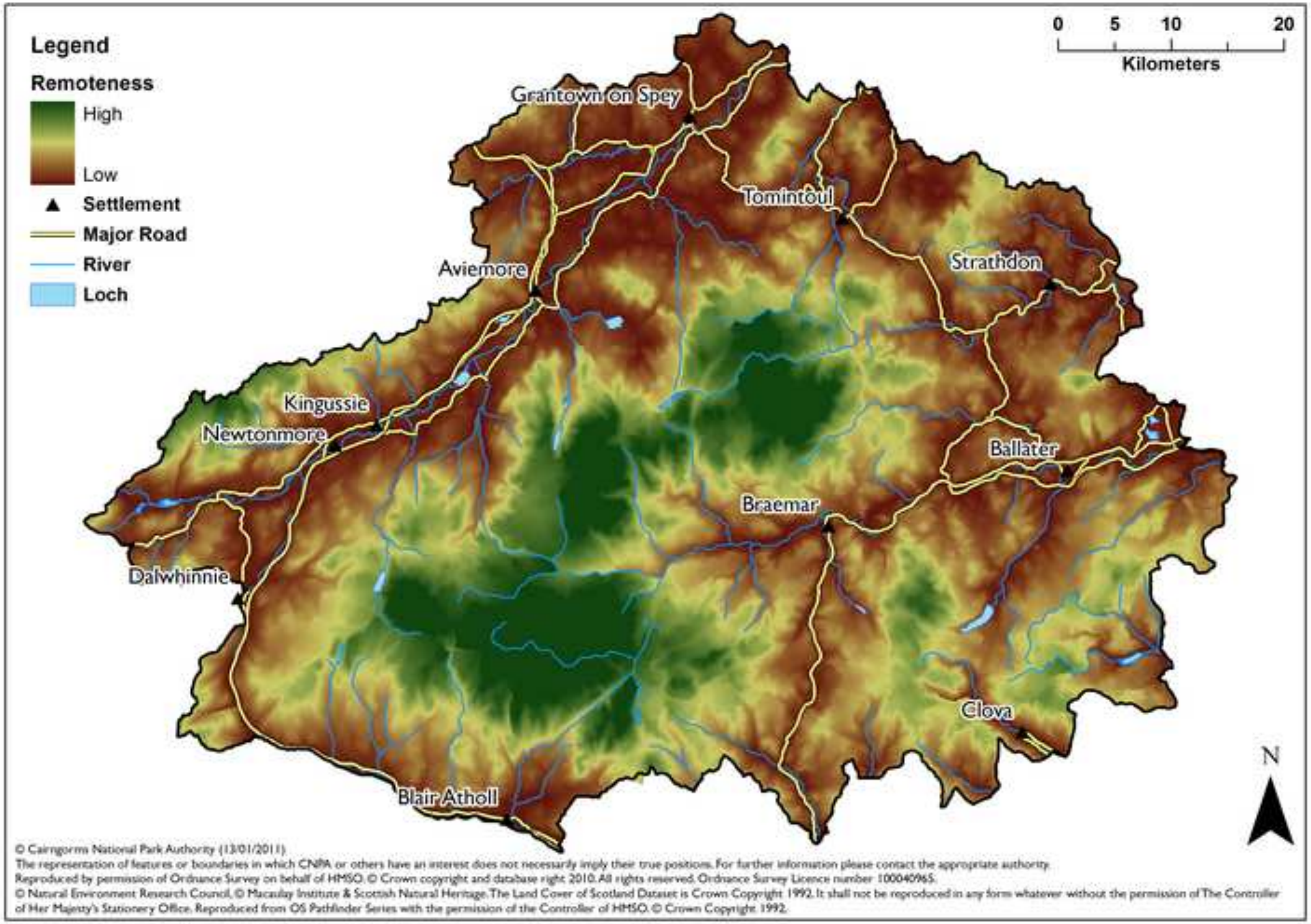

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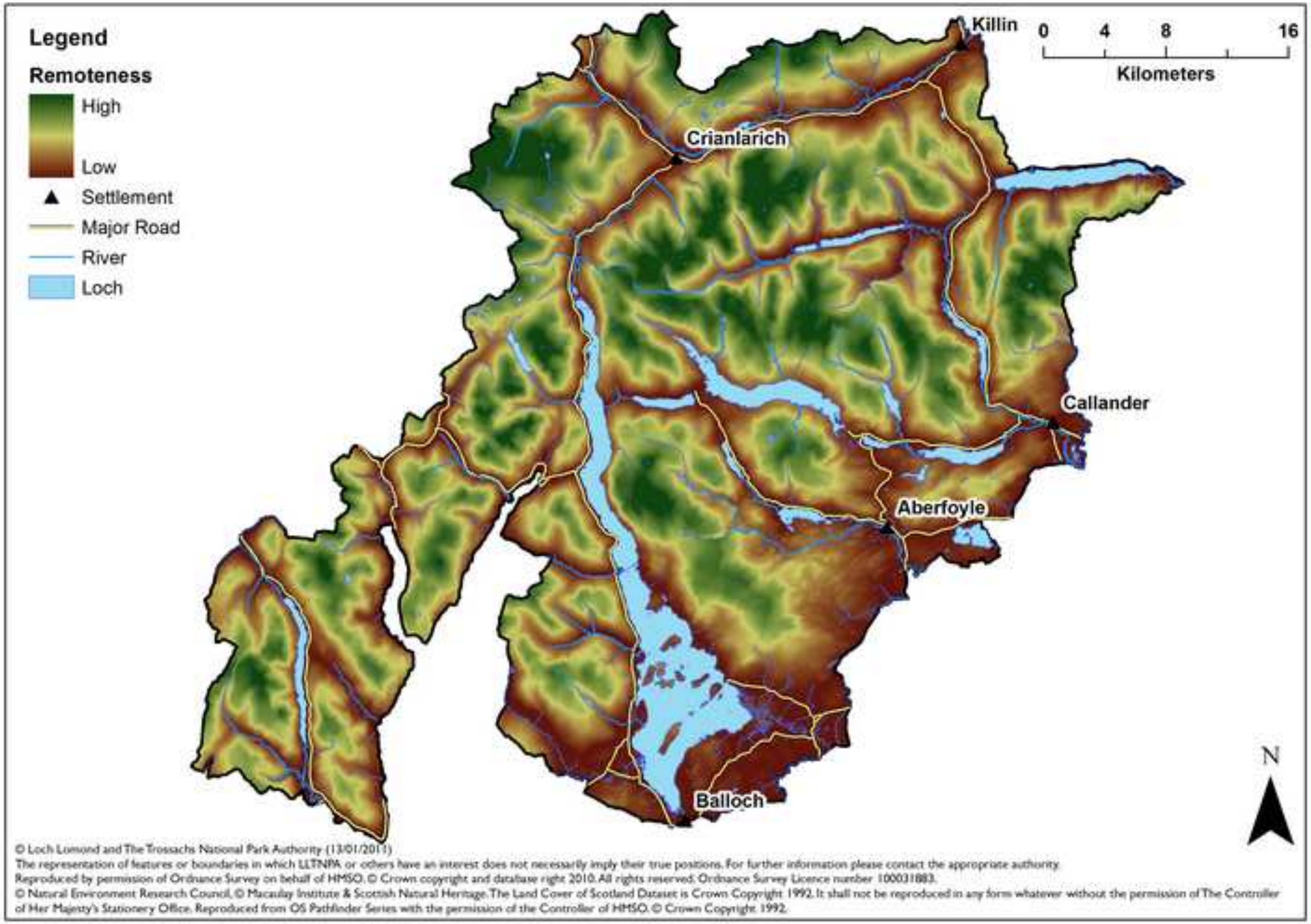

