# MAPPING SCOTLAND'S SOIL RESOURCES

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## Abstract

*The Soil Survey of Scotland began mapping Scotland's soil resource in 1938 and continued up to 1986 when the systematic survey of Scotland's soils was ended. During this period, they produced a range of soil maps at scales from 1:10,000 up to 1:250,000 but the main output was 34 maps at 1:63,360 that were based on Ordnance Survey mapping at that scale of varying dates (plus four 1:50,000 maps) and seven sheets at 1:250,000 that covered the entire country. Given the time period, much of the mapping and map production was done using traditional techniques, however, there is now a considerable effort underway to make these maps more accessible over the Internet and more suitable for use within Geographical Information Systems (GIS). This, in itself, presents a few problems that need to be overcome, in particular, issues of scale for almost infinitely zoom-able PC software.*



## Keywords

*Soil maps, peat, Soil Survey of Scotland, digital data*


## 1 Introduction

Soil can be considered as a finite resource and a soil survey is a means of characterizing the amount and quality of land, its potential productivity, and, increasingly, quantifying and qualifying the ecosystem services that a healthy soil provides society. Soil maps also provide the means to extrapolate experimental results derived from one area to another with similar soils without the need for further experimentation at that site. Similarly, although peat continues to accumulate in some areas, soil can be considered a finite resource for the purposes of its planning and management. The provision of spatial data concerning soil and peat supports associated strategic planning and on-site management.

## 2 Surveying, Field Mapping and Production of Soil Maps

The Soil Survey of Scotland began the mapping of Scotland's soil resource in 1938 and by 1947 was charged with the systematic mapping of Scotland's soil resource. The Survey effectively came to an end in 1986. During the time that the Soil Survey was active, approximately 95 per cent of the cultivated land in Scotland was mapped at a scale of 1: 63,360 (some at 1:50,000 scale) and all of the country at a reconnaissance scale of 1:250,000.[1] The initial surveys were in connection with afforestation but at the onset of World War Two, the focus switched to agricultural land and increased food production. The mapping of peatlands as a resource for fuel began in 1949 with the survey of Altnabreac Moss in Sutherland, under the auspices of the Scottish Peat Committee. It was carried out by the Peat Section of the Department of Agriculture and Fisheries for Scotland (DAFS, 1968) and latterly by the Macaulay Institute for Soil Research and the Macaulay Land Use Research Institute.

As the Soil Survey of Scotland ended in 1986, none of the modern technological advances such as tablet PCs were used in the survey. Instead, the surveyors worked with various map editions and air photographs utilizing what was known as 'free survey', where the surveyor dug inspection pits to confirm or refute his (they were all male) conceptual model of the distribution of soils in that area. The early surveyors used 'War Time' GSGS (Geographical Section, General Staff) editions of topographic maps, meticulously recording the location of inspection pits in the field and later inking abbreviated, shorthand descriptions on to these sheets using fine-nibbed ink pens (Figure 1). These maps were based on the Cassini projection system. Later, 1:25,000 Ordnance Survey maps were used. These maps had a false origin to the south-west of England and were based on the Transverse Mercator projection system and utilized the same national grid that is currently in use in Great Britain.

In the mid-60s, black-and-white stereoscopic air photographs, mainly at 1:24,000, were introduced for field mapping with inspection holes being marked on the photograph in the field along with approximate boundaries between different soils. During the winter months, these boundaries were 'fixed' to changes in topography, with the help of a stereoscope to view the relief in three dimensions. These lines were transferred to a 'field sheet', which also contained information on the inspection pits, and to 'clean copy' 1:25,000 Ordnance Survey maps using a sketchmaster, and then passed on to the cartographic section for preparation of published 1:63,360 maps (Figure 2).

**Figure 1 Soil Survey of Scotland field sheets (GSGS 1:25,000 topographic map on left) showing the location of inspection pits and provisional soil map units**

Air photographs were also used extensively in the production of the 1:250,000 National Soil Map of Scotland particularly for those areas that had not been previously mapped. The existing soil map boundaries were simplified and map polygons amalgamated for representation at 1:250,000. For the remaining 40,000 km$^2$, air photographs were used to distinguish recurrent landscape patterns (such as moundy moraine) and the associated soils (Soil Survey of Scotland Staff, 1984). As before, the lines from the air photographs were transferred using a sketchmaster but to 1:50,000 paper topographic maps and then to transparent plastic topographic maps (known as 'blues' as they were printed in blue ink). These base maps were then passed to the cartographers for photographic reduction, scribing and preparation of the seven 1:250,000 map sheets that cover Scotland. Scribing involved using a fine-pointed stylus to scrape away a film from a plastic sheet to produce a negative image of the polygons. This was then turned into a positive version and adhesive map unit symbols were added manually (Figure 3a). Paper copies were made and hand-coloured to check that all polygons were closed (Figure 3b).

