Technical report: Maps of land use data and ecosystem services for catchment level case studies in Scotland: examples applied to the National Parks and Aberdeenshire River Dee

RESAS1.4.3 Objective D [Deliverable: D3]: Mapping ESS and benefits to illustrate adaptive and integrated catchment management

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Executive summary

The purpose of this technical report is to provide an update on work in the Strategic Research Programme (Work package 1.4.3) that is collating maps/spatial datasets on land use and ecosystem services for case study locations of Scotland's two National Parks and Aberdeenshire River Dee. These maps have been produced through work on agricultural land use and its impacts (e.g. Hewitt et al 2018) and on mapping ecosystem service indicators (e.g. Gimona et al 2018), and are intended for analysis at the whole river catchment scale or smaller.

This report provides the bridge between this earlier work of data compilation and integration in year one and scheduled tasks for 2019, as follows:

1. Rapid analysis of broad tendencies of land use and land cover change at Scotland scale. (Deliverable 4a)
2. Catchment-scale analysis of recent land change developments in forestry and agriculture, e.g. for selected catchments or comparable-scale case study areas of interest to key stakeholders. (Deliverable 4b)

We provide a brief structured description of the maps/spatial datasets presented in this report: comprising general description, methods used to produce them, their recommended use, and their principal limitations. The intention is that these descriptions should serve as a guide to stakeholders, interested in using them to aid management of Scotland's natural assets. All the datasets presented in this report have been developed for all of Scotland. However, three study areas have been selected to illustrate these datasets at the landscape scale.

These data form a useful basis for spatial analysis to mitigate negative land use and ecosystems service impacts, and providing support to land managers and other policy stakeholders. However, the datasets described do have some limitations, which we summarize below. It should be noted that all datasets have errors, and detailed description of the limitations provided in this report should not be taken as an indicator of poor quality relative to other sources. Rather, good practice requires that limitations should be properly described and documented.

With respect to the integrated land use datasets described in the first part of the report, the main limitations relate to the use of mixed data from multiple sources or data not originally intended for that purpose. The IACS data are not ideally suited for use as a land use time series, since land parcels record only the use claimed under the agricultural payments system, so that cessation of claims results in the disappearance of a land use from one date to the next in a way that does not reflect land use in reality. In addition, they provide a poor record of land use outside of the most important agricultural areas, due to the lesser importance of these areas in the payments system.

With respect to the ecosystem services dataset described in the second part of the report, main limitations relate to their reliance on published, rather than directly measured data, together with insufficient resources available for acquisition of proprietary, third party data, e.g. on forest biomass, British Trust for Ornithology bird atlas data, Land Cover Map etc.

We provide recommendations relating to future development of these integrated datasets.

1. Introduction

This technical report is part of the Strategic Research Programme (SRP) on land use change and Ecosystem Services funded by the Scottish Government. The Natural Assets Theme of the Scottish Government's Strategic Research Programme 2016-21 (hereafter Theme) is concerned with identification, quantification and valuation of Scotland's environmental assets, biodiversity and ecosystem services. Modelling and mapping of land use change and key indicators of ecosystem services is an essential component of this Theme. Mapped indicators could support decision-making across land use policy priorities (such as a low carbon economy, sustainable food production and water management) by allowing spatially explicit visioning of the land use change and ecosystem services trade-offs. For example, they can highlight areas in which landscapes provide multiple services and benefits, which could be protected if necessary, and areas where intervention through a variety of policy instruments could be needed.

Modelling and mapping of land use change and indicators of ecosystem services requires adequate spatial data on land and its resources. Though land use, agriculture and forestry data are developed and maintained by a wide range of scientific and public bodies, including Scottish Government, the Centre for Ecology and Hydrology (CEH) and the Forestry Commission (FC) data are not always obtained in a form that is directly appropriate for the relevant analyses. For this reason, significant resources have been allocated under the Natural Assets Theme for the systematization, harmonisation and integration of large-scale spatial land use datasets from a range of sources.

The purpose of this technical report is to provide an update on research in Work Package 1.4.3 that is collating maps/spatial datasets on land use and ecosystem services for case study locations of Scotland's two National Parks and Aberdeenshire River Dee. These maps have been produced through work on agricultural land use and its impacts (e.g. Hewitt et al 2018) and on mapping ecosystem service indicators (e.g. Gimona et al 2018) and are intended for analysis at the whole river catchment scale or smaller.

This report therefore provides the bridge between this earlier work of data compilation and integration in year one and scheduled tasks for 2019, as follows:

1. Rapid analysis of broad tendencies of land use and land cover change at Scotland scale. (Deliverable 4a)
2. Catchment-scale analysis of recent land change developments in forestry and agriculture, e.g. for selected catchments or comparable-scale case study areas of interest to key stakeholders. (Deliverable 4b)

2. Description of datasets produced

The purpose of these sections is to provide a brief structured description of the maps/spatial datasets presented in this report: comprising of a general description, methods used to produce them, their recommended use, and their principal limitations. The intention is that these descriptions should serve as a guide to available data to inform evidence-based policy on management of Scotland's Natural Assets. All the datasets presented in this report have been developed for all of Scotland. However, three study areas have been selected to illustrate these datasets at the landscape scale. These case study areas were chosen as areas of key interest to stakeholders following national and regional level stakeholder engagement in year one. These areas are shown in Figure 1. Maps referred to throughout the text are provided for these three study areas in Appendices to this report.

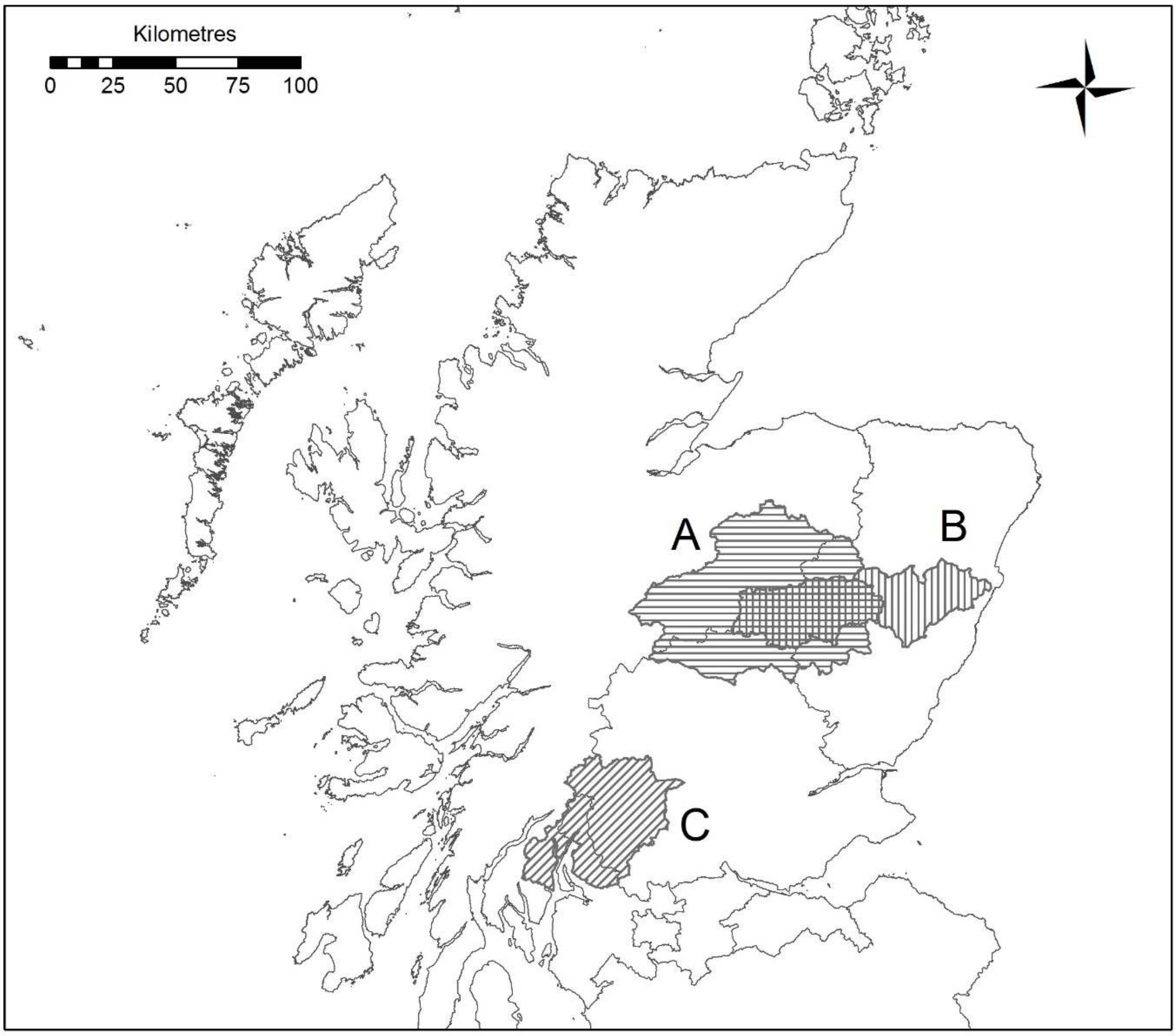

Figure 1: Mainland Scotland and three study areas chosen as exemplars for display of spatial datasets. A: Cairngorms National Park; B: Grampian River Dee; C: Loch Lomond and Trossachs National Park.

2.1 Integrated spatial land use datasets

2.1.1 Land use datasets and rationale for 2019 work programme

Since earth surface cover is a key factor in controlling erosion, water supply and climate, ecosystems and the services they provide are highly vulnerable to land use and land cover (LUC) change (Metzger et al. 2006, Turner et al. 2007). LUC monitoring therefore plays a vital role in understanding these change processes and analysing, reporting, and managing their impacts on the ecosystems that are necessary for human survival. The development of accurate, large scale LUC datasets is an essential pre-requisite for this work.

In order to assess the potential of existing land use and land cover datasets to respond to this necessity, a rapid survey of available datasets was carried out (Table 1). The survey (Table 1) shows that there is a lack of large-scale (high spatial resolution) data on land use or land cover data for a series of consecutive historical dates for Scotland. Without such a resource, the scope, nature, and extent of analysis on land change and ecosystem services is seriously constrained. For instance, while both CORINE land cover and Agcensus[1] allow a national scale understanding of agricultural land change, and are useful for highlighting areas of concern, the information is not detailed enough to be able to identify individual crop types, or fully evaluate the impacts of land use change on ecosystem services. At the same time, Forestry and Woodland Inventories are available for a range of dates at a highly detailed scale but lack accompanying data for other land use types. This makes it difficult to obtain a good understanding of the evolution of forestry in relation to other types of land use.

Table 1: Available data on land use/land cover for Scotland

Dataset	Creator	Dates available	Key limitations	URL
The Land Cover of Scotland 1988 (LCS88)	Macaulay land research institute	1988	Only one date available.	https://www.hutton.ac.uk/learning/exploringscotland/landcover-scotland-1988
Land Cover Map (LCM) series	Centre for Ecology and Hydrology (CEH)	1990,2000, 2007, 2015	Not freely available (must be purchased). JHI do not have latest map (2015), there are no plans to obtain it due to its high cost. Not recommended for comparison of different map dates due to different classification criteria at each date.	https://www.ceh.ac.uk/services/land-cover-map-2007
Forestry commission forestry surveys (various), e.g. Native Woodlands Survey for Scotland 2014, National Forestry Inventory for Scotland 2015, National Forest Estate Legal Boundary for Scotland 2016.	Forestry Commission	2010-15, earlier dates also may be available, e.g. National inventory of woodland and trees (1995-99)	Forest/Woodland land uses only.	https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/
Coordination of Information on the Environment (CORINE)	European Environment Agency	2000, 2006,2012	Small scale (1: 100,000 max). Classification not well adapted to local land cover types.	https://land.copernicus.eu/pan-

[1] http://agcensus.edina.ac.uk/

	and local partners			european/corine-land-cover
Agricultural census data for Scotland (agcensus)	Scottish Executive: SEERAD and (from 2007) Environment Directorate.	Annually from 1969	Coarse grained (1km max) Aggregated to parish scale, Agricultural land only.	http://agcensus.edina.ac.uk/
Habitat Map of Scotland (HabMoS)	Scottish Natural Heritage (SNH)	Nominal date of 2015	Land cover information (EUNIS Land Cover Scotland) is an amalgamation of many existing sources, e.g. LCS88, LCM 2000, LCM 2007, National Forest Inventory etc. Multiple dates in a single map not useful for change monitoring, and likely to be very unreliable for this purpose.	http://gateway.snh.gov.uk/natural-spaces/dataset.jsp?dsid=HABMOS https://www.spatialdata.gov.scot/geonetwork/srv/eng/catalog.search#/metadata/08d85469-bc12-4e67-819e-b41ae47b0392

To respond to these limitations in the baseline datasets available (Table 1), a range of new spatial datasets were created by Hutton staff, either by combining information from different sources (Land Cover Map (LCM), Forest Inventory), or by using information from other sources (e.g. Integrated Administration and Control System (IACS) dataset) to create new spatial datasets. These are listed in Table 2 and are described in the following sections. We describe these data as “integrated spatial datasets” because their creation involves a process of systematic unification (=integration) of the information in each dataset. Clearly, such a process makes the output dataset more useful for the required objectives (analysis of catchment level natural assets), but also introduces some limitations. These are described in detail in the following sections.

Table 2. List of integrated spatial land use datasets

No.	Name	Scale/ resolution	Time periods available	Accessible	Description/sources	Type	Filename	Format	Created by / contact
1	**IACS predominant land use 2008-15**	From 1:5000 (lowlands) to 1:50000 (uplands)	2008-15	Restricted access, contact creator	IACS surveyed land parcels with area claimed under CAP payments system, with predominant land uses assigned according to the simple classification (see documentation).	Land use informati on (spatial)	f[year]PR EDOM.sh p (e.g. f10PRED OM.shp)	ESRI Shape file	Richard Hewitt Richard.h ewitt@h utton.ac. uk
2	**IACS predominant land use, extended crops classification**	From 1:5000 (lowlands) to 1:50000 (uplands). Minimum mapped unit c. 0.2ha	2010, 2015 (can create any other date between 2008 and 2015 as required)	Restricted access, contact creator	IACS surveyed land parcels with area claimed under CAP payments system, with predominant land uses assigned according to the extended classification (see documentation).	Land use informati on (spatial)	f10PRED OM_deta iled.shp, f15PRED OM_deta iled.shp	ESRI Shape file	Richard Hewitt
3	**LCM2007 integrated with Forestry Commission woodland inventory data (LCM2007w2 and LCM2007w3)**	LCM states minimum mappable unit 0.5ha, though some woodland parcels may be smaller	2007 with 2015 woodlan d	Restricted access, contact creator	LCM2007 (produced by CEH), merged with Native Woodlands Survey for Scotland 2014, National Forestry Inventory for Scotland 2015, National Forest Estate Legal Boundary for Scotland 2016.	Land use informati on (spatial)	LCM07v6 s2_0102 17.gdb, LCM07v6 s2_Wood R2id_rast er_25m, LCM07v6 s2_Wood	ESRI Shape file, 25m raster	Marie Castellaz zi Marie.ca stellazzi @hutton .ac.uk

					2 reclassifications: WoodR3id: all as LCM INTCODE classes; WoodR2id : LCM INTCODES + 8 woodland subcategories.		R3id_raster_25m		
4	**IACS_LCM07w_raster**	As LCM2007	2007/2010, 2007/2015	Restricted access, contact creator	IACS and LCM2007w3 merged using the ArcGIS MOSAIC tool, giving overlay priority to IACS.	Land use information (spatial)	Integrated IACS simple classification (see 1, above) and LCM 2007 with forestry dataset (see 3 above)	25m raster	Richard Hewitt
5	**IACSextended_LCM07w_raster**	As LCM2007	2007/2010, 2007/2015	Restricted access, contact creator	IACS and LCM2007w3 merged using the ArcGIS MOSAIC tool, giving overlay priority to IACS.	Land use information (spatial)	Integrated IACS extended classification (see 2, above) and LCM 2007 with forestry dataset (see 3 above)	25m raster	Richard Hewitt

2.1.1 IACS predominant land use 2008-15

2.1.1.1 General description

The Integrated Administration and Control System (IACS) dataset, available under restricted licensing conditions due to the sensitivity of the data, contains information on land use at the level of the land parcel from land use declarations made by land managers as part of the requirement to receive payments under either Pillar 1 or Pillar 2 of the Common Agricultural Policy (CAP). Maps are shown in Appendix 1.1.

2.1.1.2 Methods

By joining land claims information (hectares of crop claimed in each parcel) to the corresponding parcels in the spatial database using the Field_ID, it was possible to obtain a highly detailed map of agricultural land uses claimed for each year since the first spatial database became available in 2001 until the most recent complete dataset available (2015). However, development of the spatial database was incremental, with improvements made continuously every year, and full, high quality coverage was not achieved until ca. 2008. To obtain a series of snapshots or “time slices” suitable for the study of the spatial evolution of land claims over this period, maps were generated for 3 dates, 2008, 2010 and 2015. The maps were generated by summing the total land claims per parcel and automatically assigning the predominant claim to the whole land parcel. Since the claims database contains over 100 crop types, in the first instance data were aggregated into 10 simple classes (Appendix 3.1).

The claims assigned to these 10 classes were checked by summing the total hectare amounts for the new aggregate classes and comparing with the field "TOTAL_AREA". Thus 2008 and 2009 totals were found not to match the total in the "TOTAL_AREA" column, since some of the parcels had land classified as Land Let Out" (LLO), representing a land use unknown to or undeclared by the claimant. Thus by adding the LLO amounts in each case, the totals have been corrected. Thus all totals listed are correct and checked. LLO appears only in years 2008 and 2009, and in 2008 and 2009 classes for Water, Inland_Rock and Urban are empty, as all area quantities were documented in the Unclassified category. As of 2010, these data appear in their correct classes and Unclassified is empty.

2.1.1.2 Recommended use

The recommended use of this dataset is to provide large-scale (i.e. detailed) spatial information on basic agricultural land use in Scotland and its evolution over time; this could be used to show more detailed estimates of ecosystem services and multiple benefits from Scotland’s agricultural land.

2.1.1.3 Principal limitations

In terms of the usefulness of IACS as a land use dataset, there are two key limitations that need to be taken into account. These are: 1) Errors in GIS mapping quality; 2) assigning a single land use to parcels containing multiple uses; 3) the source of the land use information. These are briefly discussed as follows:

2.1.1.3.1 Errors in GIS mapping quality.

The accuracy of the spatial data is dependent on the quality of the original IACS dataset, which contained significant errors. These errors have gradually been corrected, and from 2010 onwards datasets no longer contain significant errors. Detailed technical description of these errors is given in Appendix 4.1.

2.1.1.3.2 Assigning a single land use to parcels containing multiple uses.

Another potential source of error relates to the fact that land parcels often contain more than one land use. However, since the spatial distribution of multiple land uses within each parcel was unknown, it was necessary to choose the predominant land use in order to make the time series maps for the three snapshot years (2008, 2010, 2015). This is described in more detail in Appendix 4.2.

2.1.1.3.3 The source of the land use information

One further key limitation with this dataset relates to the origin of the information used to classify land use at the scale of an individual land parcel, which are claims submitted to the Rural Payments and Services division of Scottish government under Pillar 1 of the CAP. The presence of land use on the maps is therefore an indicator of land use, rather than an objective measurement, such as would be obtained by classification of remotely sensed data or orthophotographic mapping. For instance, the appearance of many new woodland areas between 2008 and 2010 is not an indicator of woodland growth, but rather, it reflects the full incorporation of woodland payments data into the claims database after 2008. Conversely, if a claim for a particular land use class made in one year is discontinued in subsequent years, it disappears from the map. For this reason, IACS is a rather unreliable source for year-on-year monitoring. The problems are likely to be most severe for non-agricultural land use classes. Since established agricultural land is likely to remain eligible across dates under various cropping regimes, these areas are likely to be more reliable.

2.1.2 IACS predominant land use, extended crops classification

2.1.2.1 General description

The simple crops classification adopted from the IACS simple groupings described above, e.g. arable, temporary grassland, permanent grassland etc are too broad for many types of analysis, for example, to understand differential nutrient export using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model (Sharp et al 2014). For this reason a different grouping of the IACS individual land use codes was undertaken for this specific purpose. Maps are shown in Appendix 1.2.

2.1.2.2 Method

This dataset was created from the IACS land claims database, in the same way as for the previous dataset (see 2.1.1.1). As for the preceding dataset, the maps were generated by summing the total land claims per parcel and automatically assigning the predominant claim to the whole land parcel. To provide more detail on crop type than in the previous dataset, land claims data were aggregated into 17 classes (Appendix 3.2).

2.1.2.2 Recommended use

This dataset provides large scale spatial information on agricultural land use in Scotland and its evolution over time, allowing for more detailed mapping of ecosystem services. The crop categories chosen are of particular interest for understanding nutrient retention/export.

2.1.2.3 Principal limitations
Since these data are derived from the same source as 2.1.1, the same issues noted above are also applicable to this dataset.

2.1.3 LCM2007 integrated with Forestry Commission woodland inventory data

2.1.3.1 General description
These data (LCM07v6s2_WoodR2n3.shp, or .gdb) were created in January 2017 by M. Castellazzi, with the aim of improving the representation of woodland in the LCM2007 land cover map (Appendix 1.3a, Appendix 1.3b). The integrated dataset incorporated the latest version (as of January 2017) of 3 Forestry Commission datasets:

- Native Woodlands Survey for Scotland 2014 (NWSS),
- National Forestry Inventory for Scotland 2015 (NFIS),
- National Forest Estate Legal Boundary for Scotland 2016.