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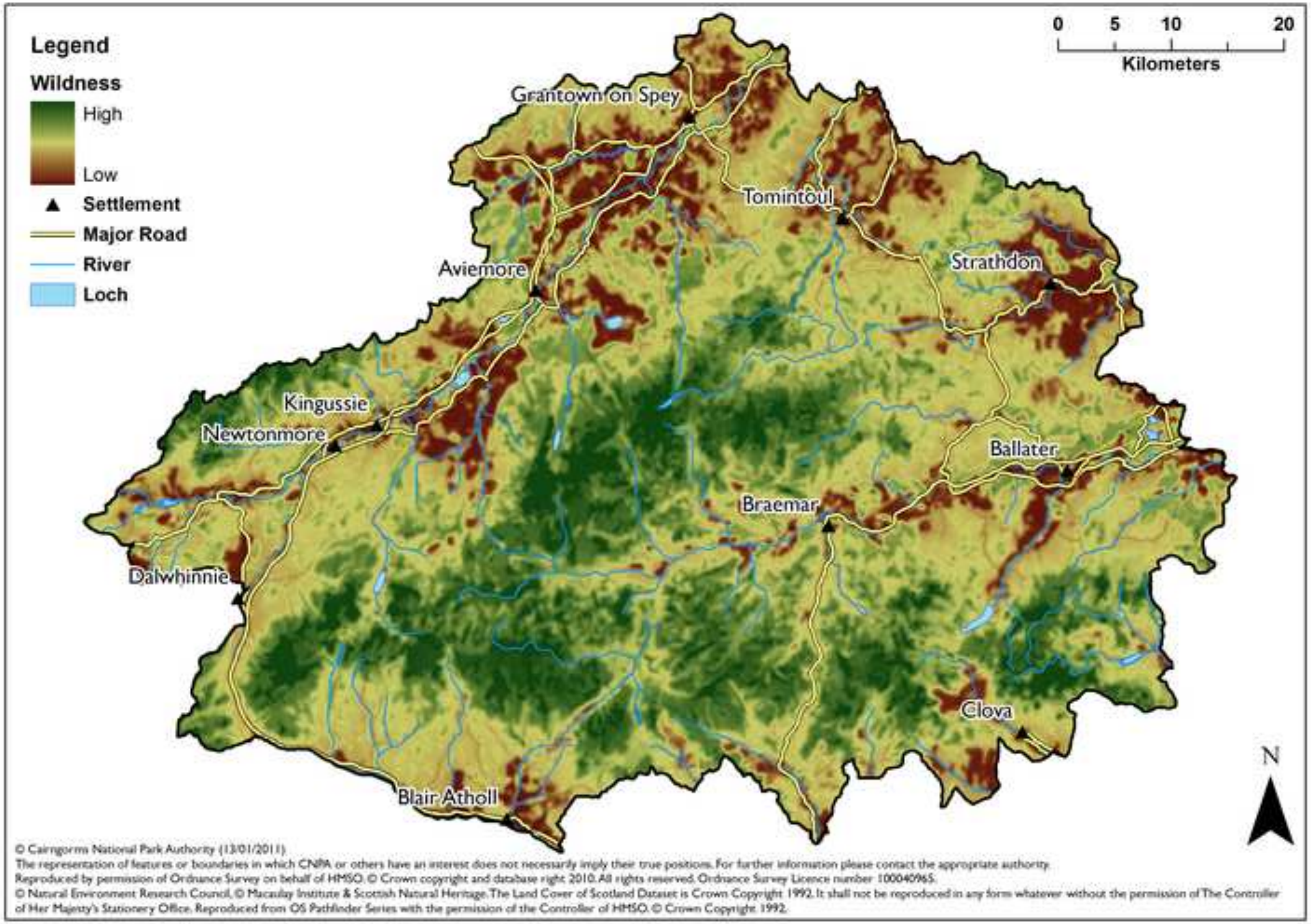

