

A web-based GIS tool to allow public exploration of the
concept of 'wild land' in Scotland

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Declaration of originality

This is to certify that the work is entirely my own and not of any other person, unless explicitly acknowledged (including citation of published and unpublished sources). The work has not previously been submitted in any form to the University of Salford or to any other institution for assessment for any other purpose.

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Abstract

Within the field of Geographical Information Systems (GIS), there has been much debate about the 'bottom-up' approach to using GIS tools and techniques for collecting and analysing data. This approach has often been given the terms 'public participation geographic information systems' (PPGIS), 'volunteered geographic information' (VGI) or 'neogeography'. The PPGIS approach has been used to support decision support systems such as local environmental planning using web-based map visualisations and the multi-criteria evaluation (MCE) method. There has also been research using GIS techniques to define the concept of 'wild land' or 'wilderness', describe and model it with spatial attributes (using features related to naturalness and remoteness), and to create maps of 'wild land'. This dissertation describes a novel method of combining these two areas, and the use of it to explore the concept of 'wild land' in the Scottish Highlands. The method involves the development of a web-based PPGIS tool allowing a wide 'public' audience to explore the subjective concept of what 'wild land' means. The tool presents visualisations of 'wild land' attributes in a web browser as map layers that can be combined using MCE and opacity blending techniques to allow variations of the relative weighting of the attributes. To fully support a PPGIS approach, the tool only uses 'open' spatial datasets without financial and licencing barriers to model the 'wild land' attributes, and a web-based client-server architecture utilising only free and open-source software (FOSS) GIS applications such as GeoServer and OpenLayers. Despite the restrictions of the PPGIS approach an effective tool is developed, showing that this is a valid approach to use in the exploration and analysis of the concept of 'wild land', leading to the potential for a more robust interpretation of the concept.

List of Acronyms

4WD	Four-Wheel Drive
ANWI	Australian National Wilderness Inventory
API	Application Programming Interface
ASCII	American Standard Code for Information Interchange
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AWS	Amazon Web Services
BNG	British National Grid
CCL	Creative Commons Licence
CDN	Content Delivery/Distribution Network
CEH	Centre for Ecology and Hydrology
CLC	CORINE Land Cover
CNP	Cairngorms National Park
CSS	Cascading Style Sheets
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
EA	Environment Agency
EPSG	European Petroleum Survey Group
EU	European Union
FOSS	Free and Open-Source Software
GeoTIFF	Georeferenced Tagged Image File Format
GDAL	Geospatial Data Abstraction Library
GIS	Geographical Information Systems
GPL	General Public Licence
GUI	Graphical User Interface
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
JRE	Java Runtime Environment
LCM	Land Cover Map
LLTNP	Loch Lomond and the Trossachs National Park
MCDA	Multiple-Criteria Decision Analysis
MCE	Multi-Criteria Evaluation

NCGIA	National Center for Geographic Information and Analysis
ODbL	Open Database License
OGC	Open Geospatial Consortium
OGL	Open Government Licence
OS	Ordnance Survey
OSGeo	Open Source Geospatial Foundation
OSM	OpenStreetMap
PNG	Portable Network Graphics
PPGIS	Public Participation Geographic Information Systems
RWD	Responsive Web Design
SEPA	Scottish Environment Protection Agency
SLD	Styled Layer Descriptor
SNH	Scottish Natural Heritage
SRS	Spatial Reference System
SRTM	Shuttle Radar Topography Mission
TRI	Terrain Ruggedness Index
URL	Uniform Resource Locator
VGI	Volunteered Geographic Information
W3C	World Wide Web Consortium
WLC	Weighted Linear Combination
WMS	Web Map Service
WOODS	Woodland Online Decision System
WRi	Wildland Research institute

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1. Introduction

1.1 Background

The theme of this dissertation is the concept of 'wilderness' or 'wild land', and the spatial mapping of this concept, particularly in a public participation geographic information systems (PPGIS) context. This has a rich and varied history of previous attempts at investigation and research. The primary problem is the definition of what the terms 'wilderness' or 'wild land' mean thematically and spatially before they can be mapped. In this respect, the US Wilderness Act of 1964 was influential in defining these terms, and this act and other early definitions centred on notions of "...absence of human artefacts and management, lack of human settlement, remoteness, opportunity for solitude, ecological condition and size" (Carver and Fritz, 2016:2). Translating these definitions or criteria of 'wilderness' or 'wild land' into spatial attributes which can be mapped has been the central focus of research in this area since then, and GIS techniques were used in this research from the early 1990s (Carver and Fritz, 2016).

There are many reasons why attempts to map 'wilderness' or 'wild land' might be productive or fulfil a requirement: protection of sensitive ecological environments; protection of wildlife; security of water supply; human recreation; preservation of control areas for environmental study. Human exploration and also exploitation of 'wild' environments has a long history up until the twentieth century, leading to unexplored, blank or 'wild' areas on early maps containing the Latin term 'terra incognita' (the popular idea that the Latin term 'HC SVNT DRACONES' or 'here are dragons' was also used widely is a modern anachronism (Van Duzer, 2014)). Many researchers also consider that 'wilderness' or 'wild land' has intrinsic value beyond anthropogenic considerations (Carver and Fritz, 2016).

There is no single agreed definition of 'wild land', and the idea that this concept can in some way be measured and mapped is heavily reliant on human subjectivity and experiences. Thus, the concept inherently contains vagueness and ambiguity. Attempts have been made to use techniques such as 'fuzzy' categories of attribute classifications to deal with this in GIS mapping applications (Comber et al., 2010;

Carver et al., 2012). Another approach is to use the idea of PPGIS. PPGIS is a relatively new concept which started around the late 1990s and its development has gone together with the development of web technologies which are fundamental to it (Sieber, 2006; Carver and Fritz, 2016). PPGIS has been defined as "...promoting the normative activity of broadening access to GIS" (Sieber, 2006:491). The history of mapping areas of 'wild land' (and mapping in general) has been dominated by governmental, commercial and academic organisations, an 'exclusive' or restricted approach which PPGIS as a 'normative' activity seeks to counter and change.

This dissertation concentrates on the aim of building a web-based platform with tools and applications that utilise the concept of PPGIS. The level of access to data and GIS applications in this area is fundamental to the PPGIS approach, and this has led to the research problem which this dissertation addresses, namely that previous work in the area of exploring and mapping 'wild land' is not fully PPGIS in context and scope, in that it uses 'closed' data that has financial and licencing restrictions on usage and hence only offers an 'exclusive' approach.

The PPGIS web tool developed and evaluated in this dissertation allows a wider, more 'open' and more 'public' exploration of the idea of 'wild land'. It is a platform that allows the gathering, investigation and analysis of subjective and individual human perceptions and notions of 'wild land'. It is based on graphical map-based visualisations that use 'open' data and standards without financial or licencing constraints, free and open-source software (FOSS) applications and modern web-based technologies, making it as accessible as possible, an approach which is novel and addresses the limitations of previous research. The work detailed in this dissertation can however be seen as pursuing a technical approach that is similar to other PPGIS projects that involve "...easing the understanding of analyses through visualization and weighting alternatives utilizing graphical user interfaces" (Sieber, 2006:493) and that enable "...participants to dynamically interact with input..." (Sieber, 2006:503).

A major influence on this dissertation is the research carried out by Dr Steve Carver and the Wildland Research Institute or WRi (Wildland Research Institute, 2017) at the University of Leeds. Some outputs of this research were early PPGIS tools that

focused on environmental issues such as the idea of 'wild land'. Much of the research has built upon and developed the idea of four attributes of 'wild land' which are used for multi-criteria mapping. The attributes (naturalness of land cover; absence of modern human artefacts; rugged and physically challenging terrain; remoteness from mechanised access) are based on two basic concepts, remoteness and naturalness, and were originally defined in work carried out for the Australian National Wilderness Inventory (ANWI) (Lesslie and Maslen, 1995). The four attributes were further defined by Scottish Natural Heritage (SNH), and Scottish Natural Heritage (2017a) defines the term 'wild land' in the context of Scotland (in preference to the term 'wilderness') thus: "The term 'wild land' is also 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" (Scottish Natural Heritage, 2017a:2).

Much of this research has a focus on Scotland and according to Carver and Fritz (2016), Scotland has "Perhaps the best mapped area in terms (of) wilderness quality..." (Carver and Fritz, 2016:7). SNH produced maps spatially defining areas of 'wild land' in Scotland in 2014 (Scottish Natural Heritage, 2017b), which are intended to be used to "...directly inform Scottish planning policy and decision-making on development" (Carver and Fritz, 2016:7). Research which directly influenced this dissertation is presented in Carver et al. (2012) which uses processed spatial data to model as closely as practical the four 'wild land' attributes, and multi-criteria evaluation (MCE) and fuzzy classification techniques to visualise and map 'wild land' in Cairngorms National Park (CNP) and Loch Lomond and the Trossachs National Park (LLTNP), and which led to the creation of the SNH maps.

This dissertation focuses on CNP because it is considered to be an area with qualities that make it important for the consideration of 'wild land' in Scotland. It is the largest national park in the United Kingdom with an area of 4528km². It contains mountainous and remote areas, and has the largest area of the UK above 600m in elevation and the largest arctic montane habitat area with important wildlife and plants. Landscapes and landforms typical to CNP can be seen in figures 1.1 and 1.2. CNP also contains major transport corridors (the A9 trunk road and the Perth to Inverness railway line), power infrastructure (the Beaulieu to Denny electricity

transmission line, the Cuaich hydroelectric scheme), three ski centres, urban areas (the largest being Aviemore) and has a total population of 17,000 residents with tourism and recreation some of its most important economies (Carver et al., 2012; Cairngorms National Park Authority, 2017). The park was created in 2003 to protect the natural heritage of the area, and the boundary of the park was extended in 2010 (Scottish Government, 2017; Scottish Natural Heritage, 2017c) (figure 1.3). The park covers most of the 'Cairngorms' (no. 15) and 'Lochnagar – Mount Keen' (no. 16) SNH 'wild land' areas, which are defined by SNH summaries of the areas at Scottish Natural Heritage (2017d) and Scottish Natural Heritage (2017e).

Although this dissertation focuses on the area of CNP, the data and methods used and the use of the PPGIS approach to investigate the concept of 'wild land' are scalable and extensible for use in any areas of Scotland.



Figure 1.1. The Cairn Gorm – Ben Macdui plateau at an elevation of around 1100m.



Figure 1.2. Coire an t-Sneachda and Glen More, town of Aviemore at top left.

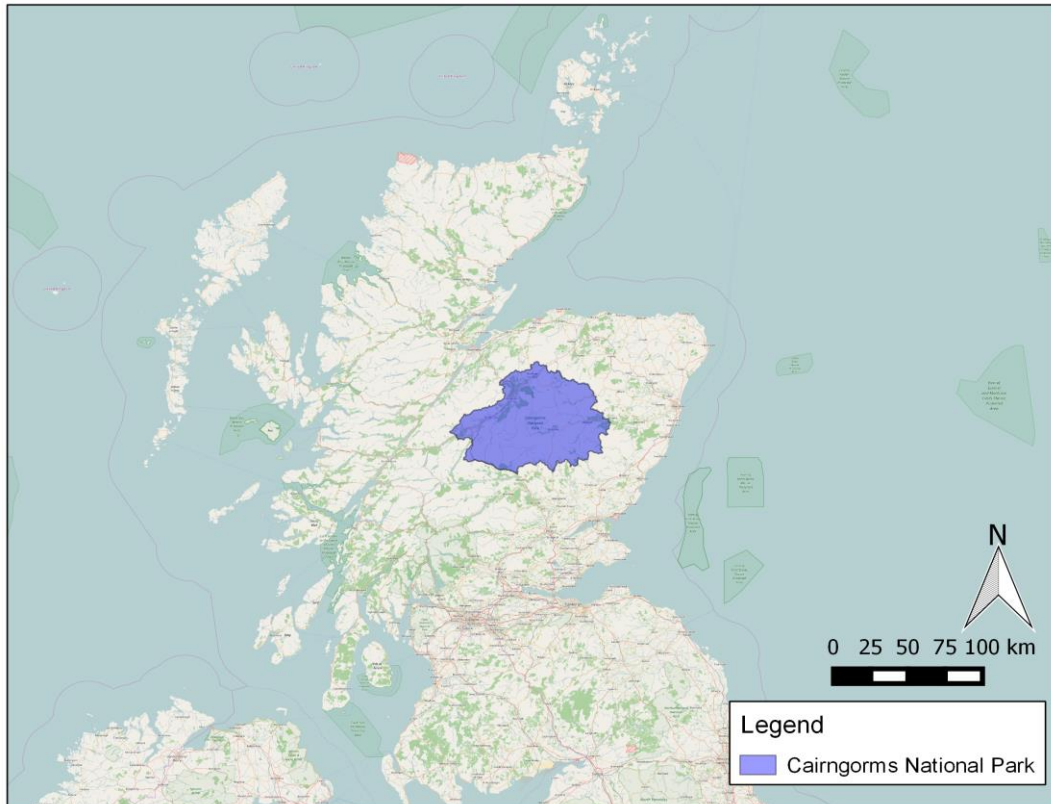


Figure 1.3. Location of Cairngorms National Park (CNP) within Scotland (2010 boundary; OpenStreetMap basemap).

1.2 Aim and objectives

The aim of this dissertation is the development of a publicly-available web-based GIS mapping tool, and the evaluation of the effectiveness of this tool in supporting a PPGIS approach, using the example of exploring the concept of 'wild land' in the Scottish Highlands.

Objectives for the dissertation are:

- Carry out a critical literature review, with a focus on PPGIS, web-based GIS, 'open' technologies and data, and previous research in the area of using GIS tools and techniques to analyse 'wild land' and the criteria or attributes used to define it.
- Investigate the implementation of FOSS applications, platforms and technology architectures combined with 'open' geospatial UK datasets that are publicly available, flexible and customisable, with no licencing or financial constraints, and which could potentially support an 'open', web-based PPGIS approach.
- Develop a web-based GIS tool (using the architecture and data identified) to allow the exploration and visualisation of what 'wild land' means on an individual human subjective level in the context of the Scottish Highlands.
- Evaluate the tool to discover how effectively the data, technologies and architecture used support the project aim, particularly in terms of supporting a PPGIS approach with minimal constraints on usage.

1.3 Structure of dissertation

The first section of this dissertation is a critical literature review of research associated with the aim and objectives of the dissertation, and an identification of the limitations of this previous literature. The second section is a detailed description of the methods and data used in the dissertation. The methods incorporate various strands: 1) a combination of the approaches of the development work used to create maps and web tools presented in Carver et al. (2012) and Markieta and Rinner

(2014); 2) full support for a PPGIS approach using FOSS components and 'open' data; 3) use of current web technologies supporting spatial visualisation and GIS techniques. This combination of methods is an entirely novel approach in an attempt to meet the aim of the dissertation and address the limitations of, and questions raised by, previous research. This section shows details of data processing steps and the development of a web-based tool that utilises this approach. The next section presents a discussion of the results of the methods, including an evaluation of the web tool. This incorporates an analysis of how well the approach and conceptual framework used in the methods meets the objectives, and explicitly, how well the data quality and web tool visualisations meet the 'fitness for purpose' requirements. This section also has a discussion of the sources of data and web technologies used and the usability of the web tool interface. The final section presents the conclusions of the dissertation involving discussions of this novel approach and the results, the limitations of the approach, and ideas for further research and potential uses of the tool.

2. Literature Review

2.1 Introduction

The rationale for this literature review is to give details and a critical analysis of recent research in the areas associated with the aim and objectives of this dissertation, and in particular the use of the PPGIS approach to analyse and explore 'wild land'. The focus is on research carried out in the last two decades but the choice of papers, books, reports, articles and web-based resources selected for the review is not intended to be systematic or completely authoritative. Rather, research has been reviewed that has been influential, comes from reliable sources with an academic or scholarly provenance and is representative of work most relevant to the aim and objectives of this dissertation.

2.2 PPGIS, FOSS technologies and 'open' data in GIS

PPGIS has much in common with the concept of volunteered geographic information (VGI). VGI was first outlined in detail in Goodchild (2007) and was defined as drawing upon the web technologies and concepts sometimes labelled as 'web 2.0' (particularly 'user-generated content') and the concepts of 'crowdsourcing' and the 'wisdom of crowds' (Surowiecki, 2004). VGI enables GIS data collection and the creation of new GI services which are carried out using methodologies which are a departure from the traditional methods used by professional geographers at National Mapping Agencies and qualified academics at academic institutions (Goodchild, 2007). Fundamentally this new methodology makes basic GIS functions accessible to a broad community of users and gives them the ability to create 'open' GI data and services (using tools such as GPS receivers) which may comprise very large datasets of geographic information at minimal cost and potentially high development and updating speeds. An influential and successful example of this is OpenStreetMap (OSM) (OpenStreetMap Foundation, 2017).

VGI allows for the empowerment of mapmaking 'non-experts', an entirely new paradigm for the creation of GI services which can be seen as a response to the social critiques of GIS, which have been labelled 'critical GIS'. These critiques focus

on the perceived potential 'negative' aspects of GIS on society such as: 1) it enforces the majority or government viewpoint and marginalises minorities and individuals who may be less powerful in society; 2) it is an 'elitist' technology that enforces existing social power structures and gender and class roles; 3) it creates many privacy and ethics problems for society as a whole (Wood and Fels, 1992; Pickles, 1995; O'Sullivan, 2006). VGI can be thought of as a 'bottom-up' approach to mapmaking as opposed to the traditional 'top-down' approach, that removes the social barriers of the 'digital divide' in geography and transfers power away from a mapmaking 'elite' to people who may have been excluded historically from the power that mapmaking can give (Goodchild, 2007; Elwood, 2006). This has been summarised in Sui et al. (2012) as: "...in contrast to the traditional top-down authoritative process of geographic data production by government agencies, citizens have played an increasingly important role in producing geographic data of all kinds through a bottom-up crowdsourcing process" (Sui et al., 2012:3).

Certain aspects of the concept and practice of VGI have spawned associated terms: the 'geoweb' (Batty et al., 2010), 'neogeography' (Goodchild, 2009) and 'public participatory GIS' (or PPGIS) (Sieber, 2006). In particular, when VGI approaches are used to support community collaboration in the use of maps and spatial data to support decisions in local planning and policy issues (such as urban development and land management) then the term PPGIS has become widely used (Kingston et al., 2000; Brown et al., 2014). Brown et al. (2014) notes that there is generally no practical difference in the usage of the terms 'PPGIS' and 'neogeography' when used in relation to GIS applications that utilise 'web 2.0' approaches and technologies. The term PPGIS and its original definition as "...approaches to engage the public in applications of GIS with the goals of improving the transparency of and influencing government policy" (Sieber, 2006:492) originated from National Center for Geographic Information and Analysis (NCGIA) meetings in 1996 (Sieber, 2006).

PPGIS can enable activism on social issues like people and areas affected by economic hardship, one example of this being Google's 'Global Awareness layers' for Google Earth (Elwood, 2011). PPGIS can also allow 'non-experts' to make 'citizen science' contributions to scientific or environmental projects (Goodchild, 2007; Goodchild, 2009). PPGIS has been seen as an activity which promotes the

'normative' influence of GIS on society (e.g. making GIS tools and techniques accessible to all without restriction, to enable empowerment and expanded participation), as opposed to the more traditional 'descriptive' approaches to GIS which are heavily influenced by logical positivism and the scientific method (Sieber, 2006).

PPGIS tools have been developed that enable the public to be involved in decision-making processes, by creating web-based mapping tools to support this. Examples of these are the 'Virtual Slaithwaite' web tool and the Woodland Online Decision System (WOODS) web tool. Virtual Slaithwaite is a forum for collecting comments about features on a map interface, to support community collaboration and discussion of local rural development and planning (figure 2.1) (Kingston et al., 2000). WOODS is a map generation tool to visualise user choices about how the importance of various criteria relating to regional woodland regeneration are ranked (Carver et al., 2001). However, a major limitation of these tools is that the spatial datasets used (from sources with a restrictive copyright or licencing model, in particular the Ordnance Survey or OS) create barriers to public availability, and hence potentially limit the authoritativeness of any results the tools may produce; Kingston et al. (2000) notes that: "The copyright issue is probably the single most important factor which will prevent publicly funded organisations and projects from developing Web-based GIS" (Kingston et al., 2000:121). In other words, the tools are not truly 'open', although problems caused by these restrictions have eased in recent years. The tools use basic maps without much detail and outdated web technologies (Java applets and the GeoTools Java GIS toolkit), and the WOODS tool is no longer functional. However, as early prototypes they proved the potential of the concept of using the PPGIS approach to support decision-making with web-based tools.

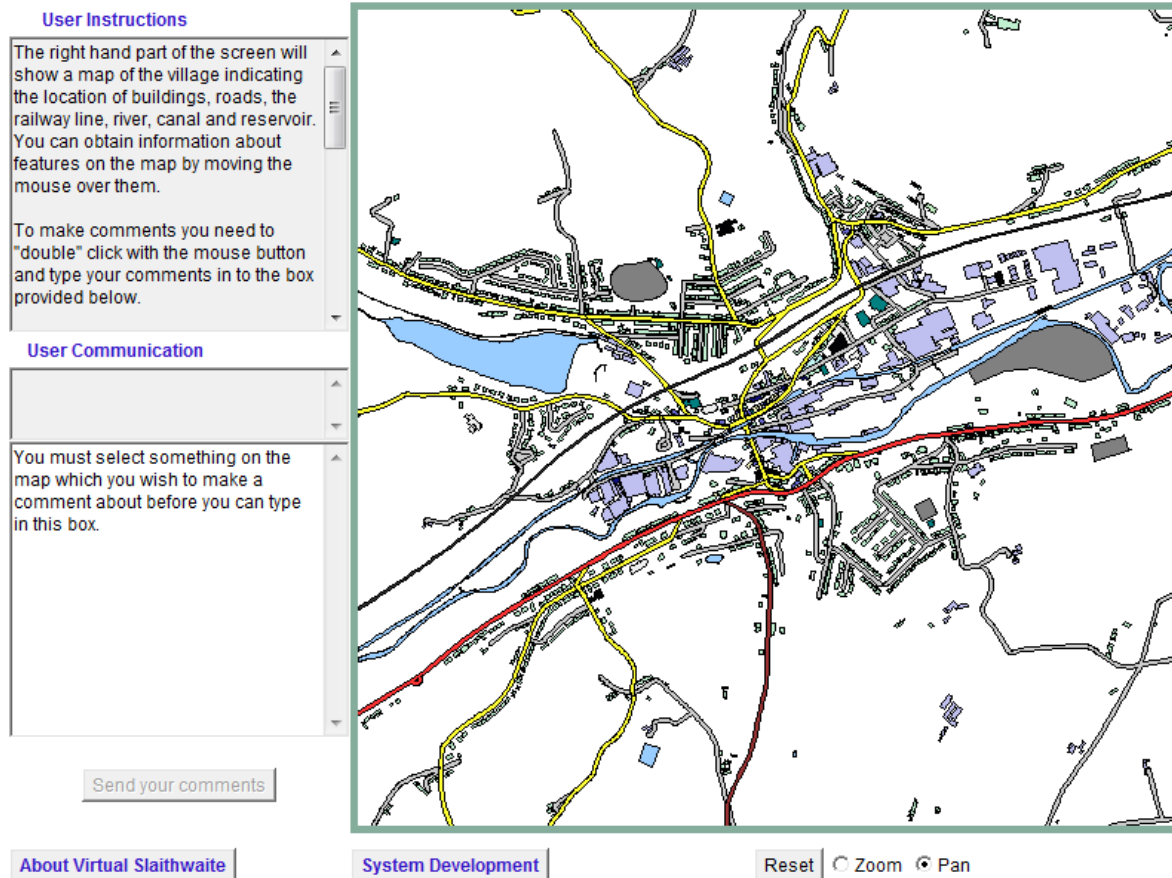


Figure 2.1. Screenshot of the interface of the 'Virtual Slaithwaite' web-based PPGIS tool (source: University of Leeds School of Geography (2017a)).

Crucial to the effectiveness of VGI and PPGIS are the concepts behind FOSS (Anderson and Moreno-Sanchez, 2003; Steiniger and Hunter, 2013; Cook, 2015) and 'open' licencing models for datasets and services (Kerski and Clark, 2012), in conjunction with 'web 2.0' technologies. Examples of PPGIS applications which successfully utilise all of these ideas are MapChat, which allows a community of people to discuss, define and provide annotations for geographic features in their area of interest (Hall et al., 2010) and Geo-Wiki, which uses 'crowdsourcing' techniques to make digital land cover maps more accurate (Fritz et al., 2012). The importance of current web technologies to a PPGIS approach has been outlined in Hall et al. (2010): "...while the current generation of spatial Web 2.0 technologies may not possess the highly technical functions of a GIS, they do offer a mechanism to realize a vision of GIS for all by virtue of their inclusiveness and openness" (Hall et al., 2010:766) and "...spatial Web 2.0 tools can play an important role in extending

public participation to encompass both traditional consumption of spatial data as well as new production and verification roles” (Hall et al., 2010:779).