Maps are shown in Appendix 1.3.

2.1.3.2 Method
Two reclassifications were carried out: WoodR2 & WoodR3; both combines in order of priority: native woodlands from NWSS + non-native woodlands from NFIS + LCM07 classes.
In WoodR2, woodlands are subdivided as broadleaved, coniferous, woodland (unspecified type) and clear fell (includes Failed and Windthrow categories). Note that shrubs, scrubs and most PAWS (Planted Ancient Woodland Sites), are not included in this reclassification.
In WoodR3, all woodlands are kept in only 2 categories to fit with the original LCM07 'INTCODE' attributes: broadleaved and coniferous. Integration of the datasets was carried out in GIS software. To limit the occurrence of small artefact polygons (slivers) when overlaying the datasets, a 10m tolerance was used.

2.1.3.2 Recommended use
The resulting aggregate map is used to all intents and purposes as a replacement for the standard LCM2007 spatial dataset for analyses of ecosystem service provision that are dependent on land use inputs.

2.1.3.3 Principal limitations
The use of a 10m tolerance when integrating the data has introduced small spatial discrepancies (<0.2% of the landscape when comparing NFIS15 woodland areas between the original dataset and the aggregated dataset). The combination of the land use classes from the different input datasets was designed for ecosystem services (ESS) models (e.g. InVEST), which needed to identify mature woodlands. Further reclassification rules could be implemented to fit requirements of other studies, e.g. taking into account shrubs or young trees.

2.1.4 IACS predominant land use integrated with LCM 2007 woodland dataset

2.1.4.1 General description
Given the limitations of the IACS data for non-agricultural land cover classes, a combined dataset was created in which agricultural land classes (arable, temporary grassland, improved grassland) from IACS simple classification (Section 2.1.1) were combined with LCM07w3 (extended LCM07 with Woodland inventory 2015 classification no.3) (Section 2.1.3). This was carried out for two IACS

periods: 2010 and 2015 (Appendix 1.4). This integrated dataset allowed changes in agricultural land (from IACS) to be monitored while at the same time incorporating accurately mapped non-agricultural land use data from LCM and the woodland inventory. Maps are shown in Appendix 1.4.

2.1.4.2 Recommended use

This dataset has a wide range of uses including land use and land cover change analysis and ecosystem services analysis and monitoring. For example, it has been used to provide land use inputs for the InVEST model (Sharp et al 2014) for the analysis of sediment and nutrient output (see, e.g. Hewitt et al 2018), and will likely form the base dataset used for land use modelling work in WP 1.4. It is recommended to review carefully the limitations of this dataset before using it.

2.1.4.3 Principal limitations

In addition to the limitations previously discussed for the IACS dataset (Section 2.1.1.3), one further limitation is that comparable land uses in each dataset do not precisely spatially coincide. The merge operation assumes IACS to be a superior measure of agricultural land use, for this reason the three agricultural categories from IACS take precedence over LCM categories which they overlap. However, LCM seems to show a larger area of agricultural land than IACS, these areas will be added to the new merged arable land category. This problem has no easy solution, since IACS is less reliable outside of agricultural land areas, so cannot serve as a replacement, but simply removing the non-coincident areas from LCM would create holes in the dataset. An idea of the extent of the problem can be obtained through a cross tabulation of LCM07 and IACS 2010 (Appendix 5.1, Appendix 5.1). The main areas of error relate to arable and grassland which are not clearly coincident across the two datasets.

2.1.5 IACS predominant land use extended classification integrated with LCM 2007 woodland dataset

2.1.5.1 General description

This dataset refers to the combined dataset created as for the previously described datasets, except that the IACS extended classification was used. Maps are shown in Appendix 1.5.

2.1.5.2 Recommended use

As for the previous dataset, this dataset was created to provide input for the InVEST nutrient and sediment model. The extended classification, in which key crop types with known nutrient loads are disaggregated, is more useful than the simple classification, since it allows different arable cropping regimes with correspondingly different nutrient loads to be separately modelled. In other words, rather than broadly estimating nutrient and sediment output for generic “arable” land, local scale differences in nutrient export associated with individual cropping regimes can be distinguished.

2.1.5.3 Principal limitations

The main limitations of this dataset relate to the different criteria used for mapping similar classes between the three datasets used, with the result that overlap between apparently similar thematic categories is not exact. See the discussion for the previous dataset (Section 2.1.4.3).

2.2 Ecosystems Services maps

The ecosystem services framework is a commonly-adopted measure of the benefits that nature provides to human well-being and quality of life (e.g. Ehrlich and Mooney 1983, Constanza and Daly 1992, Constanza et al 1997). Quantification of ecosystem services is a first step for their inclusion in policy and decision making. Ecosystem services are commonly classified according to a hierarchical framework that relates services to how they contribute to human well-being, known as the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potchin 2012). This framework, which is a refinement of the one proposed by the Millennium Ecosystems Assessment (MEA 2005), is the one chosen by the European Union and is the classification system followed in the work that we report on here.

Ecosystem services maps were commissioned by Scottish Government (in RD1.4.2 Gimona et al) and developed from available data sources under the Strategic Research Programme. Maps were prepared following the CICES classification (Haines-Young and Potchin 2012), which separates ecosystem services into three types, provisioning services, regulating services and cultural services, described in detail in the following sections. The maps produced are shown in Table 3.

Several of these spatial datasets/maps were produced using the InVEST suite of models (Sharp et al 2014). These are a set of openly available models that have been widely used to provide estimates of ecosystem services worldwide, including in the UK (e.g. Nelson et al 2009, Zhou et al 2010, Redhead et al 2016).

Table 3: Ecosystems services maps and related spatial indicators

No.	Name	Scale/resolution	Description/sources	Documentation	Created by*
Provisioning Services					
1	Water Supply	25m raster, aggregated to sub-catchment scale	The map, obtained using the InVEST 'water yield' model, ranks Scottish sub-catchments based on the total annual runoff form land.	http://www.arcgis.com/apps/MapSeries/index.html?appid=a1c9afe0f8594c3da68654f8124632fa	AG & ABC
2	Suitability for crop Production	1km	Indicator of crop production, correlated with crop yield for a range of crops but is not itself a quantification of yield of individual crops. The map was produced by integrating data from the Land Capability for Agriculture (LCA) analysis and 12 years of weekly time series of MODIS satellite data that provide a measure of plant productivity.	As above	AG
3	Cattle Density	2km gridded data on 25m raster	Gridded Agricultural Census data for cattle from EDINA (2 km resolution) were downscaled by redistributing recording cattle numbers at 2 km resolution onto 25 m grid cells of the land cover map.	As above	AG & ABC
4	Sheep Density	2km gridded data on 25m resolution raster	Data from Gridded Agricultural Census data from EDINA (2 km resolution) were down-scaled by redistributing sheep on grasslands derived from LCM 2007 and on moorland habitat that supports their grazing.	As above	AG & ABC
Regulating Services					
5	Water purification - nutrients	25m raster, aggregated to sub-catchment scale	The map, obtained using the InVEST nitrogen retention model, ranks Scottish catchments based on the total amount of nitrogen that runs off from the land but is retained before reaching the streams.	As above	AG & ABC
6	Soil retention	25m raster, aggregated to sub-catchment scale	The map, obtained using the InVEST soil and sediment retention model, ranks Scottish catchments based on the total amount of soil that is retained before reaching the streams, including soil that might be initially transported but is deposited later.	As above	AG & ABC
7	Soil Organic Carbon Stocks	1km resolution	The map, at 1 km resolution, is based on estimates of soil organic carbon stocks to up to 1 m depth. The estimates were obtained by relating field data contained in the National Soil Inventory of Scotland (NSIS) data base, to a range of environmental variables using Digital Soil Mapping methods. For example, topography and satellite data were used to produce the estimates for un-sampled locations.	As above	LP & AG
8	Pollination	100m resolution	The map shows an index of pollination service rescaled between 1 (highest) and 0 (lowest). The index is based on 6 species of bumble bee, namely *Bombus lapidarius, B. lucorum, B. muscorum, B. pascuorum, B. pratorum, and B. terrestris.* For each species the model had 4 main components:	As above	LP ,AG, RB, RP, ES

			a floral resources component (276 species), a nesting habitat component, a spatial component (to account for flight distance) and a time component (to account for flowering of floral resources and queen emergence). Flowering times of the species considered were obtained from several data bases, namely Bioflor, EcoFlora, LEDA. The species geographical distributions were taken from the Atlas of the British and Irish Flora and downscaled to 100 m (see the species richness section for more details). Each bumble bee species contributes to the service to flowering crops if these are within the species' maximum flight distance. The latter were mapped using agricultural census data from 2015. The service is defined only in proximity of flowering crops. The latter were mapped using agricultural census data.		
Cultural Services					
9	Recreation and Amenity	1km resolution (partial)	This map uses geo-referenced, crowd-sourced photographs as a synthetic indicator for intermediate cultural services such as Amenity, Aesthetics and Cultural Importance. We have mapped the number of unique submitters to Panoramio in each 1 km square as a (partial) indicator of the recreation service. Values (between 0 and 560 per per Km^2) are rescaled between 1 and 0 as in the other maps. The white areas did not have any uploaded photos.	As above	MC & AG
10	Plant Species Richness	1km resolution	The plant species richness map was obtained by down-scaling the distribution of all native flowering species (from the Atlas of the British and Irish Flora) to 1 km. For each 10 km square of the Atlas where a species was reported present, the down-scaling was carried out as follows: we attributed presence of the species to the broad habitats of the 25-m land cover map (LCM2007) in which it can live. Results were aggregated to 1 km. For each 1km square the number of present species was counted. The values were then rescaled between 1 (highest richness) and 0 (lowest).	As above	LP & AG
11	Floral Distinctivene ss	10km resolution	Local species richness is not a sufficient criterion to highlight areas that are important for the provision of plant diversity. It is also important to identify areas that have a distinctive species composition and, when taken together, provide a good overall representation of the species present in Scotland. The map, with values rescaled between 1 and 0, was obtained by using the 'Zonation' algorithm which ranks the cells in terms of their importance based on the 'global' (in this case at the scale of Scotland) loss of species suffered if a cell is removed.	As above	AG

*ABC =Andrea Baggio Compagnucci; AG = Alessandro Gimona; LP = Laura Poggio; MC = Marie Castellazzi; RB = Rob Brooker; RP = Robin Pakeman, ES = Enrico Simonetti

2.2.1 Provisioning Services

Provisioning services mainly comprise water, and food and fibres from the land. Functioning ecosystems are necessary to support the production of material goods that can be consumed directly, used for manufacturing other products or traded. The mapped indicators can be separated into two categories:

1. Water

Fresh water is used in homes and businesses, in agriculture and in power generation. The food and drink industry in Scotland crucially depends on water availability and quality, and the hydrological cycle sustains terrestrial and water ecosystems including rivers, lakes, and wetlands.

2. Food and fibres

One of the most long standing human activities, often connected to identity and culture, is the transformation of both lowland and upland ecosystems to provide food and fibres through farming. Food production creates wealth, and has impacts on health and the condition of landscapes and ecosystems. Livestock are a source of food and fibres. In Scotland cattle and hill and upland sheep farming plays an important role in the balance of multiple benefits derived from the land.

2.2.1.1 Water Supply

2.2.1.1.1 General description

Water Supply –runoff. See:

http://www.arcgis.com/apps/MapSeries/index.html?appid=a1c9afe0f8594c3da68654f8124632fa

The map, obtained using the InVEST 'water yield' model[2], ranks Scottish sub-catchments based on the total annual runoff form land. We estimated how each sub-catchment contributes annually to runoff production.

To produce this map, data were gathered from the literature, or generated our own spatial estimates, of average annual precipitation, how much water is lost (transpired) by different vegetation types, soil depth, soil water content available to plants, land use and land cover, and elevation. All original values (between 670 and 6400 m^3 per ha) were re-scaled between 0 and 1: the closer the values are to 1 the higher the runoff. Values close to 0 are at the lower end of the scale, but they don't mean that no run off occurs. Values close to 0 are at the lower end of the relative scale, but they don't mean that no run off occurs. There is a clear East-West gradient, reflecting topography and climate.

2.2.1.1.2 Recommended use

The main purpose of this dataset is to provide input data for analyses of water provision, shortages and needs.

[2] http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/reservoirhydropowerproduction.html

2.2.1.1.3 Principal limitations

The maps are based on average precipitation values taken over multiple years, and individual annual variability is not accounted for.

2.2.1.2 Suitability for Crop Production

2.2.1.2.1 General description

Suitability for crop production. See:

http://www.arcgis.com/apps/MapSeries/index.html?appid=a1c9afe0f8594c3da68654f8124632fa

This map depicts an indicator of suitability for crop production, which is correlated with crop yield for a range of crops but is not itself a quantification of yield of individual crops. The map was produced by integrating data from the Land Capability for Agriculture (LCA)[3] analysis and 12 years of weekly time series of MODIS satellite data that provide a measure of plant productivity. High LCA class labels indicate low potential for production (e.g. 7 is the lowest level of production). To produce this map, areas with land capability scores of 3.1 and below (i.e. with better potential for crop production) were classified as 'High' potential if they also had consistently high MODIS productivity over the 12 years (i.e. if their potential productivity was being realised); otherwise they were classified as 'Medium'.

Areas with land capability between 3.2 and 4.2 were classified as 'Medium' if they had high MODIS productivity otherwise they were classified as 'Low'. All areas with land capability poorer than 4.2 were classified as having 'extremely low' crop production potential. In this map, a wide range of crops expecting good yields can be cultivated commercially on high potential areas, while a more restricted range of crops can be cultivated commercially on areas of low potential.

2.2.1.2.2 Recommended use

As an indicator of suitability for crop production to be used in future analyses.

2.2.1.2.3 Principal limitations

The indicator relates to suitability only, and does not provide figures for actual yield.

2.2.1.3 Cattle Density

2.2.1.3.1 General description

Cattle density**.** See:

http://www.arcgis.com/apps/MapSeries/index.html?appid=a1c9afe0f8594c3da68654f8124632fa

The map is based on gridded Agricultural Census data, and can be used to provide a broad scale impression of the pattern of production. The Agricultural Census is conducted in June each year by the Scottish government. Each farmer declares the agricultural activity on the land via a postal questionnaire. One of the products derived from this census is a gridded data set produced by the Edinburgh University Data Library (EDINA)[4].

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[3] http://www.hutton.ac.uk/learning/exploringscotland/land-capability-agriculture-scotland

[4] http://agcensus.edina.ac.uk/

Values ranged between 0 and 4 per ha. The map shows values of cattle per ha rescaled between 0 (very low density) and 1 (highest density). Gridded Agricultural Census data for cattle from EDINA (2 km resolution) were downscaled by redistributing recording cattle numbers at 2 km resolution onto 25 m grid cells of the land cover map. The land cover map used was LCM 2007.

The greatest density of cattle is in Dumfries & Galloway, with high density also in Ayrshire, some areas of Grampian and of the Highlands. Grasslands used by cattle on farmland tend to occur where crop cultivation is limited by climate, slope, or wetness.

2.2.1.3.2 Recommended use

To provide a broad scale impression of the pattern of livestock production for cattle, to help identify areas at risk of suffering negative impacts from livestock concentrations.

2.2.1.3.3 Principal limitations

The main problem relates to the low spatial resolution of the original data, which were aggregated to 2 km resolution for data protection purposes.

2.2.1.4 Sheep Density

2.2.1.4.1 General description

Sheep density. See:

http://www.arcgis.com/apps/MapSeries/index.html?appid=a1c9afe0f8594c3da68654f8124632fa

There are ca 6.8 million sheep in Scotland with Scottish annual meat production around 61,000 tons.

Values ranged between 0 and 220 sheep per squared km (2.2/ha). The map shows values of sheep per ha, rescaled between 0 (very low density) and 1 (highest density). As for cattle, data from Gridded Agricultural Census data from EDINA (2 km resolution) were down-scaled by redistributing sheep on grasslands derived from LCM 2007 and on moorland habitat that supports their grazing.

The highest sheep density is in the Scottish Borders, Dumfries and Galloway, Aberdeenshire, and some areas of the Highlands.

2.2.1.4.2 Recommended use

To provide a broad scale impression of the pattern of livestock production for sheep, to help identify areas at risk of suffering negative impacts from livestock concentrations.

2.2.1.4.3 Principal limitations

As for cattle density, above (Section 2.2.1.3.3).

2.2.2 Regulating Services

Regulating Services refers to the beneficial regulatory functions carried out by ecosystems. Functioning ecosystems undertake processes that are beneficial for society; for example, regulation of water and soil quality through natural purification, pollination, climate regulation, disease and pest regulation. These benefits are generated through the interactions among living and non living elements of the ecosystems: for example water purification derives from soil organisms' activity and from the mechanical ability of soil and vegetation to trap and transform nutrients, pollutants and/or and pathogens.

2.2.2.1 Water purification - nutrients

2.2.2.1.1 General description

Water purification **-** Nitrogen Retention***.*** See:

http://www.arcgis.com/apps/MapSeries/index.html?appid=a1c9afe0f8594c3da68654f8124632fa

The map, obtained using the InVEST nitrogen retention model[5] , ranks Scottish catchments based on the total amount of nitrogen that runs off from the land but is retained before reaching the streams. The model uses the amount of nitrogen loaded on each land use type, calculates the annual average water runoff, and then it computes the quantity of nitrogen retained by each pixel based on the land use efficiency (expressed as the percentage of load that will be retained) and on how the water is routed through the landscape. By the routing process the model calculates how much of the nitrogen loaded on land reaches stream and how much is retained. It then aggregates the values to the sub-watershed level. As in the case of Water Supply, the values in the map were re-scaled between 0 and 1 and the same interpretation applies, with 0 being interpreted as a value indicating lowest relative nitrogen retention.

The map shows more nitrogen was added to agricultural areas, compared to non-agricultural areas, leading to greater levels retained and exported.

2.2.2.1.2 Recommended use

This indicator is principally useful for understanding the retention of nutrients at the sub-catchment scale.

2.2.2.1.3 Principal limitations

Interaction with groundwater level, transformation during the routing made by soil, bacteria or the interaction of the water with biophysical processes were not considered.

Nutrient loads were based on tables published by DEFRA, not measured in the field. Clearly, future work should consider obtaining more accurate estimates using field measurements. Since the data were aggregated to sub-catchments the provide no information on individual variation within the sub-catchment itself.

2.2.2.2 Soil retention

2.2.2.2.1 General description

Soil Retention***.*** See:

http://www.arcgis.com/apps/MapSeries/index.html?appid=a1c9afe0f8594c3da68654f8124632fa

Soil is associated with a wide range of essential functions, such as plant and crop growth, regulating the amount of water flowing into rivers, storing carbon. Vegetation provides a vital service by retaining soil. This benefits both terrestrial and aquatic systems. The map, obtained using the InVEST soil and sediment retention model[6], ranks Scottish catchments based on the total amount of soil

[5] http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/ndr.html
[6] http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/sdr.html

that is retained before reaching the streams, including soil that might be initially transported but is deposited later.

The retention service provided by vegetation cover is higher where topography and climate pose more risk of erosion. Before estimating retention, the model uses the Universal Soil Loss Equation (USLE), which integrates information on vegetation cover, soil properties, topography, rainfall and climate data to estimate soil erosion from a grid cell.

2.2.2.2.2 Recommended use
To highlight differences in soil retention provision across Scotland and areas at greatest risk of erosion, allowing potential mitigation option to be considered (e.g. tree planting).

2.2.2.2.3 Principal limitations
The soil retention service mapping is not very reliable for peat soils. Slope is the main factor which influences the soil formation and the quantity of material available to be moved from original areas and transported downstream.

2.2.2.3 Soil Organic Carbon Stocks

2.2.2.3.1 General description
Soil Organic Carbon Stocks**.** See:

http://www.arcgis.com/apps/MapSeries/index.html?appid=a1c9afe0f8594c3da68654f8124632fa

Soil is an important carbon sink, and globally soil stores two to three times more carbon than the atmosphere. In Scotland, there is often two to four times more carbon in the soil than in the vegetation. By sequestering carbon that would otherwise contribute to greenhouse gases, soil organic carbon contributes to mitigation of climate change. The map, at 1 km resolution, is based on estimates of soil organic carbon stocks to up to 1 m depth. The estimates were obtained by relating field data contained in the National Soil Inventory of Scotland (NSIS)[7] data base, to a range of environmental variables using Digital Soil Mapping methods (Poggio and Gimona 2014). For example, topography and satellite data were used to produce the estimates for un-sampled locations. The values, ranging between 60 and 1500 tons per ha, are re-scaled between 1 (highest) and 0 (lowest). The highest values occur on peatlands in the Highlands and the Hebrides. The total carbon stocks estimated for Scottish soils were around 3000 Mt.

2.2.2.3.2 Recommended use
This indicator offers a useful approximation of the total carbon sequestration capability of Scotland's soils.

2.2.2.3.3 Principal limitations
Stocks were only measured down to a depth of 1 m. Peatland soils in many areas are much deeper, so the 3000 Mt figure is certainly too low.