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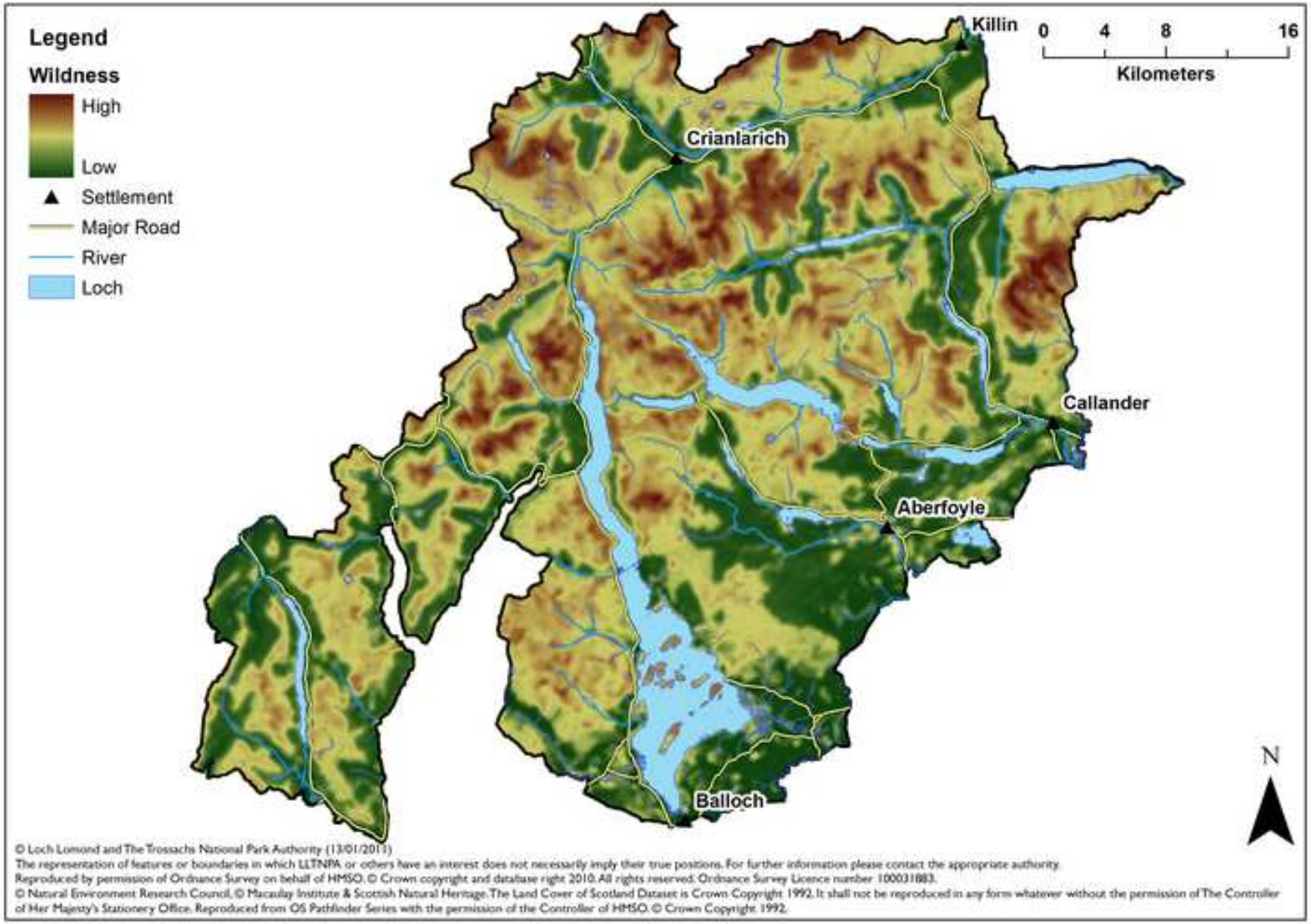

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