Irrespective of scale of the mapping, there was always a compromise between the heterogeneity present in

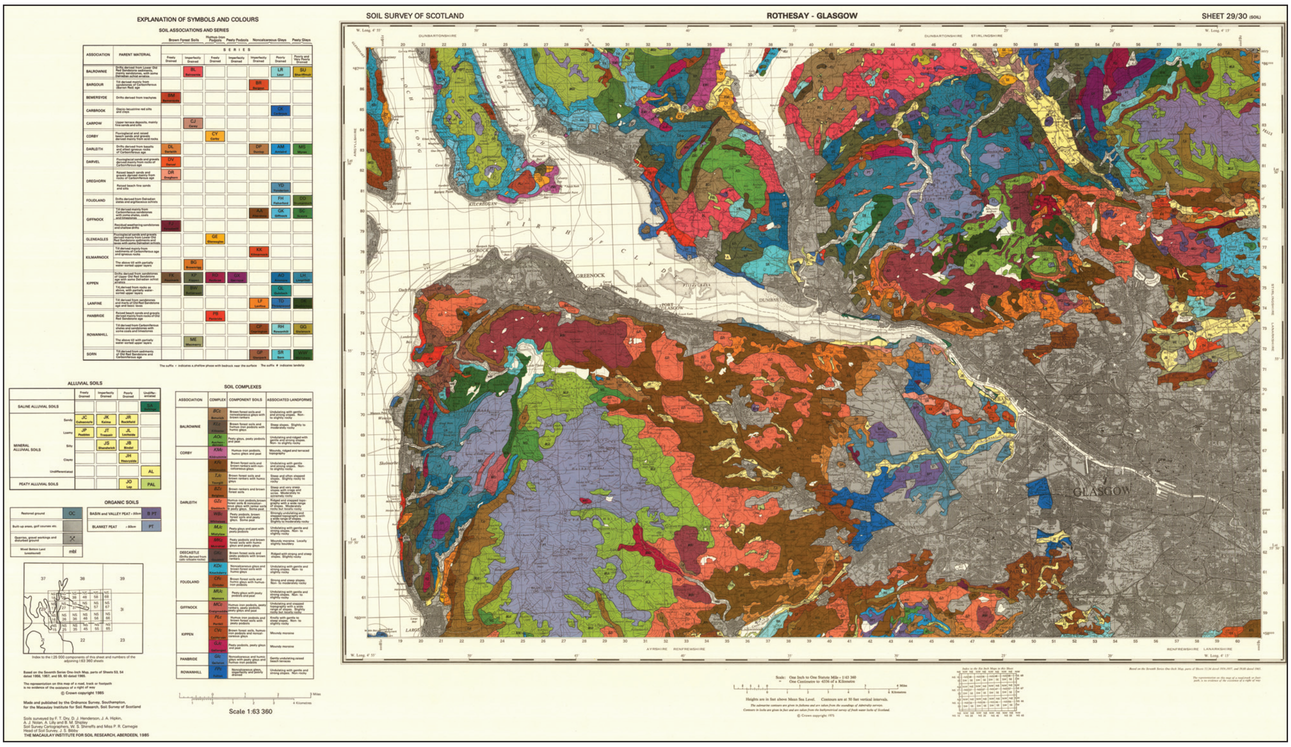



**Figure 2 Soil Survey of Scotland 1:63,360 soil map of the Glasgow area**



**Figure 3(a) Labelling soils map polygons; (b) Colouring draft colour map, based on sheets compiled from air photographic interpretation and field sheets**

the field and what could be realistically shown on a paper map. Different surveyors had widely different interpretations of what could or should be shown on the maps.

## 3 Scotland's Soil Map Series

The main output of the Soil Survey of Scotland was coloured maps at a scale of 1:63 360 (Figure 2). Although many of these maps were based on the Ordnance Survey Seventh Series topographic base maps, some of the early published soil maps were based on earlier topographic maps in this series. These maps do not align with the current Ordnance Survey national grid. Some 1:50,000 maps were produced, such as those for Orkney and Ardnamurchan.

As well as coloured 1:63,360 soil maps, the Soil Survey of Scotland also produced black-and-white 1:25,000 maps, which conveyed some additional detail over and above that portrayed on the one-inch maps, such as the presence of deeper topsoils, rock close to the surface, or excessively stony soils. The maps were printed 'on demand' from plastic master copies using a 'Dyeline' process.

In 1982, the Soil Survey of Scotland fulfilled its remit (to map the soils of Scotland) by producing the seven reconnaissance scale (1:250,000) Soil and Land Capability for Agriculture map sheets covering Scotland. These sheets were full colour and were also the first Scottish soil maps to be digitized. This was done by Laser-scan of Cambridge.[2]

Although based on the same soil classification system, the two main map series (the 1:63,360 and the 1:250,000) published by the Soil Survey of Scotland each had a different approach to formulating the map units. The 1:63,360 maps aimed (within the scale of the mapping) to show soil polygons that comprised only one soil type. This led to outputs with varying degrees of accuracy depending on the complexity of the soil heterogeneity. Where the soil pattern was too complex for this to be an effective mapping approach, soil complexes were mapped, often based on a distinct landform unit with a distinct suite of soils. This approach extended to the 1:25,000 maps and the 1:50,000 maps of Orkney and Ardnamurchan.

The 1:250,000 reconnaissance maps, on the other hand, were designed to show primarily complex map units based on recurring landform features and their associated soils and only rarely do the map units comprise only one soil type. Detailed 1:50,000 maps (known as the 'provisional brown series') for those areas of Scotland not covered by the 1:63,360 series were produced from these reconnaissance-scale maps. They were analogous to the 1:25,000 black-and-white maps and showed additional detail that could not be represented on the national 1:250,000 maps. These were held as plastic maps and printed as required.[3]

Both series of coloured maps had a common colour-coding system for the different soil types. Map units dominated by brown earths were represented cartographically in brown; podzols in pink, orange or red; mineral gleys were in blue and peaty gleys in green; immature, shallow soils and those soils of the mountain