There is now a large collection of GIS applications, software and libraries which are considered to fall under the FOSS category, and these are listed in detail in Steiniger and Hunter (2013). These make use of licencing models such as the GNU General Public Licence (GPL) and organisations such as the Open Source Geospatial Foundation (OSGeo) have done much to promote the use of these FOSS development projects, such as the GDAL/OGR geospatial libraries, the PostGIS spatial extension to the PostgreSQL database, the QGIS desktop GIS application, the GeoServer and MapServer geospatial data servers, and the OpenLayers web client for spatial data. GeoServer supports the delivery of all major spatial data formats and can use the Open Geospatial Consortium (OGC) Web Map Service (WMS) standard protocol for the delivery of data (Open Source Geospatial Foundation, 2016a) which the OpenLayers web client technology can use for displaying the data. OpenLayers contains a rich library of browser-based components using a JavaScript API to deliver dynamic graphical GIS functionality (Open Source Geospatial Foundation, 2016b). Steiniger and Hunter (2013) describe FOSS thus: “...’free software’ grants the following four freedoms: (1) the freedom to run the software for any purpose (e.g., may it be education or business), (2) the freedom to study and adapt the software for own needs, (3) the freedom to redistribute the software, and (4) the freedom to improve the software and to release improvements to the public.” (Steiniger and Hunter, 2013:137). It is these freedoms that make FOSS applications so important for the ideas behind the PPGIS approach.

In terms of ‘open’ data, in the UK in recent years two events in particular have improved the ability to develop PPGIS tools in an ‘open’ data environment: the release of the UK Open Government Licence (OGL) model (The National Archives, 2016) and in April 2010 the OS offering several datasets under this licencing model through its OpenData service (Chilton, 2011; Ordnance Survey, 2016a). OSM, which is a resource with global coverage rather than a UK-based service, bases its whole purpose on the use of ‘open’ data and uses the Creative Commons Licence (CCL) (Creative Commons Corporation, 2016) and the Open Data Commons Open Database License (ODbL) (Open Knowledge Foundation, 2016).

Issues and concerns about authority and quality can apply to GI services and data created using a VGI or PPGIS approach. National Mapping Agencies and academic institutions have traditionally been seen as having authority in the creation of GI services and data of a standardised quality in which trust and reliability can be established, in contrast to VGI which utilises resources which have no established authority and hence unknown quality (Goodchild, 2007). Goodchild (2009) claims that "...while the growth of VGI is clearly blurring the distinction between the traditional authoritative sources of geographic information and the assertions of amateurs, it falls far short of replacing the activities of academic geographers" (Goodchild, 2009:94). However, a comparison of OS and OSM data carried out by Haklay (2010) showed that (at least in urban areas of the western world) OSM data can approach OS in terms of quality, with OSM street/roads data having a match of about 85% to the accuracy of OS data (Batty et al., 2010). Brown and Kyttä (2014) claim that a PPGIS study of identifying land use attributes in New Zealand using the 'lay public' showed 'reasonable' but significant spatial accuracy and also noted that: "The debate over the spatial accuracy and quality of PPGIS data, although important, may be a proxy for the deeper question about whether land use decisions should be driven by expert judgment (i.e., top down) that often reflects the dominant power structures within society, or broader social preferences (i.e., bottom up) that can fundamentally alter existing power relations, property institutions, and the distribution of wealth." (Brown and Kyttä, 2014:131). Concerns have also been raised about issues of privacy and confidentiality of data collected by VGI tools; the lack of established protocols about who is collecting the data and for what reason may lead to problems about that data being made publicly available (Elwood, 2008; Sui, 2008). VGI can also suffer from biases in data collection, e.g. certain areas such as low-income urban areas may be neglected (Hecht and Stephens, 2014).

2.3 GIS tools and techniques for the analysis of 'wild land' and its attributes

The idea of 'wild land', its attributes and the ability of current GIS tools to map and investigate this concept on a global level has been investigated in Carver and Fritz (2016), which explores some definitions of 'wilderness' or 'wild land' and the attributes or spatial criteria used to model it in various GIS tools and applications.

Commonly-used spatial criteria in these tools and applications are a minimum areal size and distance from human activity or influence.

The history of mapping 'wild land' in a consistent way using modern techniques can be traced to a map created for the fourth World Wilderness Congress in 1987 (McCloskey and Spalding, 1989) but the first attempt to do this using the techniques of GIS was the ANWI (Lesslie and Maslen, 1995). The 'human footprint' map (Sanderson et al., 2002) extends the techniques of the ANWI to a global extent and visualises the idea of the conceptual inverse of 'wild land' with a map of global human influence, created using geographic proxies in the form of four types of data: 1) human population; 2) land use; 3) accessibility; 4) power infrastructure. Summed scores of values assigned to data categories for each of these proxies are used to create a map of the 'human influence index' for each area of the earth's landmass covered by the data, at a spatial resolution of 1km² (figure 2.2). This map and the methodological framework used to create it has subsequently been influential in further exploration of mapping global 'wilderness' e.g. for mapping 'wilderness' loss since the early 90s (Watson et al., 2016).

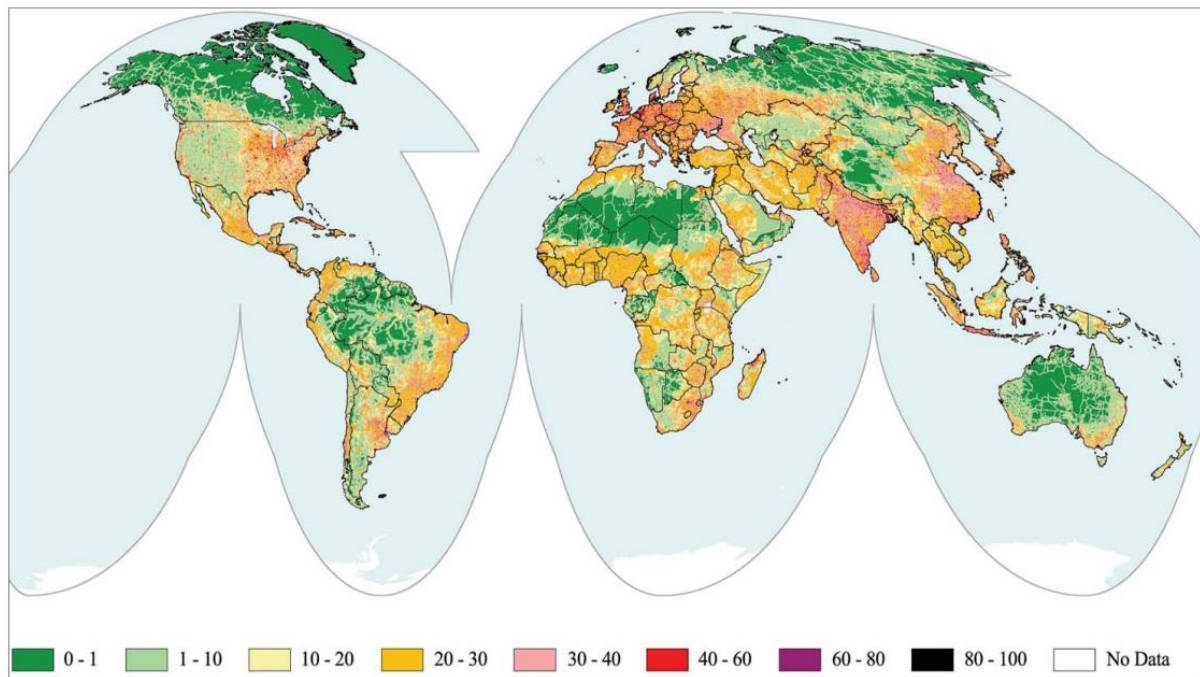


Figure 2.2. The 'human footprint' map (source: Sanderson et al. (2002)). Colours relate to the value of the human influence index with higher numbers (red and orange) denoting a higher value of human influence, and lower numbers (green) denoting a lower value and hence 'wilderness' areas.

These maps are small-scale and low resolution, with a global coverage, and use a 'top-down' approach for their creation and visualisation. They use definitions of 'wilderness' and 'wild land' that come from global considerations. In contrast, the mapping of 'wild land' on the scale of Scotland has been centred on the idea of what the perception of the term 'wild land' means in a more local context, and whether it can be applied to the landscape of the upland areas of Scotland and the Scottish Highlands in particular. Carver et al. (2002) point out that with its long history of human settlement and exploitation of the environment, there is no real 'wilderness' in Scotland, or 'wild land' in the same way as, for instance, in the landscape of North America. McMorran et al. (2008) make this point as well, but add however that: "...for most parts of Europe - including Scotland - a sociological and more flexible definition of wilderness is both more appropriate and more useful" (McMorran et al., 2008:182). Thus, the concept of mapping 'wild land' in Scotland has validity, in the context of the local environment and history of land use.

The perception of 'wild land' in Scotland has been shown to be contentious and strongly influenced by human subjectivity, with differing perceptions about which attributes contribute to the idea of 'wild land' depending on context and the social and cultural background of those who are asked to define it. Methods such as telephone interviews and email questionnaires (McMorran et al., 2008), web questionnaires (Fritz et al., 2000) and photographic questionnaires using visual perception of images (Habron, 1998) have been used to explore this in the context of the Scottish landscape. Rural inhabitants, recreational users of the countryside, wildlife/countryside organisations and land owners/managers all give differing weights to various attributes which have been used to define 'wild land' (Habron, 1998; McMorran et al., 2008). However, Habron (1998) concludes that in Scotland there is "...a wild core that is agreed by all, surrounded by a peripheral area of variable size dependent on ones perception of wild land" (Habron, 1998:54).

In 2014 SNH presented a map showing 42 'wild land areas' in Scotland (Scottish Natural Heritage, 2017b), drawing upon research by Carver et al. (2012) (figure 2.3). Most of these areas are in the Scottish Highlands.

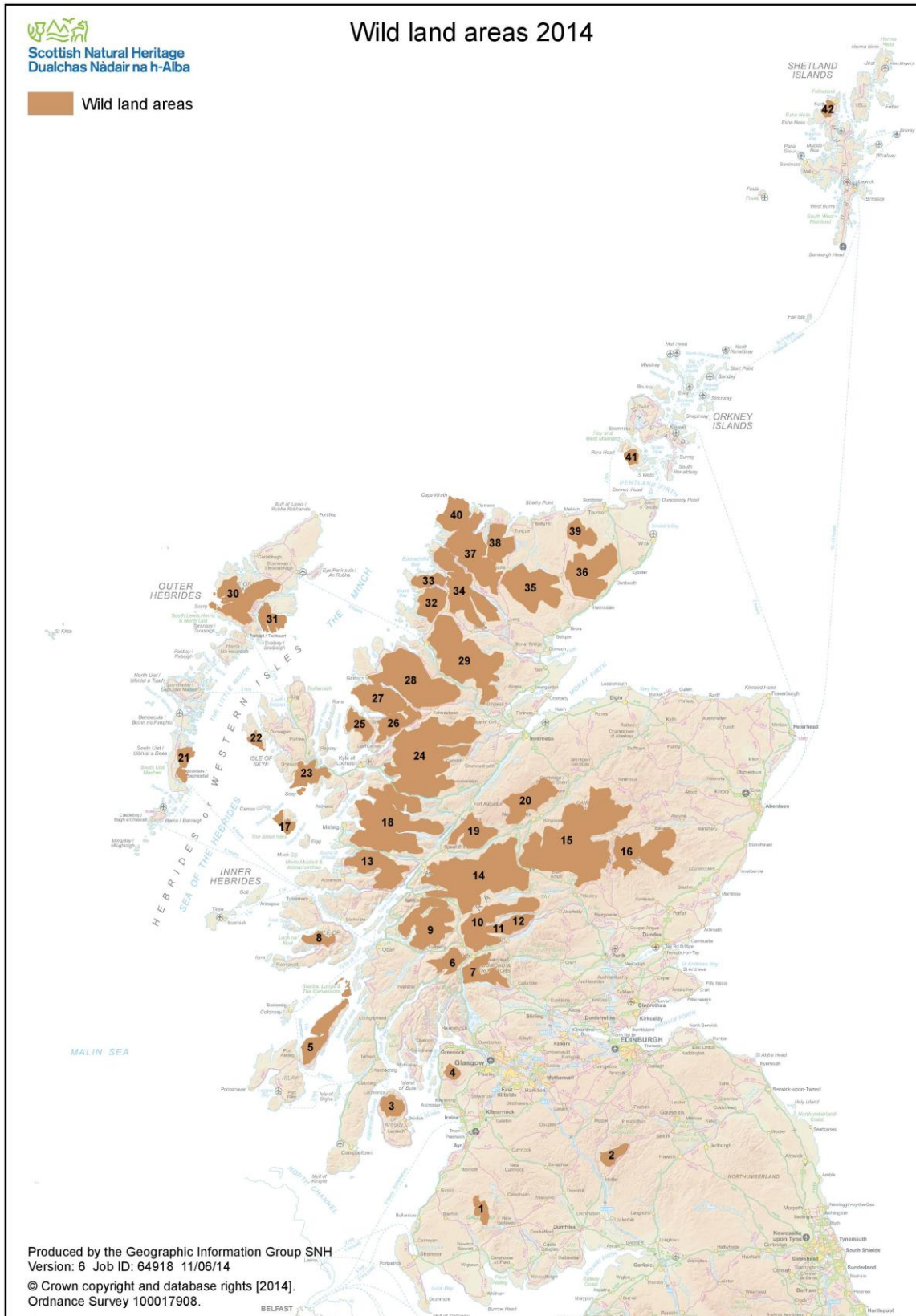


Figure 2.3. SNH map of wild land areas in Scotland (source: Scottish Natural Heritage (2017b)).

Carver et al. (2012) identify four factors or attributes that contribute to the perception of land as 'wild' in Scotland, derived from work carried out by SNH (Scottish Natural Heritage, 2017a), but which ultimately have their origins in the ANWI (Lesslie and Maslen, 1995). These 'wild land' attributes are listed in table 2.1, along with the sources of datasets which are used to model the attributes in Carver et al. (2012).

Table 2.1. 'Wild land' attributes and dataset sources used in Carver et al. (2012).

	'Wild land' attribute	Dataset sources used to model the attribute
1	Naturalness of land cover	Centre for Ecology & Hydrology (CEH) Land Cover Map 2000 (LCM 2000); Macauley Institute Land Cover of Scotland 1988; Highland Birchwoods Woodland Inventory 1999
2	Absence of modern human artefacts	NextMap Digital Surface Model (DSM); OS MasterMap topography
3	Rugged terrain	NextMap DSM; Met Office climate station data
4	Remoteness from mechanised access	NextMap DSM; LCM 2000; OS MasterMap topography; OS 25k raster maps

In Carver et al. (2012) these datasets are extensively processed using a range of data analysis/modelling techniques, which are presented in further detail in Wildland Research Institute (2008). Early versions of the analysis techniques are presented in Fritz et al. (2000). The aim of the processing is to model as closely as possible the physical concepts embodied in the four identified 'wild land' attributes. The resulting processed datasets are then used as components in a MCE analysis using weighted linear combination (WLC) (Eastman, 1999; Malczewski, 2000) to create a series of maps of two areas of 'wild land' in the area of the Scottish Highlands (see figure 2.4 for one of these maps covering the Cairngorms National Park or CNP, roughly coinciding with wild land areas 15 and 16 on the SNH map). The same techniques were also used to create a 'wildness' map of the whole of Scotland (Scottish Natural Heritage, 2017f). The weights used in the MCE analysis in Carver et al. (2012) are taken from two perception surveys of 1004 residents in Scotland and 300 residents in the CNP carried out in 2007 (table 2.2).

Table 2.2. 'Wild land' attribute weights used in Carver et al. (2012). Numbers are normalised so they sum to 1.

	'Wild land' attribute	Residents in Scotland weights	Residents in CNP weights
1	Naturalness of land cover	0.48	0.20
2	Absence of modern human artefacts	0.16	0.29
3	Rugged terrain	0.04	0.13
4	Remoteness from mechanised access	0.32	0.38

A survey carried out for SNH in 2012 (Scottish Natural Heritage, 2017g) sought to further build on this work with an analysis of the results of online and 'face-to-face' questionnaires to produce weights for the four 'wild land' attributes (table 2.3). The survey respondents were sampled according to three segments: 'nationally representative of Scotland' (1006 responses); national park residents (210 responses); outdoor organisation members (656 responses). Key findings of the analysis of the survey responses were that there were "...non-trivial differences in the wildness scores given to these attributes by the different population groups surveyed..." (Scottish Natural Heritage, 2017g:iii), and that the 4 attributes captured the notion of 'wild land' in Scotland well. However, the 2007 and 2012 surveys appear to produce quite different and inconsistent weights to each other, notably for the 'remoteness from mechanised access' attribute.

Table 2.3. 'Wild land' attribute weights (source: Scottish Natural Heritage (2017g)). Numbers are normalised so they sum to 1.

	'Wild land' attribute	'Representative of Scotland' weights	National Park residents weights	Outdoor organisations weights
1	Naturalness of land cover	0.32	0.31	0.29
2	Absence of modern human artefacts	0.41	0.36	0.38
3	Rugged terrain	0.18	0.14	0.18
4	Remoteness from mechanised access	0.09	0.18	0.14

The research presented in Carver et al. (2012) is an attempt to 'quantify the qualitative' (in terms of human subjective notions about what 'wild land' is) and this leads to some loss of the underlying detail in the final map visualisations. The idea that "...lines on maps are needed to protect natural ecosystems and their wildlife" (Carver and Fritz, 2016:191) has led to the 'wild land' areas in the SNH maps being visualised as static and fixed polygons, with an unchanging simple boundary or binary classification between 'wild' and 'not wild', hiding the complexity and interaction of the criteria used to create the map. This idea is however explicitly criticised in Carver and Fritz (2016) where it is argued that hard boundaries are inflexible in protecting 'core' areas of wilderness and the use of 'buffer zones' and 'corridors' connecting these areas more effective. The maps presented in Carver et al. (2012) show more of this complexity with a visual colour gradient of 'wild land' generated using fuzzy classification methods (figure 2.4), but the 'wild land' attribute weights are still fixed. A question can also be asked as to whether the attribute weights used to create the maps (table 2.2) and those taken from the SNH 2012 survey results (table 2.3) are an authoritative and representative sample of human perception in this area, i.e. would a more 'open' or PPGIS approach with a wider audience lead to a better representation of the 'true' values of the weights?

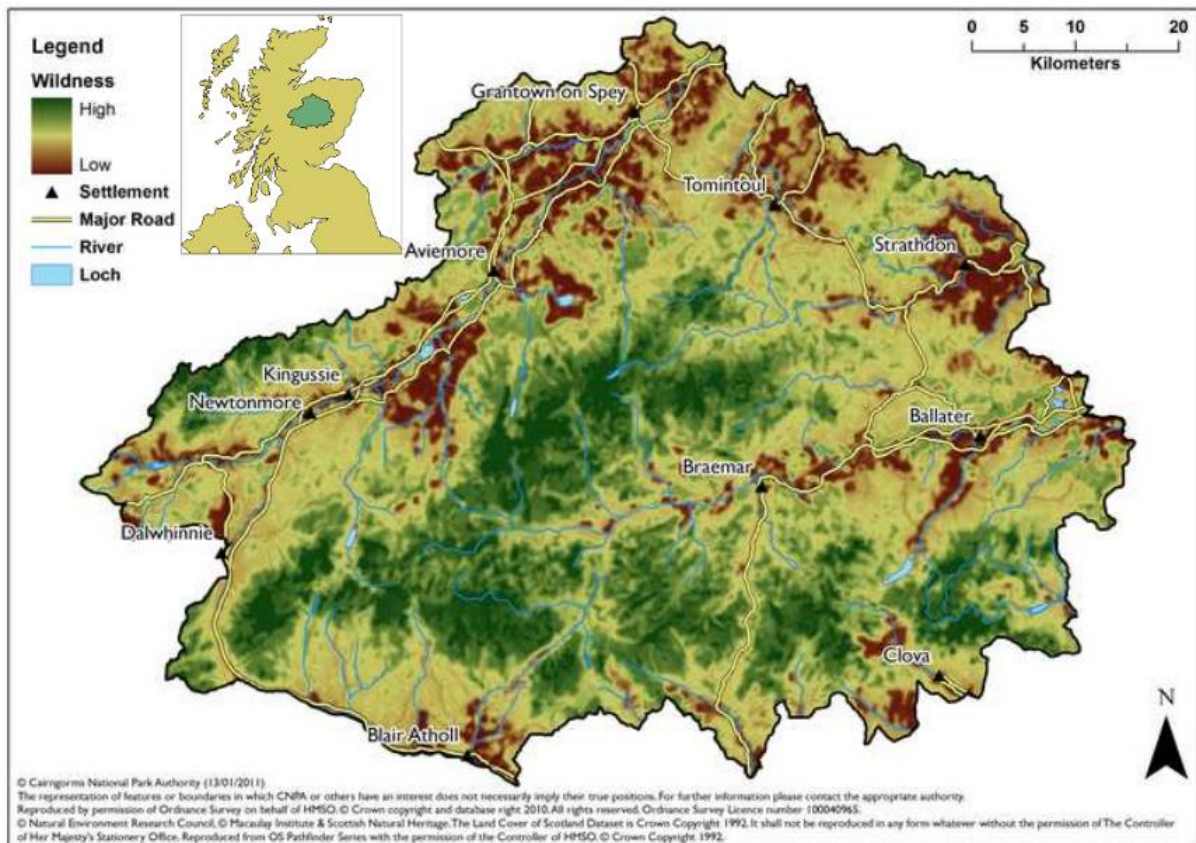


Figure 2.4. 'Wildness' map of CNP (source: Carver et al. (2012)). Insert map showing location of CNP within Scotland has been added.

Beyond exploring 'wild land', MCE or multiple-criteria decision analysis (MCDA) techniques have also been used in web-based PPGIS applications to support spatial planning and improved quality and legitimacy of decision making (Malczewski and Rinner, 2015). In particular, wind farm site suitability and selection tools using web-based PPGIS applications incorporating MCDA techniques with 3D visualisations of sites within the landscape to engage the public have been created (Higgs et al., 2008; Simao et al., 2009). Referring to these tools, Higgs et al. (2008) reach the conclusion that: "Visualisation tools within GIS when linked to a multi-criteria analysis permit...preferences to be compared using a bottom-up approach to incorporate differing values and preferences of individuals, local communities and stakeholders in order to minimise visual Impact" (Higgs et al., 2008:603). Higgs et al. (2008) also note the relative lack of web-based PPGIS tools offering this sort of GIS functionality by saying that existing tools are "...confined to straightforward overlaying of data layers that does not have the facility to incorporate value judgements and public preferences" (Higgs et al., 2008:597).

2.4 Use of PPGIS and web-based tools in exploring 'wild land'

The maps shown in figures 2.3 and 2.4 can be seen as utilising a 'top-down' approach and methodology in their creation, using data from large commercial and government organisations and using techniques for their development that are not publicly accessible (particularly in the case of the SNH maps), to present 'finalised' map visualisations of the data that are intended for decision-making by public bodies. The maps use datasets, architectures and analysis techniques that are not 'open' in the sense that a true PPGIS approach requires. PPGIS has been explicitly identified in Wildland Research Institute (2008) as an area for further investigation in relation to the research and maps presented in Carver et al. (2012): "Existing tools from this work could be used to create an online participatory GIS for the current study which would solicit public opinion about the maps developed and/or allow respondents to develop their own wilderness maps by weighting the attribute maps provided" (Wildland Research Institute, 2008:56).