[7] http://www.hutton.ac.uk/about/facilities/national-soils-archive/resampling-soils-inventory

2.2.2.4 Pollination

2.2.2.4.1 General description

Pollination**.** See:

http://www.arcgis.com/apps/MapSeries/index.html?appid=a1c9afe0f8594c3da68654f8124632fa

Healthy populations of pollinators are important for food security and for the reproduction of numerous species of wild plants. Some pollinators, especially bees, are declining, either because they lack specific resources, such as flowers and nesting habitat, and/or because multiple risk factors, including pesticides and climate change, are reducing their numbers. The map shows an index of pollination service rescaled between 1 (highest) and 0 (lowest). The index is based on 6 species of bumble bee, namely *Bombus lapidarius, B. lucorum, B. muscorum, B. pascuorum, B. pratorum, and B. terrestris.* For each species the model had 4 main components: a floral resources component (276 species), a nesting habitat component, a spatial component (to account for flight distance) and a time component (to account for flowering of floral resources and queen emergence). Flowering times of the species considered were obtained from several data bases, namely Biolflor[8], EcoFlora[9], and LEDA[10]. The species geographical distributions were taken from the Atlas of the British and Irish Flora[11] and downscaled to 100 m (see the species richness section for more details). Each bumble bee species contributes to the service to flowering crops if these are within the species' maximum flight distance. The latter were mapped using agricultural census data from 2015. The service is defined only in proximity of flowering crops. The latter were mapped using agricultural census data. High levels are predicted in areas like the Spey valley and in the upland-lowland transition, where flowering and nesting resources are more available, while many lowland areas, more intensely farmed, have relatively low levels of pollination service. While bumble bees are good indicator species, more pollinators could be used in the future to have a more complete picture of the service.

2.2.2.4.2 Recommended use

Provides an estimate of the degree of pollination service potentially available to agricultural areas, and a measure of the extent to which this service may be negatively impacted by farming or other land use practices.

2.2.2.4.3 Principal limitations

The main limitation of this indicator is that it does not account for other pollinators, such as butterflies and hoverflies. The value of this indicator would be increased by repeated sampling at frequent intervals, enabling a picture of pollination service change over time to be obtained.

2.2.3 Cultural Services

The precise definition of cultural ecosystem services (CES) is still being debated, and therefore it is challenging to decide what aspects of CES to map. The Millennium Ecosystem Assessment defined cultural ecosystem services as "the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences",

[8] http://www.ufz.de/index.php?en=38567
[9] http://ecoflora.org.uk/
[10] https://uol.de/en/biology/landeco/research/projects/leda/
[11] https://www.brc.ac.uk/plantatlas/

while the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) points out that a sense of cultural identity is needed for good quality of life. It is broadly agreed that CES are intangible, and linked to identity, meaning and experience, and this makes them both difficult and important to assess. Mapping all CES is not always possible or necessary. However, we have tried to map some indicators of recreation and amenity, and we have placed biodiversity among cultural services, emphasising its importance for human cultural fulfilment. This does not deny the important, but poorly understood, role of biodiversity in ecosystem functioning.

2.2.3.1 Recreation and Amenity

2.2.3.1.1 General description
Volunteered Photographs. See:

http://www.arcgis.com/apps/MapSeries/index.html?appid=a1c9afe0f8594c3da68654f8124632fa

Photo-sharing services, such as Panoramio[12] and Flickr[13] provide geo-referenced crowd-sourced photographs. A partial indicator of recreation service provision was obtained by mapping the number of unique submitters from several thousand contributors to Panoramio in each 1 km square. Values (between 0 and 560 per per Km^2) are rescaled between 1 and 0 as in the other maps. The white areas did not have any uploaded photos. The map shows the highest density along the Great Glen, the Spey valley, on the mountains of the Cairngorms National Park, and in some urban areas. While the submitters are self-selected, introducing potential bias, the high number of unique users (several thousand) is an advantage over rigorous surveys, with number of participants one or two orders of magnitude higher than the typical survey. Understanding the spatio-temporal patterns of photo contributions will allow us better to assess the suitability of these data for mapping recreation and amenity.

2.2.3.1.2 Recommended use
These photos can provide valuable information such as identifying travel routes and tourist hot spots. It can be argued that they provide a synthetic indicator for intermediate cultural services such as Amenity, Aesthetics and Cultural Importance.

2.2.3.1.3 Principal limitations
The crowd-sourced geo-referenced photographs are a self-selected sample from individuals who choose to submit photographs. It does not account for the preferences of other users who have visited these or other locations but not submitted a photograph. Factors like accessibility of the photographed locations are also influential but have not been controlled for. Work to address these limitations is ongoing (Baggio Compagnucci et al 2018).

2.2.3.2 Plant Species Richness

2.2.3.2.1 General description
Plant Species Richness: See

http://www.arcgis.com/apps/MapSeries/index.html?appid=a1c9afe0f8594c3da68654f8124632fa

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[12] https://www.panoramio.com/
[13] https://www.flickr.com/

This is an indicator of biodiversity, which, as explained above, in this context is related to cultural and spiritual fulfilment. Although biodiversity in general is believed to have an important role in ecosystem processes, we have not been able, so far, to investigate this aspect at the scale of Scotland. The plant species richness map was obtained by down-scaling the distribution of all native flowering species (from the Atlas of the British and Irish Flora) to 1 km. For each 10 km square of the Atlas where a species was reported present, the down-scaling was carried out as follows: we attributed presence of the species to the broad habitats of the 25-m land cover map (LCM2007) in which it can live. Results were aggregated to 1 km. For each 1 km square the number of present species was counted. The values were then rescaled between 1 (highest richness) and 0 (lowest). On the map, a lowland-upland and a North-South gradient can be observed. The richest areas are in uplands of Dumfries and Galloway, Lothians, Perthshire, and in the Spey valley. Montane areas and bogs tend to be less diverse (but often have a distinctive flora) because fewer species can tolerate conditions there. It should be noticed that plant species richness is not necessarily correlated with the richness of other taxa. Therefore, further work is needed to produce an indicator of overall species richness.

2.2.3.2.2 Recommended use
Serves as a partial indicator of biodiversity across different areas of Scotland.

2.2.3.2.3 Principal limitations
The use of species richness as a biodiversity indicator has a number of well-known limitations, including differential sampling effort and variability in species abundance (Gotelli and Colwell 2001). Aside from these general limitations, plant species richness is poorly understood at the macro scale. At the same time, lack of information on other species (e.g. for birds), due to the high cost of obtaining the data, acts a major barrier to obtaining an overall indicator.

2.2.3.3 Floral Distinctiveness

2.2.3.3.1 General description
Floral Distinctiveness: See:

http://www.arcgis.com/apps/MapSeries/index.html?appid=a1c9afe0f8594c3da68654f8124632fa

This is another indicator of biodiversity, and therefore related to cultural and spiritual fulfilment. Local species richness is not a sufficient criterion to highlight areas that are important for the provision of plant diversity. It is also important to identify areas that have a distinctive species composition and, when taken together, provide a good overall representation of the species present in Scotland. The map, with values rescaled between 1 and 0, was obtained by using the Zonation algorithm (Moilanen 2007) which ranks the cells in terms of their importance based on the 'global' (in this case at the scale of Scotland) loss of species suffered if a cell is removed.

The more distinctive the contribution, the higher the importance of a map square. If a species were present in only a small area, that area would be deemed irreplaceable. The footprint of 10 km squares of the floral Atlas is still clearly visible; therefore, borders between areas of different value are sharper than in reality. Notice that the areas of high distinctiveness have to be conserved together because they have complementary species composition. Therefore, while map squares with high distinctiveness might not have a particularly high local diversity, they provide a distinctive contribution to the overall set of plant species present in Scotland.

2.2.3.3.2 Recommended use

Serves as a partial indicator of biodiversity across different areas of Scotland.

2.2.3.3.3 Principal limitations

The main limitations of this indicator relate to the use of plant species only. Further future work could include further indicators that encompass more species of vertebrates and invertebrates, and provide a more complete picture.

3. Discussion and Recommendations

The above overview has provided a concise summary of the integrated spatial datasets recently developed under RESAS WP 1.4.2 and 1.4.3 on land use and ecosystem services for the whole of Scotland, we have presented these for the two National Parks and for the Aberdeenshire River Dee. These spatial datasets have potential to support evidence-driven policy making around adaptive and integrated land management in these areas. These data form a useful basis for analysis aimed to mitigating negative land use and ecosystems service impacts, and providing support to land managers and other policy stakeholders. However, the datasets described do have some limitations, which we summarize below. It should be noted that all datasets have errors, and detailed description of the limitations provided in this report should not be taken as an indicator of poor quality relative to other sources. Rather, good practice requires that limitations should be properly described and documented.

3.1 Integrated spatial land use datasets

The integrated land use datasets suffer from a range of limitations inherent in the use of mixed data from multiple sources or data not originally intended for that purpose. The IACS data are not ideally suited for use as a land use time series, since land parcels record only the use claimed under the agricultural payments system, with the result that cessation of claims results in the disappearance of a land use from one date to the next in a way that does not reflect reality. In addition, they provide a poor record of land use outside of the most important agricultural areas due to the lesser importance of these areas in the payments system. Integration of these datasets with the Land Cover Map for 2007 is also fraught with difficulties, since broadly equivalent thematic categories in each of the datasets do not coincide spatially, meaning that combining the two datasets introduces errors from each and multiplies the level of uncertainty. Additionally, some of the data used (e.g. LCM 2007) are outdated. Clearly, integration with a more recent land cover map (LCM 2015) would be more desirable, yet this is at present unavailable to the James Hutton Institute due to its high cost.

3.2 Ecosystems Services maps

Limitations of the individual ecosystems services maps have been described above and will not be repeated here. Overall, the main limitations of the ecosystems services dataset as a whole relate to its reliance on published, rather than directly measured data, together with insufficient resources available for acquisition of proprietary, third party data, e.g. on forest biomass, BTO Bird Atlas data, Land Cover Map etc. Additionally, several indicators relate to environmental variables undergoing constant change, e.g. pollination, biodiversity; these would be more useful as part of an ongoing monitoring programme rather than as a standalone collection of maps.

3.3 Suggestions for future work to address these limitations

A number of recommendations can be made relating to the future development of these kinds of integrated datasets and acquisition of the base datasets that facilitate such development. In particular:

1. We recommend the development of a land use and land cover time series for Scotland (updated at least at decadal intervals) using a single methodology and thematic classification. Though such a task is well within the technical capabilities of the JHI, it requires a long-term funding commitment. The difficulty of securing this commitment in the past has meant that LCS88, developed by the then Macaulay Land Research Institute, has remained as a single time snapshot, severely compromising its usefulness for change monitoring.

2. In terms of ecosystems services and natural capital mapping generally, aspirations for understanding the evolution of Scotland's natural capital and services flowing from it need to be matched by appropriate data collection campaigns. Effective monitoring of Scotland's land-based natural capital would require a considerable sampling effort over many years, similar to that carried out by environment agencies on the water environment. Although it is expensive, this cannot be avoided if estimates of change are needed with a degree of uncertainty low enough to be useful for policy. In the short term, significant improvements can be made with relatively minor investment, e.g. collecting data on livestock nutrient production and spreading (on land) from Scottish catchments, instead of relying on published data from DEFRA.

4. Next steps

The datasets developed provide a springboard for a series of land-based analyses beginning in November 2018. These include (but are not limited to) the following (where these relate to specific aspects of the delivery framework, the WP number is given):

1. Analysis of land use and land cover change in case study areas (WP 1.4.3)
2. Analysis of land cover change in relation to land capability (WP 1.4.2)
3. Modelling land use change scenarios for agriculture and forestry in Scotland under Representative Concentration Pathways (RCPs) storylines (WP 1.4.2)
4. Investigation of trade-offs in natural Protected areas (e.g. Cairngorms National Park)
5. Identification of ecological connectivity for broadleaved and coniferous woodland
6. Work to improve the quality of cultural ecosystems services, e.g. integration of Flickr with other user-created photographic datasets, and improved methods for determining landscape attractiveness.

Acknowledgements

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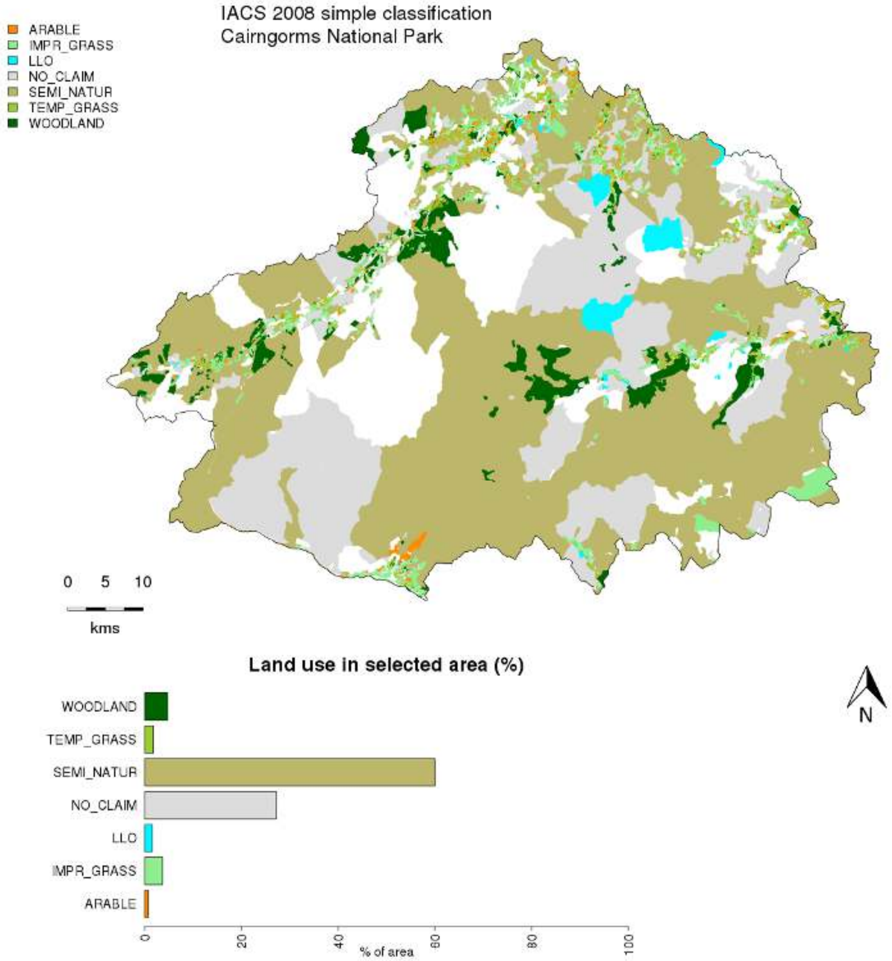
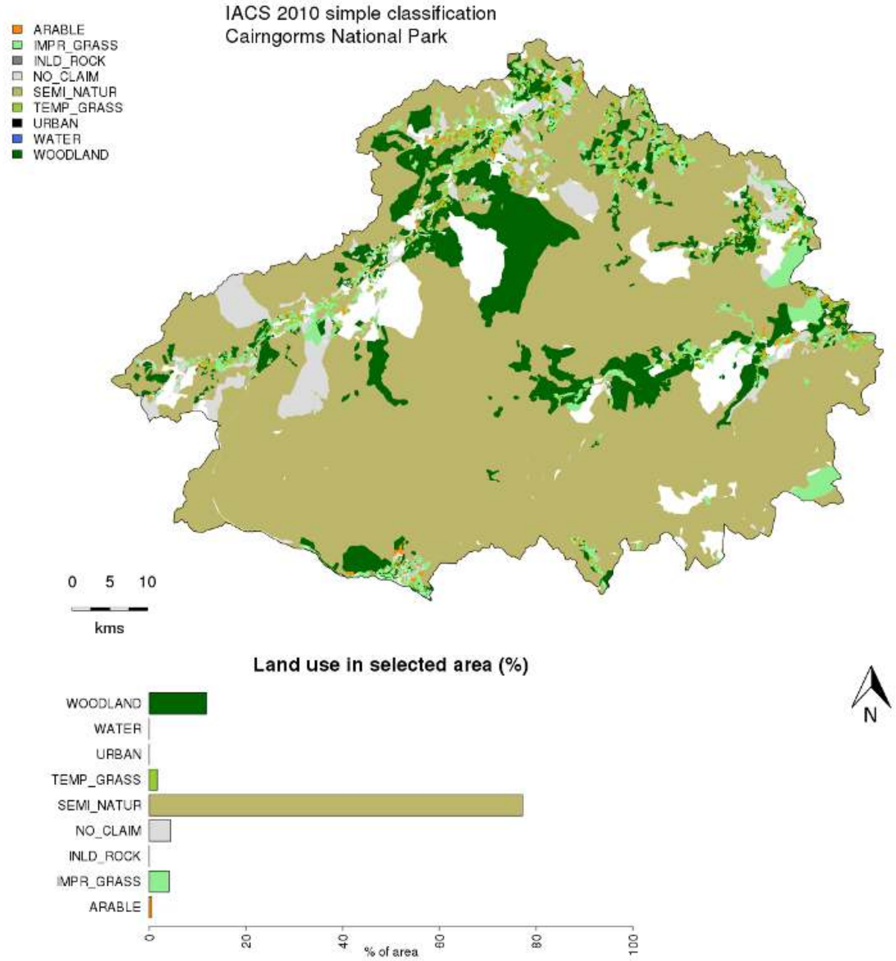
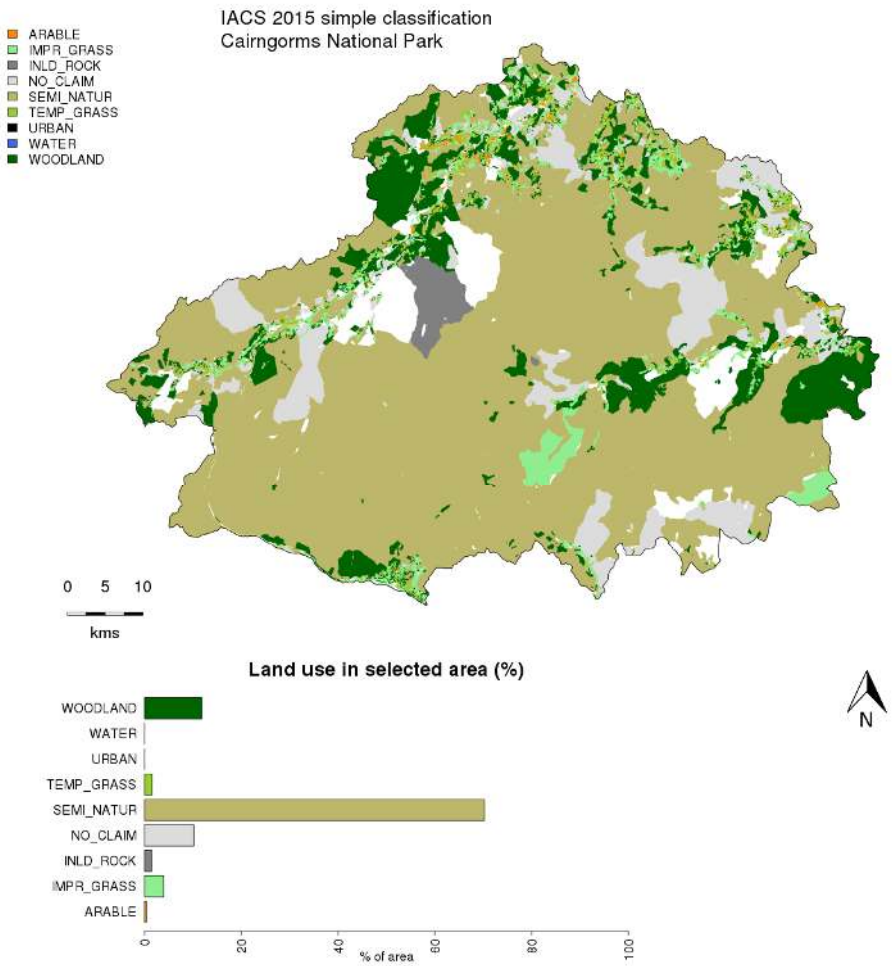
Appendices

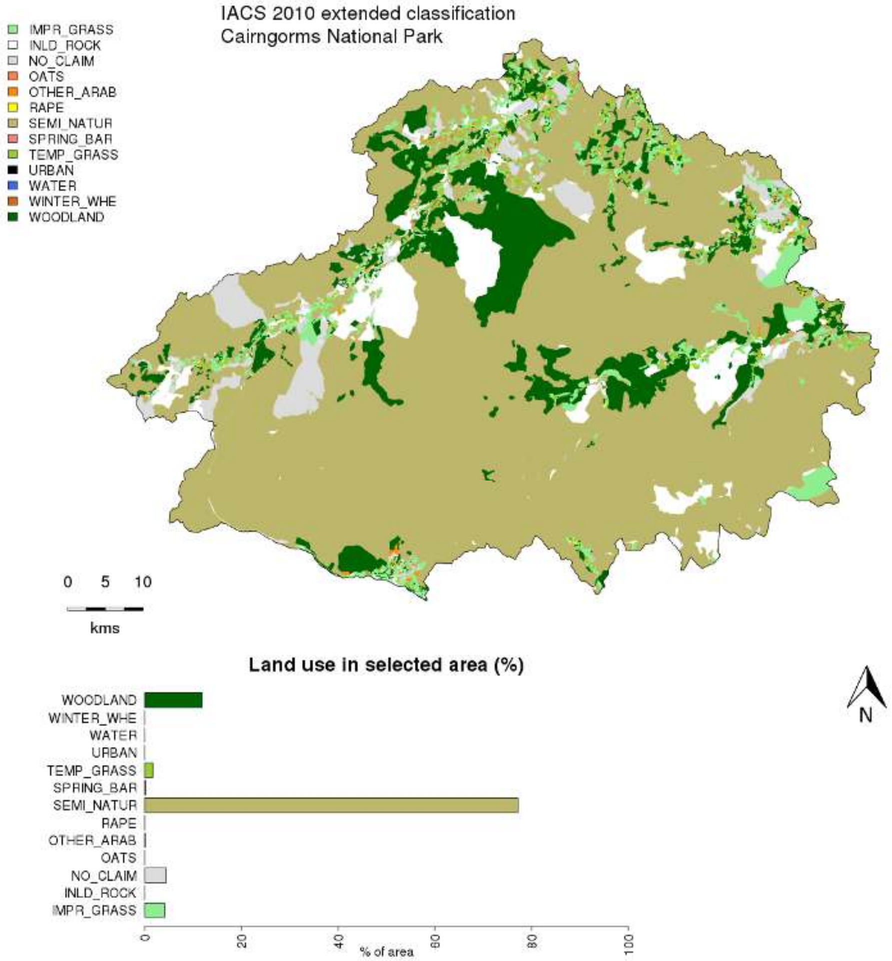
Appendix 1: Maps of integrated land use datasets