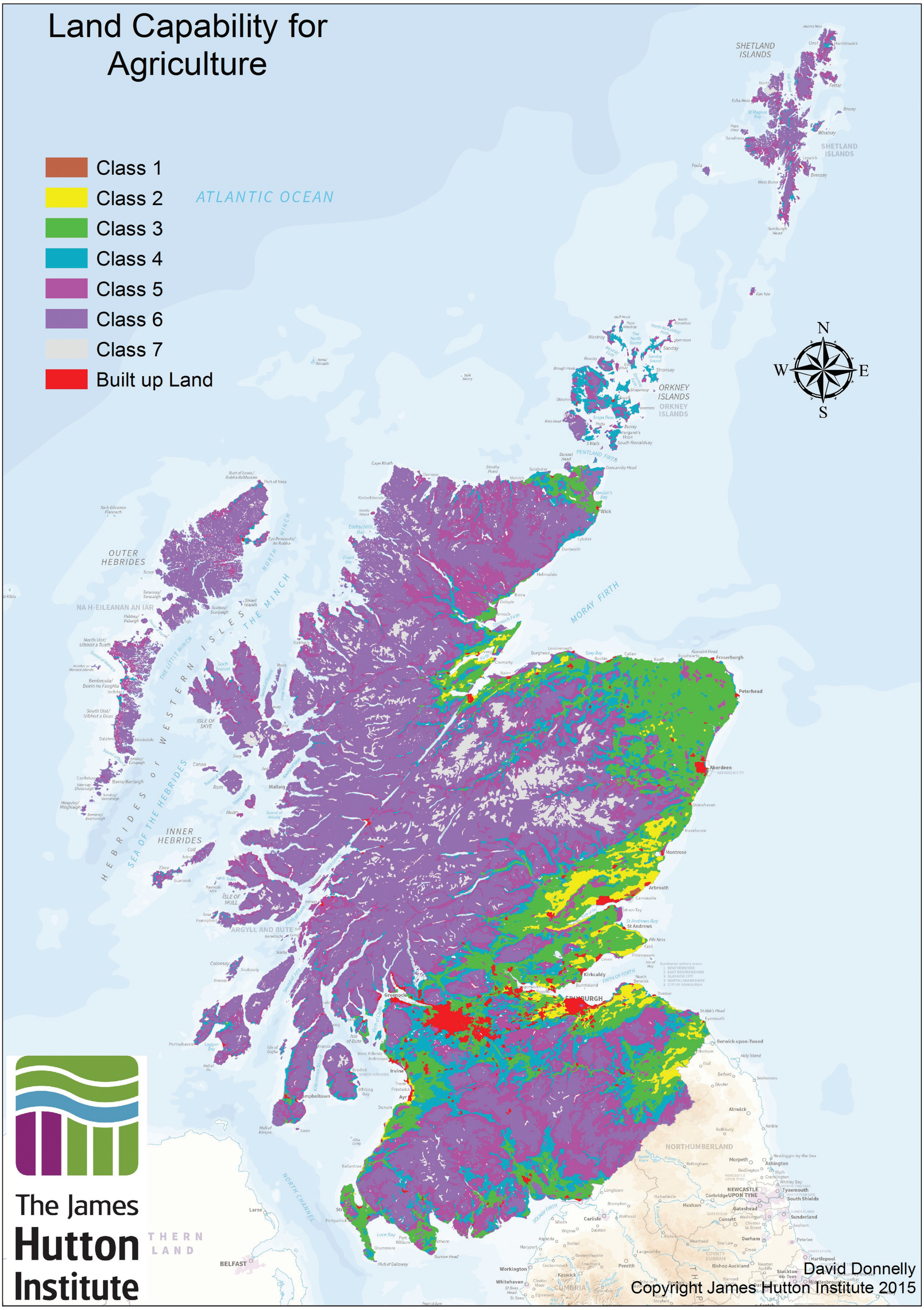



**Figure 4(a) Land Capability for Agriculture for Scotland**

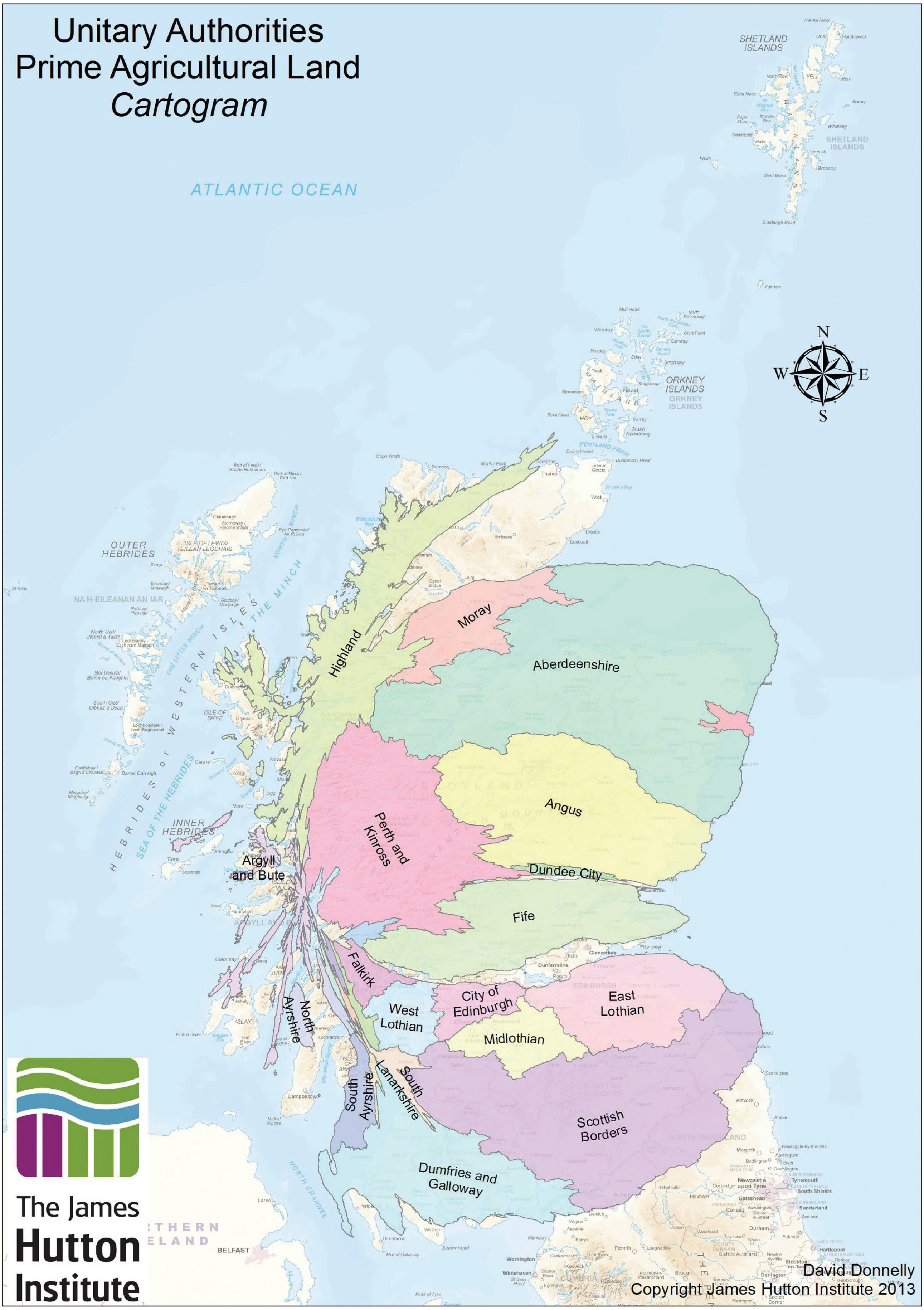



**Figure 4(b) Representation of the prime agricultural land per local authority in Scotland by means of a cartogram**

tops were shown in grey; while yellow was reserved for soil derived from alluvial deposits. By adhering to the same colour scheme across scales, it provided consistency in visual recognition of the distribution of soils in an area by simply glancing at a soil map of either scale.

## 4 Interpretive Mapping and Land Evaluation

Soil maps, and the extensive soil database that underpins the maps and characterizes the component soils, are key to a number of derived maps that the Macaulay Institute for Soil Research and its successor institutes have produced. Before GIS and database technology, these were produced by surveyors following a set of published guidelines to allocate different soils to different classes, but increasingly the utility of digital data allows a more flexible approach to land evaluation.

The best known and probably most widely used example is the Land Capability for Agriculture (LCA) classification (Bibby *et al.*, 1982; 1991). Its objective is to assess the value of land for agriculture based on an assessment of the degree of constraint that soil, climate and topography impose on agricultural options. It is a seven-class system; Class 1 offers the most flexibility, whereas Class 6 is only suited to rough grazing, and Class 7 has little agricultural value.

A generalized map of the Land Capability for Agriculture for Scotland is shown in Figure 4(a). Figure 4(b) shows a representation of the LCA classes which define 'prime agricultural land' (LCA classes 1–3.1) by local authority in the form of a cartogram (the area of the local authority is presented in relation to the area of the prime agricultural land). This is an example of how these data can be used to communicate information about agricultural land in alternative ways to that of a conventional map.