The idea of a wilderness continuum in the British landscape and the ability of GIS MCE techniques to model this has been explored in a web-based PPGIS mapping tool (figure 2.5) (Carver et al., 2002). This tool, described on the Wildland Research Institute website as: "An early web-based participatory GIS mapping tool for identifying wilderness areas in Britain" (Wildland Research Institute, 2017), uses a browser-based web interface to control the opacity of data layers on a map visualisation corresponding to various 'wild land' criteria. This allows users to dynamically alter the proportional weighting influence of these layers on the resulting map. The research and development work carried out to create the interface and map visualisation are outlined in Fritz et al. (2000) and Carver et al. (2002). This web tool has a number of limitations: 1) it has coverage of the whole of Great Britain at a fairly coarse resolution so that it lacks detail; 2) it is not very accessible, being hidden behind a series of textual web pages and a web form that must be completed and submitted before the interface can be seen; 3) it uses outdated web technologies (Java applets) so that it does not function in a straightforward manner in modern browsers; 4) it uses nine different attributes or criteria to define 'wild land', which make the process of visualising and comparing the differing weights given to each attribute difficult; 5) it is restricted in the datasets it uses to create the map interface

as the data requires 'open' licences as the interface is intended to be used by a wide public audience on the internet, so only UK government census and CEH datasets are used; 6) the datasets used are no longer current; 7) it uses a simpler MCE approach to that used in Carver et al. (2012). However, one outcome of this work was the conclusion that web-based 'wilderness' or 'wild land' attribute mapping allows the public "...to interact with the geographical context and actively contribute to the process of policymaking, planning, and conservation" (Carver et al., 2002:29).

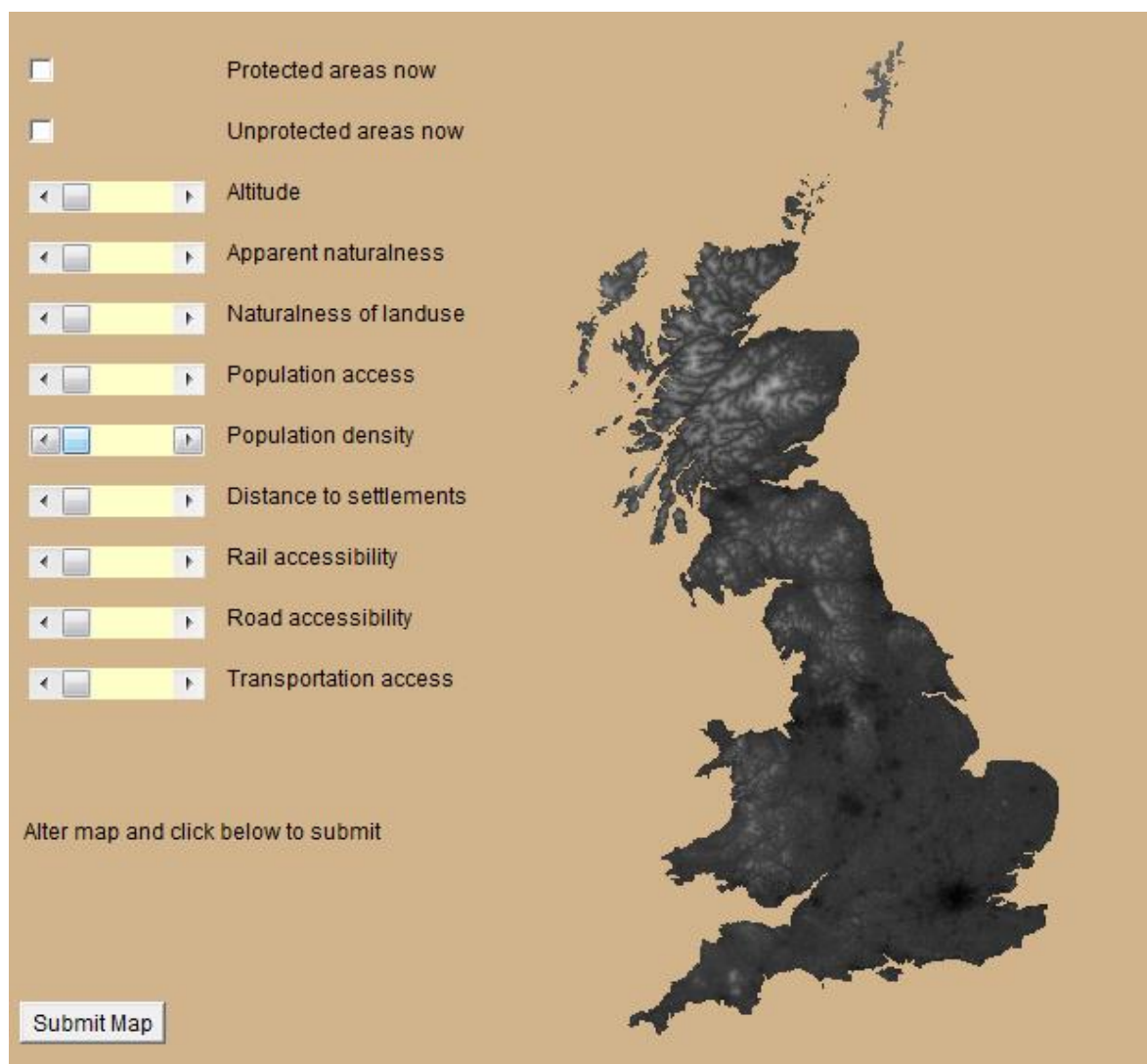


Figure 2.5. Screenshot of the interface of a web-based participatory GIS mapping tool for identifying wilderness areas in Britain (source: University of Leeds School of Geography (2017b)).

An associated PPGIS web tool (figure 2.6) is described on the Wildland Research Institute website as: “An early fuzzy mapping tool for surveying public opinion on wild land in Scotland” (Wildland Research Institute, 2017). This tool uses a ‘spray can’ technique to model and visualise ‘vague’ spatial data with a focus on subjective notions of what ‘wild land’ means in Scotland, and led to the development of the Map-Me PPGIS tool which can be used to explore a wide variety of personal geographical information (Huck et al., 2014; University of Leeds School of Geography, 2017d).

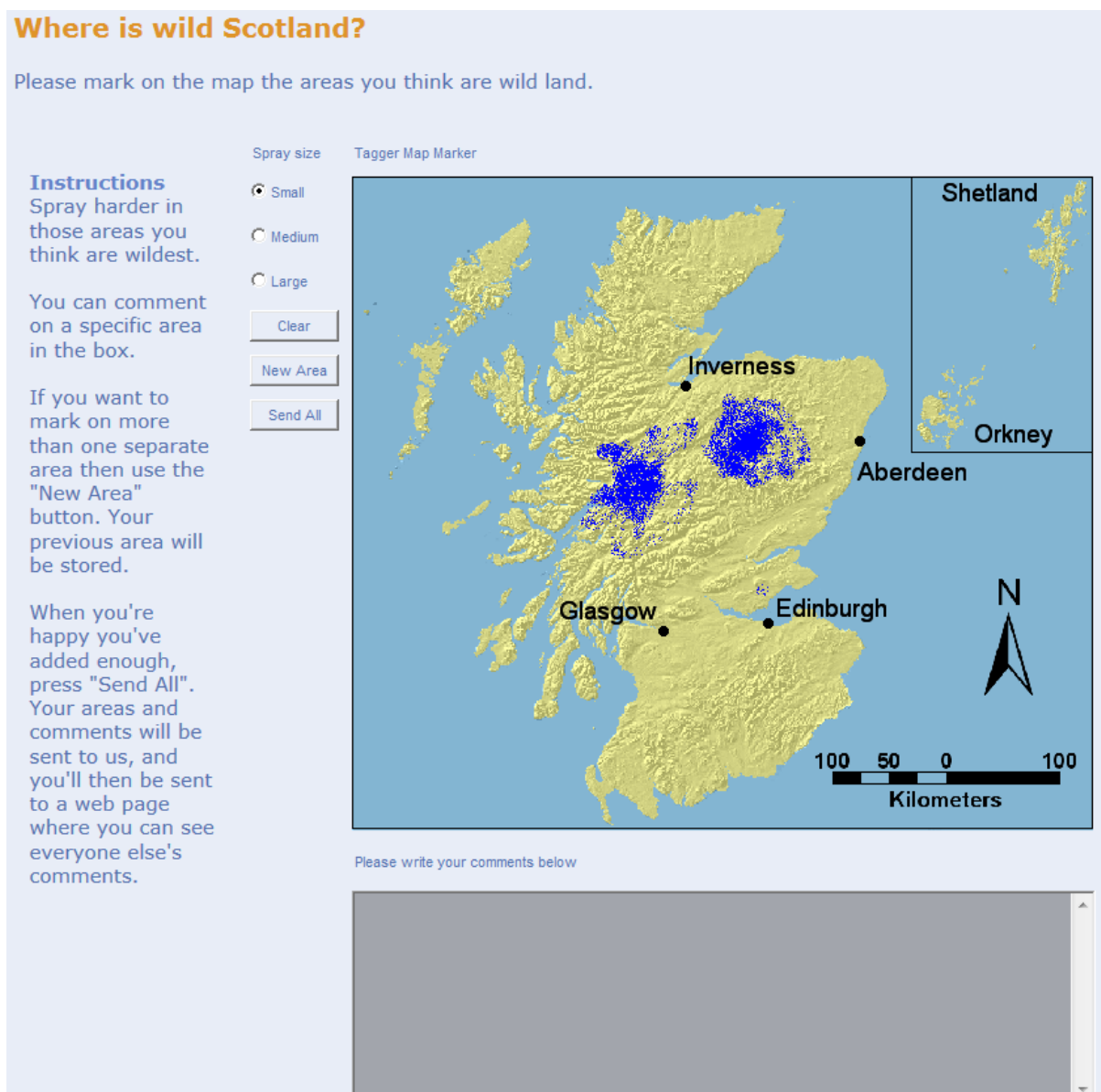


Figure 2.6. Screenshot of the interface of the ‘Where is wild Scotland?’ web-based PPGIS tool (source: University of Leeds School of Geography (2017c)).

Beyond the UK, the development of a web-based mapping tool called the 'map overlay and opacity tool' (moot2) is presented in Rinner and Düren (2011) and Markieta and Rinner (2014) (figure 2.7). This tool uses a browser-based web interface to control the opacity of six data layers on a map visualisation corresponding to 'human influence on the landscape' criteria (the conceptual inverse of 'wild land') to allow proportional weighting influence of these layers on the resulting map, in a similar fashion to the web tool at University of Leeds School of Geography (2017b) (figure 2.5). This work uses techniques that offer a similar approach to that of Sanderson et al. (2002) and Carver et al. (2012) with the added benefit that the map visualisation uses 'dynamic' weighting controlled by the user. There are some limitations with this tool: 1) it uses a simpler MCE approach to that used in Carver et al. (2012), without incorporating 'fuzzy' classification of the criteria; 2) it uses data from at least one commercial source (DMTI Spatial), and cannot be considered to be a true 'open' or PPGIS tool; 3) it uses data and criteria that are localised for the specific requirements and area of Ontario, Canada; 4) the tool is not currently publicly available to use (the publicised URL of the tool is <http://rinnerweb.arts.ryerson.ca/moot2>); 5) it is not clear how closely or accurately the six data layers used in the interface model the real-world concept of 'human influence'. A slightly different approach has been taken by the Geo-Wiki PPGIS application which maps 'human impact' on a global level, using 'bottom-up' crowdsourcing techniques with Google Earth aerial imagery. The map created from these data collection 'campaigns' has been compared quantitatively to the 'human footprint' map created using traditional 'top-down' GIS techniques in Sanderson et al. (2002) and shown to have both advantages and disadvantages in its methods and results (Fritz et al., 2012; Carver and Fritz, 2016).

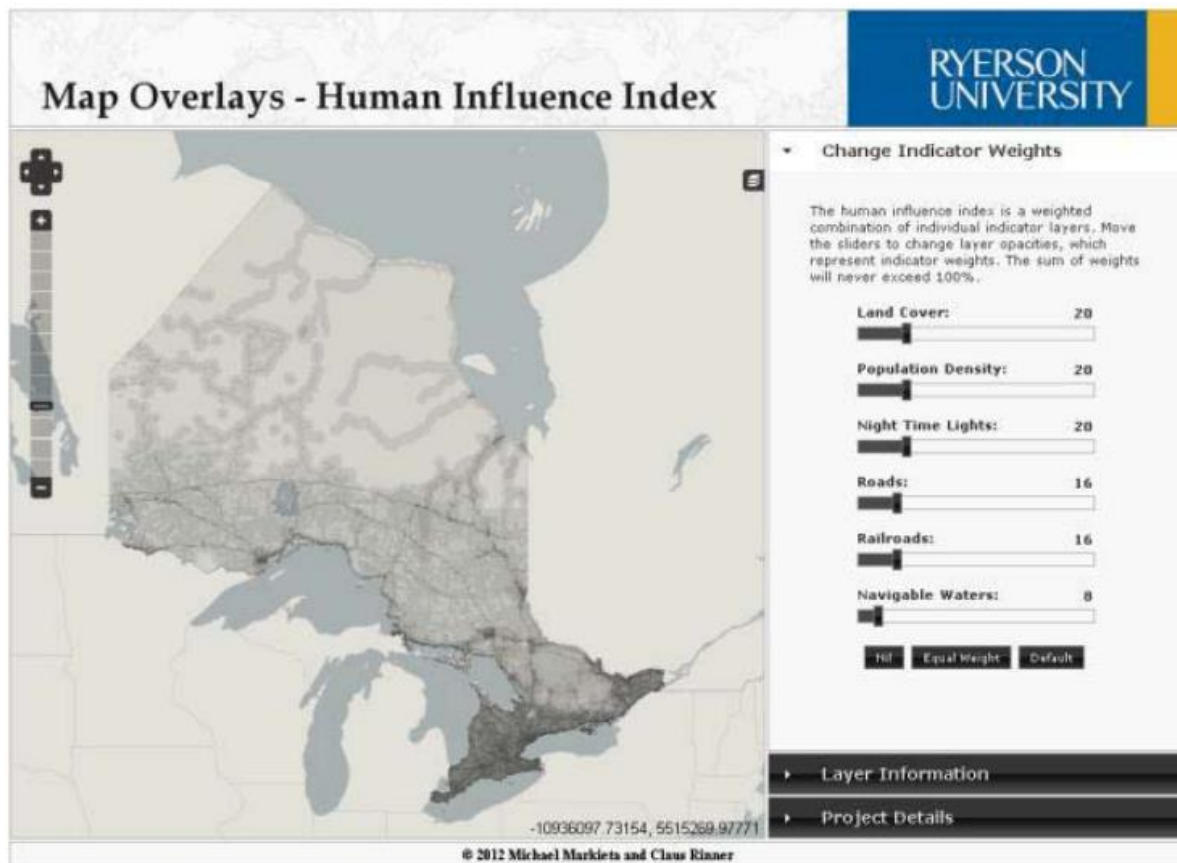


Figure 2.7. Screenshot of the map overlay and opacity tool (moot2) interface (source: Markieta and Rinner (2014)).

2.5 Conclusions

It can be seen from a close inspection of the relevant research in this area and the tools that have been developed that there is scope for further development of web-based PPGIS tools to explore and analyse the notion of 'wild land' in Scotland. In particular, existing approaches arguably do not fully support a PPGIS approach in terms of accessibility and availability by using 'open' and current GIS data and web-based platforms and technologies.

There is also now an opportunity to use the mature environment of FOSS applications, libraries and toolkits, 'open' platforms and data to create PPGIS tools which build on previous methodologies to extend functionality with new web-based interfaces to explore what results a more comprehensive and rigorous PPGIS approach can potentially achieve.

3. Methods and data

3.1 Methodological approach

A diagram showing the workflow of the methods used in this dissertation can be seen at figure 3.1. This shows the key stages of the methods, and the structure of this methods and data section follows these stages. The objectives (section 1.2) that each stage covers are shown as numbers in brackets in the boxes of each stage of the workflow. The dotted line indicates an iterative step in the development of the web tool, namely evaluating, refining and reselecting data and components multiple times depending on their suitability to meet the objectives.

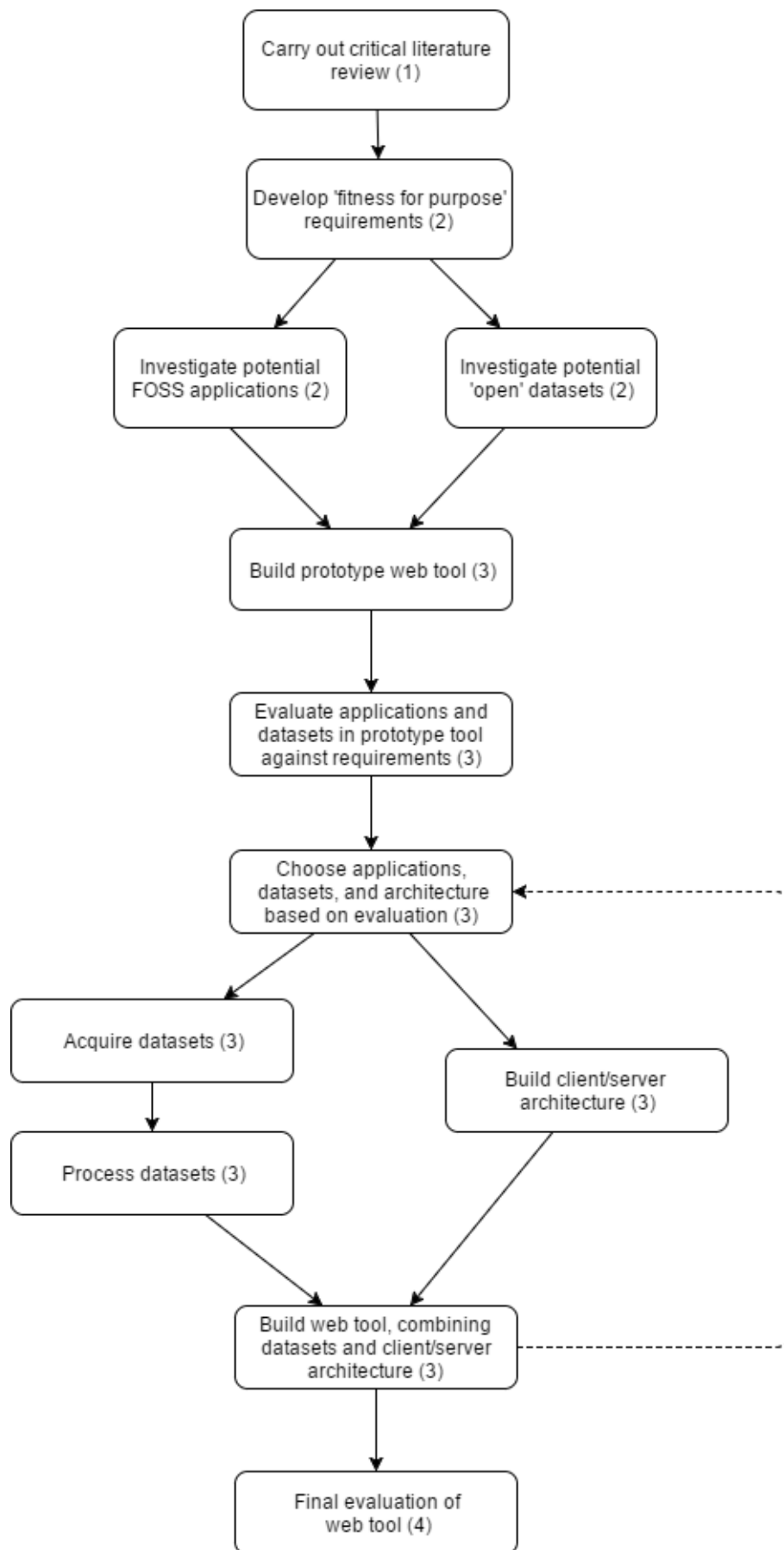


Figure 3.1. Workflow diagram of methods.

3.2 FOSS applications

A primary step in the development of the web tool is the identification of suitable FOSS applications for the architecture components of the tool that can support the objectives (Anderson and Moreno-Sanchez, 2003; Steiniger and Hunter, 2013; Cook, 2015). The technology choices and architecture of the web tool are driven primarily by ‘fitness for purpose’ requirements that follow from the objectives (table 3.1) and are informed by the results of the literature review. Initial candidate architecture components identified for this step are listed in table 3.2.

Table 3.1. Fitness for purpose requirements for selected tool architecture components.

1	Be ‘open’, flexible and customisable, with no licencing or financial constraints (Kerski and Clark, 2012).
2	Support a client-server architecture.
3	Support GIS data formats, GIS standards and specifications and GIS techniques of analysis and visualisation.
4	Be scalable in terms of maintaining the currency of the data stored on the system and increasing the scope and functionality of the system.
5	Be accessible to a wide web-based audience for a sufficient timescale (i.e. the system should have no downtime or slow data transfer speeds, or have a reliance on fee payments).

Table 3.2. FOSS tool architecture components.

Architecture component	Server	Data	Client
Description	web server platform and associated server software, technologies, standards and specifications	geospatial data storage and delivery	web client software, libraries and frameworks
Initial candidates identified	Apache HTTP Server, GeoServer, UMN MapServer, MapGuide, OGC WMS	GeoServer, PostGIS	OpenLayers, Leaflet, JavaScript, jQuery, D3.js, TileMill

3.3 'Open' data

Another primary step in the development of the web tool is the investigation, identification, acquisition and preparation of existing geospatial datasets with levels of data quality that fulfil the 'fitness for purpose' requirements as closely as possible that follow from the objectives (table 3.3) and are informed by the results of the literature review. Initial candidate geospatial datasets identified for this step are listed in table 3.4.

Table 3.3. Fitness for purpose requirements for selected tool datasets.

1	'Open' access or lack of licencing/financial constraints (Kerski and Clark, 2012).
2	Ability to be used in secondary applications with a public audience and with no data protection or privacy issues which might limit this usage.
3	Provenance/lineage from an established source that can be investigated and trusted.
4	Geographic features with attributes that correspond to the four identified 'wild land' criteria defined in Carver et al. (2012) (section 2.3).
5	Sufficient level of resolution, scale, accuracy, generalisation and detail - only relatively small-scale data (e.g. enough to show features within CNP such as the locations of buildings, roads, broad land types and general topography) is required as the focus for the tool is on the subjective visualisations of relative weighting of the four attributes of 'wild land', with a level of spatial detail sufficient to support this - the trade-off between performance and resolution is another factor in this.
6	Currency (up to date). Major features such as roads and buildings must be current. Land cover should ideally not be more than 10 years old. The Digital Elevation Model data does not have the same currency requirement as it is not anticipated that broad topographic features will have changed much.
7	Coverage of the Scottish Highlands (with a specific focus on CNP) - the coverage of the data should be limited to the extent of the park (however edge effects should be taken into consideration in the analysis techniques used in the final tool).

Table 3.4. Potential candidate 'open' geospatial datasets.

Source	Dataset(s)	Availability and licencing model
Environment Agency (EA)	UK LiDAR Digital Terrain/Surface Model (DTM/DSM)	https://data.gov.uk/publisher/environment-agency
Centre for Ecology & Hydrology (CEH)	25m UK Land Cover Map 2007, Corine Land Cover Map 2012	https://catalogue.ceh.ac.uk/documents
Ordnance Survey (OS)	OpenSpace, OpenData	https://www.ordnancesurvey.co.uk/business-and-government/products/opendata-products.html
OpenStreetMap (OSM)	Global built features (buildings, bridges, roads, railways)	https://www.openstreetmap.org/copyright
NASA/METI ASTER GDEM V2	Global 30m resolution Digital Elevation Model (DEM)	https://lpdaac.usgs.gov/user_services/aster_policies http://asterweb.jpl.nasa.gov/
NASA SRTM3	Global 90m resolution DEM	https://lta.cr.usgs.gov/SRTM

Other sources of potential data are the MAGIC website (<http://www.magic.gov.uk/>) and the SEPA website (<https://www.sepa.org.uk/environment/environmental-data/>).

3.4 Development of web tool prototype to select suitable FOSS components and 'open' data

To test that the concept and design of the web tool proposed is technically feasible, a 'proof of concept' technology demonstrator is constructed, with limited functionality, but with the ability to act as a prototype for the final tool and to demonstrate that further development is possible along the lines proposed. Another task for the prototype tool is to test and select suitable potential candidates for datasets.

For the client-server architecture of the prototype there are several candidates (see table 3.2), but GeoServer (server) and OpenLayers (client) are chosen for the web tool prototype as they fit the requirements well (table 3.1 and section 2.2). The requirements for the scalability and accessibility of the tool are in some ways the most difficult to achieve. The choice of GeoServer for the server technology requires a Linux server with Java Runtime Environment (JRE) installed, with sufficient access privileges for GeoServer installation and setup, sufficient disk space and processing power, and the ability to provide this long-term, with the ability to access the service over the web in an unrestricted fashion at minimal cost. Fortunately, a service exists which can provide this, Amazon Web Services (an example of 'cloud' hosting), which offers the EC2 option with no payment required for a year of usage (Amazon, 2016).

The prototype is used to evaluate potential datasets and build up a selection of datasets obtained from various sources (table 3.5) that can be used in the development of the web tool. The selection of these datasets is driven by the requirements (table 3.3) as well as these considerations: 1) the requirement for coverage excludes data from the Environment Agency (EA) and the MAGIC website, which only offer datasets for England & Wales; 2) the datasets should be in a format that can be processed by QGIS, delivered by GeoServer and visualised by the OpenLayers client.