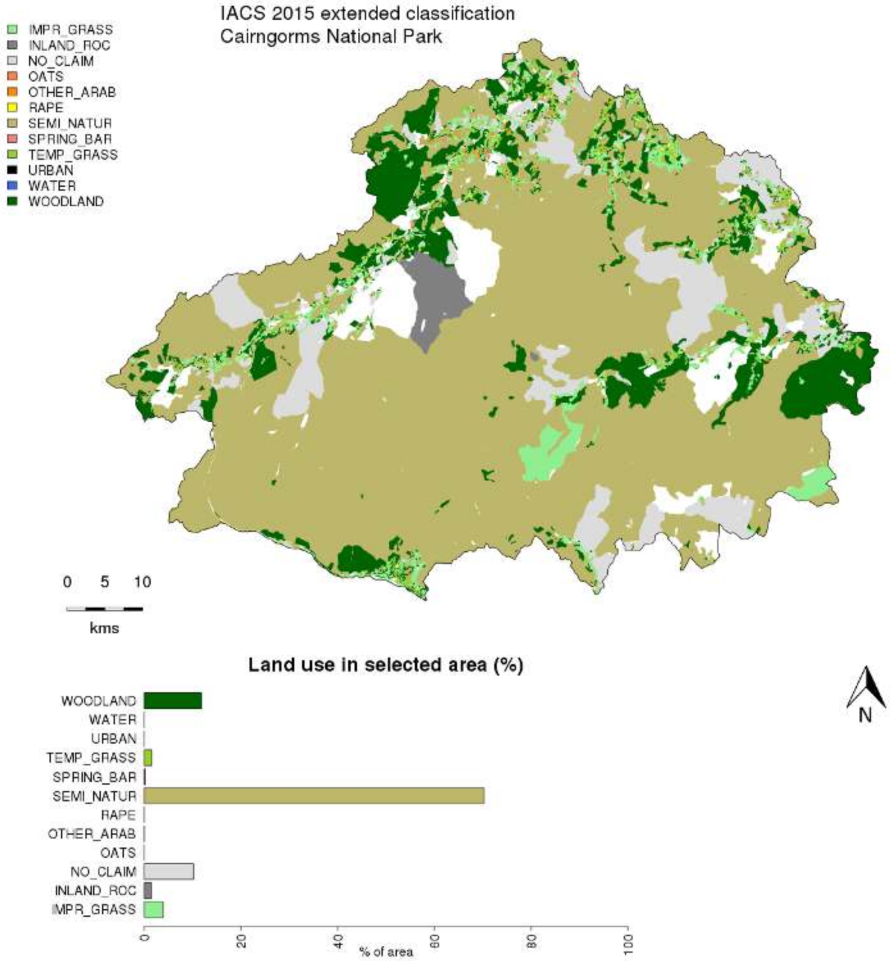

IACS 2008 simple classification
Cairngorms National Park
ARABLE
IMPR_GRASS
LLO
NO_CLAIM
SEMI_NATUR
TEMP_GRASS
WOODLAND
0 5 10
kms
Land use in selected area (%)
WOODLAND
TEMP_GRASS
SEMI_NATUR
NO_CLAIM
LLO
IMPR_GRASS
ARABLE
0
20
40
60
80
100
% of area
N

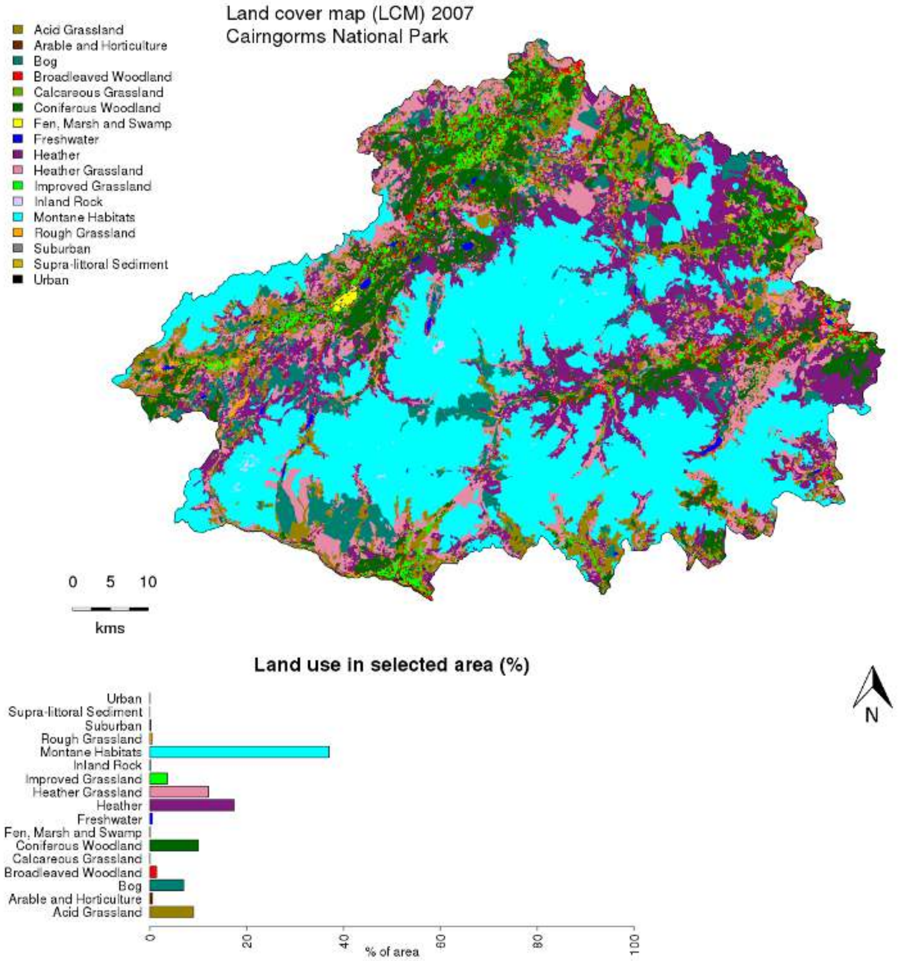

IACS 2010 simple classification
Cairngorms National Park
ARABLE
IMPR_GRASS
INLD_ROCK
NO_CLAIM
SEMI_NATUR
TEMP_GRASS
URBAN
WATER
WOODLAND
0 5 10
kms
Land use in selected area (%)
WOODLAND
WATER
URBAN
TEMP_GRASS
SEMI_NATUR
NO_CLAIM
INLD_ROCK
IMPR_GRASS
ARABLE
0
20
40
60
80
100
% of area
N



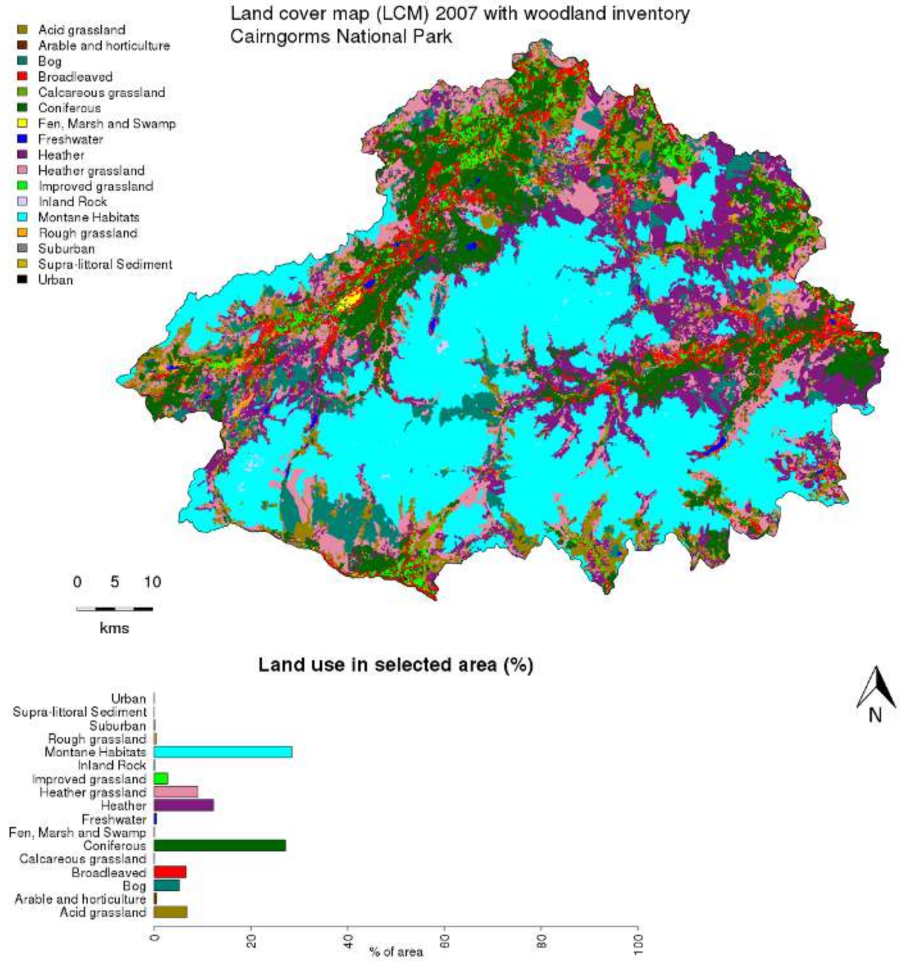
IACS 2015 simple classification
Cairngorms National Park
ARABLE
IMPR_GRASS
INLD_ROCK
NO_CLAIM
SEMI_NATUR
TEMP_GRASS
URBAN
WATER
WOODLAND
0 5 10
kms
N
Land use in selected area (%)
WOODLAND
WATER
URBAN
TEMP_GRASS
SEMI_NATUR
NO_CLAIM
INLD_ROCK
IMPR_GRASS
ARABLE
0
20
40
60
80
100
% of area


IACS 2010 extended classification
Cairngorms National Park
IMPR_GRASS
INLD_ROCK
NO_CLAIM
OATS
OTHER_ARAB
RAPE
SEMI_NATUR
SPRING_BAR
TEMP_GRASS
URBAN
WATER
WINTER_WHE
WOODLAND
0 5 10
kms
Land use in selected area (%)
WOODLAND
WINTER_WHE
WATER
URBAN
TEMP_GRASS
SPRING_BAR
SEMI_NATUR
RAPE
OTHER_ARAB
OATS
NO_CLAIM
INLD_ROCK
IMPR_GRASS
0
20
40
60
80
100
% of area
N

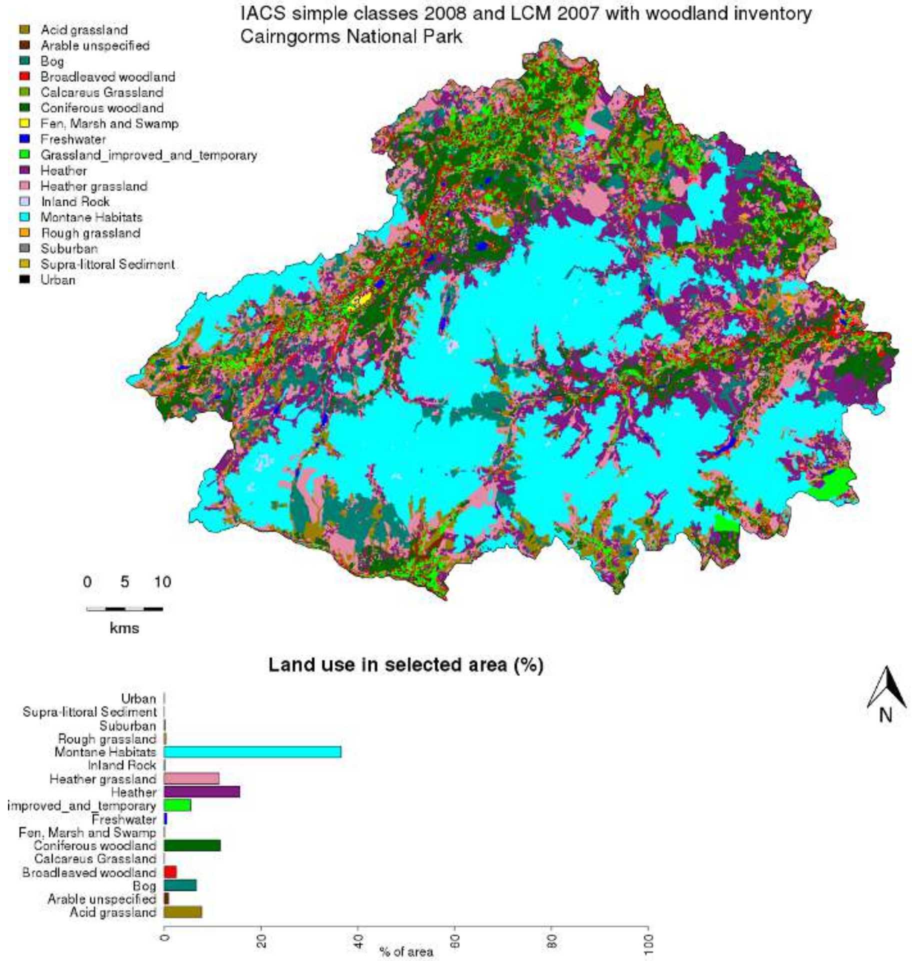

IACS 2015 extended classification
Cairngorms National Park
IMPR_GRASS
INLAND_ROC
NO_CLAIM
OATS
OTHER_ARAB
RAPE
SEMI_NATUR
SPRING_BAR
TEMP_GRASS
URBAN
WATER
WOODLAND
0 5 10
kms
Land use in selected area (%)
WOODLAND
WATER
URBAN
TEMP_GRASS
SPRING_BAR
SEMI_NATUR
RAPE
OTHER_ARAB
OATS
NO_CLAIM
INLAND_ROC
IMPR_GRASS
0
20
40
60
80
100
% of area
N

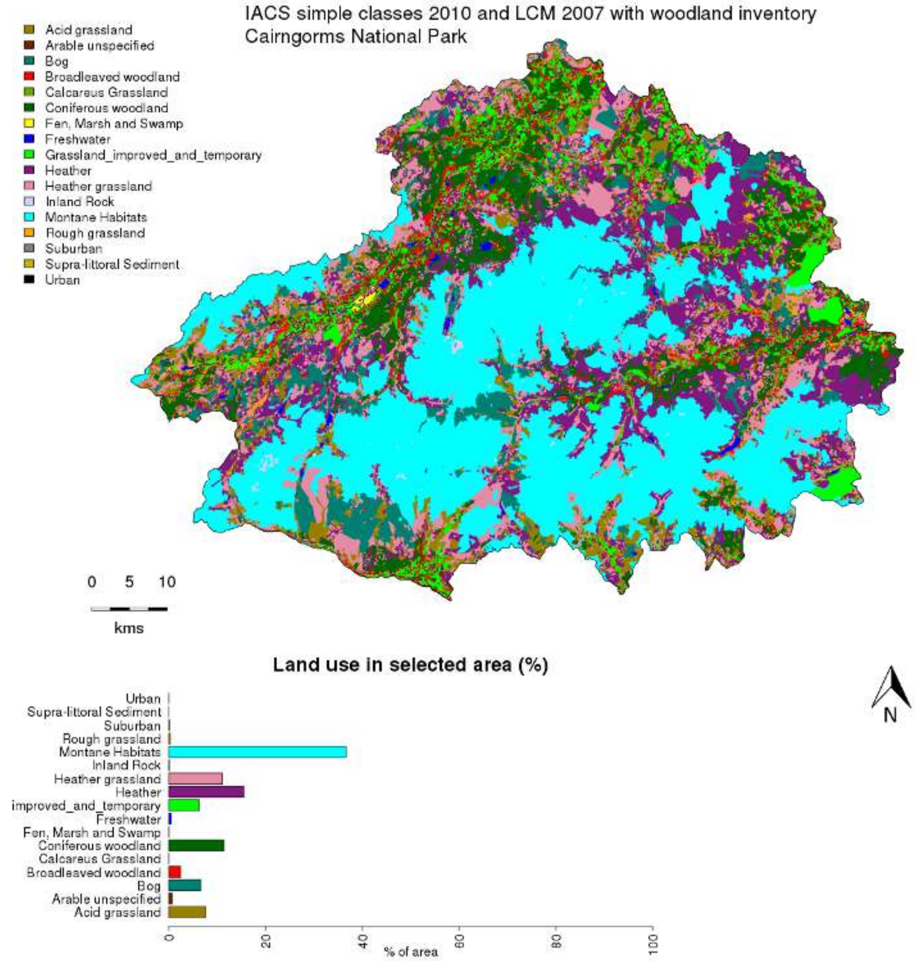


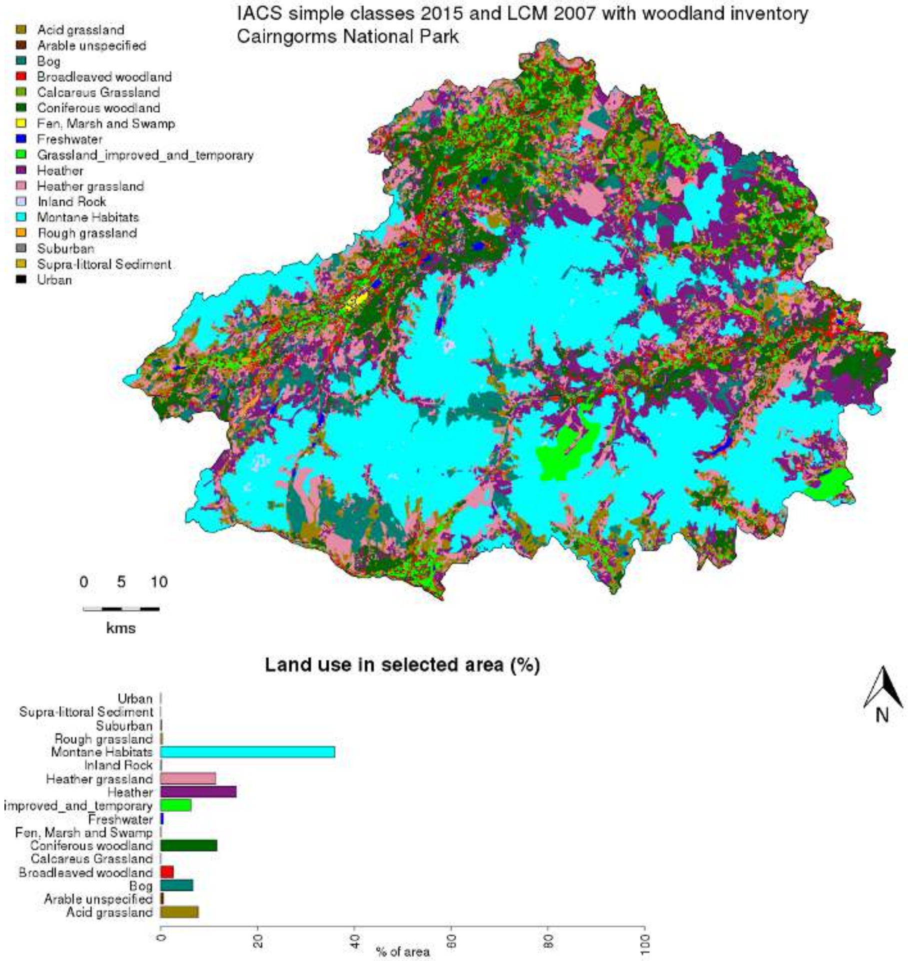
Land cover map (LCM) 2007
Cairngorms National Park
Acid Grassland
Arable and Horticulture
Bog
Broadleaved Woodland
Calcareous Grassland
Coniferous Woodland
Fen, Marsh and Swamp
Freshwater
Heather
Heather Grassland
Improved Grassland
Inland Rock
Montane Habitats
Rough Grassland
Suburban
Supra-littoral Sediment
Urban
0 5 10
kms
N
Land use in selected area (%)
Urban
Supra-littoral Sediment
Suburban
Rough Grassland
Montane Habitats
Inland Rock
Improved Grassland
Heather Grassland
Heather
Freshwater
Fen, Marsh and Swamp
Coniferous Woodland
Calcareous Grassland
Broadleaved Woodland
Bog
Arable and Horticulture
Acid Grassland
0
20
40
60
80
100
% of area