## 5 Mapping Scotland's Peatlands

Initially the main aim in mapping the peatlands was to determine the potential of peat resources to supply peat-fired electricity generating stations. Work naturally concentrated on the larger, lowland and basin bogs, and focused on the estimation of peat volumes and quality for the principal purpose of making a strategic assessment of potential fuel supplies. A total of 161 sites were surveyed at an initial reconnaissance scale followed by full and detailed topographic mapping.[4] The methods are set out in detail in the Scottish Peat Surveys (Department of Agriculture and Fisheries for Scotland, 1968), although a summary of the process for the surveys, the output maps, and derived data for peat deposits is as follows:

(i) Reconnaissance survey of site to identify site boundary, baseline(s) for the survey, and link to the national height network, e.g. a benchmark or triangulation pillar (Figure 5a);

(ii) Production of a mosaic of aerial photographs to cover the area (particularly if it was a large deposit and imagery was available);

(iii) A field survey using a grid system, with a set of baselines, measurement points at a density chosen to suit the local conditions and purpose of the survey but typically at intervals of between 25 m x 25 m to 100 m x 100 m, at which the bog surface was recorded with respect to a local datum, and the depth of the peat;

(iv) Topographic detail such as ditches, fences, and edges of peat-bank cuttings;

(v) Typically, samples of peat were taken for 10 per cent of all depths at 0.5 m vertical intervals, distributed across the range of depths and geographic extent of the area surveyed (Figure 5b); and

(vi) Production of a map of the surface contours and of height and depth of peat at survey points (Figures 6a and 6b).

For most of these peat deposits, the survey data were used to calculate information about the peat resources including the area, volume (typically calculated using trapezoidal methods), and a report on peat quality and its potential for exploitation.