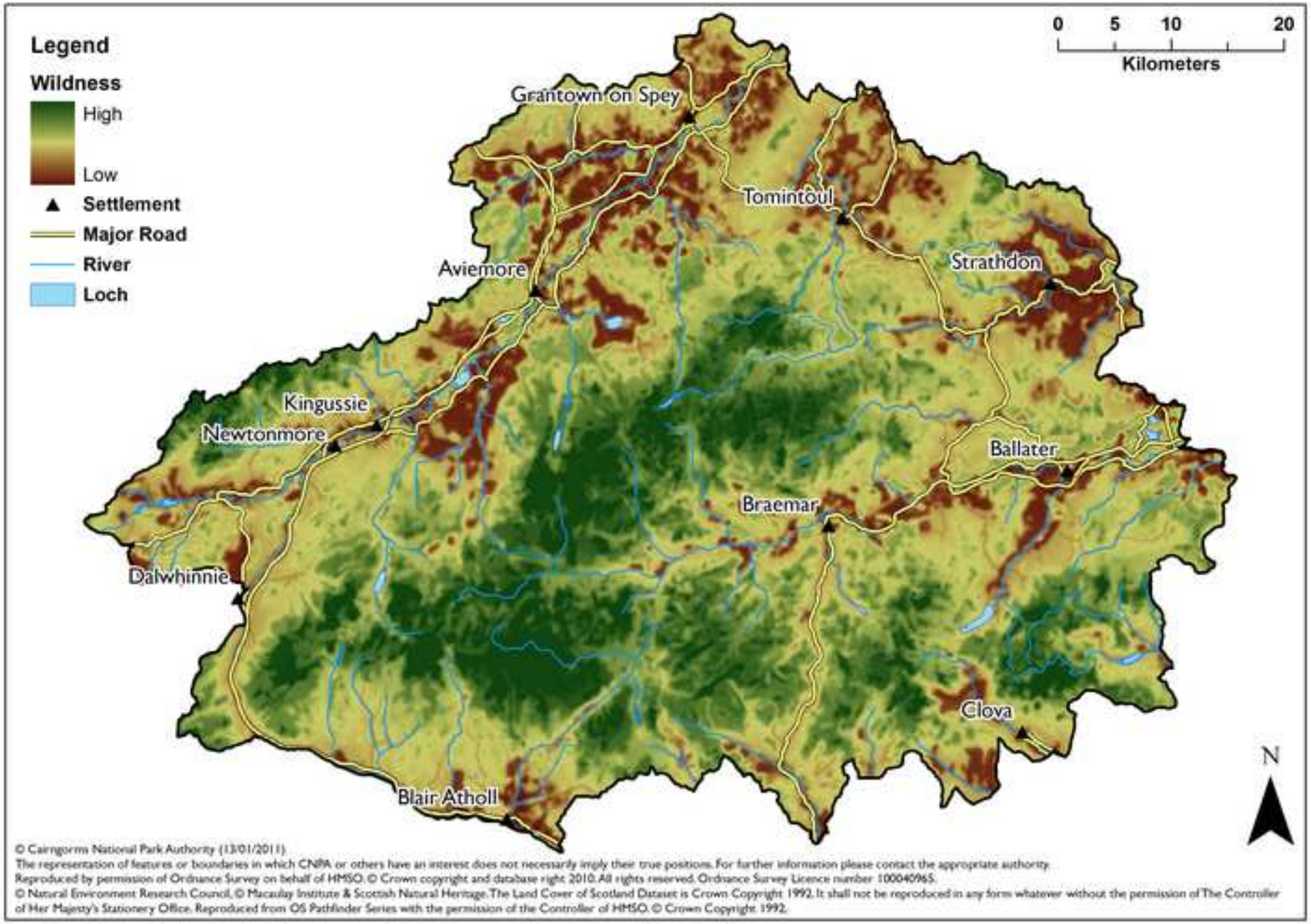

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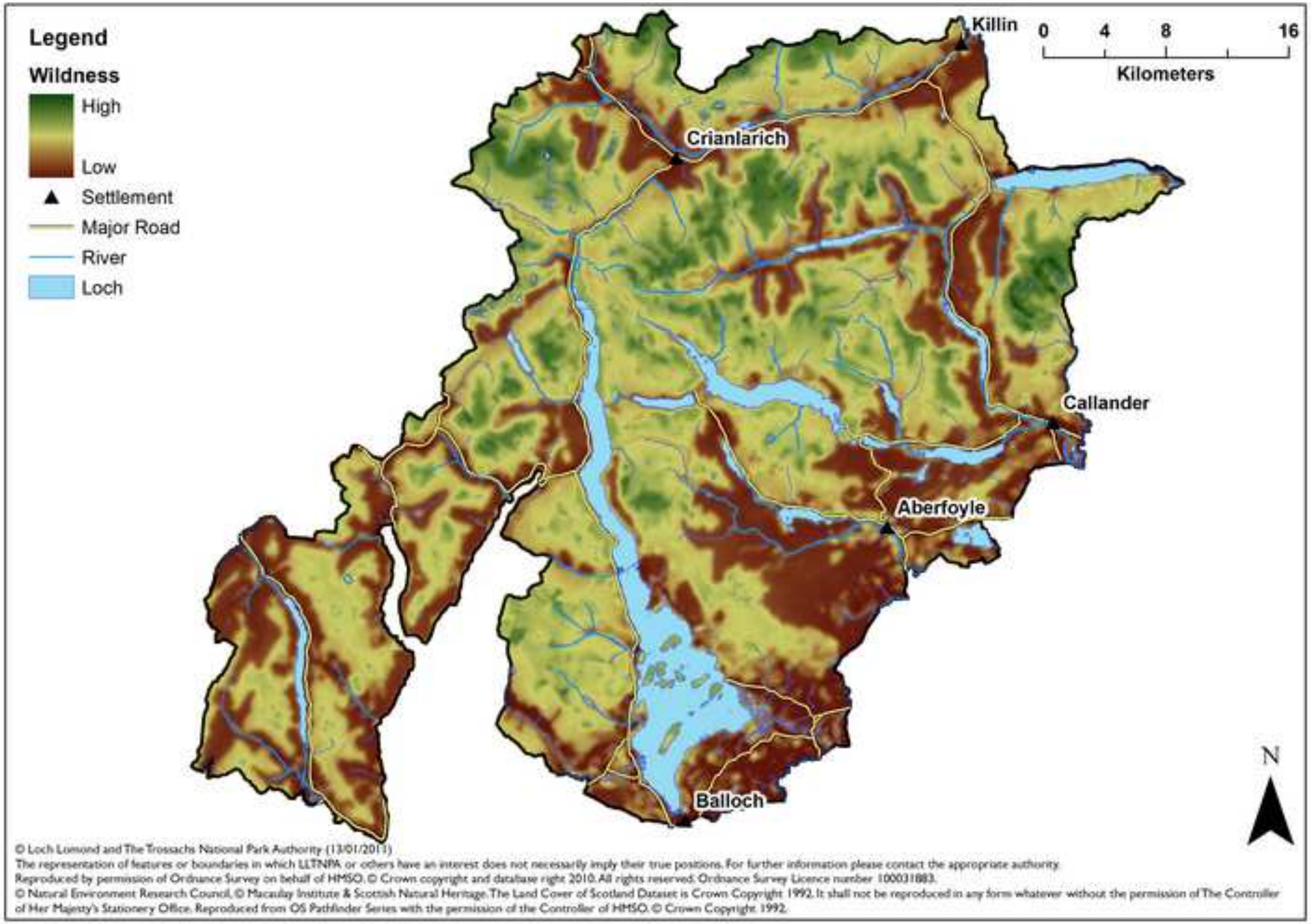