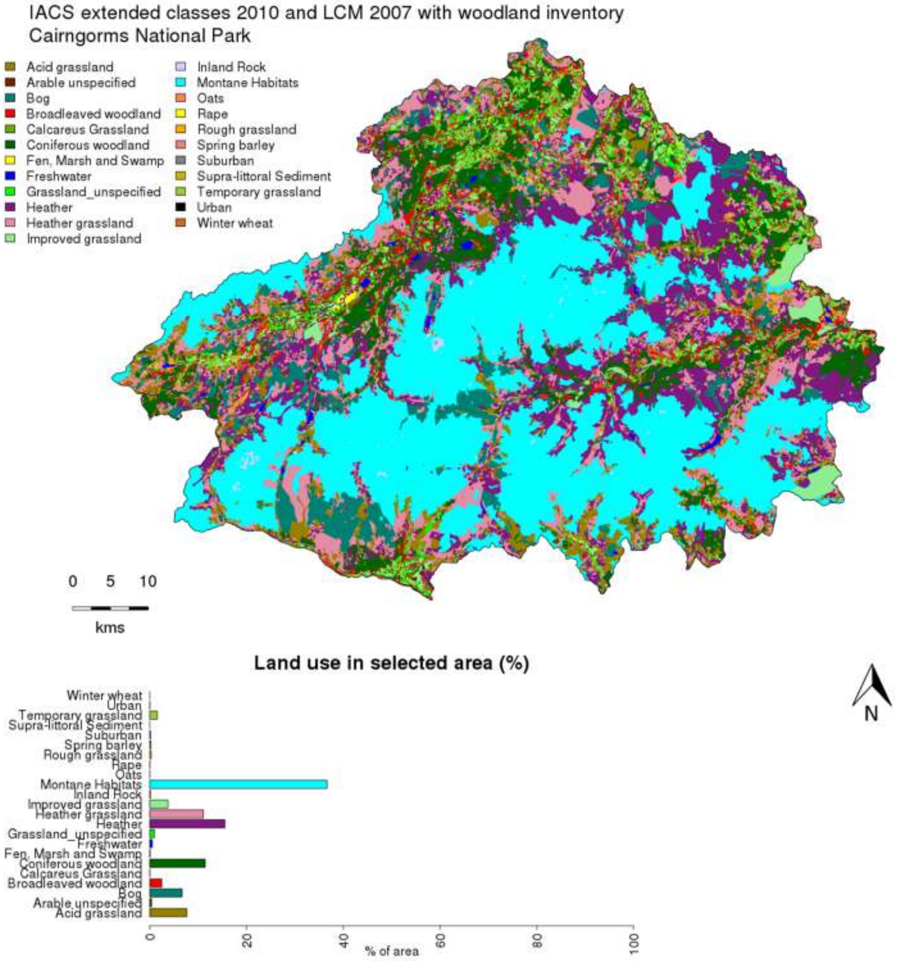


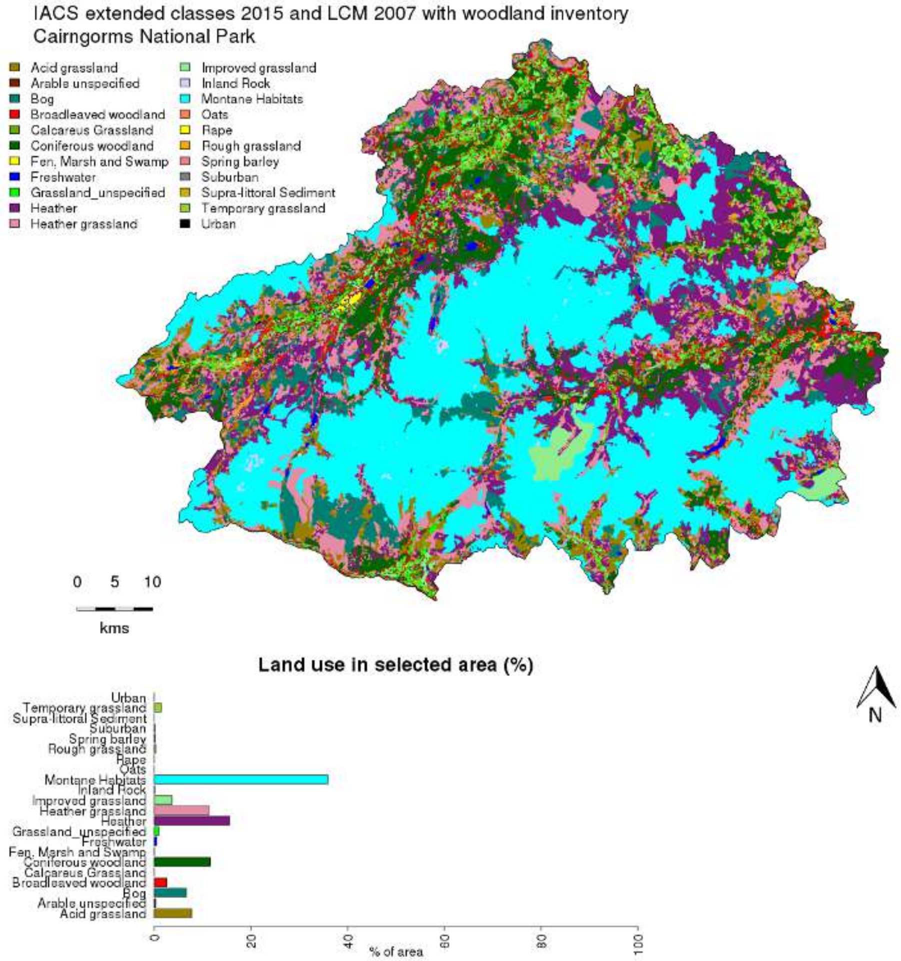
Land cover map (LCM) 2007 with woodland inventory
Cairngorms National Park
Acid grassland
Arable and horticulture
Bog
Broadleaved
Calcareous grassland
Coniferous
Fen, Marsh and Swamp
Freshwater
Heather
Heather grassland
Improved grassland
Inland Rock
Montane Habitats
Rough grassland
Suburban
Supra-littoral Sediment
Urban
0 5 10
kms
N
Land use in selected area (%)
Urban
Supra-littoral Sediment
Suburban
Rough grassland
Montane Habitats
Inland Rock
Improved grassland
Heather grassland
Heather
Freshwater
Fen, Marsh and Swamp
Coniferous
Calcareous grassland
Broadleaved
Bog
Arable and horticulture
Acid grassland
0
20
40
60
80
100
% of area

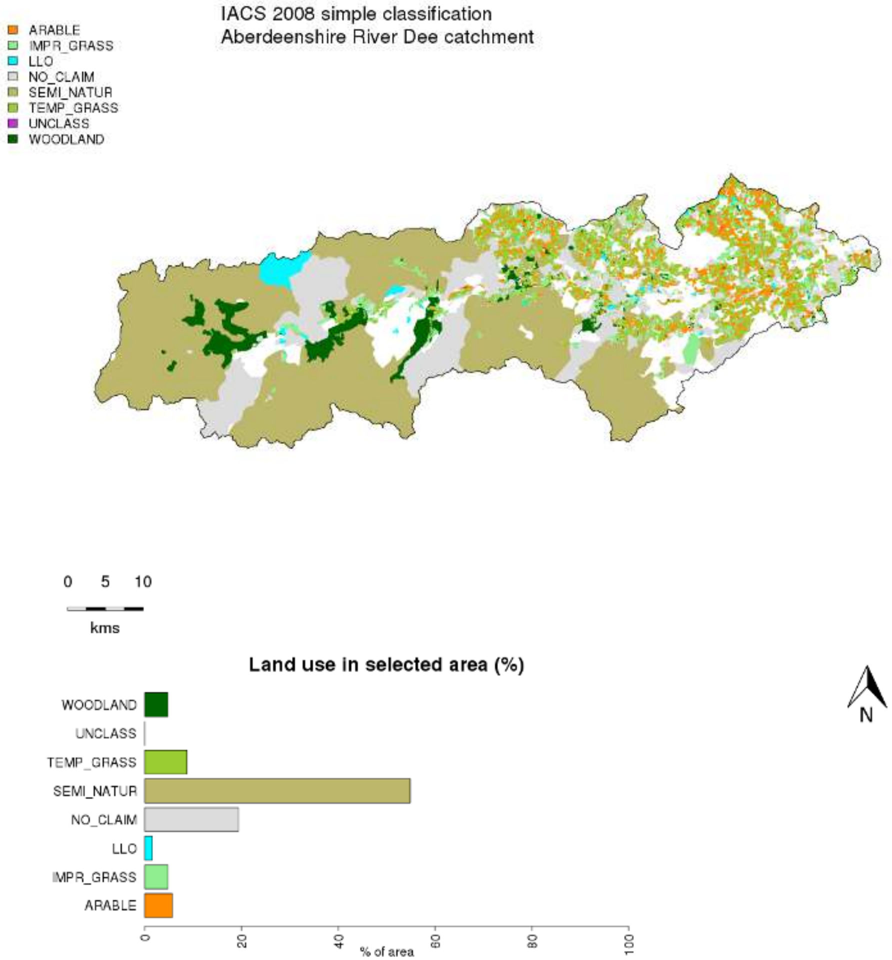

IACS simple classes 2008 and LCM 2007 with woodland inventory
Cairngorms National Park
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Calcareus Grassland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_improved_and_temporary
Heather
Heather grassland
Inland Rock
Montane Habitats
Rough grassland
Suburban
Supra-littoral Sediment
Urban
0 5 10
kms
N
Land use in selected area (%)
Urban
Supra-littoral Sediment
Suburban
Rough grassland
Montane Habitats
Inland Rock
Heather grassland
Heather
improved_and_temporary
Freshwater
Fen, Marsh and Swamp
Coniferous woodland
Calcareus Grassland
Broadleaved woodland
Bog
Arable unspecified
Acid grassland
0
20
40
60
80
100
% of area

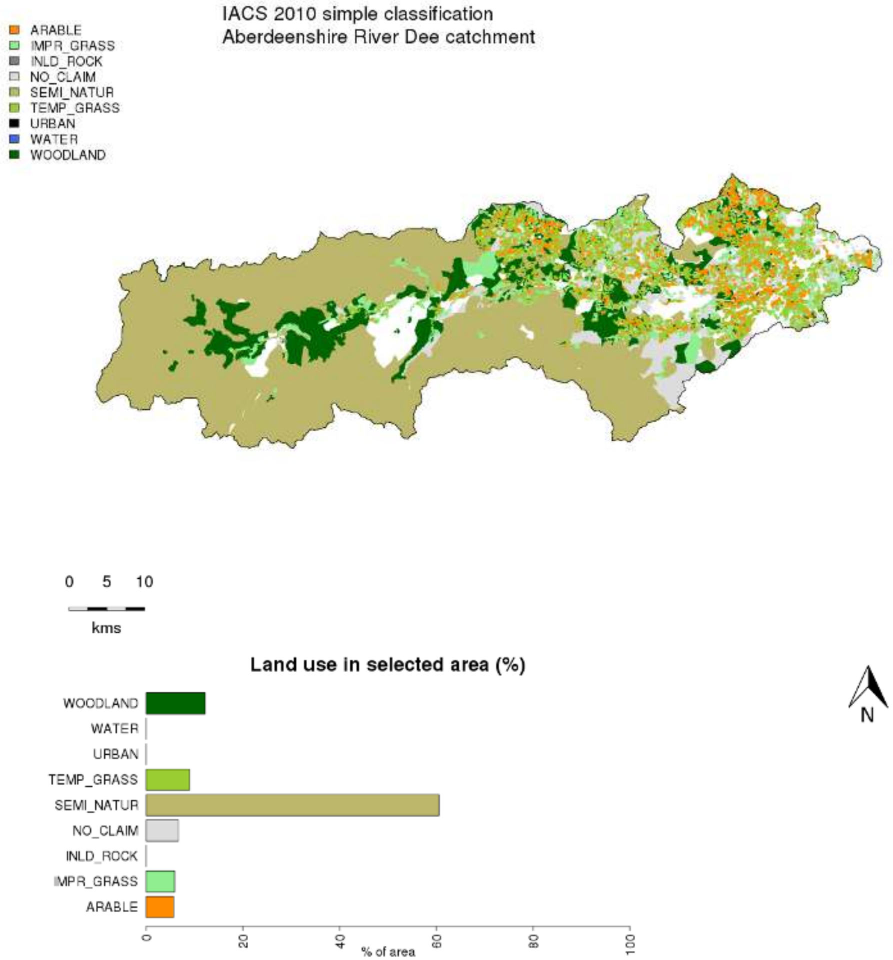

IACS simple classes 2010 and LCM 2007 with woodland inventory
Cairngorms National Park
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Calcareus Grassland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_improved_and_temporary
Heather
Heather grassland
Inland Rock
Montane Habitats
Rough grassland
Suburban
Supra-littoral Sediment
Urban
0 5 10
kms
N
Land use in selected area (%)
Urban
Supra-littoral Sediment
Suburban
Rough grassland
Montane Habitats
Inland Rock
Heather grassland
Heather
improved_and_temporary
Freshwater
Fen, Marsh and Swamp
Coniferous woodland
Calcareus Grassland
Broadleaved woodland
Bog
Arable unspecified
Acid grassland
0
20
40
60
80
100
% of area

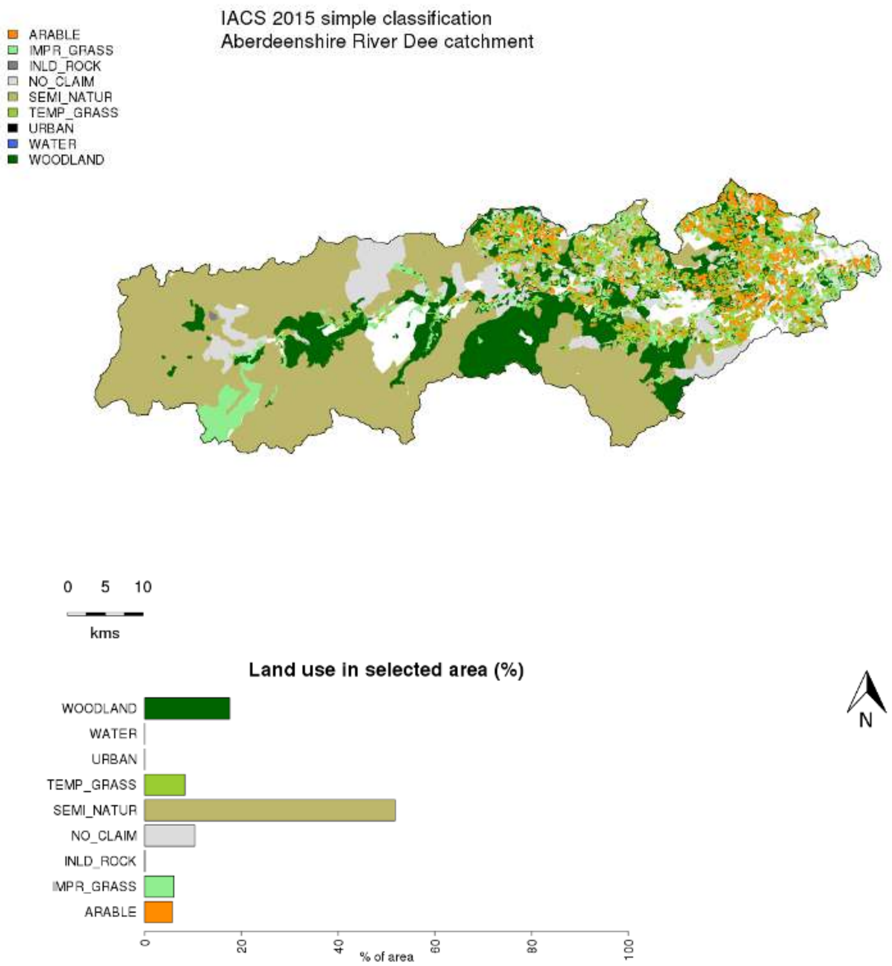

IACS simple classes 2015 and LCM 2007 with woodland inventory
Cairngorms National Park
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Calcareus Grassland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_improved_and_temporary
Heather
Heather grassland
Inland Rock
Montane Habitats
Rough grassland
Suburban
Supra-littoral Sediment
Urban
0 5 10
kms
Land use in selected area (%)
Urban
Supra-littoral Sediment
Suburban
Rough grassland
Montane Habitats
Inland Rock
Heather grassland
Heather
improved_and_temporary
Freshwater
Fen, Marsh and Swamp
Coniferous woodland
Calcareus Grassland
Broadleaved woodland
Bog
Arable unspecified
Acid grassland
0
20
40
60
80
100
% of area
N

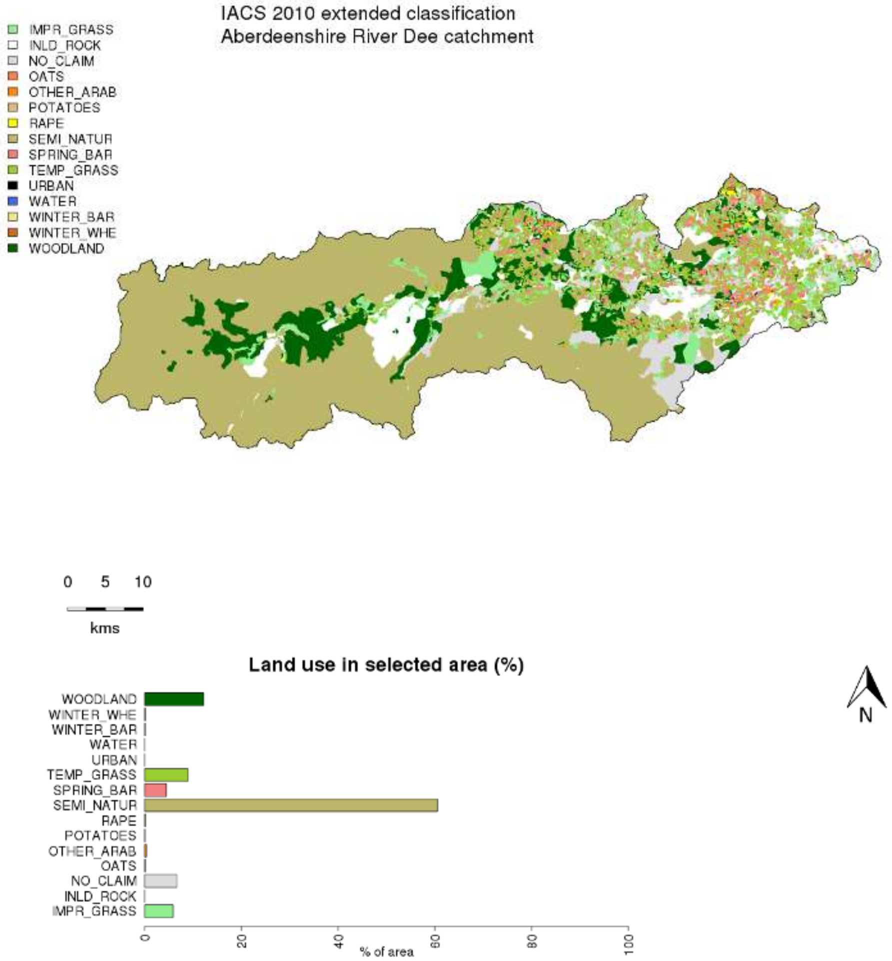

IACS extended classes 2010 and LCM 2007 with woodland inventory
Cairngorms National Park
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Calcareus Grassland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_unspecified
Heather
Heather grassland
Improved grassland
Inland Rock
Montane Habitats
Oats
Rape
Rough grassland
Spring barley
Suburban
Supra-littoral Sediment
Temporary grassland
Urban
Winter wheat
0 5 10
kms
Land use in selected area (%)
N
% of area
0
20
40
60
80
100

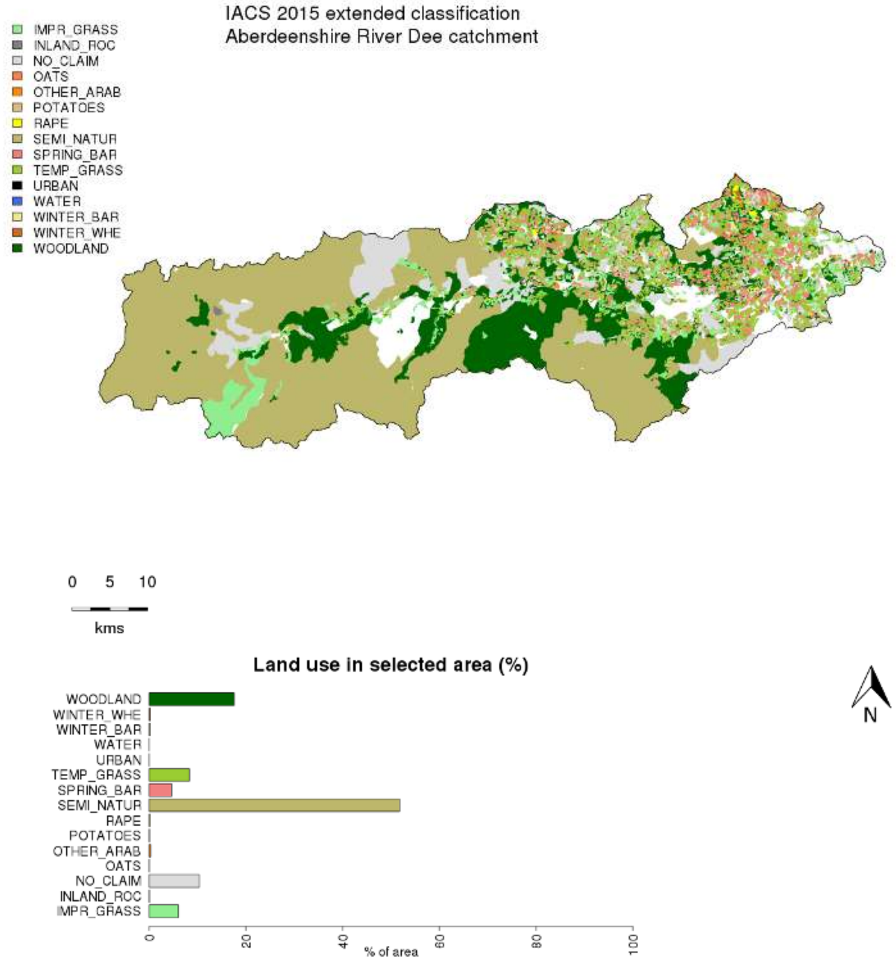

IACS extended classes 2015 and LCM 2007 with woodland inventory
Cairngorms National Park
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Calcareus Grassland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_unspecified
Heather
Heather grassland
Improved grassland
Inland Rock
Montane Habitats
Oats
Rape
Rough grassland
Spring barley
Suburban
Supra-littoral Sediment
Temporary grassland
Urban
0 5 10
kms
Land use in selected area (%)
N
% of area
0
20
40
60
80
100