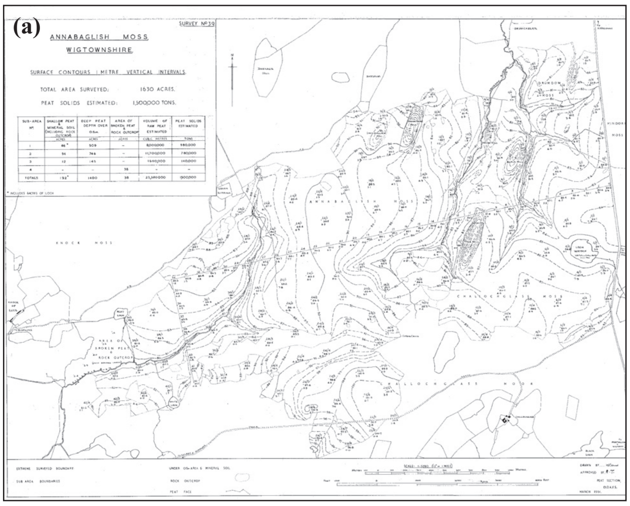
From around 1982 onwards, the surveys used electronic distance measurement (EDM) equipment and moved progressively towards field data capture which could be downloaded for use with digital mapping tools. By 1985, the mapping of peat deposits included the field survey of selected contextual information such as surrounding boundary features, and observations for transforming the coordinates of the survey data into the Ordnance Survey National Grid. That enabled the plotting of maps of surface and bottom contours, or isopachytes on media suitable for their overlay on maps from other sources, at a range of scales.

## 6 Scotland's Digital Soils and Peatland Data

### *6.1 Soils*

The move from analogue to digital representations of maps of soil and peat has been ongoing in Scotland since the early 1980s, with the scanning of the 1:250,000 National Soil Map to produce a digital dataset that could be manipulated within GIS. Later, many of the 1:25,000 soil maps were also digitized. More recently, paper copies of these soil maps and those at 1:63,360, the associated field sheets, and peat maps pre-1984, and associated transects and records, have been scanned to provide a digital archive to support future reproduction of materials as well as long-term protection of the data and materials. The creation of such an archive has also become increasingly important for the long-term custody of these materials, some of which are fragile and over 60 years old.

Figure 5(a) Theodolite being levelled at a survey point; (b) Sampling of a peat core at a survey point using a 'Russian Sampler'



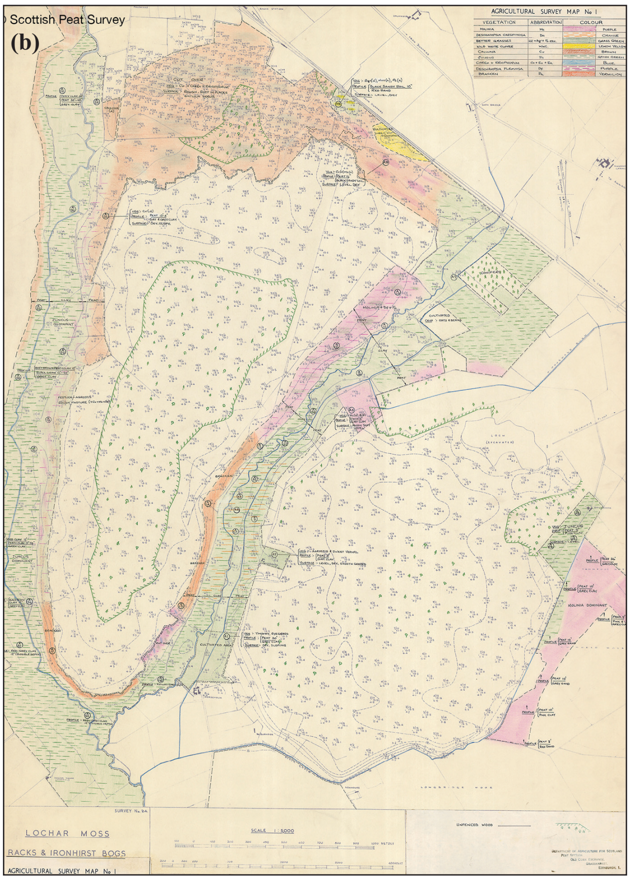




**Figure 6(a) Map of the surface contours of Annabaglish Moss, Wigtownshire; (b) Map of the survey of Lochar Moss, south east of Dumfries showing survey points (height and depth), surface contours, and agricultural land use**

The product of this programme of archiving has also enabled improved access to, and use of, the information for printing, viewing on-screen, and moving progressively towards more data being made available online. Figure 7 shows the raster representation of the 1:250,000 map of soils for north-east Scotland viewed in ArcGIS and the data available via the World Wide Web for the interrogation of attributes such as carbon, pH, and so on.

The digital data of Scotland's soils are also made available through the web mapping service of Scotland's Environment Web (*www.environment.scotland.gov.uk/get-informed/land/soils/*), as part of public policy of enabling access to data about the environment, as per the Aarhus Convention on access to public information


**Figure 7 Digital representations of the 1:250,000 soils of north-east Scotland, viewed in ArcGIS on the right screen, and via the World Wide Web on the left screen**

(UNECE, 1998). Figure 8 shows an extract of the 1:250,000 soil map of north-east Scotland, as represented on Scotland's soils website (*www.soils-scotland.gov.uk/*).

These data are now also being made available via smartphone apps, enabling users to interrogate both the soil map data (currently the 1:250,000 National Soil Map) and soil data (*http://sifss.hutton.ac.uk/*). Users can explore the characteristics of approximately 600 different Scottish soil types, and to examine a range of key indicators of soil quality such as soil pH, organic carbon content and nutrient status. The soil map acts as an interface via a web mapping service (WMS) to allow users to determine the characteristics of the soil at any point in Scotland and to provide graphical and numeric output with contextual information.

### *6.2 Peatland*

The scanned peat maps have been georectified for all the major deposits mapped before 1970. Those since 1985 were collected and handled in vector data structures and thus the production of the outputs have used vector-based spatial data handling techniques, and analysis for the derivation of areas and volumes. Through to the present day, the approaches to handling digital spatial data have been upgraded progressively, as more data became available to which the peat surveys could be related, using GIS to handle the vector and image data.