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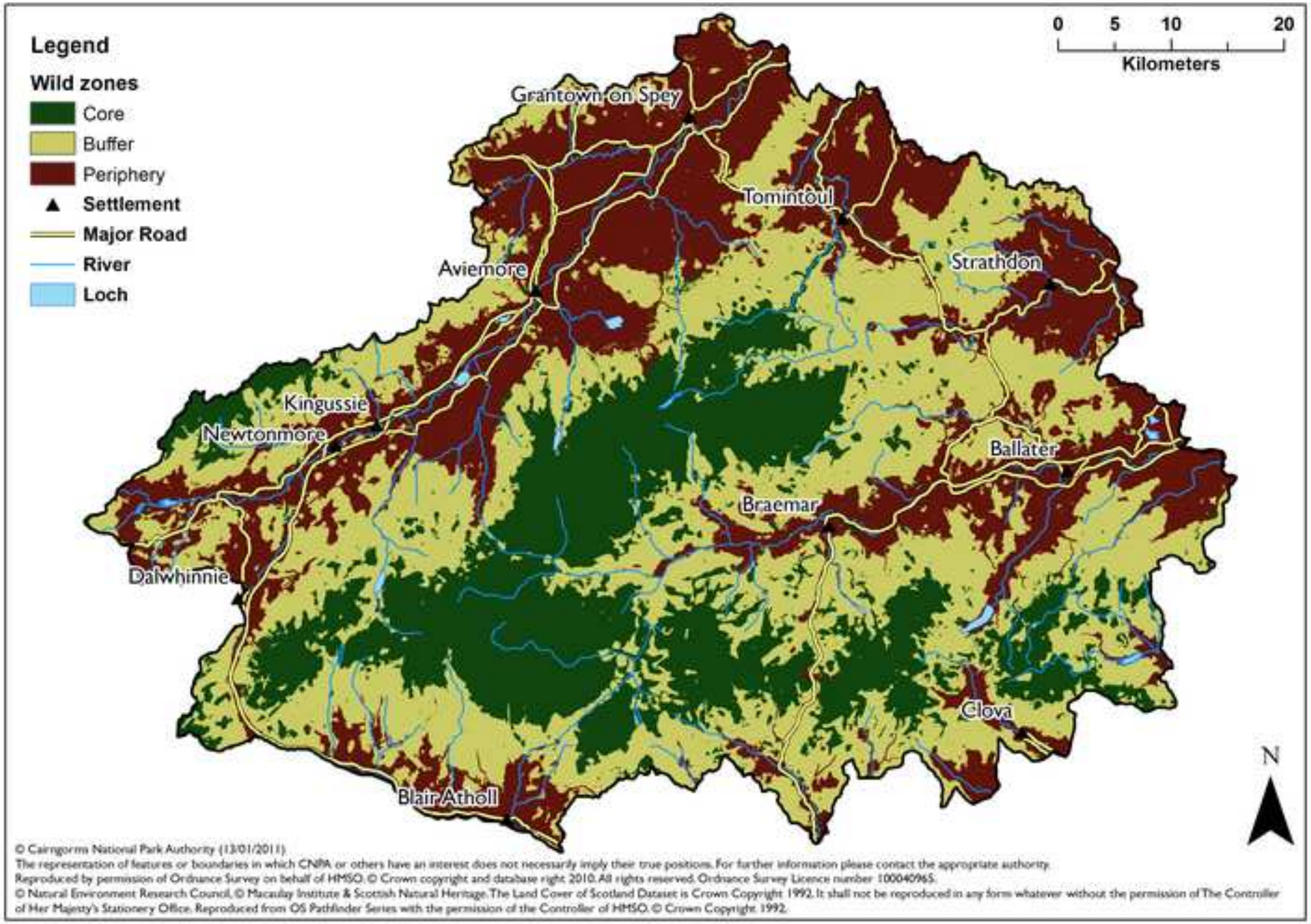