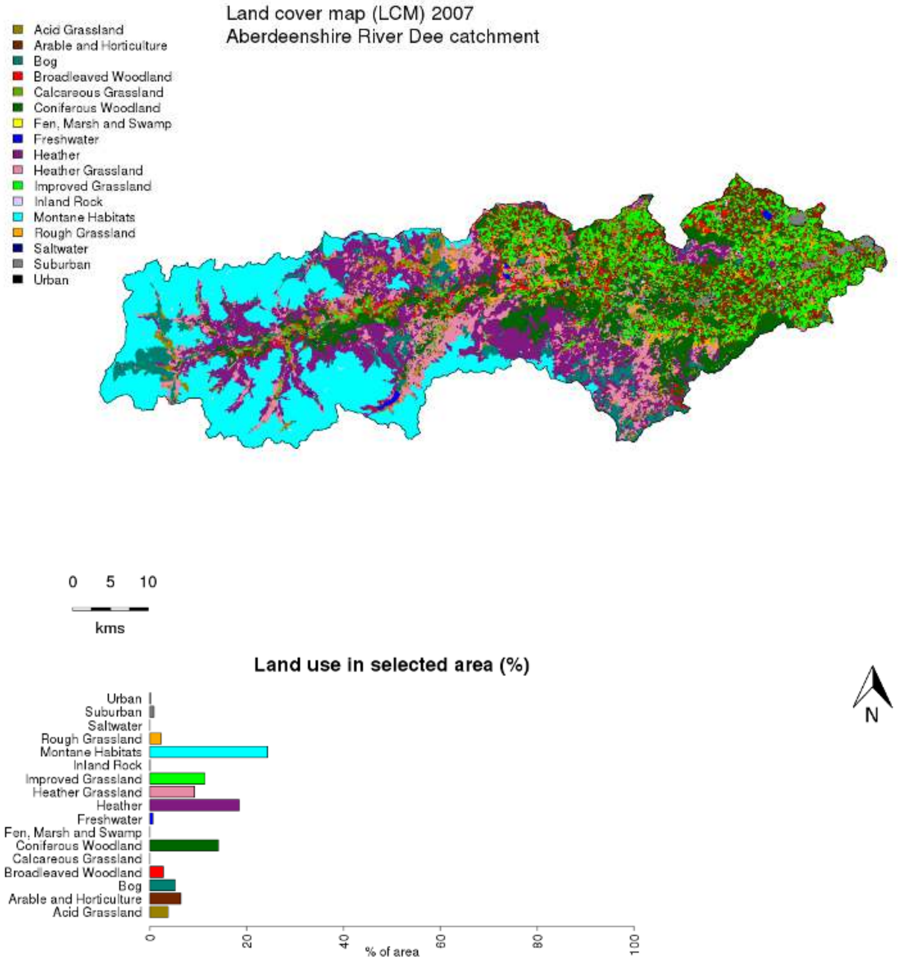

IACS 2008 simple classification
Aberdeenshire River Dee catchment
ARABLE
IMPR_GRASS
LLO
NO_CLAIM
SEMI_NATUR
TEMP_GRASS
UNCLASS
WOODLAND
0 5 10
kms
Land use in selected area (%)
WOODLAND
UNCLASS
TEMP_GRASS
SEMI_NATUR
NO_CLAIM
LLO
IMPR_GRASS
ARABLE
0
20
40
60
80
100
% of area
N

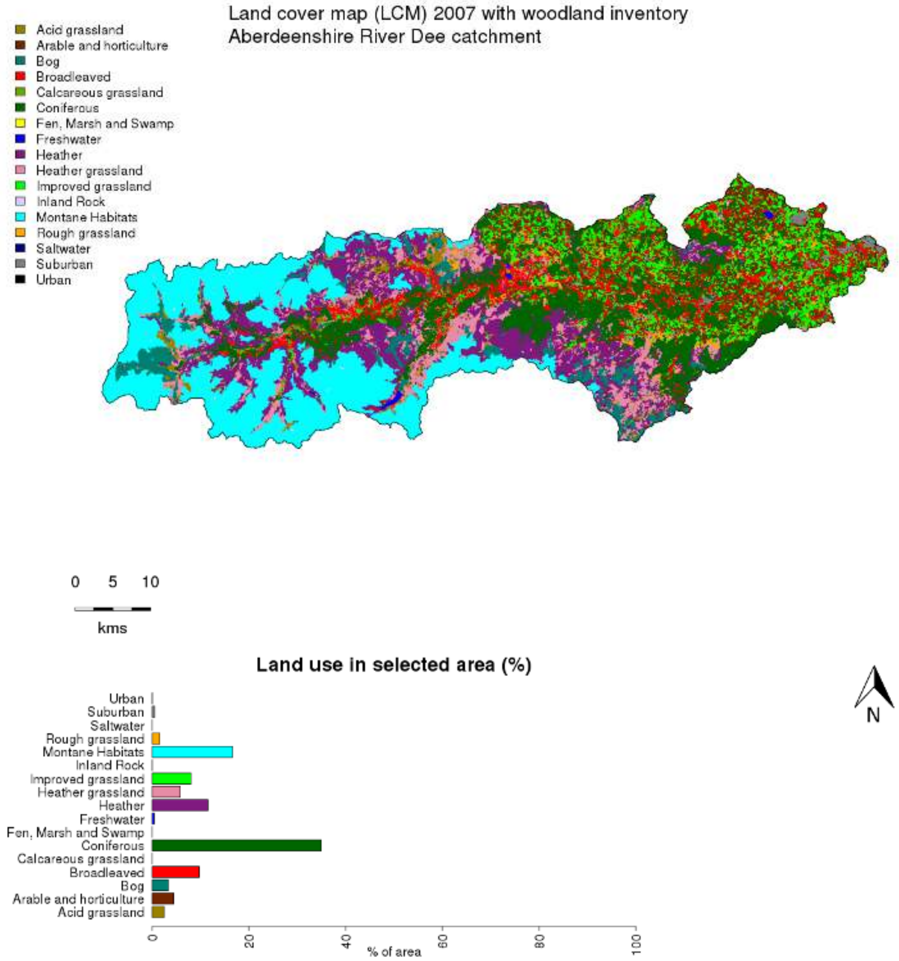

IACS 2010 simple classification
Aberdeenshire River Dee catchment
ARABLE
IMPR_GRASS
INLD_ROCK
NO_CLAIM
SEMI_NATUR
TEMP_GRASS
URBAN
WATER
WOODLAND
0 5 10
kms
Land use in selected area (%)
WOODLAND
WATER
URBAN
TEMP_GRASS
SEMI_NATUR
NO_CLAIM
INLD_ROCK
IMPR_GRASS
ARABLE
0
20
40
60
80
100
% of area
N

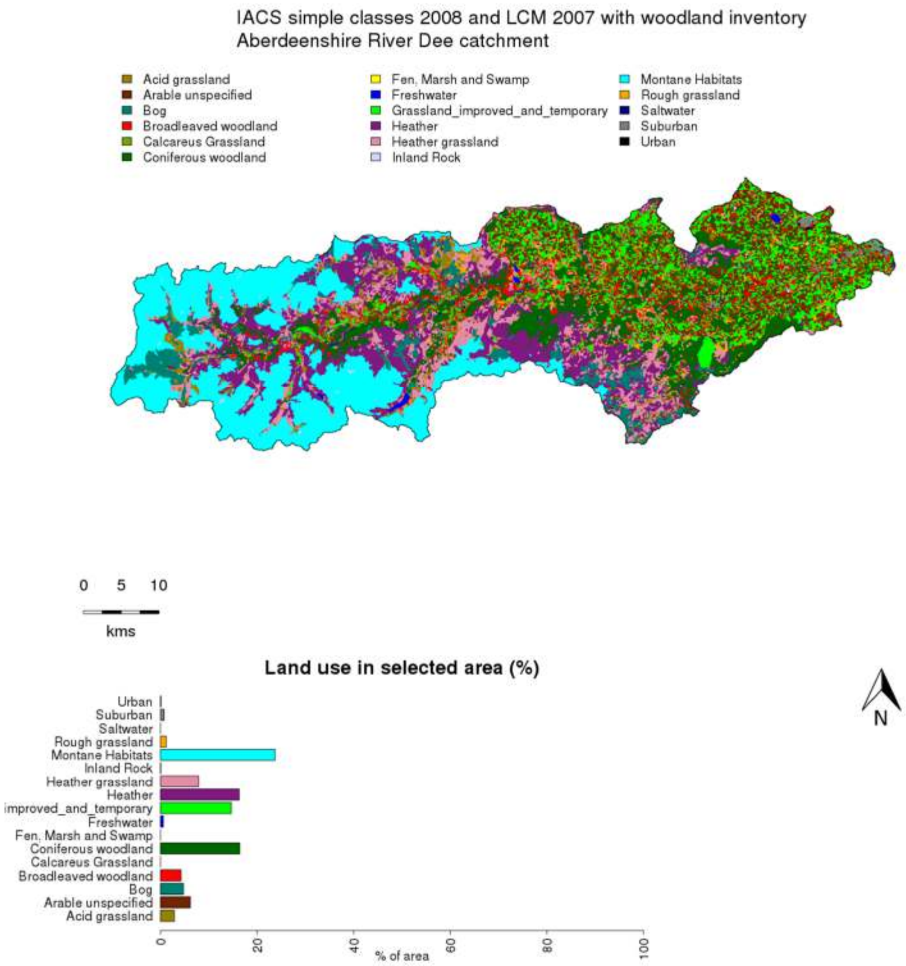

IACS 2015 simple classification
Aberdeenshire River Dee catchment
ARABLE
IMPR_GRASS
INLD_ROCK
NO_CLAIM
SEMI_NATUR
TEMP_GRASS
URBAN
WATER
WOODLAND
0 5 10
kms
N
Land use in selected area (%)
WOODLAND
WATER
URBAN
TEMP_GRASS
SEMI_NATUR
NO_CLAIM
INLD_ROCK
IMPR_GRASS
ARABLE
0
20
40
60
80
100
% of area

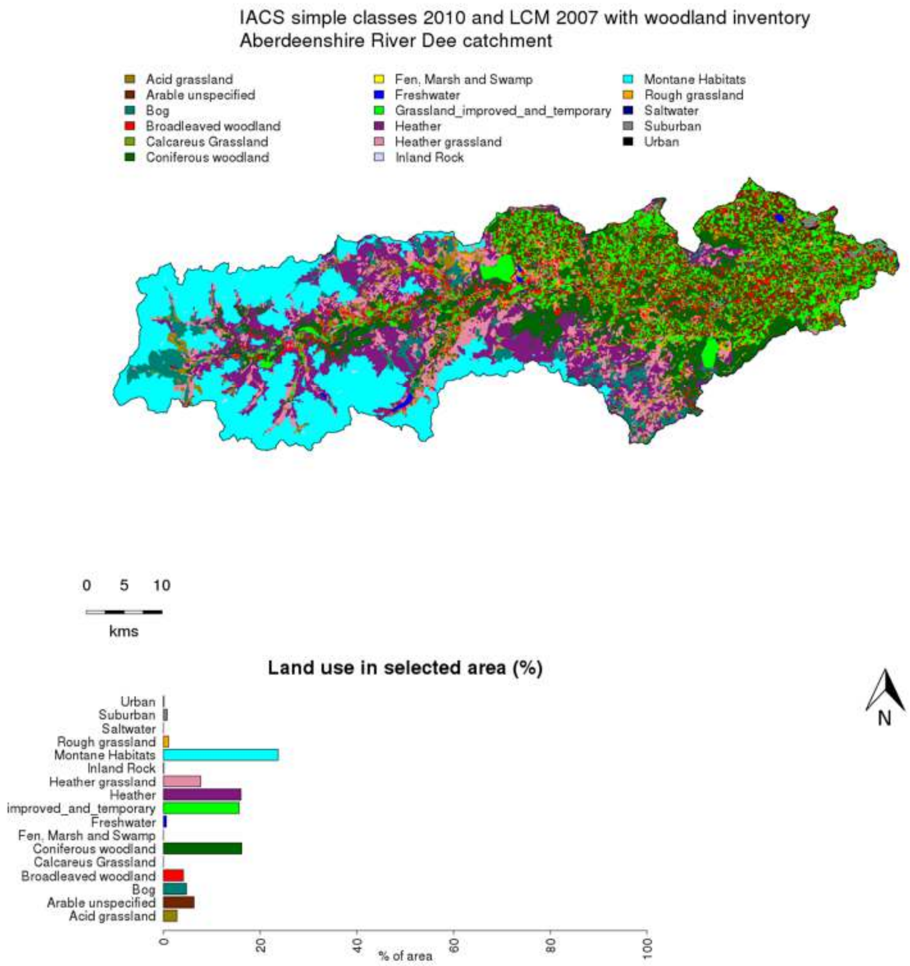

IACS 2010 extended classification
Aberdeenshire River Dee catchment
IMPR_GRASS
INLD_ROCK
NO_CLAIM
OATS
OTHER_ARAB
POTATOES
RAPE
SEMI_NATUR
SPRING_BAR
TEMP_GRASS
URBAN
WATER
WINTER_BAR
WINTER_WHE
WOODLAND
0 5 10
kms
N
Land use in selected area (%)
WOODLAND
WINTER_WHE
WINTER_BAR
WATER
URBAN
TEMP_GRASS
SPRING_BAR
SEMI_NATUR
RAPE
POTATOES
OTHER_ARAB
OATS
NO_CLAIM
INLD_ROCK
IMPR_GRASS
0 20 40 60 80 100
% of area

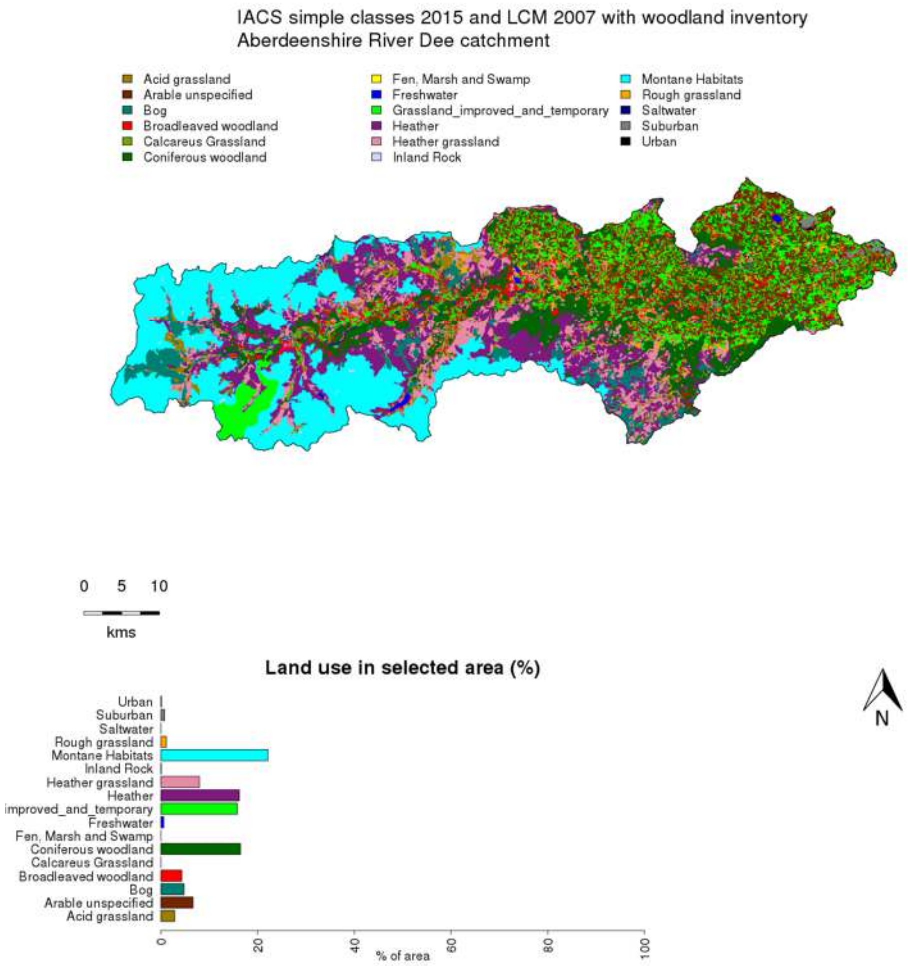

IACS 2015 extended classification
Aberdeenshire River Dee catchment
IMPR_GRASS
INLAND_ROC
NO_CLAIM
OATS
OTHER_ARAB
POTATOES
RAPE
SEMI_NATUR
SPRING_BAR
TEMP_GRASS
URBAN
WATER
WINTER_BAR
WINTER_WHE
WOODLAND
0 5 10
kms
N
Land use in selected area (%)
WOODLAND
WINTER_WHE
WINTER_BAR
WATER
URBAN
TEMP_GRASS
SPRING_BAR
SEMI_NATUR
RAPE
POTATOES
OTHER_ARAB
OATS
NO_CLAIM
INLAND_ROC
IMPR_GRASS
0 20 40 60 80 100
% of area

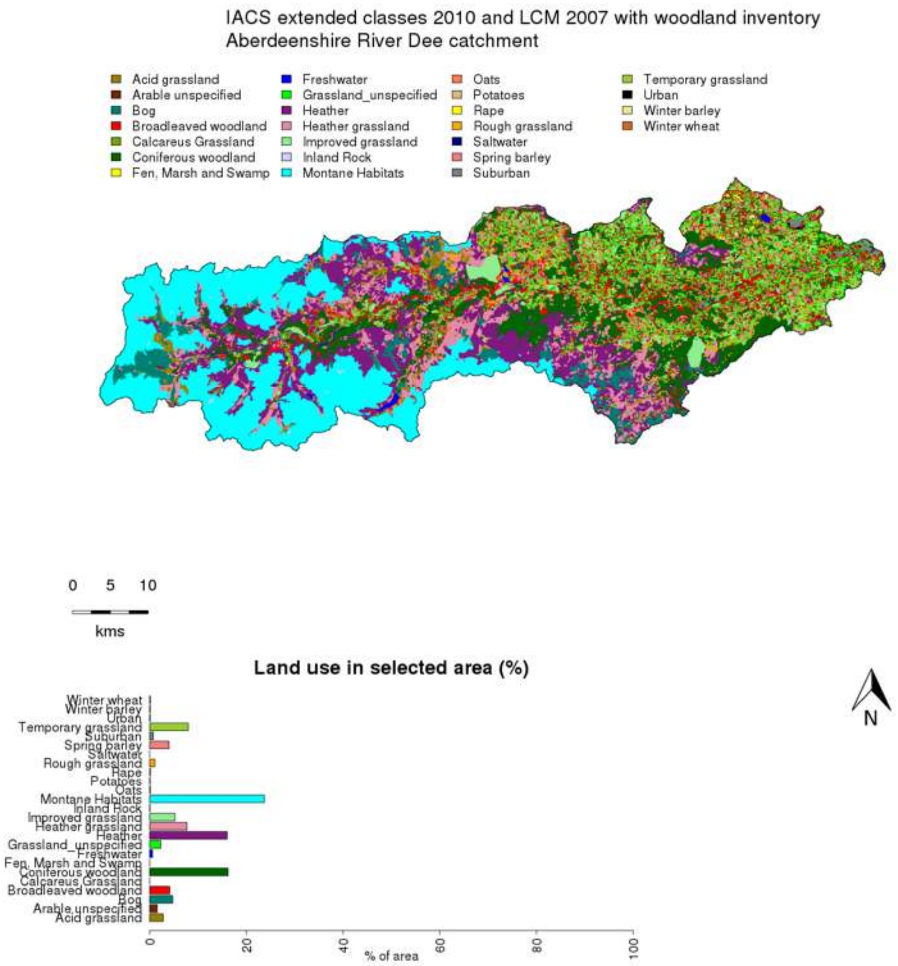

Land cover map (LCM) 2007
Aberdeenshire River Dee catchment
Acid Grassland
Arable and Horticulture
Bog
Broadleaved Woodland
Calcareous Grassland
Coniferous Woodland
Fen, Marsh and Swamp
Freshwater
Heather
Heather Grassland
Improved Grassland
Inland Rock
Montane Habitats
Rough Grassland
Saltwater
Suburban
Urban
0 5 10
kms
Land use in selected area (%)
% of area
0
20
40
60
80
100
N