Table 3.5. Geospatial datasets used in prototype tool and selected as suitable.

Dataset	Data type	'Wild land' attribute	Licencing	Source	Spatial resolution
CEH Corine UK Land Cover Map 2012	Vector polygon Shapefile	Naturalness of land cover	OGL	Centre for Ecology & Hydrology (CEH)	Minimum mapping unit = 25 hectares (500m x 500m)
OSM buildings	Vector polygon Shapefile	Absence of modern human artefacts	CCL, ODbL	OpenStreetMap	Undefined?
OS OpenData OpenMap - Local	Vector polygon and polyline Shapefiles	Absence of modern human artefacts	OGL	Ordnance Survey	Nominal viewing scale is 1:10,000
OS OpenData Terrain 50	Raster ASCII Grid DEM (multiple tile files)	Rugged terrain	OGL	Ordnance Survey	50m cell size
OS OpenData OpenRoads	Vector polyline Shapefile	Remoteness from mechanised access	OGL	Ordnance Survey	Digitised and generalised from OS 25k raster data
CNP Boundary (2010)	Vector polygon Shapefile	N/A	OGL	Cairngorms National Park Authority; Scottish Natural Heritage (SNH)	Digitised and generalised from OS 10K raster data

A crucial aspect of the suitability of these datasets for usage in the web tool is the licencing model (Kerski and Clark, 2012). Most of these datasets use the UK OGL licencing model (The National Archives, 2016) which allows for 'open' usage. In particular, the OS through its OpenData service offers several datasets, three of which are appropriate for use in the web tool. Although there are alternative DEM datasets available through ASTER/SRTM, the assurance of quality provided by the lineage of the derived DEM used in the prototype from the OS OpenData service acts as an important factor in favour of its use. OSM data uses the CCL licence model (section 2.2).

The prototype demonstrates that the conceptual and technical framework used is robust and has the potential to deliver the objectives. The data is of sufficient quality, coverage, detail and resolution and the OpenLayers client web tool has a rich enough feature set of spatial and graphical tools to support the proposed functionality of the final deliverable web tool.

3.5 Development and evaluation of web tool

3.5.1 Development

The outcome of the 'proof of concept' of the client-server architecture of the web tool prototype (section 3.4) to potentially successfully deliver the objectives using FOSS components and 'open' data, leads to the decision to continue with this architecture to build the final web tool.

The four attributes of 'wild land' used for the development of the web tool (naturalness of land cover, absence of modern human artefacts, ruggedness or rugged terrain, remoteness from mechanised access) are taken from the research presented in Carver et al. (2012), and the detailed processing presented in Wildland Research Institute (2008). The datasets and methods used in this research to create derived datasets to model these attributes are used as a general guideline for the development of the web tool, with some differences, which are noted where applicable.

To model the 'wild land' attributes, the development of the web tool requires processing of the selected datasets (section 3.5.2), but an important point concerning this processing is that even with the extensive data processing carried out to produce the maps presented in Carver et al. (2012), the data and modelling always represents proxy indicators for the physical attributes and the data layers are never more than approximations or generalisations.

The interface and functionality of the web tool focuses on usability in the context of PPGIS, and rather than attempting to emulate exactly the approach taken with data and maps in Carver et al. (2012) and Wildland Research Institute (2008), instead the development of the tool follows the approach taken in Markieta and Rinner (2014) where data layers represent proxies for the concept in question (in this case 'human influence on the landscape', the conceptual inverse of 'wild land') and the importance of the interface being on the relative weighting choices made by a user to explore their own subjective notions of that concept.

3.5.2 Data acquisition and processing

All processing is carried out using the FOSS QGIS v2.10 application (QGIS Development Team, 2016). All datasets are acquired in or transformed to the British National Grid (BNG) Spatial Reference System (SRS) (EPSG:27700). As in Carver et al. (2012), all datasets are processed to a standardised raster layer using a standard cell-size (in the case of this tool, 50m x 50m, which is the resolution of the OS OpenData DEM), and normalised to a data value range of 1-256.

3.5.2.1 Naturalness of land cover

In Carver et al. (2012) and Wildland Research Institute (2008), the naturalness of land cover attribute is modelled using a variety of land cover datasets, including the UK Land Cover Map (LCM) 2000. There is an updated version of this, the LCM 2007 (available from the CEH), with a vector data resolution of 0.5ha minimum mapping unit in area, and a raster data resolution cell size of 25m x 25m, but this cannot be considered an 'open' dataset as it is only available under licence on request from CEH and licence fees may apply for some users and some applications. It is also 10

years old. The CEH also offers the coarser resolution (25ha minimum mapping unit) CORINE Land Cover (CLC) 2012 dataset for the UK. This is a fully 'open' dataset using the OGL licence model and is more recent than the LCM 2007. The emphasis with the web tool is on using completely 'open' data to support a PPGIS approach, so the CORINE data has been selected for use in the web tool over the LCM 2007 dataset.

The CLC 2012 dataset is acquired as a Shapefile of vector polygons covering the whole of the UK (it is possible to acquire a subset of this data by selecting an area of the UK using a mapping interface on the CEH website), and this is clipped to a polygon representing the CNP boundary with a 10k buffer, using the QGIS Vector GDAL Clip tool, to reduce edge effects. To do this, the CLC 2012 dataset first has to be converted from multistring to singleparts vector polygons to enable clipping of the vector data using QGIS. Edge effects need to be taken into account when the vector data is rasterized to a GeoTIFF raster layer (with 50m x 50m cells) and the raster data values are modified using the QGIS Simple Filter tool (which carries out a mean focal statistic calculation on the raster cells using a circle of radius 5 cells or 250m) which has the effect of a low-pass filter, 'smoothing' the values (Lloyd, 2010). A further QGIS Raster Clipper tool operation is carried out to create a raster covering the CNP area without the buffer, but retaining the data without edge effects. A workflow diagram showing these processing steps can be seen at figure 3.2.

The use of the Simple Filter tool in this processing of the land cover data is an attempt to emulate the equivalent process in Wildland Research Institute (2008), where 'perceived' naturalness is modelled. 'Perceived' naturalness uses the idea of the influence that a pattern of land cover in an area immediately adjacent to a location has upon the perceived naturalness of that location, and a similar filter technique using a circle of radius 250m of nearby cells is used for this. It can be seen from a visual comparison of the maps created using this technique in Wildland Research Institute (2008), and figure 4.1 (results section) that there is little qualitative difference between the maps.

An important step in the processing of this data is the categorisation of the land cover polygons appropriately. For this, the five naturalness classes of land cover

used in Wildland Research Institute (2008) are used (with a value of 1 being least 'natural', and 5 the most). In Wildland Research Institute (2008) these five naturalness classes are mapped to LCM 2000 classifications of land cover category so an attempt has been made to map these classes to the CLC 2012 classifications (table 3.6). Only those CLC 2012 land cover classifications that appear within the boundary of CNP are used (20 classifications from a total of 44). The five mapped naturalness classes are added to the CLC 2012 data polygons as new attributes and then the data is rasterized using these attributes as raster values to create a GeoTIFF data layer of the naturalness 'wild land' attribute in CNP.

To create a standardised range of values in the raster data (so that it can be used when comparing with other attribute data layers), the raster calculator tool is used to create a new raster data layer with normalised values in a 1-256 range (the value of zero is reserved for 'no data' locations of the raster, which is rendered transparent in the final web visualisations). The following calculation is used for this:

$$\text{new_val} = (((\text{cur_val} - \text{minx}) * \text{smax}) / (\text{maxx} - \text{minx})) + \text{smin}$$

Where:

`new_val` = new value of raster data cell

`cur_val` = current value of raster data cell

`minx` = lowest raster value in data

`maxx` = highest raster value in data

`smin` = lowest normalised value (in this case 1)

`smax` = highest normalised value (in this case 256)

This GeoTIFF raster data layer is added to GeoServer as a datastore and WMS data layer.

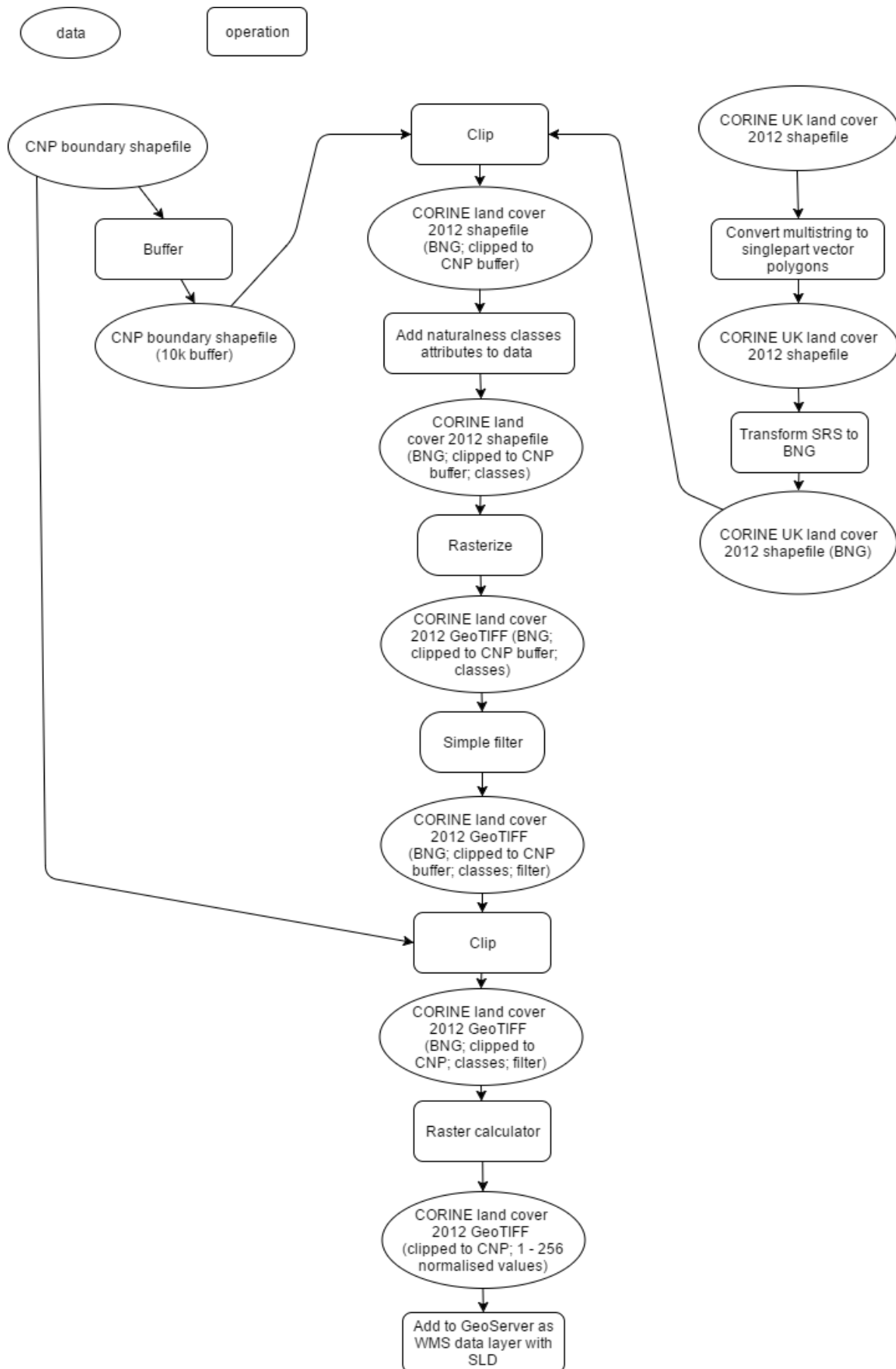


Figure 3.2. Processing of naturalness of land cover data.

Table 3.6. CLC 2012 classes mapped to naturalness classes, with 1 being least 'natural', and 5 most 'natural' (source: Wildland Research Institute, (2008)).

CLC 2012 class nomenclature	CLC 2012 class code	Naturalness class value
Artificial surfaces; urban	112	1
Artificial surfaces; industrial/commercial	121	1
Artificial surfaces; mine	131	1
Artificial surfaces; sport & leisure	142	1
Agricultural areas; arable	211	2
Agricultural areas; pastures	231	2
Agricultural areas; agriculture/natural vegetation	243	2
Forest and semi-natural areas; broad-leaved	311	4
Forest and semi-natural areas; coniferous	312	3
Forest and semi-natural areas; mixed	313	3
Forest and semi-natural areas; natural grassland	321	3
Forest and semi-natural areas; moors/heathland	322	4
Forest and semi-natural areas; shrub	324	4
Forest and semi-natural areas; rocks	332	5
Forest and semi-natural areas; sparse vegetation	333	5
Forest and semi-natural areas; burnt areas	334	3
Wetlands; marsh	411	4
Wetlands; peat bog	412	5
Water bodies; water course/river	511	4
Water bodies; water bodies	512	4

3.5.2.2 Absence of modern human artefacts

In Carver et al. (2012) and Wildland Research Institute (2008), the absence from human infrastructure and manmade or modern artefacts attribute is modelled using OS MasterMap data and the spatial proximity of areas to the nearest manmade structures. However, the primary requirement of using 'open' data for the purposes of building a PPGIS web tool means that OS MasterMap data cannot be used as it is a commercial product which requires licence fee payments for usage. OS OpenMap - Local (an 'open' OS OpenData dataset with an OGL licence) is used for the web tool instead. OSM buildings data is also considered for usage but from a visual inspection of the two datasets using QGIS it is seen that the OS OpenData dataset has a better coverage of buildings in urban as well as rural areas. Not all buildings in an urban area are included as polygons in the OSM buildings data, often only major buildings such as hospitals and schools. Some rural areas (e.g. the Glen Clova area of the Scottish Highlands) are not covered well and have no buildings in the OSM data at all, despite the existence of many buildings in this area. In Carver et al. (2012) and Wildland Research Institute (2008), the absence of modern human artefacts attribute is also modelled using visibility analysis of manmade structure features and the creation of 'viewsheds', requiring a DEM of high resolution such as the NextMap 5m DEM dataset. However, this dataset is not available for the development of the web tool as it is not an 'open' dataset so a simpler approach using the linear distance to features in the OS OpenMap – Local data is used instead.

The OS OpenMap - Local data is acquired in the form of Shapefiles, each covering a single OS national grid 100km x 100km tile. Four of these tiles cover the area of CNP, for both buildings features and electricity transmission features, so several vector merge operations and a polygon to lines conversion for the buildings data (as vector merge operations can only be done with Shapefiles containing the same vector geometry) are carried out using QGIS. This creates one single Shapefile containing buildings and electricity transmission features in vector lines format. This merged Shapefile is then clipped to a polygon representing the CNP boundary with a 10k buffer, using the QGIS Vector GDAL Clip tool. The reason a buffer is used for the clipped area is to reduce edge effects when creating a GeoTIFF distance raster

from the Shapefile. This distance raster represents proximity values (measured in metres) to the features contained in the data, namely the manmade features of buildings and electricity transmission lines. A further QGIS Raster Clipper tool operation is carried out to create a raster covering the CNP area without the buffer, but retaining the data without edge effects. A workflow diagram showing these processing steps can be seen at figure 3.3.

A new raster data layer of normalised values is then created in a similar fashion to that carried out for the naturalness of land cover attribute and the GeoTIFF data layer is added to GeoServer as a datastore and a WMS data layer.

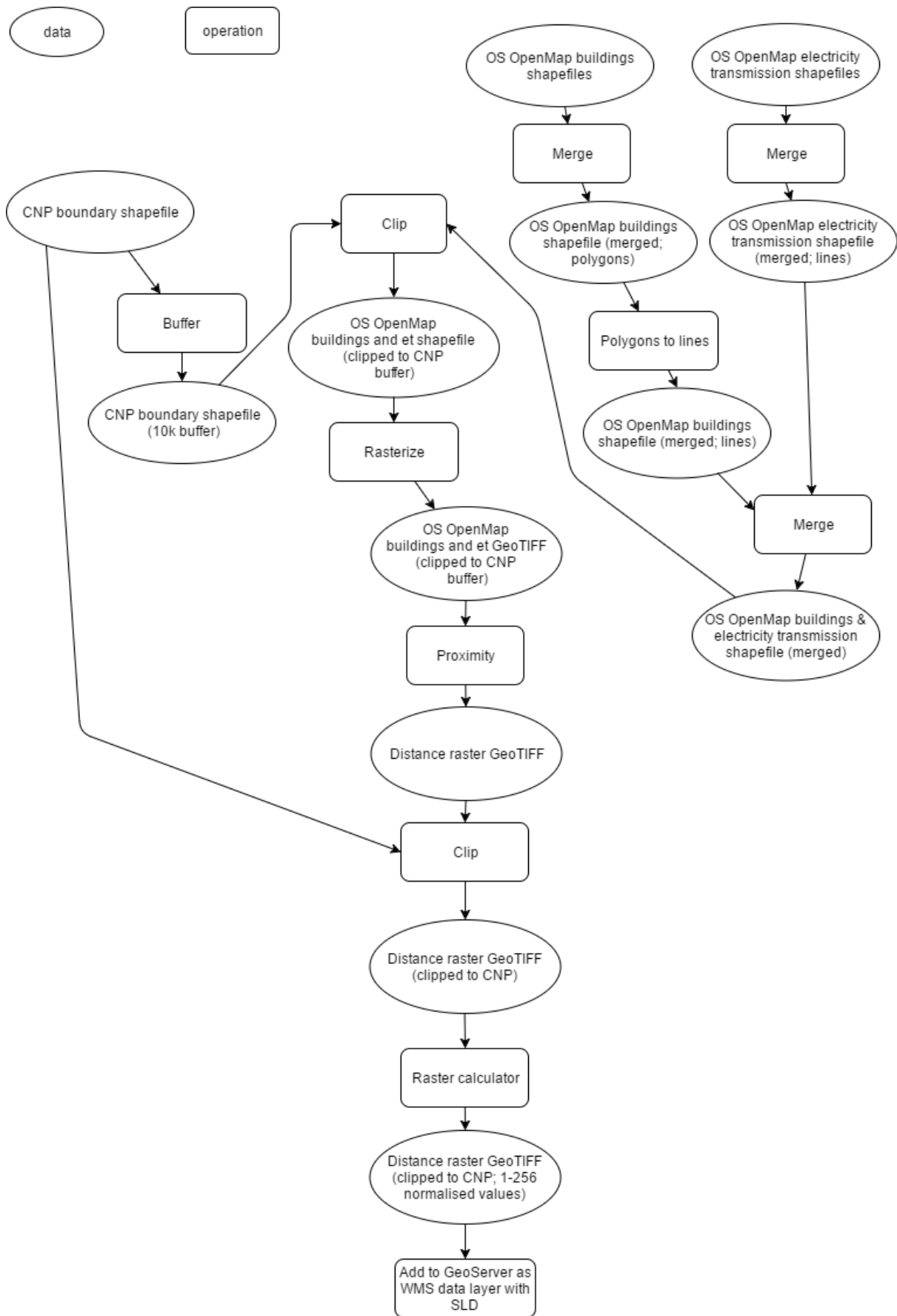


Figure 3.3. Processing of absence of modern human artefacts data.

3.5.2.3 Ruggedness or rugged terrain

Modelling the ruggedness attribute relies crucially on a DEM dataset of sufficient resolution and accuracy. In Carver et al. (2012) and Wildland Research Institute (2008), the ruggedness attribute is modelled using a NextMap DEM of 5m resolution, but this is not an 'open' dataset and cannot be used for the development of the web tool. The OS OpenData Terrain 50 dataset is used instead, which offers 10km x 10km DEM tiles of OS topographic data in ASCII raster format at a resolution of 50m per cell.

65 of these tiles cover the area of CNP, and these are merged into a mosaic of one GeoTIFF DEM raster data layer using the QGIS Raster Merge tool, which is clipped to the CNP boundary polygon using the QGIS Raster Clipper tool. QGIS has a tool which can create a raster of 'Terrain Ruggedness Index' (TRI) values from a DEM. This value is calculated using the tool for every location in the DEM raster data layer by summarising the change in elevation within a 3x3 cell grid. Full details of this calculation can be seen in Riley et al. (1999). No consideration of edge effects is required for this calculation. A workflow diagram showing these processing steps can be seen at figure 3.4. In Wildland Research Institute (2008), ruggedness is defined differently, using the standard deviation of the curvature of the DEM values, but this operation is only available with the commercial ArcGIS product. Ruggedness is also defined in Wildland Research Institute (2008) as having a component related to climate and weather, as well as topography, and this has been modelled using elevation data as an established proxy dataset with a correlation to climate and weather data. In Wildland Research Institute (2008), the weather/climate component (in the form of elevation data) of ruggedness is given half the weight of purely topographically-related ruggedness. This leads to the following calculation which is used to create a ruggedness raster GeoTIFF data layer (using the QGIS Raster Calculator) for the development of the web tool:

```
ruggedness value = DEM value (elevation) + (2 * TRI raster value)
```

A new raster data layer of normalised values is then created in a similar fashion to that carried out for the naturalness of land cover attribute and the GeoTIFF data layer is added to GeoServer as a datastore and a WMS data layer.

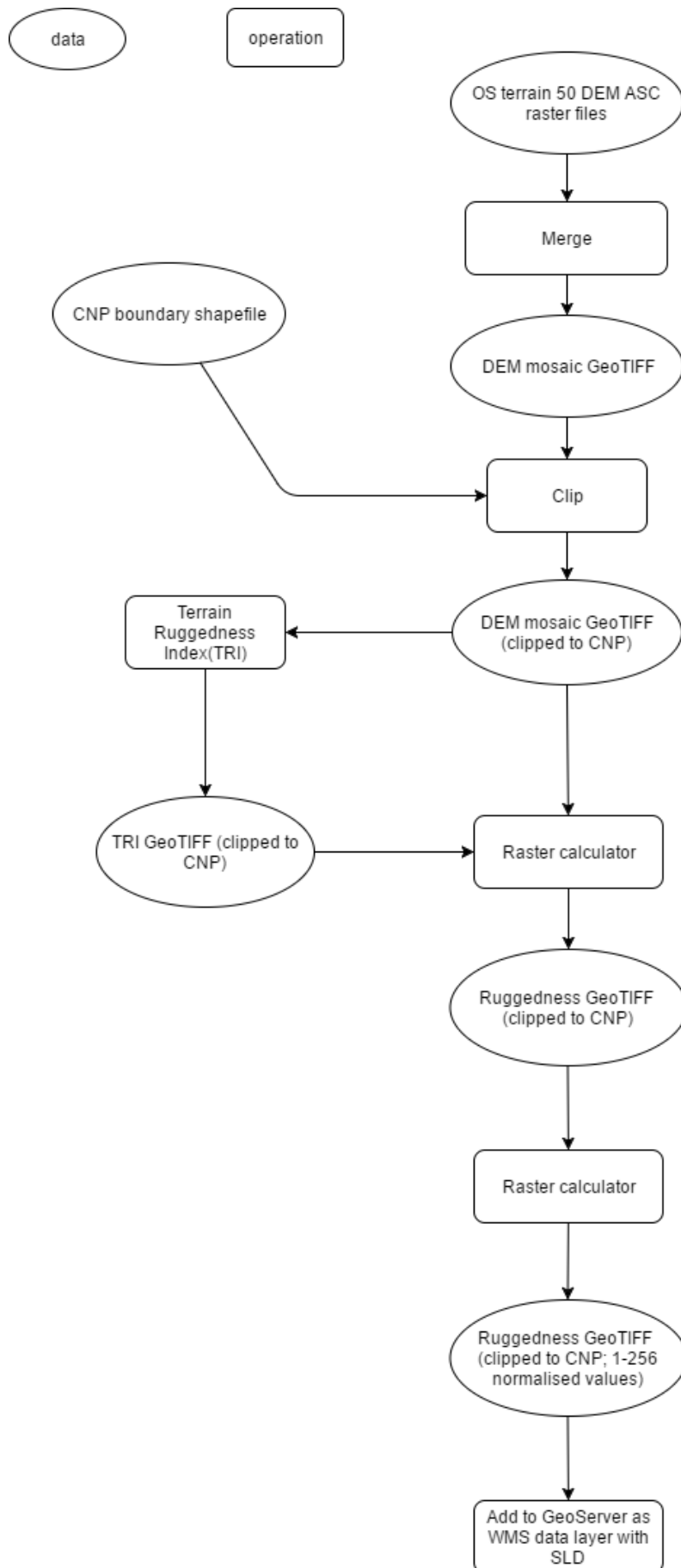


Figure 3.4. Processing of ruggedness data.