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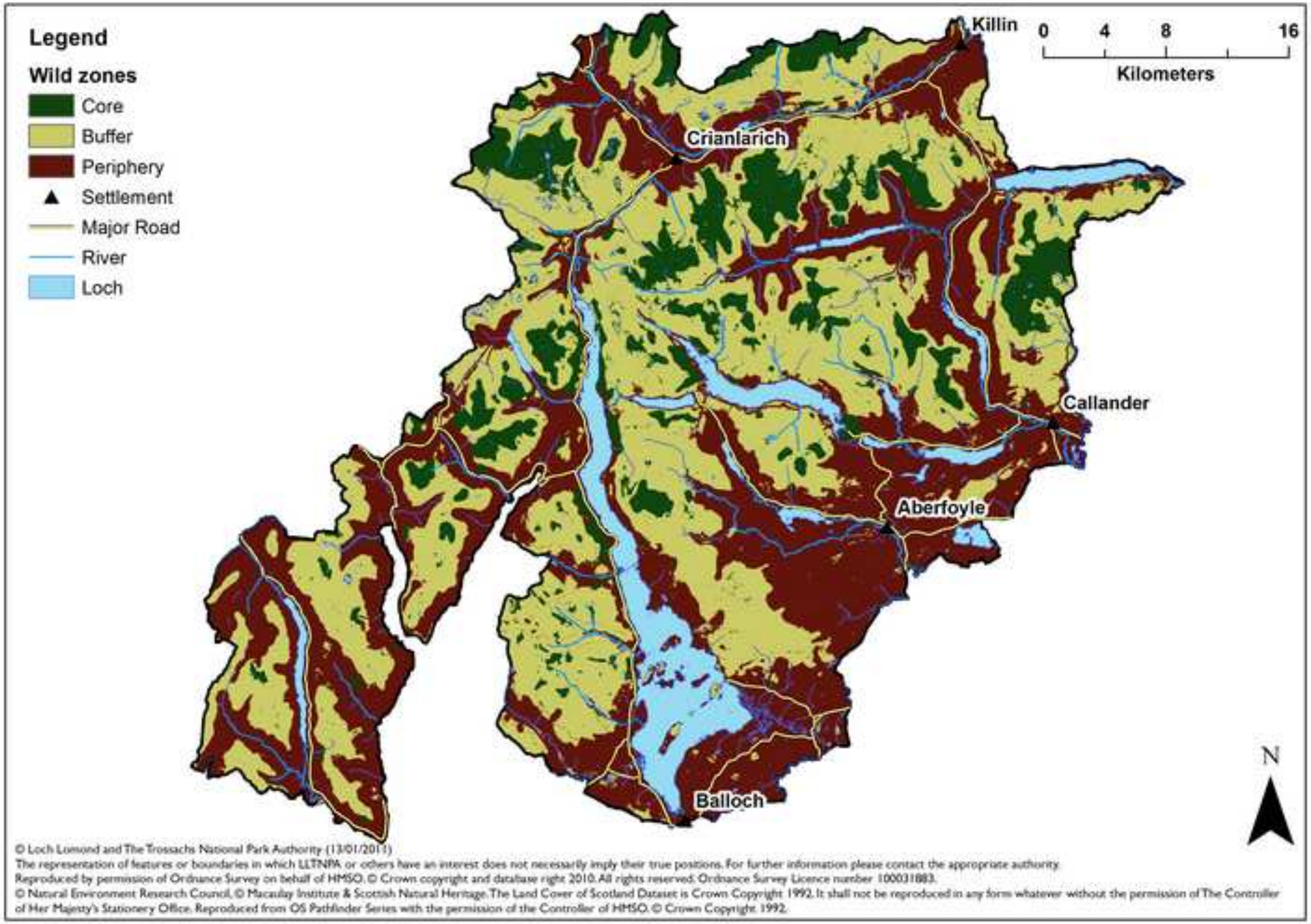

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