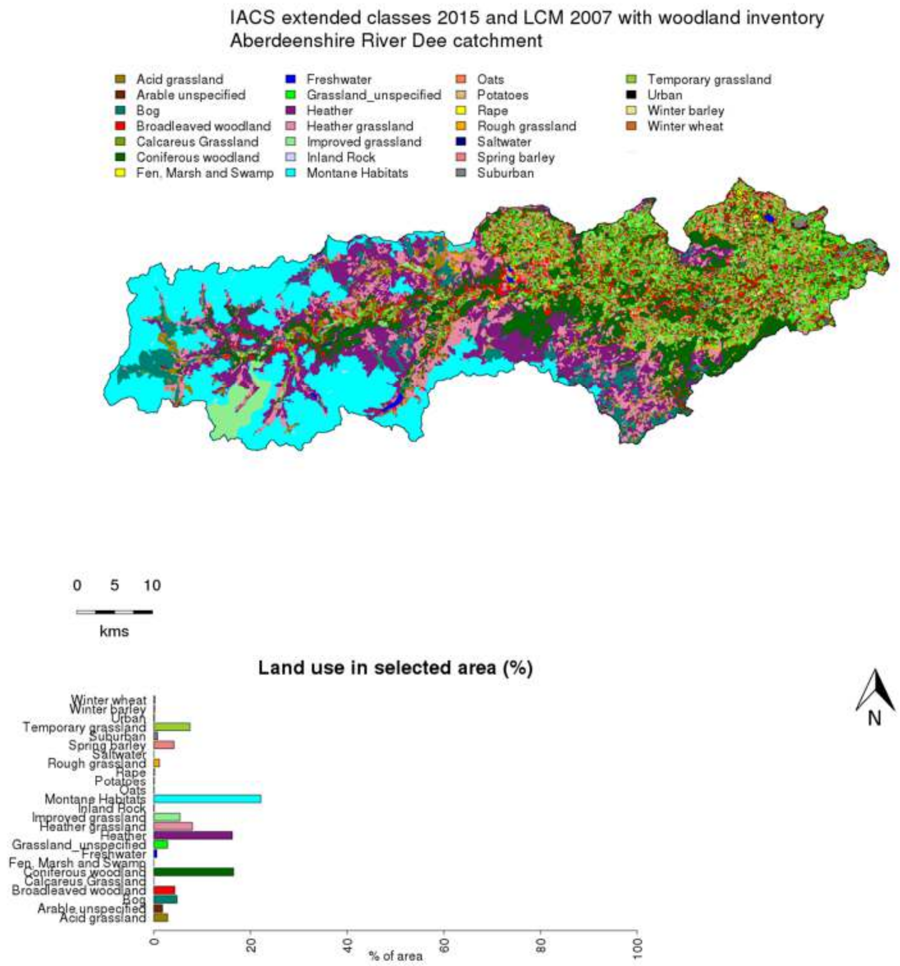

Land cover map (LCM) 2007 with woodland inventory
Aberdeenshire River Dee catchment
Acid grassland
Arable and horticulture
Bog
Broadleaved
Calcareous grassland
Coniferous
Fen, Marsh and Swamp
Freshwater
Heather
Heather grassland
Improved grassland
Inland Rock
Montane Habitats
Rough grassland
Saltwater
Suburban
Urban
0 5 10
kms
Land use in selected area (%)
% of area
0
20
40
60
80
100
N

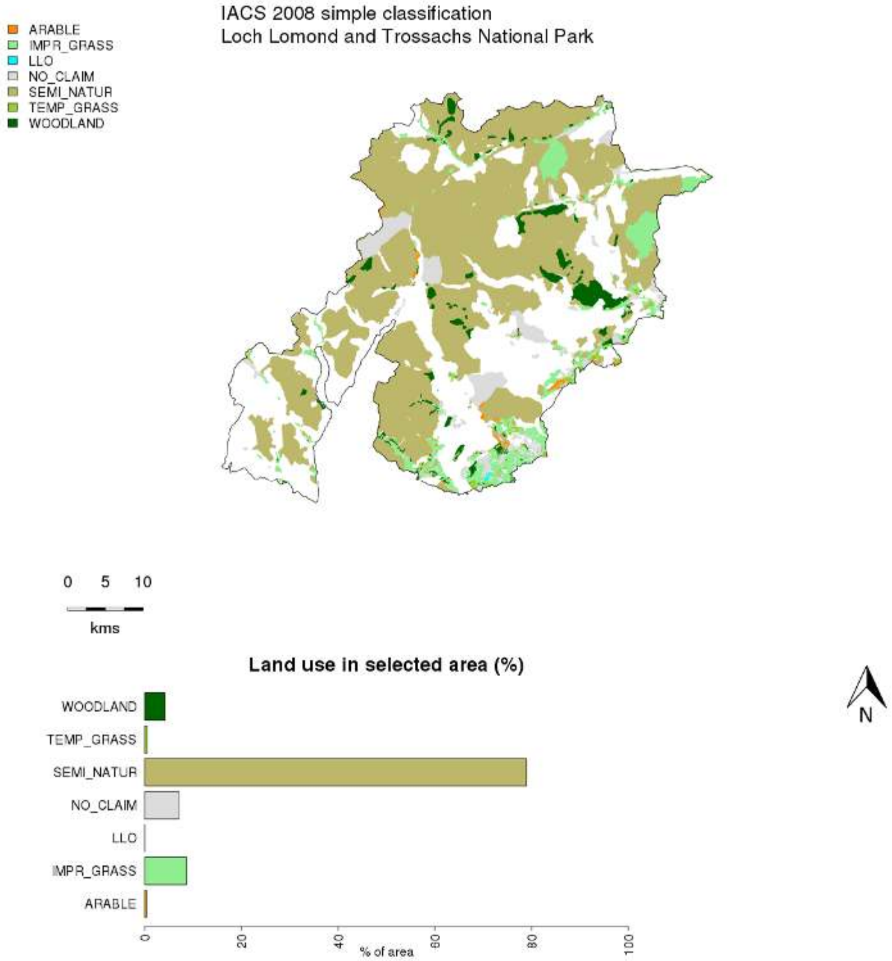

IACS simple classes 2008 and LCM 2007 with woodland inventory
Aberdeenshire River Dee catchment
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Calcareus Grassland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_improved_and_temporary
Heather
Heather grassland
Inland Rock
Montane Habitats
Rough grassland
Saltwater
Suburban
Urban
0 5 10
kms
Land use in selected area (%)
Urban
Suburban
Saltwater
Rough grassland
Montane Habitats
Inland Rock
Heather grassland
Heather
improved_and_temporary
Freshwater
Fen, Marsh and Swamp
Coniferous woodland
Calcareus Grassland
Broadleaved woodland
Bog
Arable unspecified
Acid grassland
0
20
40
60
80
100
% of area
N

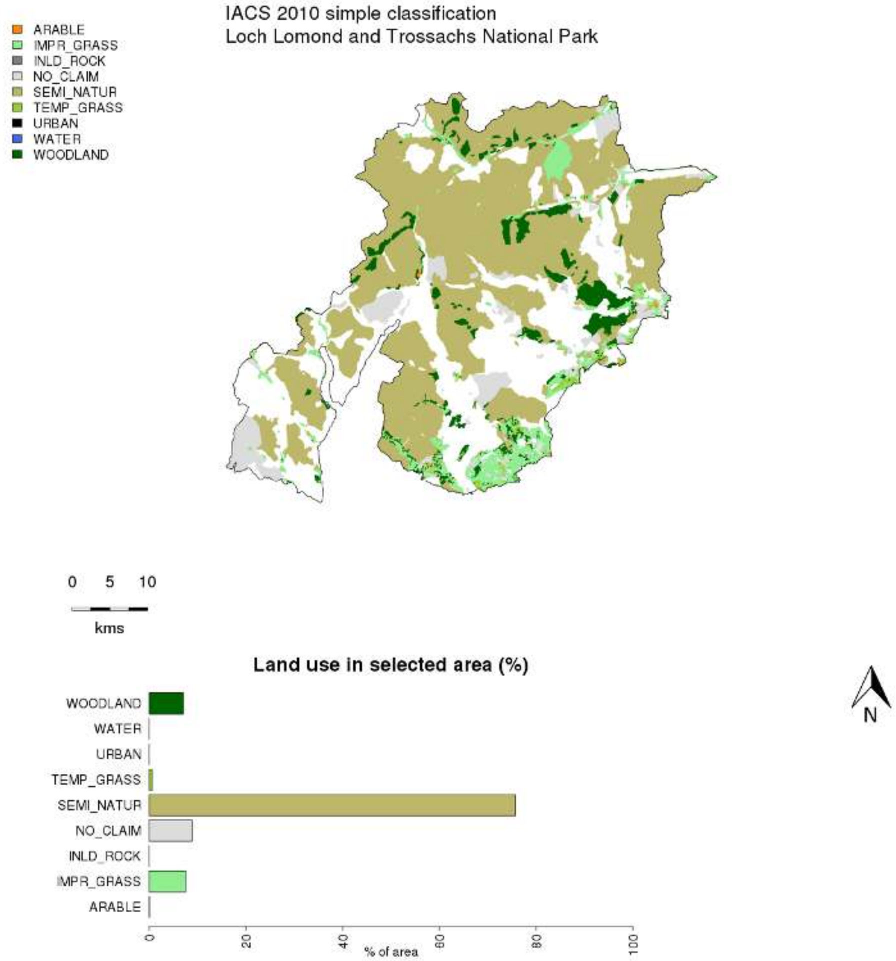

IACS simple classes 2010 and LCM 2007 with woodland inventory
Aberdeenshire River Dee catchment
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Calcareus Grassland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_improved_and_temporary
Heather
Heather grassland
Inland Rock
Montane Habitats
Rough grassland
Saltwater
Suburban
Urban
0 5 10
kms
Land use in selected area (%)
Urban
Suburban
Saltwater
Rough grassland
Montane Habitats
Inland Rock
Heather grassland
Heather
improved_and_temporary
Freshwater
Fen, Marsh and Swamp
Coniferous woodland
Calcareus Grassland
Broadleaved woodland
Bog
Arable unspecified
Acid grassland
0
20
40
60
80
100
% of area
N

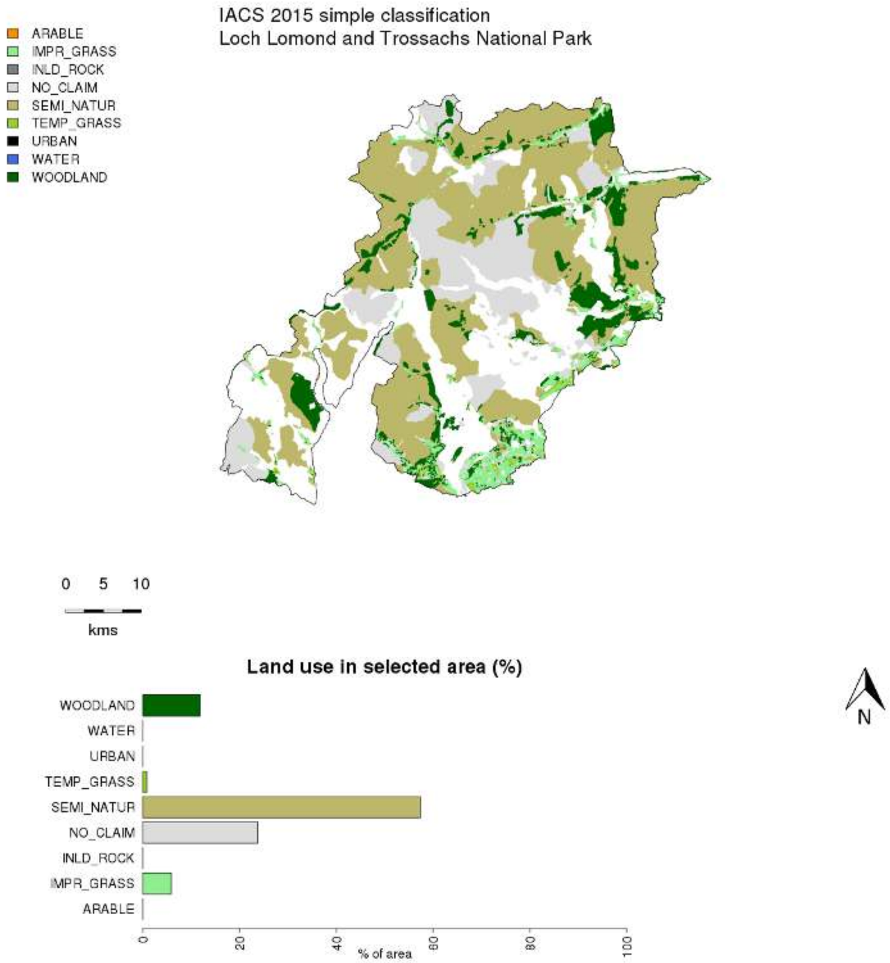

IACS simple classes 2015 and LCM 2007 with woodland inventory
Aberdeenshire River Dee catchment
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Calcareus Grassland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_improved_and_temporary
Heather
Heather grassland
Inland Rock
Montane Habitats
Rough grassland
Saltwater
Suburban
Urban
0 5 10
kms
Land use in selected area (%)
Urban
Suburban
Saltwater
Rough grassland
Montane Habitats
Inland Rock
Heather grassland
Heather
improved_and_temporary
Freshwater
Fen, Marsh and Swamp
Coniferous woodland
Calcareus Grassland
Broadleaved woodland
Bog
Arable unspecified
Acid grassland
0
20
40
60
80
100
% of area
N

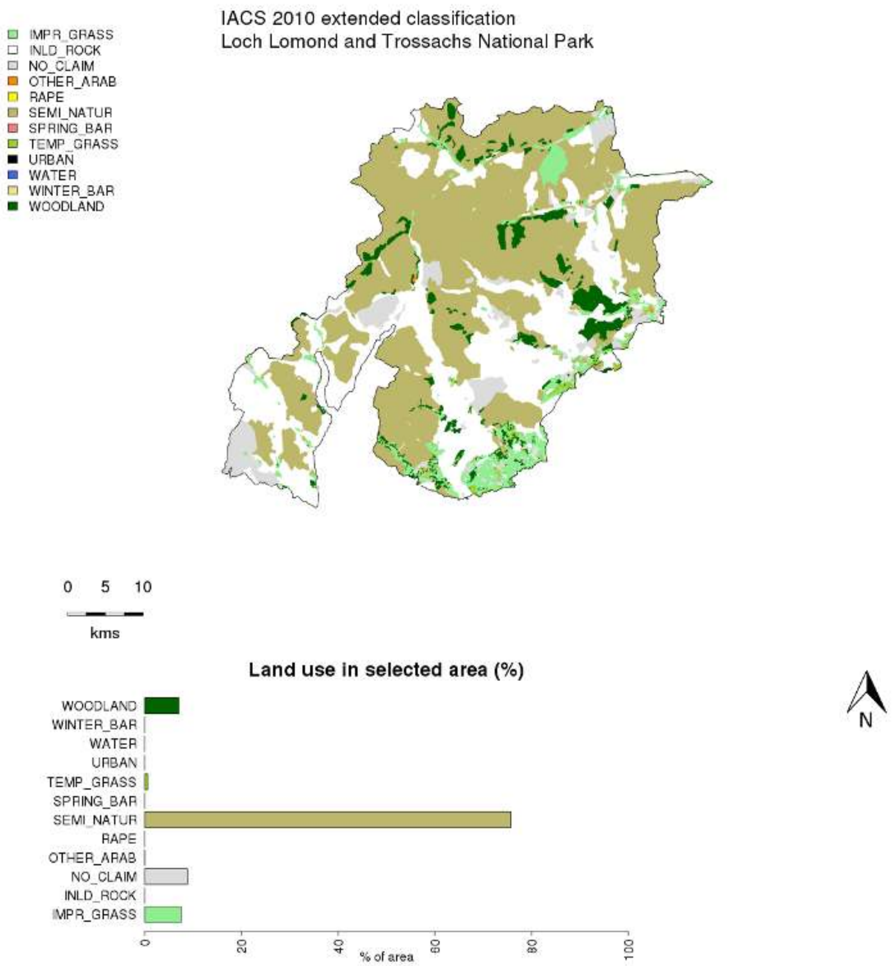

IACS extended classes 2010 and LCM 2007 with woodland inventory
Aberdeenshire River Dee catchment
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Calcareus Grassland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_unspecified
Heather
Heather grassland
Improved grassland
Inland Rock
Montane Habitats
Oats
Potatoes
Rape
Rough grassland
Saltwater
Spring barley
Suburban
Temporary grassland
Urban
Winter barley
Winter wheat
0 5 10
kms
Land use in selected area (%)
N
% of area
0
20
40
60
80
100

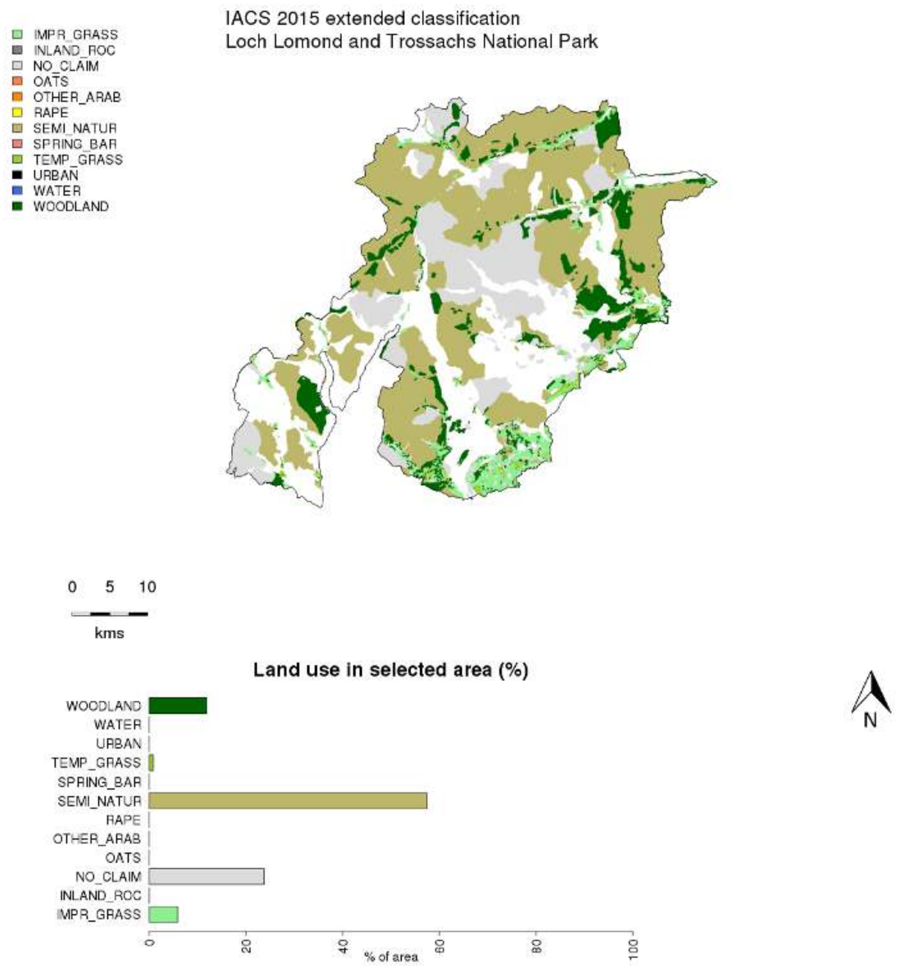

IACS extended classes 2015 and LCM 2007 with woodland inventory
Aberdeenshire River Dee catchment
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Calcareus Grassland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_unspecified
Heather
Heather grassland
Improved grassland
Inland Rock
Montane Habitats
Oats
Potatoes
Rape
Rough grassland
Saltwater
Spring barley
Suburban
Temporary grassland
Urban
Winter barley
Winter wheat
0 5 10
kms
Land use in selected area (%)
N
% of area
0
20
40
60
80
100

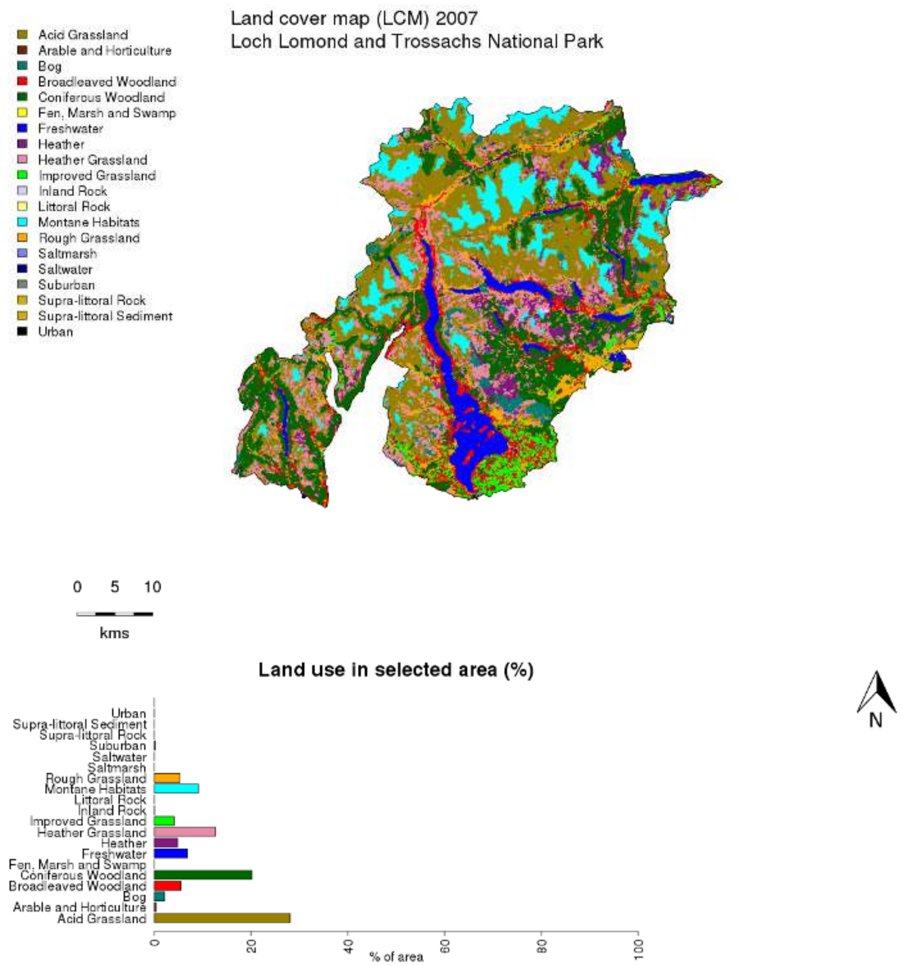

IACS 2008 simple classification
Loch Lomond and Trossachs National Park
ARABLE
IMPR_GRASS
LLO
NO_CLAIM
SEMI_NATUR
TEMP_GRASS
WOODLAND
0 5 10
kms
Land use in selected area (%)
WOODLAND
TEMP_GRASS
SEMI_NATUR
NO_CLAIM
LLO
IMPR_GRASS
ARABLE
0
20
40
60
80
100
% of area
N