The data on individual peat deposits have been compiled into a spatial database with details of the site, a summary of information collected from the survey, such as mean depth, volume and area greater than 1.5 metres. Access to the summary information has been made available online with aerial imagery and Ordnance Survey map data providing context as a backdrop (Figure 9).

Data from the surveys of peatlands are a source of information that can be used in modelling of natural resources. For example, understanding peatlands as three-dimensional landforms is as important as mapping their spatial extent, and studying the 3D structure of peatlands contributes to improving both the understanding of carbon dynamics and hydrology (Holden, 2005). This can help prioritize peatlands for restoration and the associated benefits of reduced GHG (greenhouse gas) emissions and carbon storage.

The data on attributes such as depth which were recorded at specific georeferenced points in the historic surveys can be digitally captured and used in the derivation of continuous surfaces, with geostatistical approaches used to model the properties of soils and peat. Figure 10(a) shows the output of an analysis of the 1955 survey of the Dava Moss (Morayshire). The locations of boreholes were selected following a preliminary analysis of maps and aerial photographs. The digitized survey data were used in an approach which combines 3D generalized additive models and kriging to produce a map of peat depths and 3D representations of water and carbon content (Figures 10(b) and (c)). Such outputs are increasingly useful for informing policy teams and land managers about the protection and management of carbon stocks in peatlands.

## 7 Challenges for Cartography

The evolution of the use of maps and other means of digital representation of data on Scotland's soils and peat

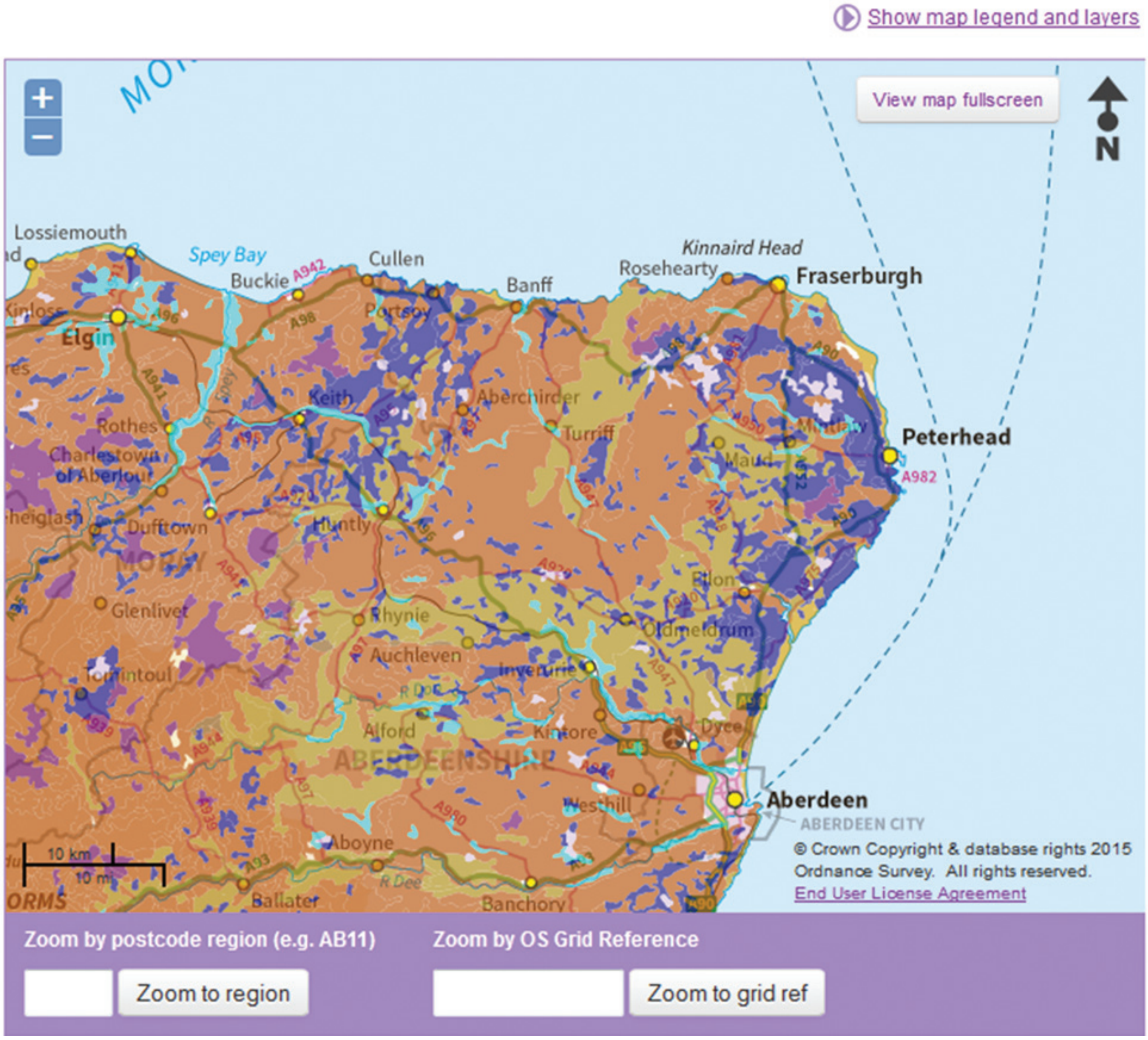



**Figure 8 An extract of the 1:250,000 soil map of north-east Scotland, as represented on Scotland's soils website (minus legend)**

creates a number of challenges for cartography. Converting paper products into a usable digital form is a challenge and an opportunity for many sectors beyond that of cartography and mapping, and one which has been significantly boosted by digital infrastructure such as Google Maps and equivalent products and near ubiquitous location sensing. However, some significant challenges remain to be fully addressed, amongst which there are three of particular note.