3.5.2.4 Remoteness from mechanised access

In Carver et al. (2012) and Wildland Research Institute (2008), the remoteness from mechanised access attribute is modelled using a variety of datasets including NextMap DEM, LCM 2000 land cover data, and road, tracks and 'barrier features' in the form of water features and bridges, taken from OS MasterMap. This data is used to create an anisotropic 'cost surface' of access from roads and tracks, using a version of Naismith's Rule, which estimates the time taken to walk over terrain of varying land cover type, altitude and steepness. However, the accuracy and resolution of this calculation relies heavily on a DEM with sufficient resolution such as the NextMap 5m DEM data, which is not 'open' data. The level of complexity and detail in this calculation is also probably not necessary for the development of the purely visualisation aspect of the web tool. Thus, a simpler approach is taken, using the OS OpenData OpenRoads dataset to measure the linear distance from the road network in CNP. Railway lines are not considered, as there is a single railway line that passes through CNP that follows the line of the A9 road throughout its length in CNP.

The OS OpenRoads data is acquired in the form of a single Shapefile covering the entire UK. As with the absence of modern human artefacts attribute, this Shapefile is clipped to a polygon representing the CNP boundary with a 10k buffer, using the QGIS Vector GDAL Clip tool, to reduce edge effects when creating a GeoTIFF distance raster from the Shapefile. This distance raster represents proximity values (measured in metres) to the features contained in the data, namely the road network. A further QGIS Raster Clipper tool operation is carried out to create a raster covering the CNP area without the buffer, but retaining the data without edge effects. A workflow diagram showing these processing steps can be seen at figure 3.5.

As with the absence of modern human artefacts attribute, the raster data values are normalised and the GeoTIFF data layer is added to GeoServer as a datastore and a WMS data layer.

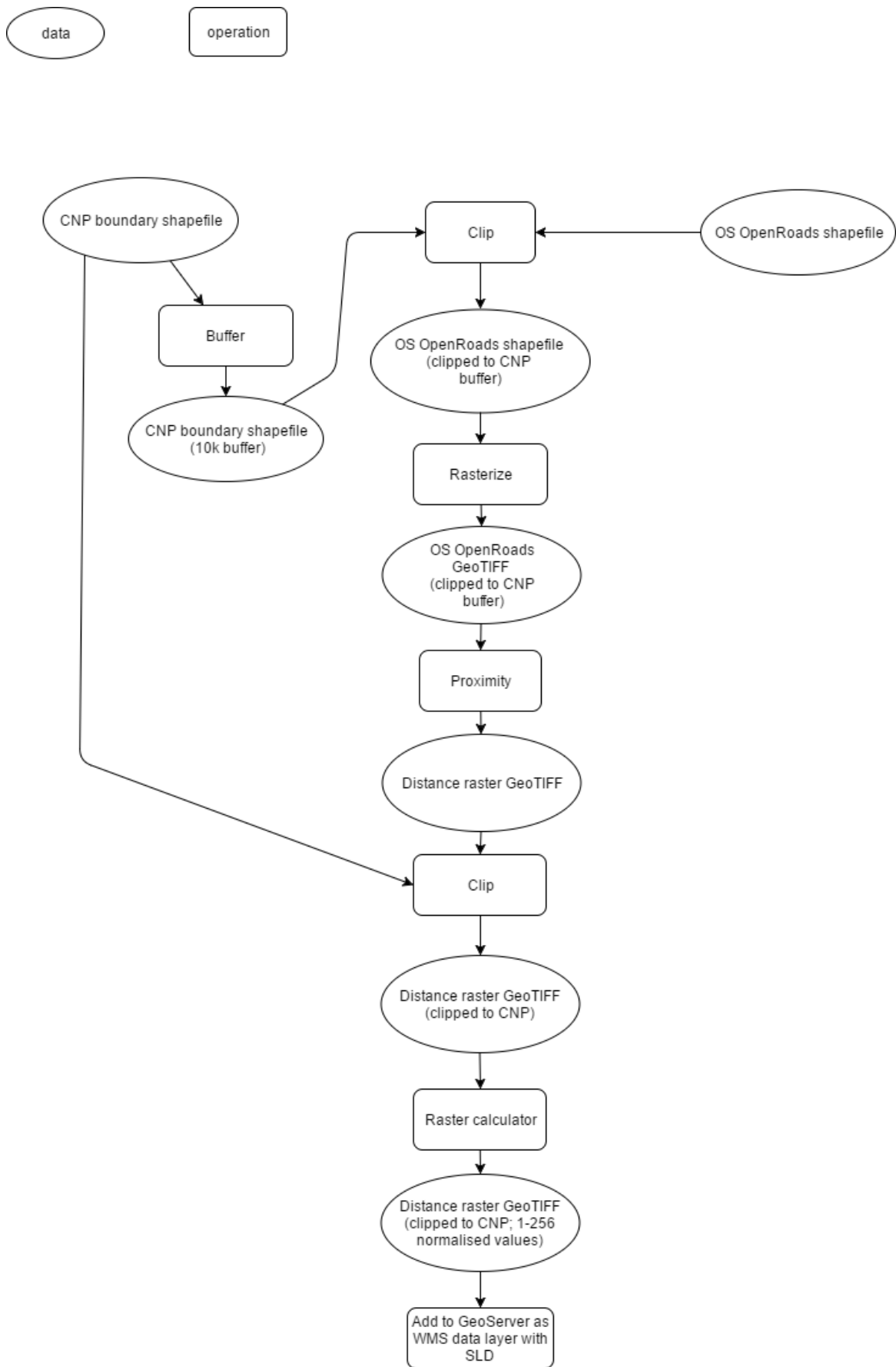


Figure 3.5. Processing of remoteness from mechanised access data.

3.5.3 Evaluation

The architecture and interface of the web tool is evaluated to see how well it matches the fitness for purpose requirements (tables 3.1 and 3.3) which follow from the objectives in section 1.2. The usability of the web tool is also evaluated and it is useful to do this making reference to criteria established in Bugs et al. (2010). These criteria are used to evaluate a similar web-based PPGIS tool and the criteria used are: 1) cost of entry; 2) intended users; 3) ease of use; 4) satisfaction; 5) usefulness. The criteria are interrelated and this evaluation reflects this. The results of this evaluation can be seen at section 4.

An important point to note is that some of these criteria can only be completely evaluated through a user survey involving a questionnaire and user testing in a structured environment like a workshop, as in the example given in Bugs et al. (2010). In Bugs et al. (2010) the criteria are also used to evaluate a web-based PPGIS tool that offers 'web 2.0' techniques in terms of user-generated content, such as forum discussions about particular features on a map and feedback about the results of the use of the map. An example of this is the 'Virtual Slaithwaite' web-based PPGIS tool (Kingston et al., 2000) (section 2.2). The tool developed for this dissertation does not offer these kinds of features.

4. Results and discussion

4.1 Visualisation of processed data

For each of the four processed 'wild land' attribute datasets stored in GeoServer, a WMS Styled Layer Descriptor (SLD) is used to display the raster values using a three-colour ramp similar to that used in Carver et al. (2012), with transparency for zero and 'no data' values, green representing the highest values of the 'wild land' attribute, and red the lowest. Another single-colour ramp SLD is also available. The datasets are then visualised in a browser using WMS requests and the results are shown in figures 4.1 to 4.4. The full WMS request URLs are listed in the appendix.

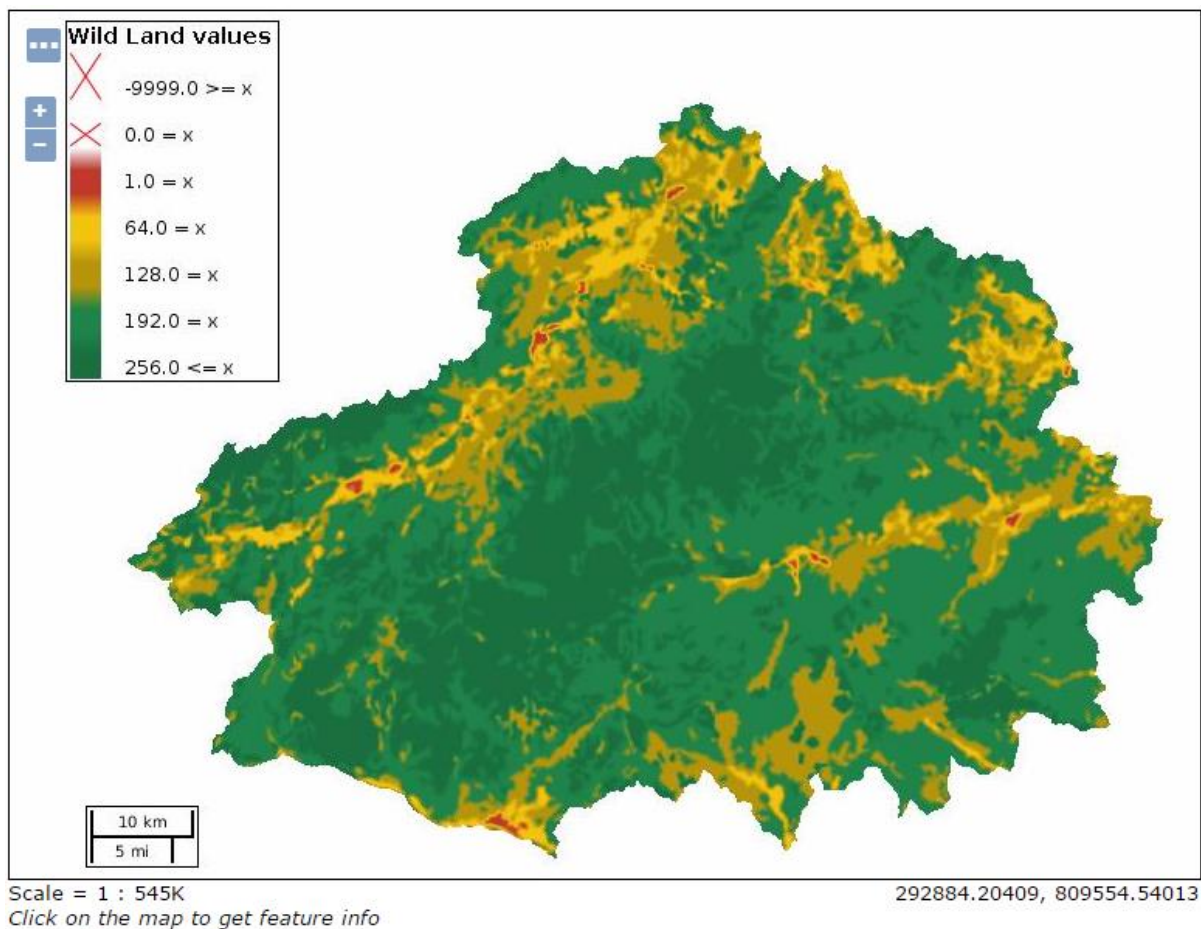
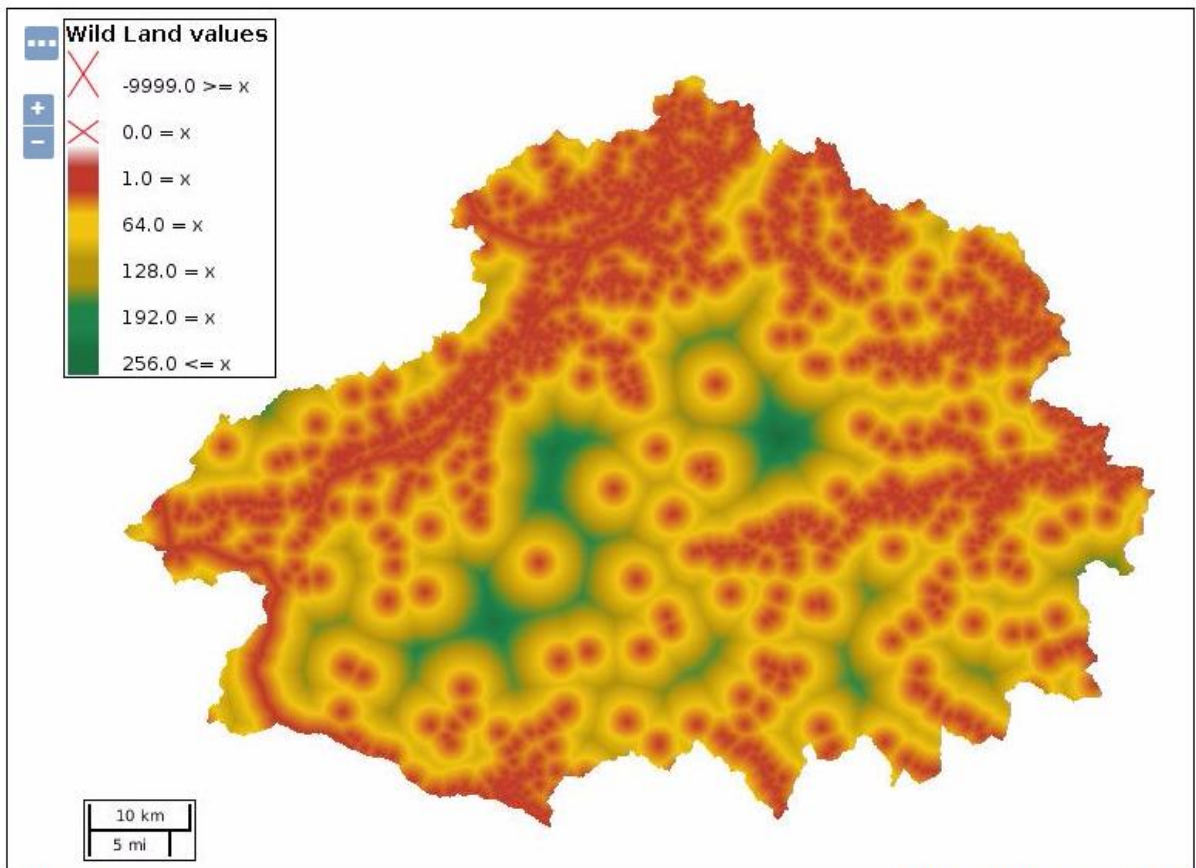


Figure 4.1. GeoServer OpenLayers WMS request showing preview of processed naturalness of land cover CNP 'wild land' attribute raster data.



Scale = 1 : 545K

[Click on the map to get feature info](#)

Figure 4.2. GeoServer OpenLayers WMS request showing preview of processed absence of modern human artefacts CNP 'wild land' attribute raster data.

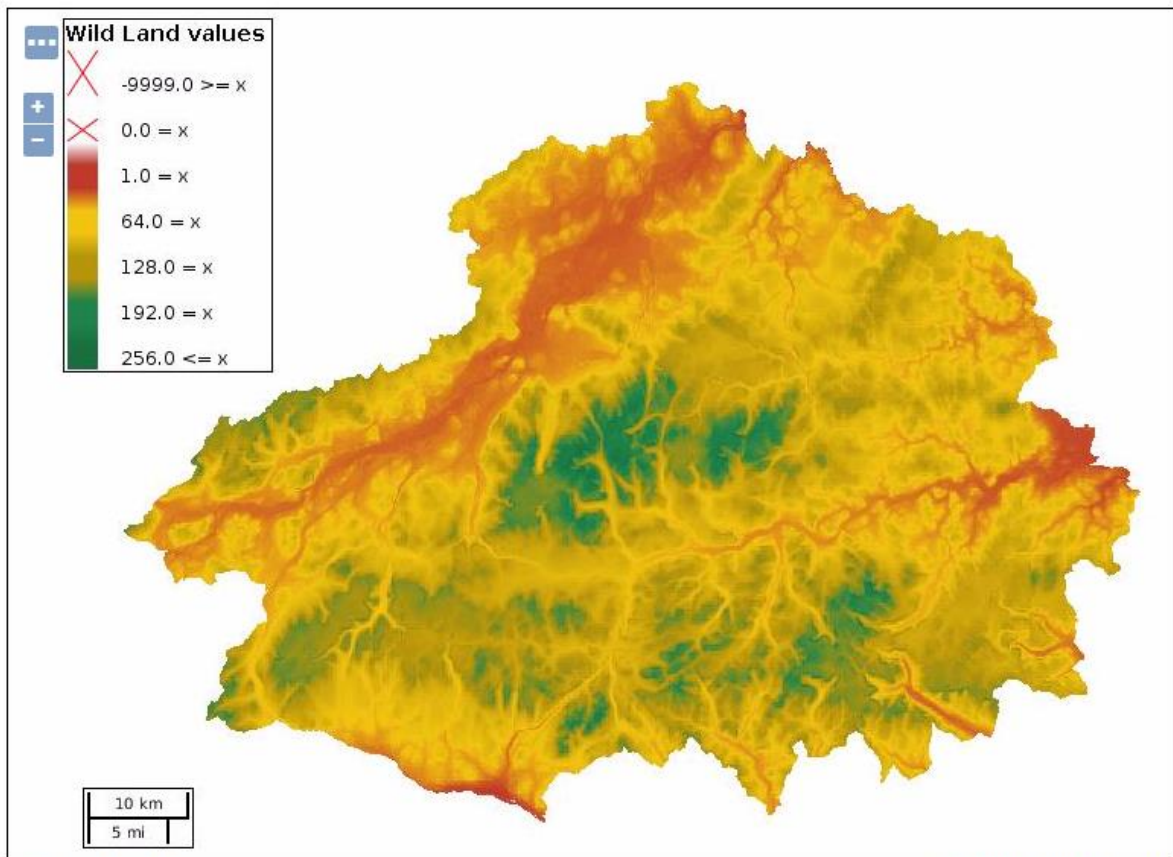


Figure 4.3. GeoServer OpenLayers WMS request showing preview of processed ruggedness CNP 'wild land' attribute raster data.

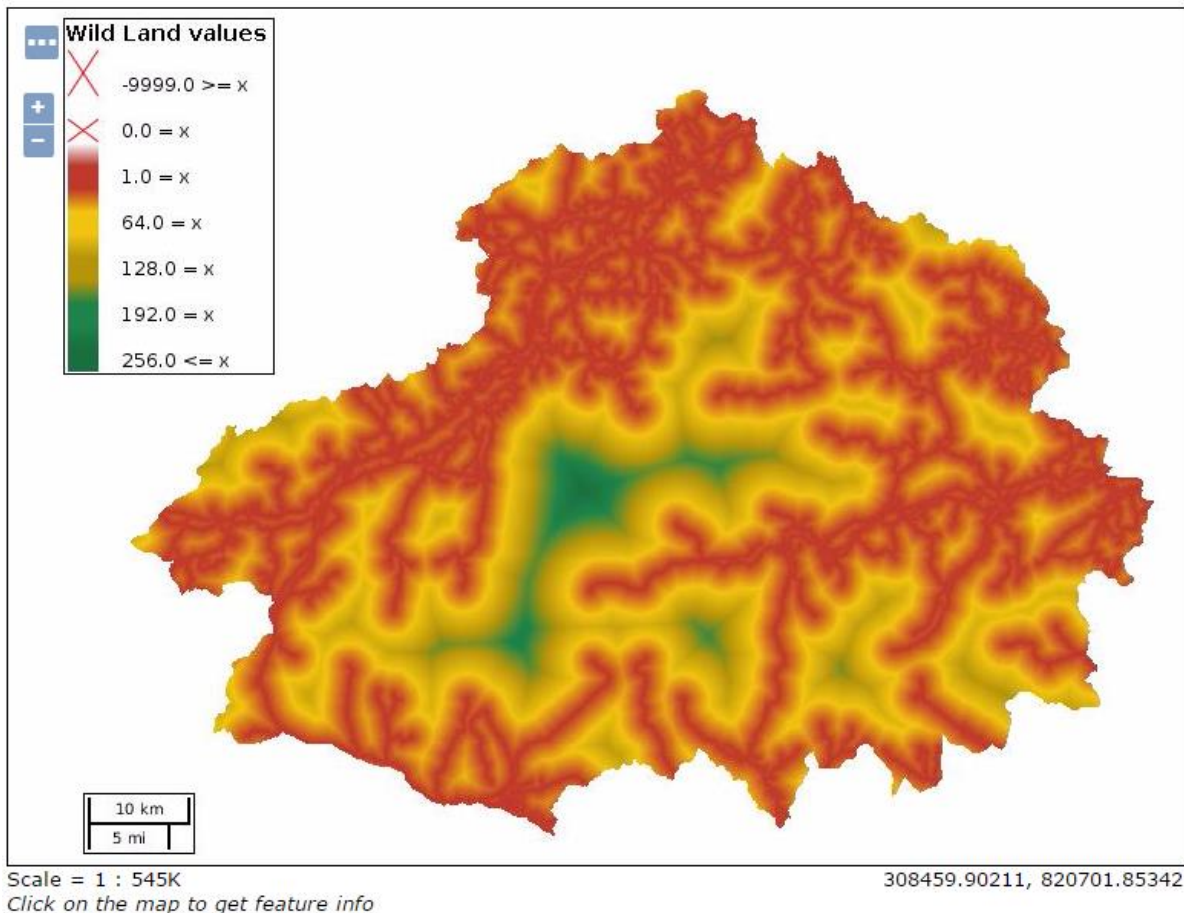


Figure 4.4. GeoServer OpenLayers WMS request showing preview of processed remoteness from mechanised access CNP 'wild land' attribute raster data.

4.2 Web tool client/server architecture

The primary technical objective of the web tool is that it has the functionality to allow individual subjective selection and choice of data layers corresponding to identified 'wild land' attributes, in a dynamic, weighted, web-based map visualisation using opacity overlay and MCE web technologies (Rinner and Düren, 2011; Malczewski and Rinner, 2015). As a general guideline, the development of the web tool client/server architecture is influenced by the platforms, applications, standards and technologies used in Rinner and Düren (2011) and Markieta and Rinner (2014). A diagram of this architecture can be seen at figure 4.5. The crucial aspect of this diagram is that every identified component of the architecture is 'open' and accessible so that a PPGIS approach can be fully supported, without barriers or exclusion.

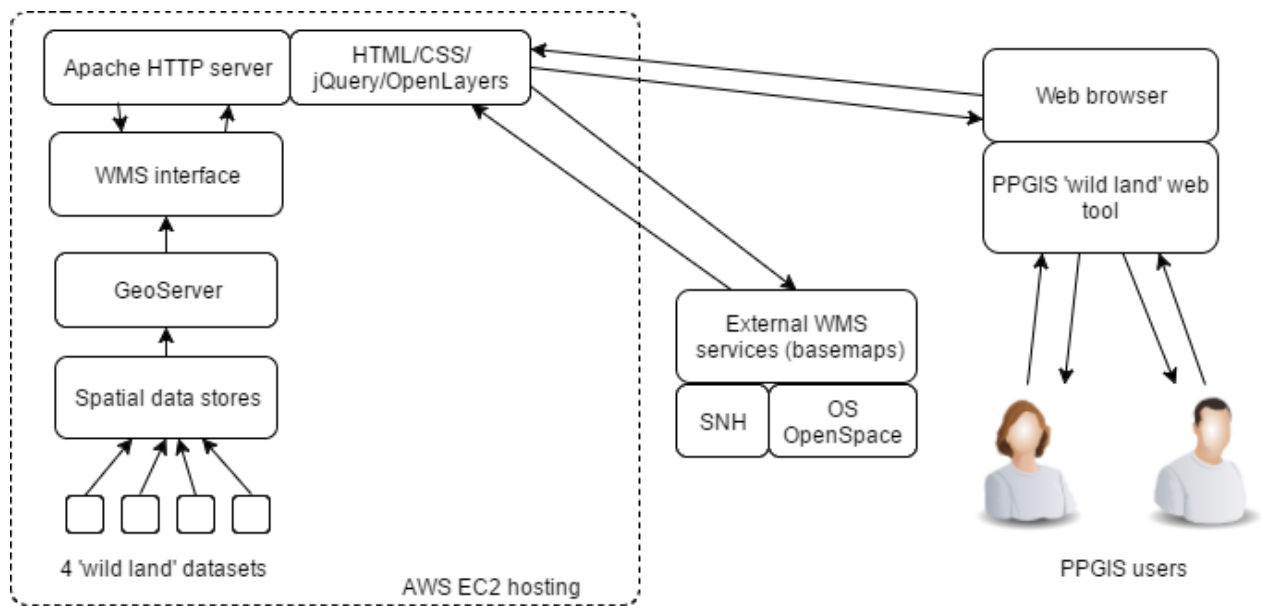


Figure 4.5. Diagram of PPGIS 'wild land' web tool architecture.

4.2.1 Server

The GeoServer application is installed on an AWS EC2 instance (using the Ubuntu v14 operating system), offering the ability to deliver the four processed 'wild land' attribute datasets as WMS layers styled with SLD files, via HTTP requests from a web client to GeoServer.