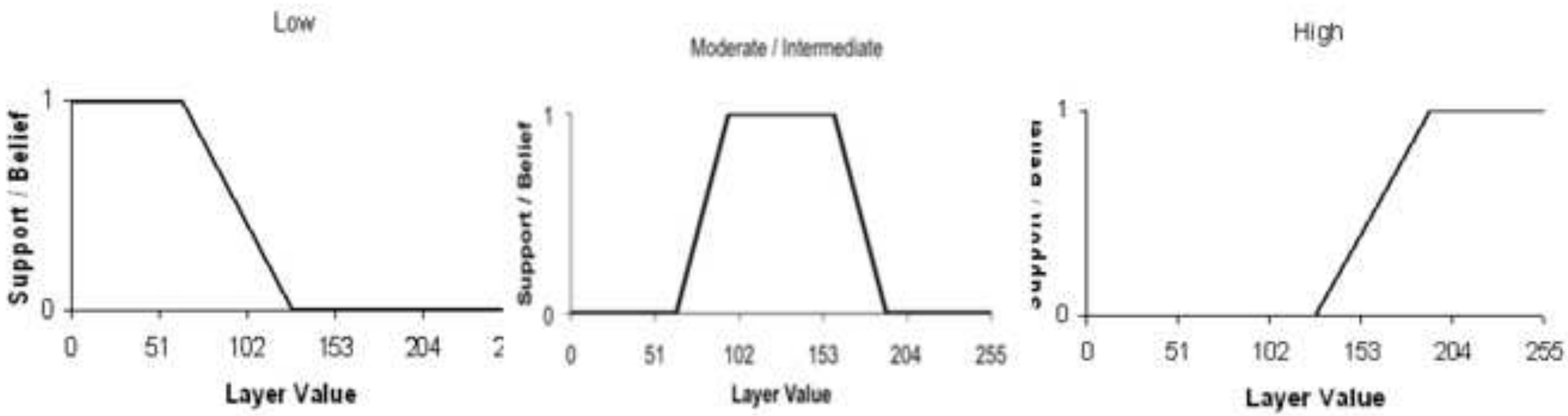

Understanding spatial patterns and distribution of wild land: developing GIS

approaches to modelling wildness in Scotland's national parks

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