### *7.1 Scale*

The conversion of existing paper maps into raster formats benefits from relative simplicity of the process, and dissemination of the output. However, there remains the risk of maps, such as those of soils, being used at a scale larger than that supported by the data. Software tools can restrict such actions, but the increased scope to download and combine data with those at other geographic scales increases the risk of unintended interpretation of the map content. So, increased access to map data should encourage increased communications about the use of maps.

The challenge is how we can assist users to understand scale when maps are presented on different devices.

### *7.2 Format*

The benefit of large, hardcopy maps compared to maps viewed on smartphones and tablets is that the paper map can often be large enough to allow the viewer to gain an overall impression of the distribution of the soil types. Small screens on tablets and smartphones generally do not allow this. The provision of information through mobile devices should significantly increase opportunities for the demand for information on 'place'. However, the means of communicating the meaning of the complexity of

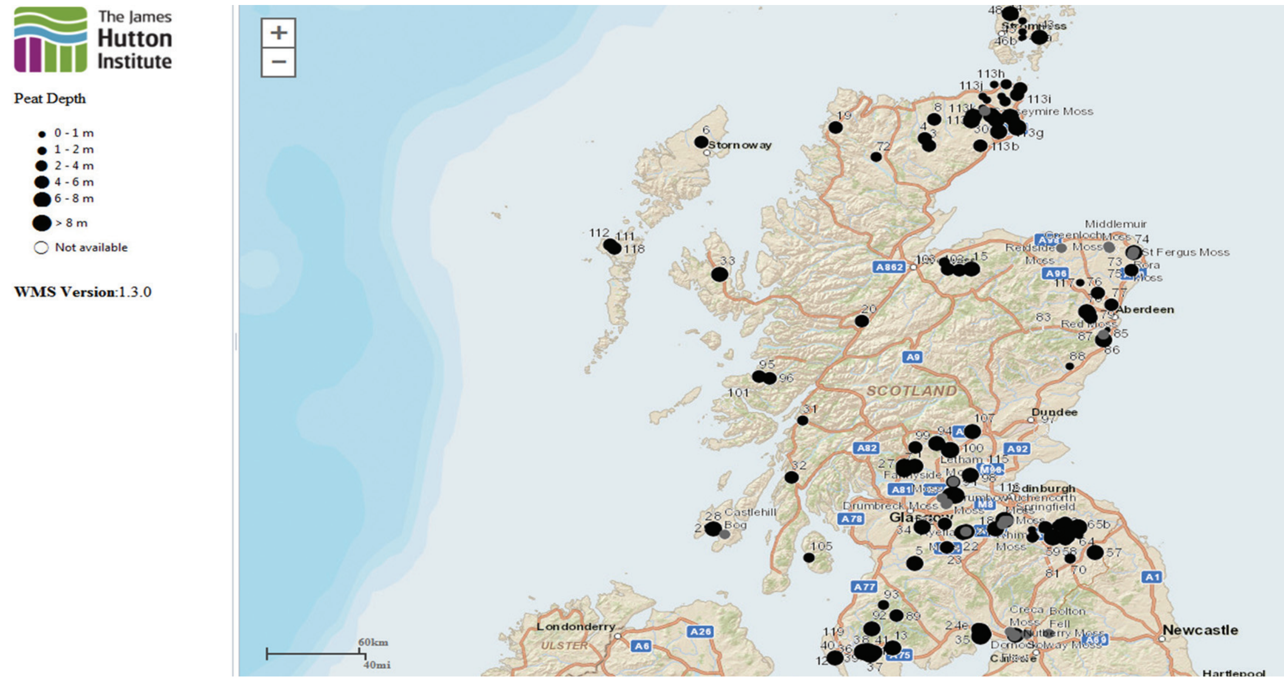


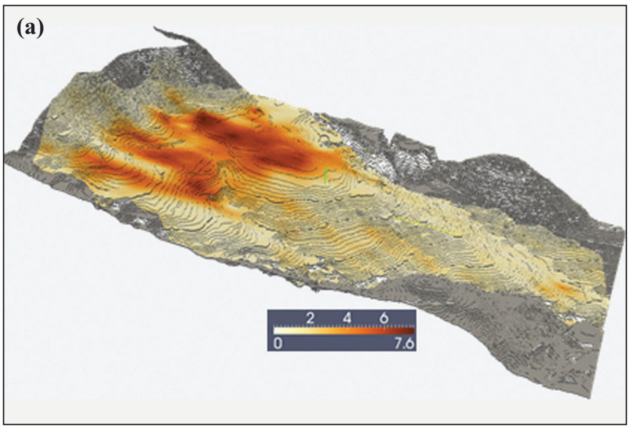

**Figure 9 Map of the surveys of peat deposits in Scotland (see *http://idee.hutton.ac.uk/PeatSurveys_with_Qmsoils.html*)**

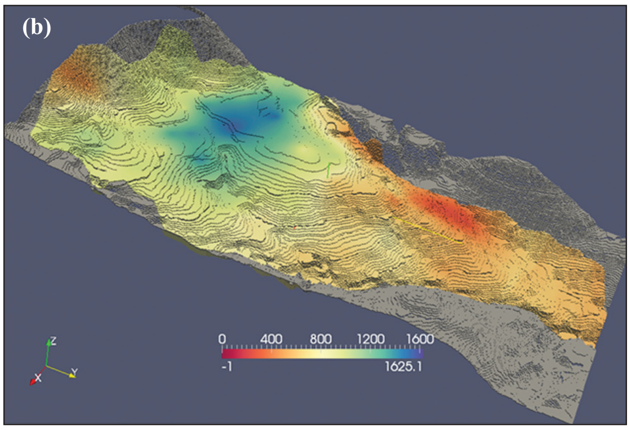
information which is simplified to a single polygon on a soil map is restricted.