4.2.2 Client

The web tool client uses HTML files with external CSS and JavaScript/jQuery CDN libraries with the OpenLayers JavaScript API. The client files are also installed on the AWS EC2 instance and accessed by a standard Apache HTTP server as a convenience, although the nature of the open web standards used means that these files can potentially be located anywhere on the internet. The data is retrieved from the server as WMS requests using OpenLayers. URLs for the code listings for these files are contained in the appendix. A screenshot of the web tool client can be seen at figure 4.6.

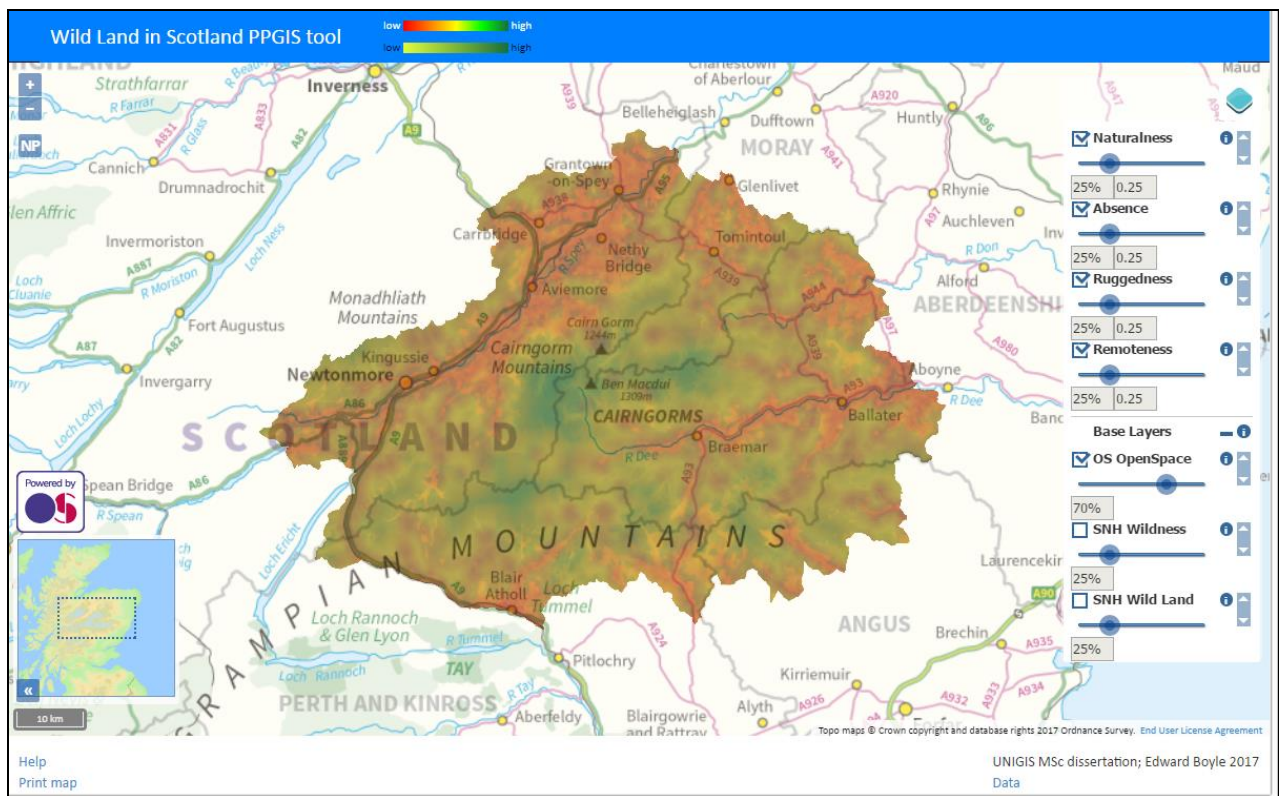


Figure 4.6. Screenshot of the web tool client.

The URL of the web tool client is:

<http://www.edwardboyle.com/MSc/tool1.html>

The most important aspect of the web tool client is the ability to vary the opacity of the different 'wild land' attribute map layers and vary the corresponding weights in a similar fashion to the web tools and interfaces described in Rinner and Düren (2011) and Markieta and Rinner (2014). A set of browser-based GUI components containing opacity slider controls for this is accessed by clicking on the icon at the top right of the map (figure 4.6). The opacity of the data layers, as well as the corresponding weights (which are always normalised so the sum of the weights equals one), are displayed dynamically in boxes below the opacity sliders as they are moved. Layers can also be switched off so that an individual layer or a group of layers can be viewed in isolation from the others. This functionality is achieved by using the OL3-ext OpenLayers extension library (OL3-ext, 2017) which uses JavaScript jQuery extensively.

An important point to note is that the opacity of the different layers is combined using the sliders to produce a visualisation corresponding to weighting of the layers, but this combination of opacities (or 'alpha blending') is not 'additive' as would be the case with a true combination in the form of WLC, but 'multiplicative'. This point is explained further in Rinner and Düren (2011). Using this combination of opacities however means that the order of layers does not matter and delivers a visualisation in a web browser that is more intuitive in terms of deciding on relative weights of the 'wild land' attributes, which can then potentially be used in a full MCE WLC analysis using a GIS application such as ArcGIS or QGIS.

The data used for the map layers is transformed 'on-the-fly' in OpenLayers dynamically to the BNG SRS and projection (EPSG:27700), so that the OS OpenSpace service can be used to 'stream' a base layer map of OS data directly, which makes the geographic context of the four 'wild land' attribute data layers in CNP more accessible and intuitive. For further context, comparisons and background reference material, SNH datasets of 'wild land' areas and a 'wildness' map of the whole of Scotland are also provided via WMS requests to a SNH WMS server.

A help window with basic instructions about how to use the tool is available with the 'help' option in the footer of the tool interface (figure 4.7). An option to export a screenshot of the map display as a PNG image is also provided via the 'print map' option in the footer. Information about the data used in the tool, including licencing, is available with the 'data' option in the footer.

The colours used to represent the attribute values on the map are important for visualisation purposes, and there are two colour ramps available to use (using GeoServer SLDs), with a differing range of colour values to allow greater flexibility of visualisation. Legends showing the colour ramps and what they represent are contained in the header of the interface, and clicking on these allows the differing colour values to be used in the map. 'Low' colour values are lower values of the attributes and indicate land areas that are less 'wild'. 'High' colour values are higher values of the attributes and indicate land areas that are more 'wild'.

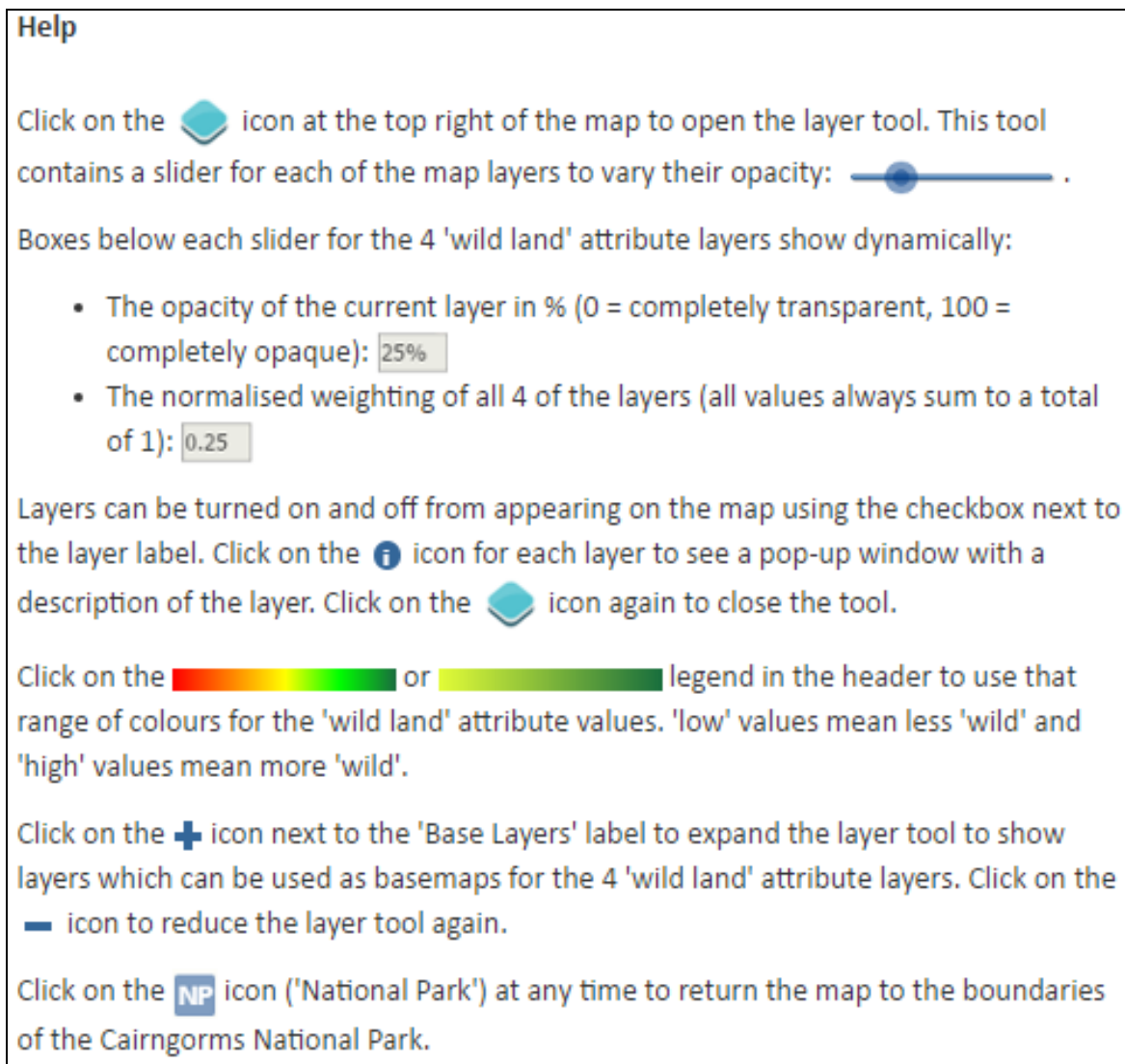


Figure 4.7. Screenshot of the web tool client showing the online help window with guidelines about how to use the tool.

4.3 Evaluation of web tool

4.3.1 Fitness for purpose requirements

In terms of the 'fitness for purpose' requirements listed in table 3.1, the architecture of the tool (section 4.2) meets all the requirements with the choice of technologies chosen, such as GeoServer, OpenLayers for the client tool and Amazon Web Services for the hosting platform. These technologies are fully 'open' and customisable with no constraints on usage such as licencing barriers. They also support the GIS functionality, scalability and accessibility requirements.

The fitness for purpose requirements listed in table 3.3 focus on the data used in the tool. The final choice of datasets selected all use the OGL licence, and the provenance or lineage of the data from established sources such as OS and CEH ensures that the tool can be used for general usage without restrictions for any non-commercial purpose, and hence all the data used meets the requirement for an 'open' PPGIS tool. The use of OS OpenData datasets ensures that the geographic features, scale, resolution, coverage and currency requirements are also met, for three of the four 'wild land' attribute data layers, plus the OS OpenSpace basemap.

The land cover data (CLC 2012), which is obtained from CEH and was originally created by the EU CORINE programme, matches requirements in terms of provenance, coverage and currency, but does not have the same level of resolution as the OS data and hence the naturalness of land cover 'wild land' attribute layer data cannot be said to match the requirements as well the other data. There is also some scope in the CLC 2012 data for errors of ambiguity and classification relating to 'wild land' (Foody, 2002). In particular, the CLC 2012 data has no 'montane habitat' land cover class defined by elevation as the LCM 2007 data does. The CLC 2012 classes '333' and '412' appear to be the closest classes to this, from an examination of the areas on the map covered by polygons with these classes, notably the high Cairngorm plateaux (table 3.6). The CLC 2012 data also does not differentiate between natural forest, ancient woodlands and modern plantations, and between natural lakes and artificial reservoirs. The resolution of the CLC 2012 data is coarse compared to the LCM 2007 data and one area of further investigation could be to see whether there is any potential for the higher resolution LCM 2007 data to be used in an 'open' PPGIS context.

One weakness of the OS OpenData OpenMap - Local dataset is that it does not include features such as wind turbines, telecommunication towers, power pylons or hydroelectric infrastructure features such as dams and artificial reservoirs. The OS OpenData OpenMap - Local dataset does however include electricity transmission lines (see figure 4.8), as well as skiing infrastructure (the Cairn Gorm, Glen Shee and Lecht ski centres), and remote buildings such as the Ptarmigan restaurant near the summit of Cairn Gorm (figure 4.9). It also contains ruined or unused buildings in

remote or upland areas such as bothies and abandoned farm buildings, which can be perceived to be a weakness in the data as these are not differentiated from urban buildings. The OS OpenData OpenRoads dataset includes 4WD tracks in remote and upland areas but this can also be perceived to be a weakness in the data as 4WD tracks in the mountains and public highways are not differentiated. All of these features appear in remote areas of the Scottish Highlands and would undoubtedly have an effect on the derived data and maps if they could all be included at a sufficient level of scale and resolution with attributes to differentiate different types of each feature.

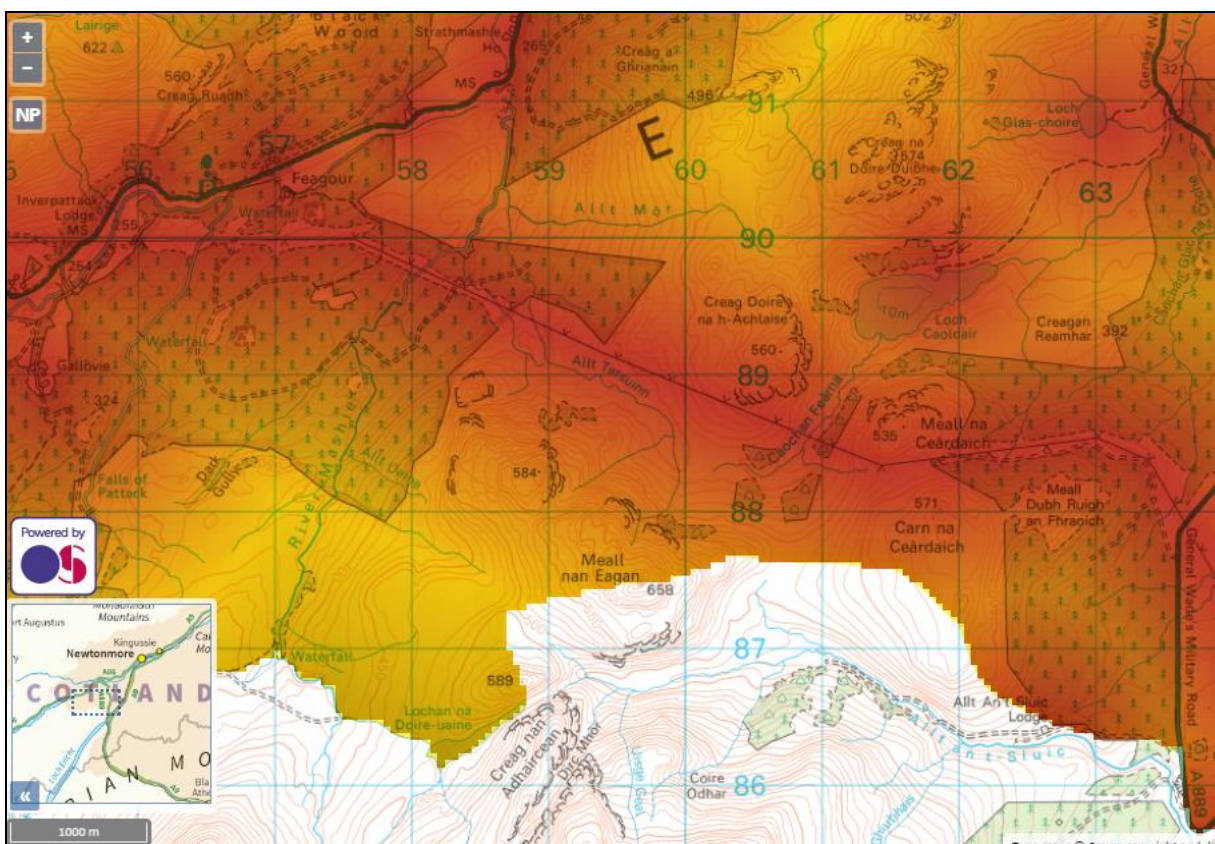


Figure 4.8. Screenshot of the web tool showing the area of a section of the Beaulieu-Denny power transmission line crossing through an area of CNP without roads or buildings. Red areas are lower values of the absence of modern human artefacts 'wild land' attribute (and thus less 'wild').

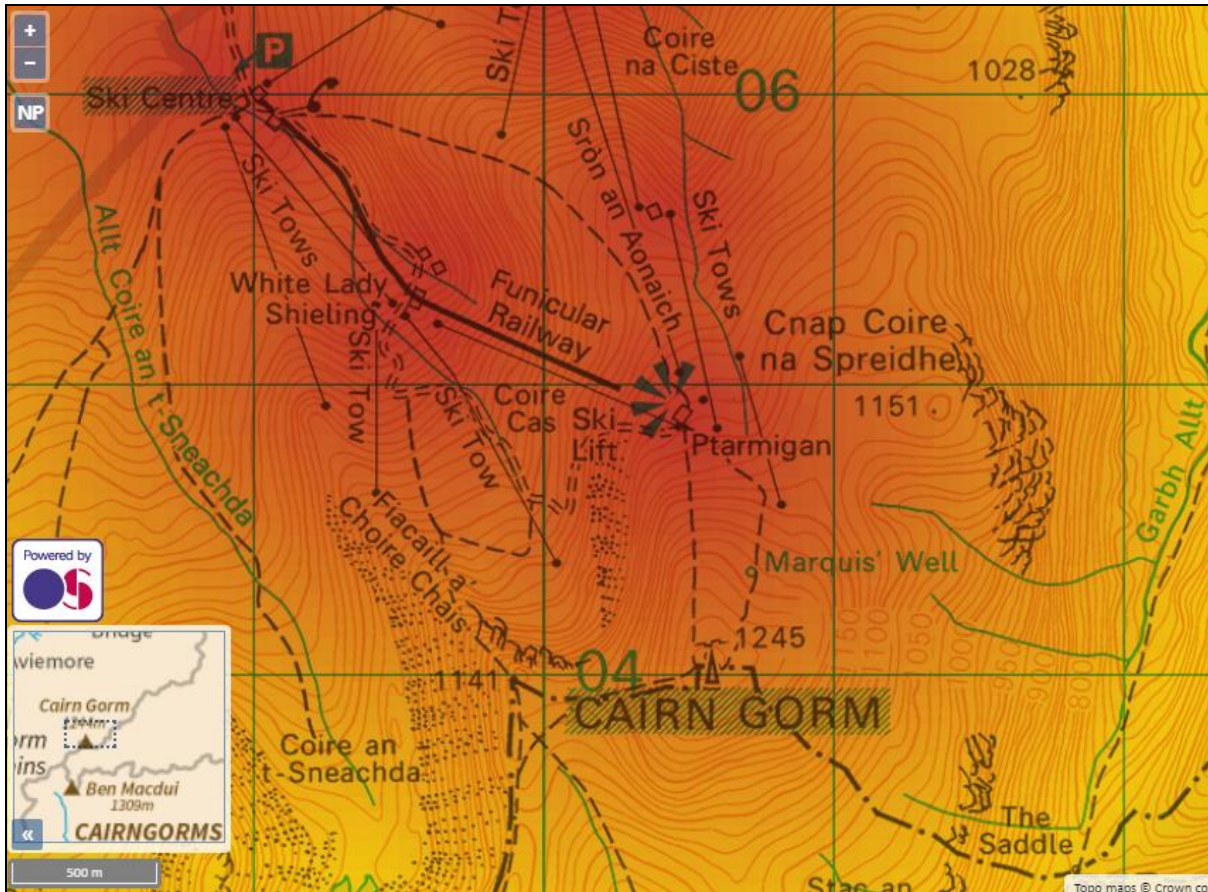


Figure 4.9. Screenshot of the web tool showing the area of the Cairn Gorm ski centre and the Ptarmigan restaurant, a high-elevation mountainous area in CNP. Red areas are lower values of the absence of modern human artefacts ‘wild land’ attribute (and thus less ‘wild’).

The resolution of the OS OpenData Terrain 50 DEM dataset is 50m x 50m cells and this provides a resolution to which all the other raster datasets are standardised to. This puts a limit on the scale to which the web tool can be used, and using the maps at large scales means that the usefulness is reduced. However, the map visualisation allows an effective exploration of the subjective concept of ‘wild land’ as this concept covers relatively broad geographic features, distances and areas on the scale of roads, towns and mountains which are appropriately visualised with the data resolution used in the tool. Scale effects are relevant also with the relatively coarse resolution of the land cover data.

It can be seen from a visual inspection of the detail in the maps in the web tool that the 50m resolution of the OS OpenData Terrain 50 DEM dataset and the data

derived from it effectively shows areas of 'rugged land' such as the corries (or cirques) of the mountain Braeriach (figure 4.10) and is adequate for the purposes of visualising the ruggedness 'wild land' attribute.

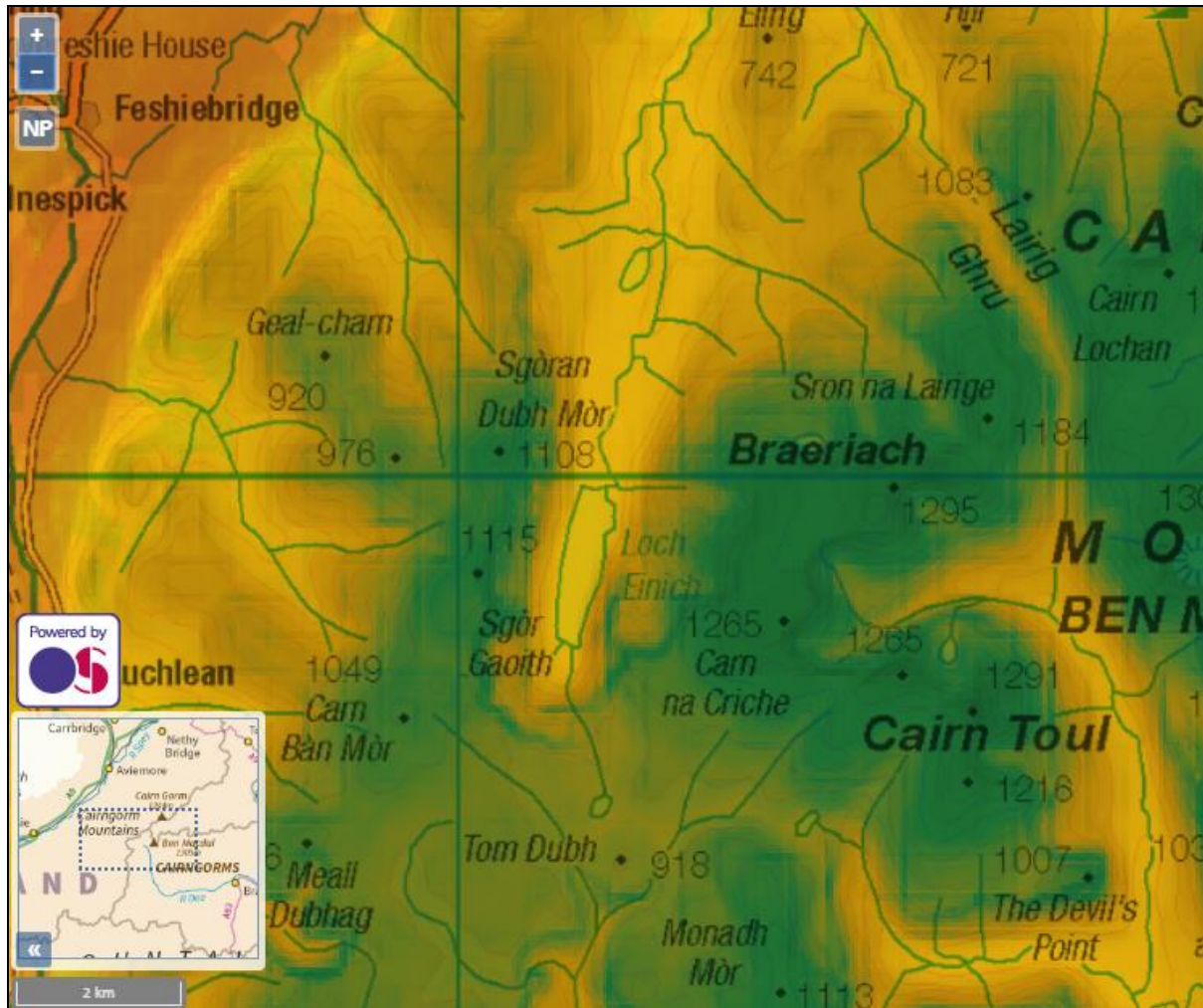


Figure 4.10. Screenshot of the web tool showing the area of the corries of the mountain Braeriach in CNP. Red areas are lower values of the ruggedness 'wild land' attribute (and thus less 'wild'). Green areas are higher values of the ruggedness 'wild land' attribute (and thus more 'wild').

One feature of the tool is that it visualises strongly in graphical terms certain areas in CNP that highlight the difficulty in measuring or quantifying what 'wild land' is and how 'wild' a particular area actually is. Examples of this are the areas surrounding Gaick Lodge and Glen Avon, both areas which lie in what could be described as remote and mountainous areas, surrounded by terrain that is very rugged, but which contains buildings and 4WD tracks. The effect of all of these factors is to produce a

combined value for the area that is not particularly high in terms of 'wild land' (figures 4.11 and 4.12). The visualisation of this can be explored well using the tool to change the colour range used for the values, alter the opacity of the attribute map layers or turn layers on and off.

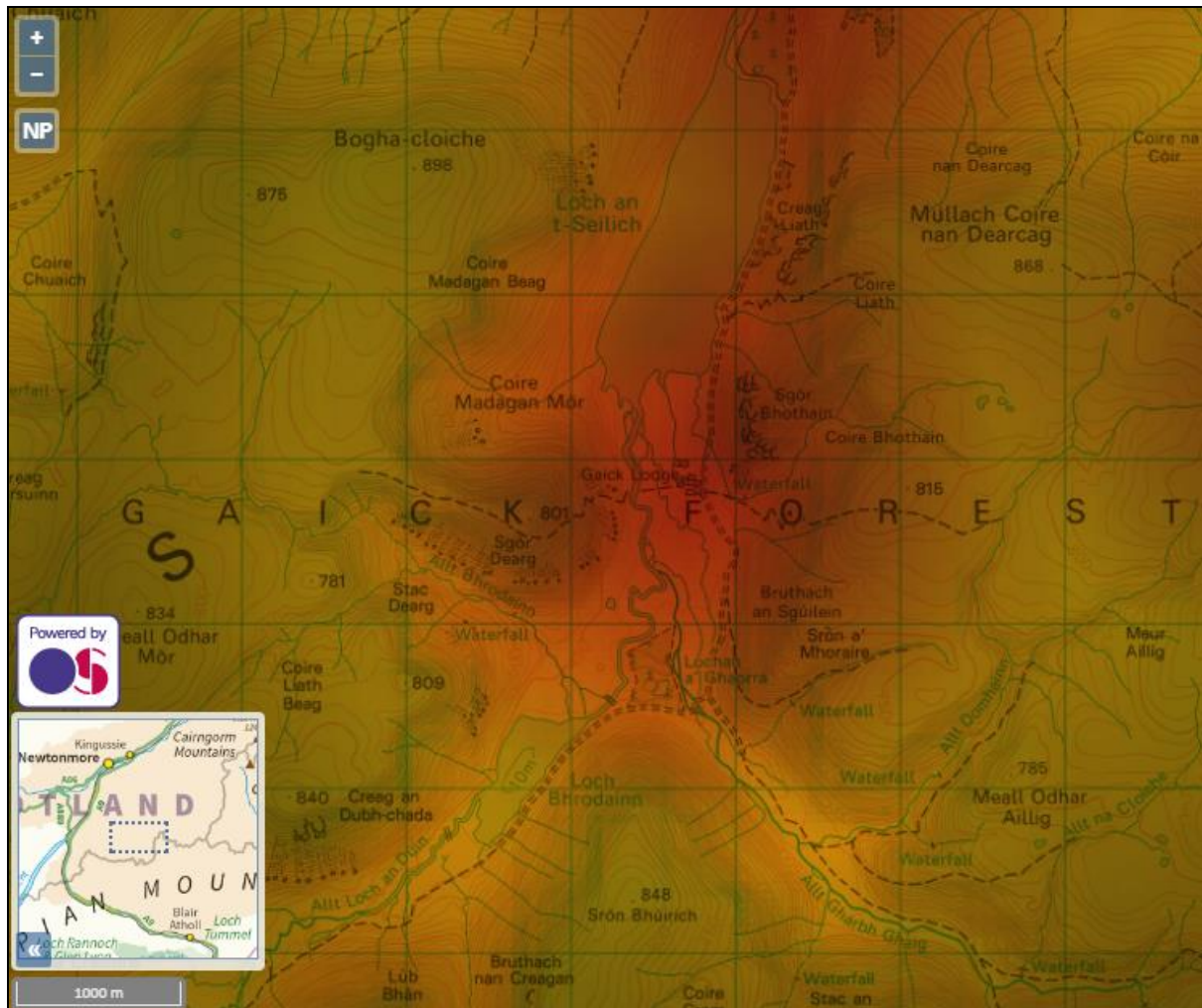


Figure 4.11. Screenshot of the web tool showing the area of Gaick Lodge in CNP. Red areas are lower values of the four combined 'wild land' attributes (and thus less 'wild'). Green areas are higher values of the four combined 'wild land' attributes (and thus more 'wild').

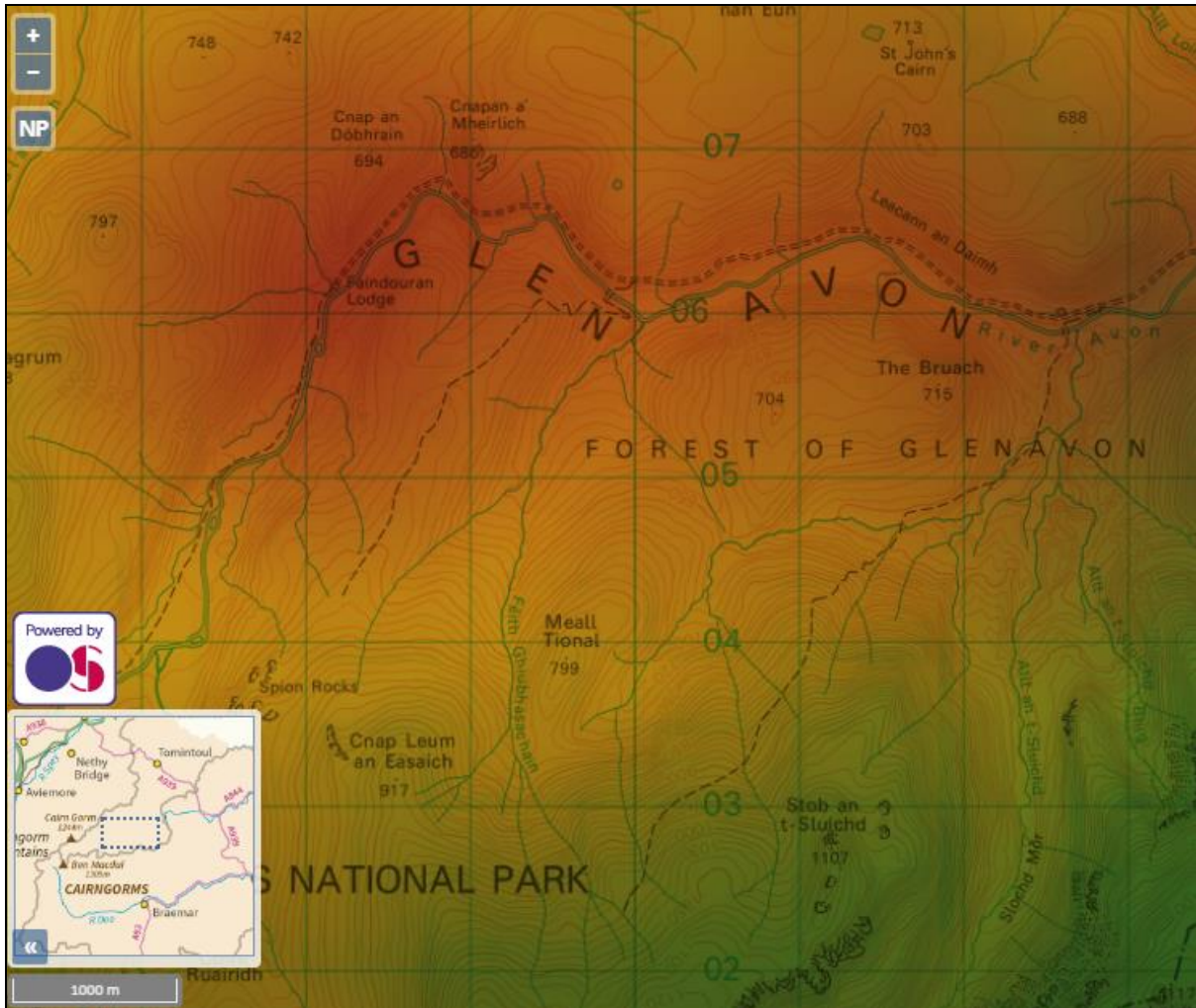


Figure 4.12. Screenshot of the web tool showing the area of Glen Avon in CNP. Red areas are lower values of the four combined ‘wild land’ attributes (and thus less ‘wild’). Green areas are higher values of the four combined ‘wild land’ attributes (and thus more ‘wild’).

Some roadless, remote and mountainous areas such as the Lairig Ghru mountain pass can have their ‘wild land’ value decreased by a single building, in this case the Corrour Bothy (figure 4.13).

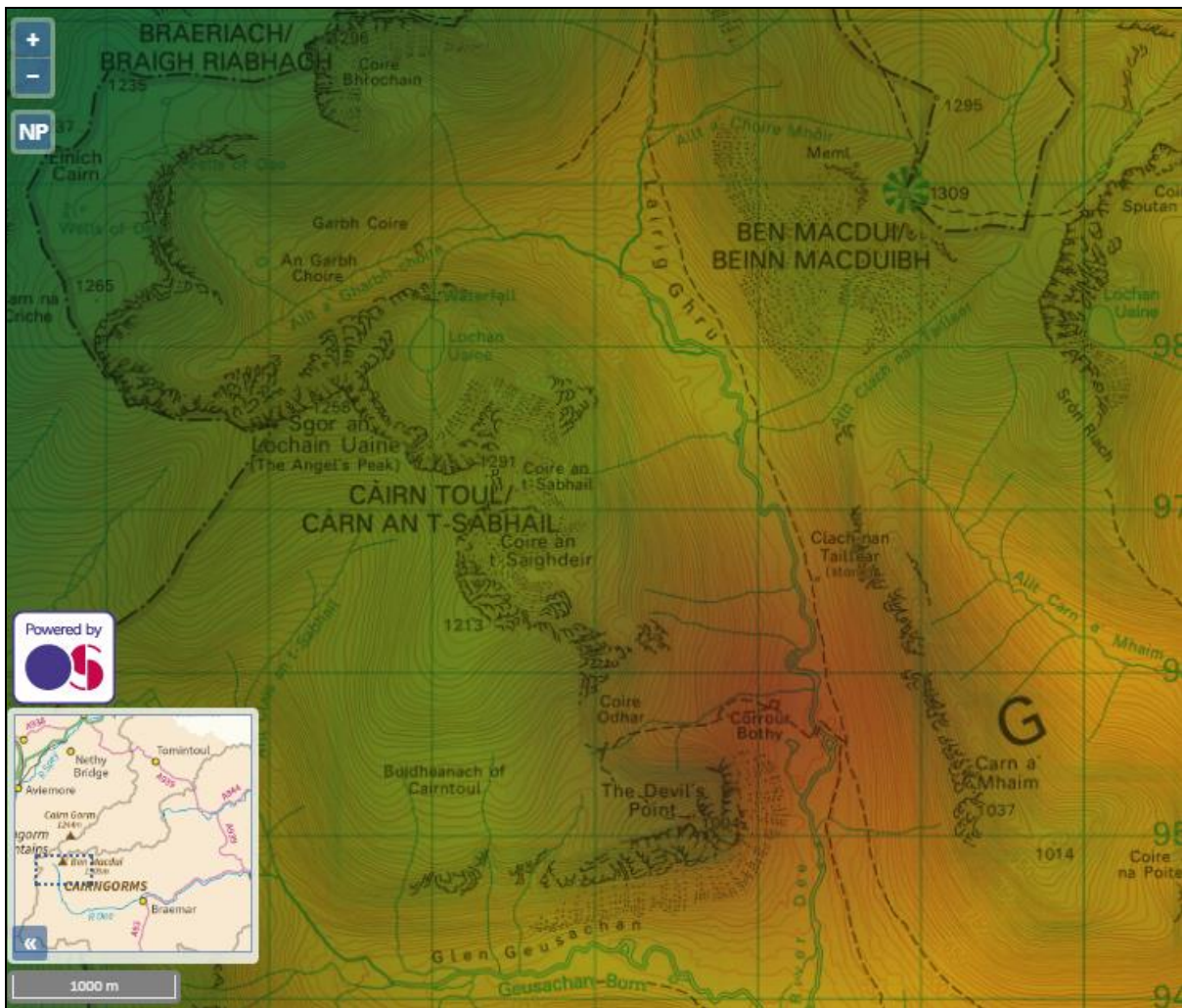


Figure 4.13. Screenshot of the web tool showing the area of the Lairig Ghru and Corrou Bothy in CNP. Red areas are lower values of the four combined 'wild land' attributes (and thus less 'wild'). Green areas are higher values of the four combined 'wild land' attributes (and thus more 'wild').

4.3.2 Web tool usability

The usability of the web tool is evaluated using criteria taken from Bugs et al. (2010) (table 4.1).

Table 4.1. PPGIS web tool usability evaluation criteria (source: Bugs et al. (2010))

Name	Description
Cost of entry	Includes the price of the tools and components needed to run or access the tool.
Intended users	Background of the different users. Includes features such as the involvement in using similar software and educational level.
Ease of use	Do users find the application easy to use. In Bugs et al. (2010) ease of use is evaluated by direct observations of the levels of speed, completeness and correctness in a user's performance and from a questionnaire.
Satisfaction	Degree of emotion the user obtains from using the tool when carrying out tasks. In Bugs et al. (2010) satisfaction is determined qualitatively via opinion reported through an evaluation questionnaire.
Usefulness	The degree to which the tool would enhance user tasks.

4.3.2.1 Cost of entry

In web-based PPGIS, accessibility of data, information, maps, and tools is crucial and the cost of entry should be minimal or negligible (i.e. it should be 'open'). This is reflected in the 'fitness for purpose' requirements listed in tables 3.1 and 3.3 and evaluated in section 4.3.1.

4.3.2.2 Intended users

The background and 'map literacy' of prospective users of the tool is an important factor in the usability of the tool. The intended users of the tool should ideally be familiar with the area in question (CNP and the Scottish Highlands) and hence be able to identify well-known landmarks in the area so that they can successfully use the tool to investigate their own subjective idea of the concept of 'wild land'. Bugs et al. (2010) claim that users of web-based PPGIS tools "...need to identify...locations of interest...that link user mental maps..." (Bugs et al., 2010:174). The map visualisation should be able to support this and utilise the 'tacit' or 'local' knowledge

of users. The 'fitness for purpose' requirements of the tool (tables 3.1 and 3.3) in terms of accuracy, resolution, coverage and level of geographic features used, particularly for the OS data, are well met in this tool (evaluated in section 4.3.1) and thus the range of intended users is as broad as possible within the context of PPGIS.

4.3.2.3 Ease of use

It has been shown that there are differing levels of engagement amongst different types of users of a web-based PPGIS tool and that "...providing an improved access to the systems and relevant data no longer is sufficient to enhance the degree of public engagement in the participatory decision-making process" (Meng and Malczewski, 2010:57), meaning that a tool must have an interface that is intuitive, maximises ease of use (Meng and Malczewski, 2010) and should offer a "...clear, well-presented and understandable interactive map" (Kingston, 2007:143). 'Non-spatial' users must also be considered and anything requiring knowledge of GIS techniques and principles should be kept to a minimum (Cavan and Kingston, 2012; Cavan et al., 2014).

A certain level of web skills and experience is assumed for the intended users of the tool. Critical in this evaluation is an appreciation of the effect that Google Maps and similar web mapping services have had on the web-based 'map literacy' of general users, with these services becoming ubiquitous in the last few years with widespread usage on smartphones (at least in the industrialised world) (Elwood et al., 2012). Of web-based map interfaces, Kingston (2007) makes the claim that "...many people are quite adept at navigating around such an on-line interface" (Kingston, 2007:141) and Bugs et al. (2010) claim that users are "...already familiar with web mapping services" (Bugs et al., 2010:180). As early as 2008, three years after the introduction of the Google Maps service, Rinner et al. (2008) claimed of the Google Maps service that "...it provides an interface that many Internet users are already comfortable with. There are few functions that a user would not know from Google Maps." (Rinner et al., 2008:394). Thus, for ease of use, the standard functionality of a web-based PPGIS tool should ideally mimic as closely as possible the browser-based map interface controls and layout that Google Maps has popularised such as draggable 'slippy' maps, panning and zooming of the map using a mouse, and selecting

different map layers (such as aerial imagery or topography) to display. By using the OpenLayers API, which uses these types of controls as standard, the web-based PPGIS tool developed for this dissertation ensures that the ease of use criteria is met as closely as possible.

4.3.2.4 Satisfaction

A complete evaluation of the satisfaction criteria is dependent on the experiences of each individual user and requires a full user survey, but the primary task that users of the tool require it to support is to translate their personal subjective feelings and thoughts about the concept of 'wild land' into map-based visualisations. This task is achievable with the tool. Basic functionality such as the speed and responsiveness of the maps (bearing in mind that map data is sent from remote servers to the client continually) and the ability of the web tool to be available at all times with limited downtime (which are part of the 'fitness for purpose' requirements; see table 3.1), contribute to the satisfaction criteria and the tool meets this requirement well. With the architecture of data being served over the internet and displayed in a browser (as opposed to more traditional desktop-based GIS applications) there is a trade-off between the resolution of datasets and the performance of the display. Higher resolution maps mean a larger amount of data for the browser to retrieve from a remote source and render, and the tool balances these competing demands (Cavan and Kingston, 2012; Cavan et al., 2014).

4.3.2.5 Usefulness

Usefulness is defined in Bugs et al. (2010) as "...the degree to which the application would enhance user tasks" (Bugs et al. 2010:178). If the task is also defined as one of the objectives of this dissertation, namely "to allow the exploration and visualisation of what 'wild land' means on an individual human subjective level in the context of the Scottish Highlands" (section 1.2), then usefulness is how well the tool developed for this dissertation allows this objective to be met. The ability of the tool to allow a user to select individual map layers according to the four 'wild land' attributes, vary their opacity and see how they combine visually along with a dynamic display of the associated weightings of each attribute means that this criterion is met

effectively. The flexibility of the tool to give the user the ability to choose the weightings of the four 'wild land' attribute map layers and dynamically see map-based visualisations of those weightings, or vice-versa, to alter the four map layer opacities and see the resultant weightings, unlike previous research such as Carver et al. (2012), is a major strength of the tool (figures 4.14 and 4.15).

The choice of colours used in the map-based visualisations to represent values of the 'wild land' attributes is important to the usefulness of the tool. Different hues, shades and ranges of colours introduce subtly different effects into the visualisation and conceivably affect the weightings arrived at by users. Two different colour scales are offered for use in the tool with different colour ranges and levels of contrast to allow different types of visualisations but this is an area with scope for further research.

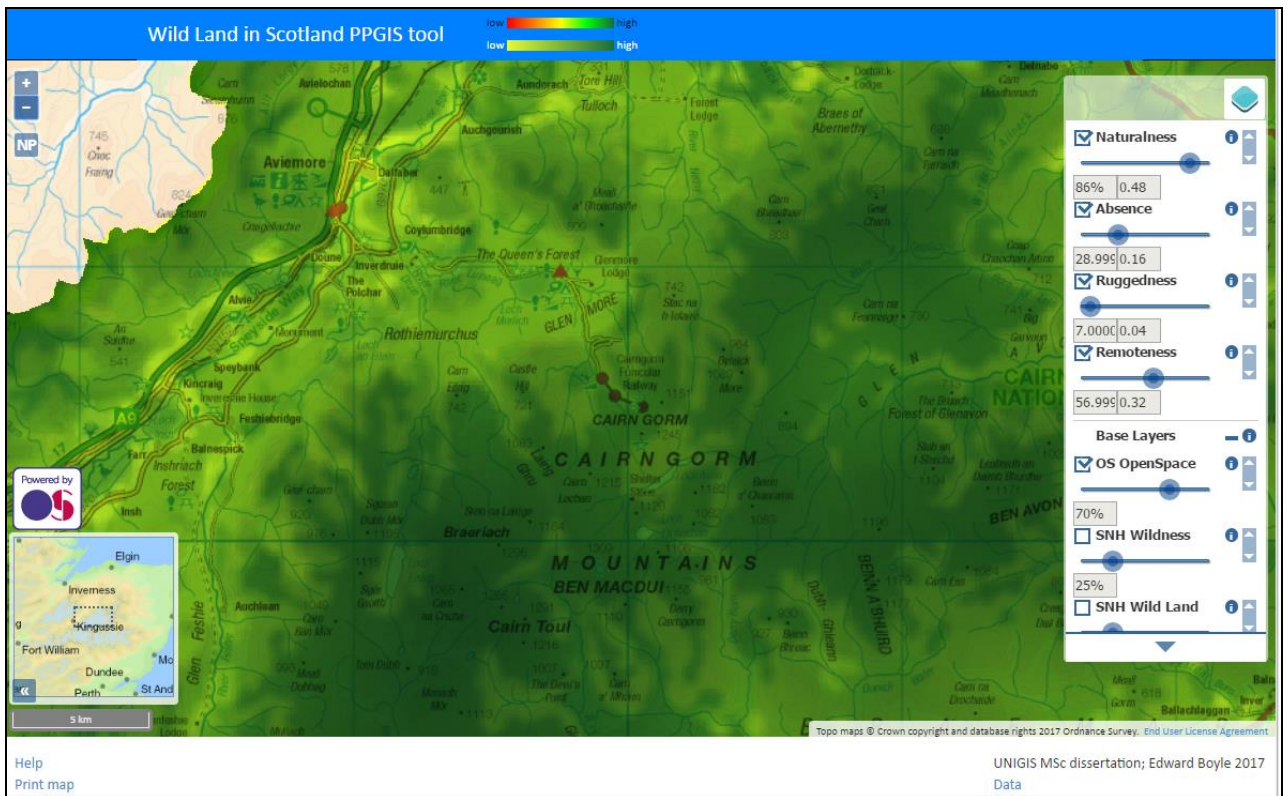


Figure 4.14. Screenshot of the tool showing the area of the town of Aviemore and the Northern Corries of the Cairngorms. The visualisation of the combined map layers uses opacities corresponding to the 'Residents in Scotland' 'Wild land' attribute weights (table 2.2; source: Carver et al. (2012)) and shows the effect of the relatively large weighting for the naturalness of land cover 'wild land' attribute. Dark green areas are higher values of the four combined 'wild land' attributes (and thus more 'wild').



Figure 4.15. Screenshot of the tool showing the area of the whole of CNP area with these chosen weights for the four 'wild land' attributes: naturalness of land cover 0.11; absence of modern human artefacts 0.3; ruggedness or rugged terrain 0.25; remoteness from mechanised access 0.34. Dark green areas are higher values of the four combined 'wild land' attributes (and thus more 'wild').

4.3.2.6 Accessibility

Beyond the criteria identified in Bugs et al. (2010) to evaluate the usability of web-based PPGIS tools, a further criterion of accessibility can be defined, related to the ease of use, intended users and usefulness criteria. Web-based accessibility of mapping interfaces is defined by the World Wide Web Consortium (World Wide Web Consortium (W3C), 2017) with explicit reference to people with visual disabilities, deaf or hard-of-hearing people, people with cognitive disabilities or elderly people. In Nivala et al. (2008), many of the most well-used web-based mapping interfaces are found to suffer some accessibility issues in this context, but notes that the Google Maps interface shows the least amount of problems. Nivala et al. (2008) list many design guidelines for web-based mapping interfaces to ameliorate these problems,

most of which are incorporated into the tool designed for this dissertation, particularly: 1) a simple uncluttered map interface with logically-placed icons (zoom buttons and a button to return the user to the default map display showing the whole of CNP); 2) a help window; 3) intuitive navigation and menu options; 4) a layer selection tool; 5) a choice of colours to use for the map layers; 6) an overview map; 7) a scale; 8) a legend. The use of mapping data from OS and the use of the OpenLayers API also contributes to these design considerations. An important convention to note with many current web-based maps is that compasses are no longer included in the interfaces as the direction of north is always assumed to be towards the top of the display screen.