The challenge is to find innovative ways of conveying the content of a complex legend.

### *7.3 Colour*

Throughout its history, the Soil Survey of Scotland has used specific colours to represent specific soil types, providing consistency in representation between different scales of map. Once in a digital form the subtleties of combinations of colour and textures can be lost, with the



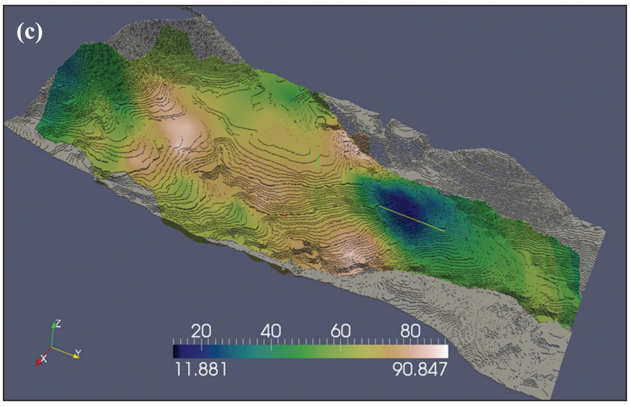




**Figure 10(a) Modelled peat depth; (b) Moisture content; and (c) Organic carbon contents, of Dava Moor, Morayshire based on original peat survey data**

loss of producer control over the final medium of use. So, the original logic and consistency of the uses of particular colour schemes for the high-level representation of types of soils can be lost.

The challenge is to enable smarter means of representation in which colour plays its part in communicating the content of the map, whilst recognizing the attraction of greater flexibility in its use.

## 8 Conclusion

Over the last 50 years, the principal purposes behind the mapping of Scotland's natural soil and peat resources have evolved to reflect changing societal demands and practice. The tools available to enable such mapping have also evolved, to a stage where information is more easily captured, accessed, used and shared. In this field, the principal investments are now less for undertaking primary data capture and more towards the exploitation of existing data, and meaningful forms of representation and dissemination.

The fundamental stages in the capture of data about soils and peat remain largely unchanged, relying upon on-site observation and measurement, interpretation as appropriate, and recording. The use of remotely sensed imagery, combined with pre-existing information, is enabling significant advances in digital soil mapping, and the interpretation of characteristics of peatland resources. However, the outputs in the form of maps still require some form of verification and representation which is usable for the purpose intended.

Where such outputs are in the form of maps, the requirements of representation remain largely unchanged: account taken of input scale compared to that presented; appropriate levels of generalization; coherent use of colour and texture; intuitive association of labels with object; and overall legibility.

The James Hutton Institute is committed to making data on the natural resources of Scotland, such as those of the Soil Survey of Scotland, available online and freely available. A challenge for the Institute and its collaborators in the provision of maps and spatial data of public goods, such as soils and peatlands, is to apply the most appropriate tools for maximizing the uptake of products, based on understanding the principles which ensure high-quality data capture and their presentation as maps.

Arguably, the tools for handling data which are then represented as maps have evolved at such a pace that the application of cartographic principles has been put aside. In some applications of spatial data the priority can now move back to address the quality of presentation so to capitalize on the accessibility of maps and increase map literacy. This is in the belief that ensuring the integrity of any product will benefit the uptake of its content and the means of its dissemination over the long term.

## Notes

1. See *http://mapapps2.bgs.ac.uk/ukso/home.html*
2. See *www.soils-scotland.gov.uk/data/soil-survey* for more information.
3. See *www.huttonsoils.com/maporderform.php*
4. Lists of the sites surveyed can be accessed at: *http://www.hutton.ac.uk/sites/default/files/files/Scottish_Peat_Surveys_Scottish_Peat_Committee_MISR.pdf*

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## Biographies

**Allan Lilly** is a Principal Soil scientist at the James Hutton Institute and has over 30 years' experience in mapping Soil in Scotland and collecting soil data. His main research focus is in interpreting soils data to make it available for use in biogeochemical and hydrological models. He is responsible for a current RESAS-funded project to enhance the current soil data holdings and to make soils data more accessible via web interfaces and for researchers.

**David Miller** obtained a BSc in Topographic Science from University of Glasgow and a PhD on expert systems from the University of Aberdeen. He has over 30 years' experience working on techniques for handling and analysing geographic information and applying them to mapping, monitoring and modelling changes in peatlands, land cover, urban and rural land use, landscape and seascape, and the development of Geographic Information Systems for use by government and its agencies. He was an advisor to the recent Scottish Government Land Reform Review Group.

**Willie Towers** is a Principal Soil Scientist at the James Hutton Institute and has almost 40 years' experience in mapping and characterizing soils in Scotland and using the data in a number of research and policy-related applications. He co-led the development of Scotland's Soils website *http://www.soils-scotland.gov.uk/*.

**David Donnelly** is a Geographic Information Systems Consultant at the James Hutton Institute. He has been working in digital mapping since the late 1980s and has produced spatial data tools and applications.

**Laura Poggio** is a research scientist at the James Hutton Institute. Her research interests focus on mapping spatio-temporal relationships between ground data and remote sensing-derived information for digital soil mapping and for integration of information on soil-climate interactions with land use and ecosystem processes.

**Patricia Carnegie** began work in the Soil Survey Department of the former Macaulay Institute for Soil Research (now the James Hutton Institute) in 1975. She moved to the Cartography section in 1979 and made a major contribution to the production of the 1:250,000 series of soil maps of Scotland as well as a number of 1:63,360 soil and 1:50,000 Land Capability For Agriculture maps.