The idea of accessibility also includes responsiveness and Responsive Web Design (RWD) techniques (using the Bootstrap JavaScript and CSS libraries) are used in the design of the tool so that it can be used in a variety of browsers and platforms including smartphones and tablets with touchscreens. These techniques include a map interface that uses 100% of the available browser window height and width without scrollbars, a fixed map centre that is stable with browser window resizes and headers and footers that contain navigation and menu options that remain fixed while the map itself is panned and zoomed. It should be noted however that the best results in terms of visualisation and usability are obtained by using the largest possible screen.

One important general usability consideration is that the 'multiplicative' alpha blending of layer opacities and the 'print map' option (section 4.2.2) do not work in the Internet Explorer browser.

5. Conclusions

5.1 Aim and objectives - outcomes

From the evaluation of the web-based PPGIS tool developed for this dissertation (section 4.3), a clear result is that it largely fulfils the aim and objectives of this dissertation (section 1.2). In particular, it is a fully 'open' tool supporting the PPGIS approach and allows for the subjective visualisation and exploration of the concept of 'wild land' for the largest possible audience. The development of the tool utilises a novel approach, building on previous research and combining approaches and techniques from various sources, to create something that offers a valid new way of potentially furthering knowledge in this area. Although the data processing steps in Wildland Research Institute (2008) were used as a general guideline to model the four 'wild land' attributes in the tool, they were not followed precisely. It is clear however that this has not limited the effectiveness of the tool. In terms of the personal subjectivity of the concept of what 'wild land' is, one person may feel that remoteness from human structures is the most important criteria, and another person may feel that rugged ground is the most important criteria. With its support for the PPGIS approach, the tool allows the visualisation, comparison and exploration of these types of choices. The quality of the mapping interfaces and the opacity selection and blending of map layers allows these choices to be adequately fulfilled in terms of degree of how strongly the choice is felt and expressed, with a quantitative result in the form of a normalised weighting value for each of the four attributes of 'wild land'.

One outcome of the development of the tool is a demonstration of the usefulness of data supplied by OS for PPGIS applications. The National Mapping Agency of the UK has traditionally been seen as a supplier of high quality data with a trusted and authoritative provenance and lineage but the usage of this data was until 2010 limited to applications that used commercial licencing. With the advent of the OS OpenData and OS OpenSpace services and their usage of OGL licencing and a Developer Agreement (Ordnance Survey, 2016b), this situation has now changed for the better with direct relevance to PPGIS platforms, tools and approaches (Chilton, 2011). This can be seen in the effectiveness of the usage in the tool of the OpenData

service for the modelling of three of the four 'wild land' attributes and the usage of the OpenSpace service for the main basemap of the tool. During development of the tool, OSM data was considered for use in these areas, but the availability of higher-quality OS data meant that it was not used in the final version of the tool. The quality of OSM data is not far behind OS though, and this situation may change in the future (Haklay, 2010). Land Cover data is not available from either OS or OSM and this is one area in which another source of data (CEH) had to be used.

The approach presented in this dissertation is entirely scalable by design, and can be used for many other purposes. The 'open' nature of the architecture and data means that it is fully customisable, extensible and portable to other areas of research. Different geographical areas can be covered, different datasets can be used to model the attributes, and different processing steps can be used to create those data models. The data can also easily be updated so that it remains current.

5.2 Limitations

As discussed in section 4.3.1, the resolution of the data used to derive the processed data for modelling the four 'wild land' attributes is a limitation of the approach used in this dissertation. In particular, the 50m resolution of the OS DEM used (which results in standardised 50m x 50m raster cells across all the data layers used) and the resolution of the CLC 2012 data are limiting factors. The CLC 2012 data also has issues with ambiguous land cover classifications and lack of classifications relating specifically to 'wild land'. The evaluation of the web tool shows that the data is of adequate resolution and quality to meet the objectives, but equivalent 'open' datasets of higher resolution may allow the development of a more robust web tool, if they could be acquired.

As also discussed in section 4.3.1, another limitation of the data is the lack of coverage of certain features which are relevant to the concept of 'wild land' in Scotland. Some of these features are: wind turbines, telecommunication towers, power pylons and hydroelectric infrastructure features. Lack of differentiation of the different types of certain features such as roads, buildings, forests and water bodies is another limitation.

A limitation of the processing of the data to model the four 'wild land' attributes is that the data values are normalised in a linear fashion so that gradations of 'wildness' on the resulting map are linear (e.g. the 'wild land' value of an area increases directly proportionally to the straight-line distance on the ground of the area from a modern human artefact such as a building). One possible variation of this, which may model more accurately subjective human visualisations of the concept of 'wild land' is to incorporate a non-linear normalisation, possibly using a logarithmic scale to model distance decay effects. This idea is discussed in Wildland Research Institute (2008).

A limitation of the evaluation of the web tool is that feedback has not been collected from users about the usability of the interface, utilising methods such as workshops or questionnaires.

5.3 Further research

Quantitative research could potentially be carried out using the tool for further analysis and investigation using user-generated weighting values of the four 'wild land' attributes. These values could be collated as part of a systematic web-based PPGIS survey using the tool to see how people from different cultural and social backgrounds, locations, experiences and knowledge of remote or 'wild' areas and levels of education view the concept of 'wild land' in the context of the Scottish Highlands, and overcoming biases to one particular social group (Habron, 1998; Kingston et al., 2000). The use of different colours and shading in the map visualisations and the effect on weightings could also be explored.

Weighting values obtained from user surveys using the tool could be used in a MCE analysis to explore and build upon research such as that presented in Carver et al. (2012), possibly using the WLC and 'fuzzy' classification techniques of that research. The strength of this approach is that with weighting values of map layers so crucial to the final map visualisations presented in this type of research, a wider, more inclusive and hence more robust theoretical and conceptual framework for the weighting values would make the visualisations of 'wild land' more valid and authoritative. The notion of a more robust conceptual framework for this research involving the PPGIS approach also leads to the question of what 'public' actually

means in this context. The scale and coverage used by maps in PPGIS applications defines who this 'public' is, and this notion is explored in Sieber (2006) and Brown et al. (2014) which make the claim that this has been ill-defined in PPGIS research and the influence of indigenous, intangible and tacit spatial knowledge and priorities of the 'public' in PPGIS applications is largely unexplored. An example of the difficulty in defining the 'public' can be seen in the inconsistent weights obtained for the 'wild land' attributes in tables 2.2 and 2.3. The tool developed for this dissertation could be used in this exploration.

Another area of potential research concerns the four 'wild land' attributes modelled in this dissertation. These are taken directly from the research presented in Wildland Research Institute (2008) and Carver et al. (2012), but potentially other attributes could be explored in this context. Scottish Natural Heritage (2017g) also defines these 'wild land' attributes: lack of people; loneliness; isolation; wildlife; natural or unspoiled beauty; beautiful scenery; weather. Jackson et al. (2008) also define these 'wild land' attributes: solitude; tranquillity; inspiration/awe; threat. Carver and Fritz (2016) also define these 'wild land' attributes: ecological condition; size.

References

Amazon (2016) Amazon Web Services [Online] [accessed 20th November 2016]
<https://aws.amazon.com/>

Anderson, G. and Moreno-Sanchez, R. (2003) Building web-based spatial information solutions around Open Specifications and Open Source Software. *Transactions in GIS*, **7(4)**: 447-466.

Batty, M., Hudson-Smith, A., Milton, R. and Crooks, A. (2010) Map mashups, Web 2.0 and the GIS revolution. *Annals of GIS*, **16(1)**: 1-13.

Brown, G. and Kyttä, M. (2014) Key issues and research priorities for public participation GIS (PPGIS): A synthesis based on empirical research. *Applied Geography*, **46**: 122-136.

Brown, G., Kelly, M. and Whitall, D. (2014) Which 'public'? Sampling effects in public participation GIS (PPGIS) and volunteered geographic information (VGI) systems for public lands management. *Journal of Environmental Planning and Management*, **57(2)**: 190-214.

Bugs, G., Granell, C., Fonts, O., Huerta, J. and Painho, M. (2010) An assessment of Public Participation GIS and Web 2.0 technologies in urban planning practice in Canela, Brazil. *Cities*, **27(3)**: 172-181.

Cairngorms National Park Authority (2017) Cairngorms National Park Partnership Plan 2012-2017 [Online] [accessed 4th March 2017]
<http://cairngorms.co.uk/resource/docs/publications/21062012/CNPA.Paper.1827.Cairngorms%20National%20Park%20Partnership%20Plan%202012-2017.pdf>

Carver, S., Evans, A., Kingston, R. and Turton, I. (2001) Public participation, GIS, and cyberdemocracy: evaluating on-line spatial decision support systems. *Environment and planning B: planning and design*, **28(6)**: 907-921.

Carver, S., Evans, A. J. and Fritz, S. (2002) Wilderness attribute mapping in the United Kingdom. *International Journal of Wilderness*, **8(1)**: 24-29.

Carver, S., Comber, A., McMorran, R. and Nutter, S. (2012) A GIS model for mapping spatial patterns and distribution of wild land in Scotland. *Landscape and Urban Planning*, **104(3)**: 395-409.

Carver, S. J. and Fritz, S. (eds.) (2016) *Mapping Wilderness: Concepts, Techniques and Applications*. Springer.

Cavan, G. and Kingston, R. (2012) Development of a climate change risk and vulnerability assessment tool for urban areas. *International Journal of Disaster Resilience in the Built Environment*, **3(3)**: 253-269.

Cavan, G., Butlin, T., Gill, S., Kingston, R. and Lindley, S. (2014) Web-GIS Tools for Climate Change Adaptation Planning in Cities. *Handbook of Climate Change Adaptation*, 2161-2191.

Chilton, S. (2011) OS OpenData and its effect on non-commercial cartography. *The Cartographic Journal*. **48(3)**: 183-185.

Comber, A., Carver, S., Fritz, S., McMorran, R., Washtell, J. and Fisher, P. (2010) Different methods, different wilds: Evaluating alternative mappings of wildness using fuzzy MCE and Dempster-Shafer MCE. *Computers, Environment and Urban Systems*, **34(2)**: 142-152.

Cook, J. (2015) Open Geospatial in 2020. In Wheeler, S., Wallace, G. and Bee, E. (eds.) *AGI Foresight Report 2020*, AGI 81-84.

Creative Commons Corporation (2016) Creative Commons [Online] [accessed 21st November 2016] <https://creativecommons.org/>

Eastman, J. R. (1999) Multi-criteria evaluation and GIS. In: Longley, P. A., Goodchild, M. F., Maguire, D. J., and Rhind, D. W. (eds.) *Geographical Information Systems: Principles, Techniques, Management and Applications (2nd ed.)*(vol. 1). New York: John Wiley & Sons: 493–502.

Elwood, S. (2006) Critical Issues in Participatory GIS: Deconstructions, Reconstructions, and New Research Directions. *Transactions in GIS*, **10(5)**: 693–708.

Elwood, S. (2008) Volunteered geographic information: future research directions motivated by critical, participatory, and feminist GIS. *GeoJournal*, **72(3-4)**: 173-183.

Elwood, S. (2011) Geographic information science: Visualization, visual methods, and the geoweb. *Progress in Human Geography*, **35(3)**: 401-408.

Elwood, S., Goodchild, M.F. and Sui, D.Z. (2012) Researching volunteered geographic information: Spatial data, geographic research, and new social practice. *Annals of the association of American geographers*, **102(3)**: 571-590.

Foody, G. M. (2002) Status of land cover classification accuracy assessment. *Remote sensing of environment*, **80(1)**: 185-201.

Fritz, S., Carver, S. and See, L. (2000) New GIS approaches to wild land mapping in Europe. *USDA Forest Service Proceedings RMRS-P-15-VOL-2*, 120-127.

Fritz, S., McCallum, I., Schill, C., Perger, C., See, L., Schepaschenko, D., Van der Velde, M., Kraxner, F. and Obersteiner, M. (2012) Geo-Wiki: An online platform for improving global land cover. *Environmental Modelling & Software*, **31**: 110-123.

Goodchild, M. F. (2007) Citizens as sensors: the world of volunteered geography. *GeoJournal*, **69(4)**: 211-221.

Goodchild, M. (2009) NeoGeography and the nature of geographic expertise. *Journal of location based services*, **3(2)**: 82-96.

Habron, D. (1998) Visual perception of wild land in Scotland. *Landscape and urban planning*, **42(1)**: 45-56.

Haklay, M. (2010) How good is volunteered geographical information? A comparative study of OpenStreetMap and Ordnance Survey datasets. *Environment and planning. B, Planning & design*, **37(4)**: 682-703.

Hall, G. B., Chipeniuk, R., Feick, R. D., Leahy, M. G. and Deparday, V. (2010) Community-based production of geographic information using open source software and Web 2.0. *International journal of geographical information science*, **24(5)**: 761-781.

Hecht, B. and Stephens, M. (2014) A tale of cities: Urban biases in volunteered geographic information. In *Proceedings of the Eighth International AAAI Conference on Weblogs and Social Media*, ICWSM '14: 197–205.

Higgs, G., Berry, R., Kidner, D. and Langford, M. (2008) Using IT approaches to promote public participation in renewable energy planning: Prospects and challenges. *Land Use Policy*, **25(4)**: 596-607.

Huck, J., Whyatt, D., and Coulton, P. (2014) Spraycan: a PPGIS for capturing imprecise notions of place. *Applied Geography*, **55**: 229-237.

Jackson, S., Fuller, D., Dunsford, H., Mowbray, R., Hext, S., MacFarlane, R. and Haggett, C. (2008) Tranquillity Mapping: developing a robust methodology for planning support. *Report to the Campaign to Protect Rural England, Centre for Environmental and Spatial Analysis, Northumbria University, Bluespace environments and the University of Newcastle upon on Tyne.*

Kerski, J. J. and Clark, J. (2012) *The GIS guide to public domain data*. Redlands, CA: Esri Press

Kingston, R., Carver, S., Evans, A. and Turton, I. (2000) Web-based public participation geographical information systems: an aid to local environmental decision-making. *Computers, environment and urban systems*, **24(2)**:109-125.

Kingston, R. (2007) Public participation in local policy decision-making: the role of web-based mapping. *The Cartographic Journal*, **44(2)**: 138-144.

Lesslie, R. G. and Maslen, M. (1995) *National wilderness inventory: Handbook of procedures, content and usage (2nd ed.)*. Canberra: Australian Government Publishing Service.

Lloyd, C. D. (2010) *Spatial data analysis: an introduction for GIS users*. Oxford: Oxford University Press.

Malczewski, J. (2000) On the use of weighted linear combination method in GIS: common and best practice approaches. *Transactions in GIS*, **4(1)**: 5-22.

Malczewski, J. and Rinner, C. (2015) Web-Based and Mobile GIS-MCDA. In: *Multicriteria Decision Analysis in Geographic Information Science*: 311-324. Springer.

Markieta, M. and Rinner, C. (2014) Using distributed map overlay and layer opacity for visual multi-criteria analysis. *Geomatica*, **68(2)**: 95-105.

McCloskey, M. J. and Spalding, H. (1989) A reconnaissance-level inventory of the amount of wilderness remaining in the world. *Ambio*, **18(4)**: 221–227.

McMorran, R., Price, M. F. and Warren, C. R. (2008) The call of different wilds: the importance of definition and perception in protecting and managing Scottish wild landscapes. *Journal of Environmental Planning and Management*, **51(2)**:177-199.

Meng, Y. and Malczewski, J. (2010) Web-PPGIS usability and public engagement: a case study in Canmore, Alberta, Canada. *URISA Journal*, **22(1)**: 55-64.

Nivala, A.M., Brewster, S. and Sarjakoski, T.L. (2008) Usability evaluation of web mapping sites. *The Cartographic Journal*, **45(2)**: 129-138.

OL3-ext (2017) OL3-ext: Extensions for OpenLayers 3 [Online] [accessed 22nd March 2017] <http://viglino.github.io/ol3-ext/>

Open Knowledge Foundation (2016) Open Data Commons Open Database License (ODbL) [Online] [accessed 21st November 2016] <http://opendatacommons.org/licenses/odbl/>

Open Source Geospatial Foundation (2016a) GeoServer [Online] [accessed 20th November 2016] <http://geoserver.org/>

Open Source Geospatial Foundation (2016b) OpenLayers [Online] [accessed 20th November 2016] <http://openlayers.org/>

OpenStreetMap Foundation (2017) OpenStreetMap [Online] [accessed 14th January 2017] <http://www.openstreetmap.org/>

Ordnance Survey (2016a) OS OpenData [Online] [accessed 21st November 2016] <https://www.ordnancesurvey.co.uk/business-and-government/products/opendata-products.html>

Ordnance Survey (2016b) OS OpenSpace Developer Agreement [Online] [accessed 19th March 2017] <https://www.ordnancesurvey.co.uk/business-and-government/licensing/licences/os-openspace-developer-agreement.html>

O'Sullivan, D. (2006) Geographical information science: critical GIS. *Progress in Human Geography*, **30(6)**: 783.

Pickles, J. (ed.) (1995) *Ground truth: The Social Implications of Geographic Information Systems*. New York/London: Guilford Press.

QGIS Development Team (2016) QGIS [Online] [accessed 21st November 2016]
<http://www.qgis.org/>

Riley, S. J., De Gloria S. D. and Elliot R. (1999) A Terrain Ruggedness Index That Quantifies Topographic Heterogeneity. *Intermountain Journal of Sciences*, **5(1-4)**: 23-27.

Rinner, C., Keßler, C. and Andrulis, S. (2008) The use of Web 2.0 concepts to support deliberation in spatial decision-making. *Computers, Environment and Urban Systems*, **32(5)**: 386-395.

Rinner, C. and Düren, M. (2011) Design with Nature 2.0 - a geodata infrastructure approach to map overlay. *Geoinformatik*: 21-28.

Sanderson, E. W., Jaiteh, M., Levy, M. A., Redford, K. H., Wannebo, A. V. and Woolmer, G. (2002) The Human Footprint and the Last of the Wild. *BioScience*, **52(10)**: 891-904.

Scottish Government (2017) National Parks in Scotland [Online] [accessed 4th March 2017] <http://www.gov.scot/Topics/Environment/Countryside/16131>

Scottish Natural Heritage (2017a) Policy Statement: Wildness in Scotland's countryside [Online] [accessed 4th March 2017]
<http://www.snh.gov.uk/docs/A150654.pdf>

Scottish Natural Heritage (2017b) Mapping Scotland's wildness and wild land [Online] [accessed 13th May 2016] <http://www.snh.gov.uk/protecting-scotlands-nature/looking-after-landscapes/landscape-policy-and-guidance/wild-land/mapping/>

Scottish Natural Heritage (2017c) National Parks [Online] [accessed 4th March 2017]
<http://www.snh.gov.uk/protecting-scotlands-nature/protected-areas/national-designations/national-parks/>

Scottish Natural Heritage (2017d) Descriptions of Wild Land Areas – 2017 -
Lochnagar – Mount Keen Wild Land Area [Online] [accessed 4th March 2017]
<http://www.snh.gov.uk/docs/A2177516.pdf>

Scottish Natural Heritage (2017e) Descriptions of Wild Land Areas – 2017 –
Cairngorms Wild Land Area [Online] [accessed 4th March 2017]
<http://www.snh.gov.uk/docs/A2177521.pdf>

Scottish Natural Heritage (2017f) Mapping Scotland's wildness Map 5 - Relative
wildness of Scotland 2014 [Online] [accessed 28th January 2017]
<http://www.snh.gov.uk/docs/A1323310.pdf>

Scottish Natural Heritage (2017g) Public perception survey of wildness in Scotland
[Online] [accessed 29th January 2017] <http://www.snh.gov.uk/docs/A769658.pdf>

Sieber, R. (2006) Public participation geographic information systems: A literature
review and framework. *Annals of the Association of American Geographers*, **96(3)**:
491-507.

Simao, A., Densham, P. J. and Haklay, M. M. (2009) Web-based GIS for
collaborative planning and public participation: An application to the strategic
planning of wind farm sites. *Journal of environmental management*, **90(6)**: 2027-
2040.

Steiniger, S and Hunter, A. J. (2013) The 2012 free and open source GIS software
map - a guide to facilitate research, development, and adoption. *Computers,
Environment and Urban Systems*, **39**: 136-150.

Sui, D.Z. (2008) The wikification of GIS and its consequences: Or Angelina Jolie's
new tattoo and the future of GIS. *Computers, Environment and Urban Systems*,
32(1): 1-5.

Sui, D., Elwood, S. and Goodchild, M. (eds.) (2012) *Crowdsourcing geographic knowledge: volunteered geographic information (VGI) in theory and practice*. Springer Science & Business Media.

Surowiecki, J. (2004) *The wisdom of crowds*. Abacus.

The National Archives (2016) Open Government Licence [Online] [accessed 21st November 2016]

<http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/>

University of Leeds School of Geography (2017a) The Slaithwaite Public Participation Geographical Information System [Online] [accessed 14th January 2017] <http://www.ccg.leeds.ac.uk/slaithwaite/>

University of Leeds School of Geography (2017b) Exploring environmental decision making using Internet GIS; Deciding where the wildest and most remote places are in Britain [Online] [accessed 4th January 2017]

<http://www.ccg.leeds.ac.uk/teaching/wilderness/>

University of Leeds School of Geography (2017c) Where is wild Scotland? [Online] [accessed 4th January 2017] <http://www.ccg.leeds.ac.uk/projects/wild-scotland>

University of Leeds School of Geography (2017d) Map-Me [Online] [accessed 4th January 2017] <http://map-me.org/>

Van Duzer, C. (2014) Bring on the Monsters and Marvels: Non-Ptolemaic Legends on Manuscript Maps of Ptolemy's Geography. *Viator*, **45(2)**: 303-334.

Watson, J. E., Shanahan, D. F., Di Marco, M., Allan, J., Laurance, W. F., Sanderson, E. W., Mackey, B. and Venter, O. (2016) Catastrophic declines in wilderness areas undermine global environment targets. *Current Biology*, **26(21)**: 2929-2934.

Wildland Research Institute (2017) Mapping [Online] [accessed 4th January 2017] <http://www.wildlandresearch.org/our-work/mapping/>

Wildland Research Institute (2008) Wildness Study in the Cairngorms National Park; Final Report [Online] [accessed 31st October 2016]
<http://www.wildlandresearch.org/media/files/Cairngorm2008.pdf>

Wood, D. and Fels, J. (1992) *The power of maps*. Guilford Press.

World Wide Web Consortium (W3C) (2017) Accessible Maps [Online] [accessed 18th March 2017] [https://www.w3.org/WAI/RD/wiki/Accessible Maps](https://www.w3.org/WAI/RD/wiki/Accessible_Maps)

Appendix

GeoServer WMS request URLs

1. Naturalness of land cover

http://52.209.201.41:8080/geoserver/cite/wms?service=WMS&version=1.1.0&request=GetMap&layers=cite:CNP_naturalness2&styles=&bbox=249588.31449,762436.41935,351547.77249,836671.46237&width=768&height=559&srs=EPSG:27700&format=application/openlayers&format_options=layout:layout1

2. Absence of modern human artefacts

http://52.209.201.41:8080/geoserver/cite/wms?service=WMS&version=1.1.0&request=GetMap&layers=cite:CNP_absence2&styles=&bbox=249588.31449,762436.41935,351547.77249,836671.46237&width=768&height=559&srs=EPSG:27700&format=application/openlayers&format_options=layout:layout1

3. Ruggedness or rugged terrain

http://52.209.201.41:8080/geoserver/cite/wms?service=WMS&version=1.1.0&request=GetMap&layers=cite:CNP_ruggedness1&styles=&bbox=249588.31449,762436.41935,351547.77249,836671.46237&width=768&height=559&srs=EPSG:27700&format=application/openlayers&format_options=layout:layout1

4. Remoteness from mechanised access

http://52.209.201.41:8080/geoserver/cite/wms?service=WMS&version=1.1.0&request=GetMap&layers=cite:CNP_remote1&styles=&bbox=249588.31449,762436.41935,351547.77249,836671.46237&width=768&height=559&srs=EPSG:27700&format=application/openlayers&format_options=layout:layout1

Web tool HTML URLs

<http://www.edwardboyle.com/MSc/tool1.html>

<http://www.edwardboyle.com/MSc/tool2.html>

Web tool JavaScript/jQuery URLs

http://www.edwardboyle.com/MSc/OL_1.js

http://www.edwardboyle.com/MSc/OL_2.js

Web tool CSS URLs

http://www.edwardboyle.com/MSc/OL_1.css

http://www.edwardboyle.com/MSc/OL_2.css