IACS 2010 simple classification
Loch Lomond and Trossachs National Park
ARABLE
IMPR_GRASS
INLD_ROCK
NO_CLAIM
SEMI_NATUR
TEMP_GRASS
URBAN
WATER
WOODLAND
0 5 10
kms
Land use in selected area (%)
WOODLAND
WATER
URBAN
TEMP_GRASS
SEMI_NATUR
NO_CLAIM
INLD_ROCK
IMPR_GRASS
ARABLE
0
20
40
60
80
100
% of area
N

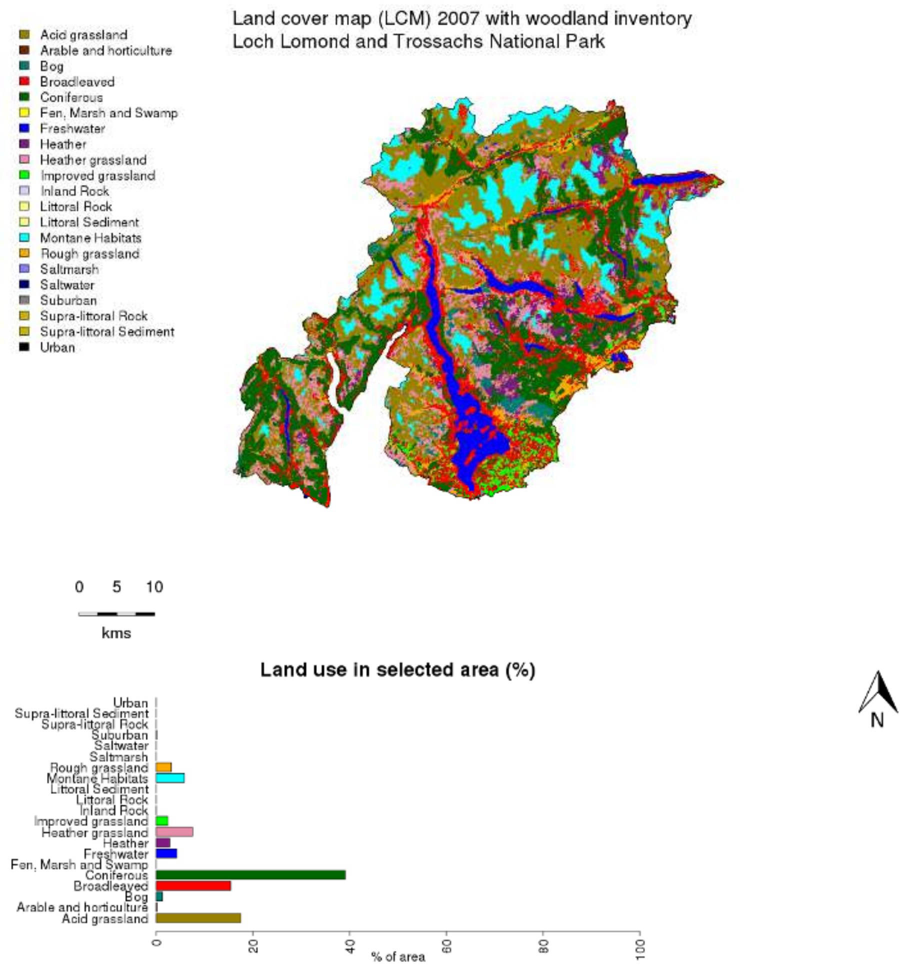

IACS 2015 simple classification
Loch Lomond and Trossachs National Park
ARABLE
IMPR_GRASS
INLD_ROCK
NO_CLAIM
SEMI_NATUR
TEMP_GRASS
URBAN
WATER
WOODLAND
0 5 10
kms
N
Land use in selected area (%)
WOODLAND
WATER
URBAN
TEMP_GRASS
SEMI_NATUR
NO_CLAIM
INLD_ROCK
IMPR_GRASS
ARABLE
0
20
40
60
80
100
% of area


IACS 2010 extended classification
Loch Lomond and Trossachs National Park
IMPR_GRASS
INLD_ROCK
NO_CLAIM
OTHER_ARAB
RAPE
SEMI_NATUR
SPRING_BAR
TEMP_GRASS
URBAN
WATER
WINTER_BAR
WOODLAND
0 5 10
kms
N
Land use in selected area (%)
WOODLAND
WINTER_BAR
WATER
URBAN
TEMP_GRASS
SPRING_BAR
SEMI_NATUR
RAPE
OTHER_ARAB
NO_CLAIM
INLD_ROCK
IMPR_GRASS
0
20
40
60
80
100
% of area

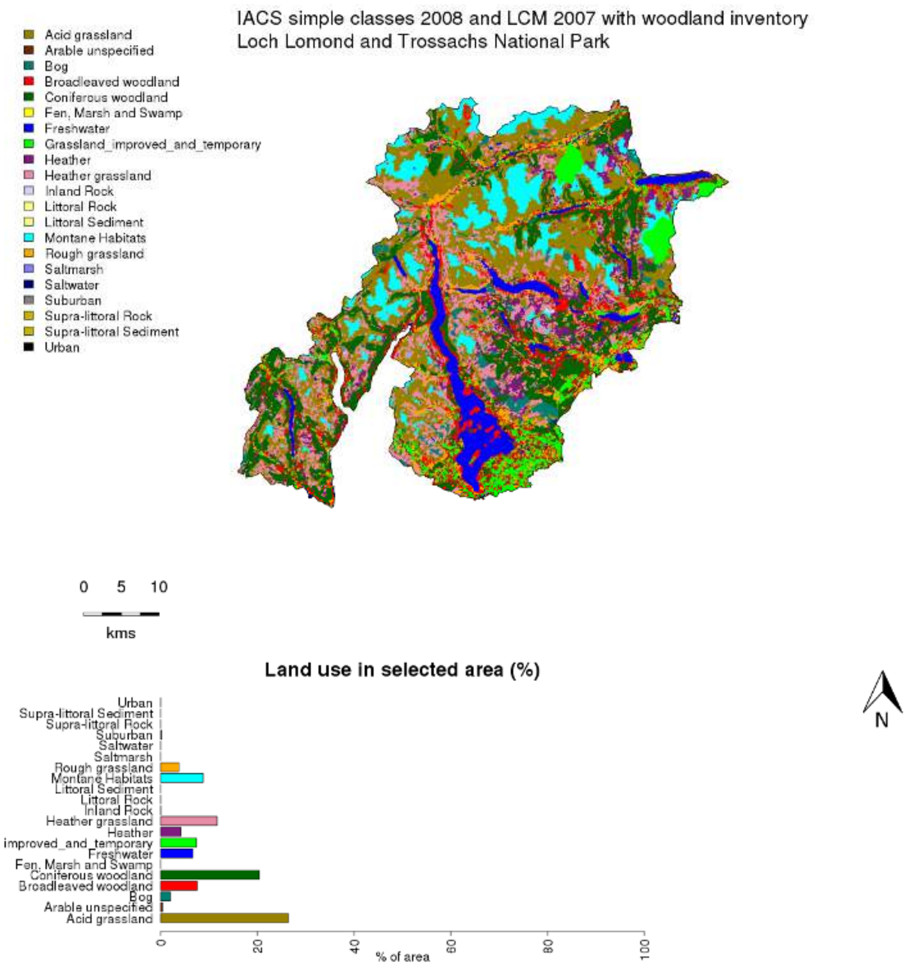

IACS 2015 extended classification
Loch Lomond and Trossachs National Park
IMPR_GRASS
INLAND_ROC
NO_CLAIM
OATS
OTHER_ARAB
RAPE
SEMI_NATUR
SPRING_BAR
TEMP_GRASS
URBAN
WATER
WOODLAND
0 5 10
kms
N
Land use in selected area (%)
WOODLAND
WATER
URBAN
TEMP_GRASS
SPRING_BAR
SEMI_NATUR
RAPE
OTHER_ARAB
OATS
NO_CLAIM
INLAND_ROC
IMPR_GRASS
0
20
40
60
80
100
% of area

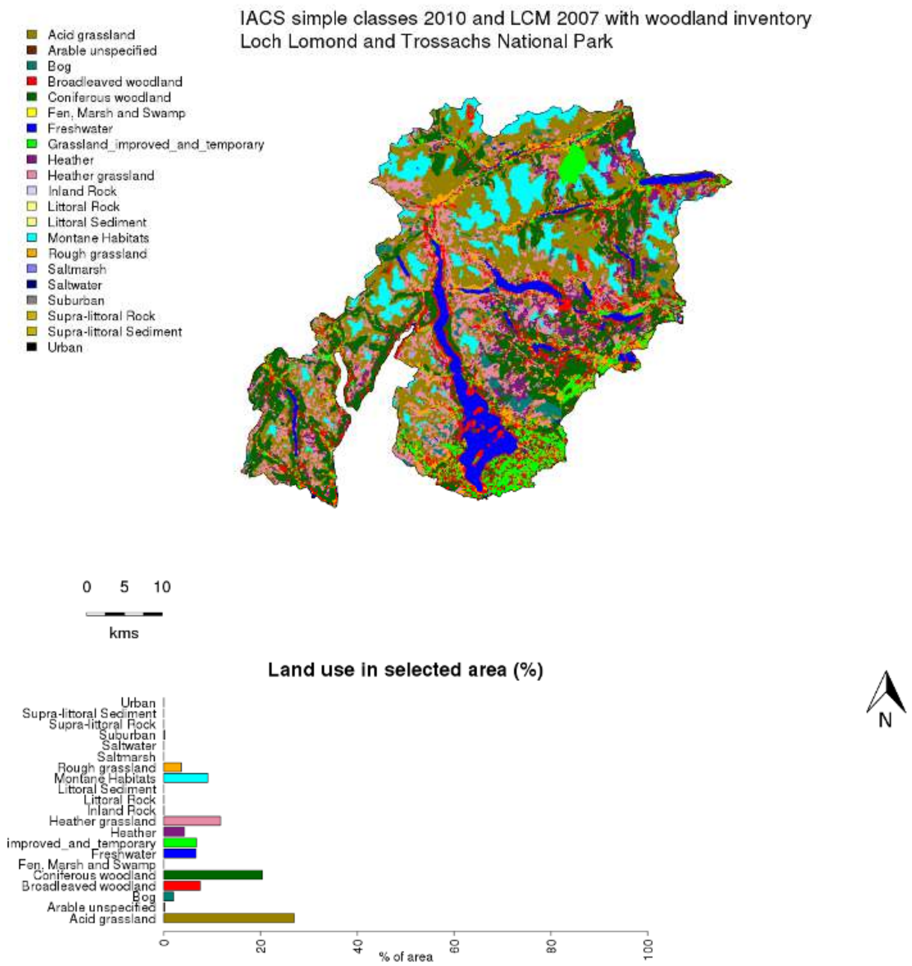


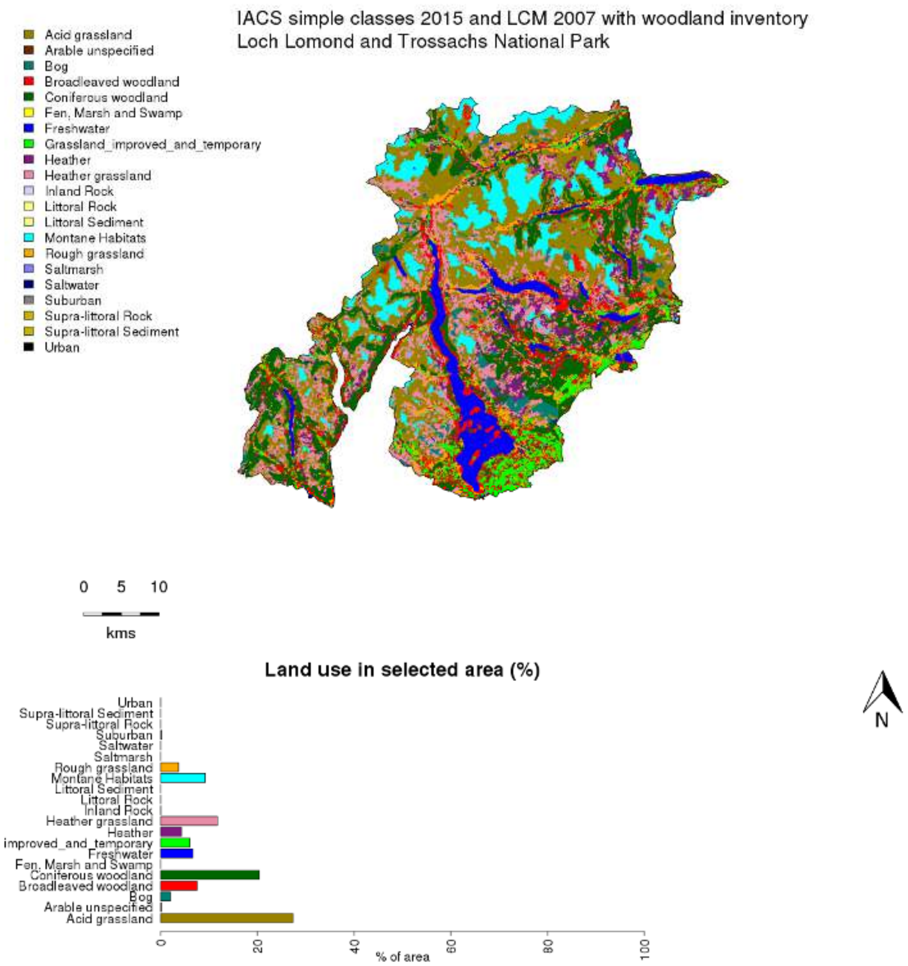
Land cover map (LCM) 2007
Loch Lomond and Trossachs National Park
Acid Grassland
Arable and Horticulture
Bog
Broadleaved Woodland
Coniferous Woodland
Fen, Marsh and Swamp
Freshwater
Heather
Heather Grassland
Improved Grassland
Inland Rock
Littoral Rock
Montane Habitats
Rough Grassland
Saltmarsh
Saltwater
Suburban
Supra-littoral Rock
Supra-littoral Sediment
Urban
0 5 10
kms
N
Land use in selected area (%)
Urban
Supra-littoral Sediment
Supra-littoral Rock
Suburban
Saltwater
Saltmarsh
Rough Grassland
Montane Habitats
Littoral Rock
Inland Rock
Improved Grassland
Heather Grassland
Heather
Freshwater
Fen, Marsh and Swamp
Coniferous Woodland
Broadleaved Woodland
Bog
Arable and Horticulture
Acid Grassland
0 20 40 60 80 100
% of area

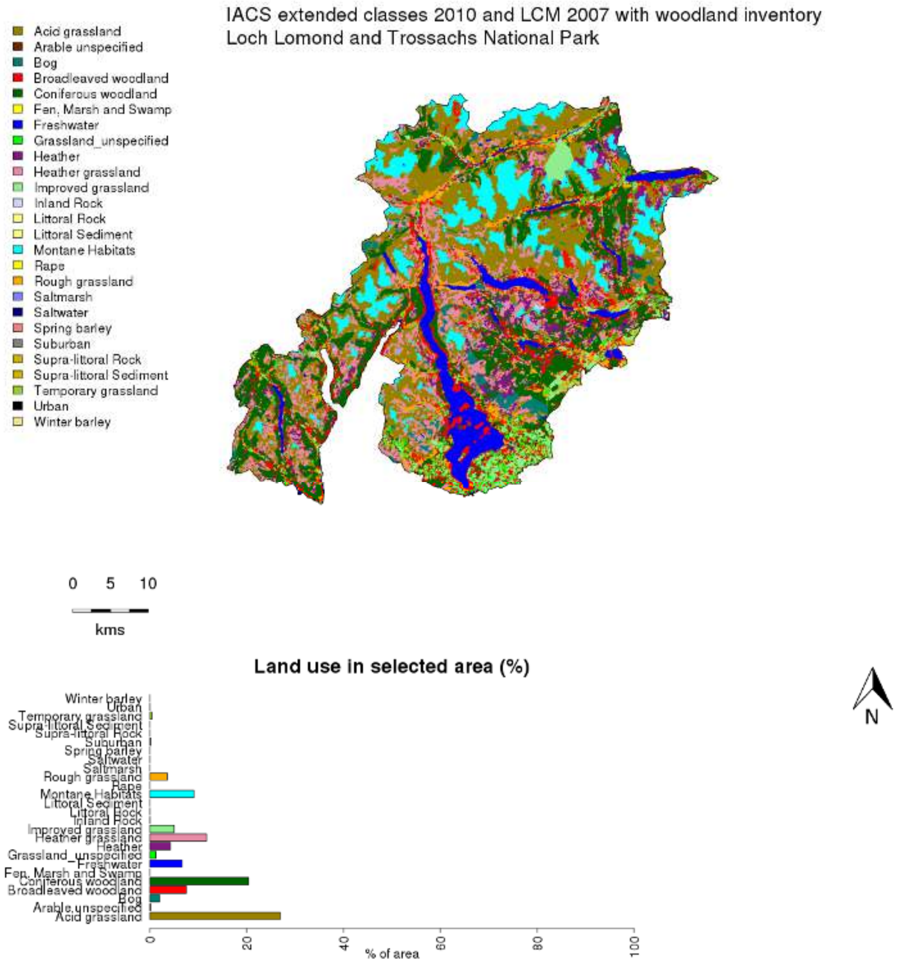


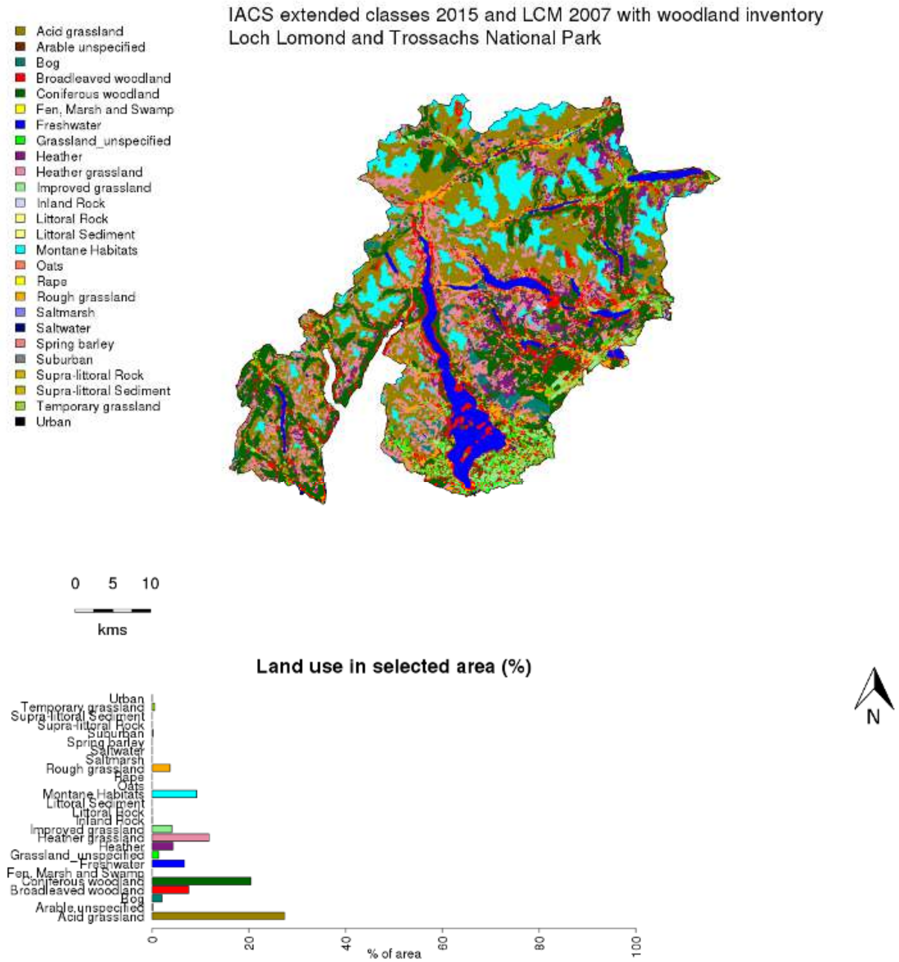
Land cover map (LCM) 2007 with woodland inventory
Loch Lomond and Trossachs National Park
Acid grassland
Arable and horticulture
Bog
Broadleaved
Coniferous
Fen, Marsh and Swamp
Freshwater
Heather
Heather grassland
Improved grassland
Inland Rock
Littoral Rock
Littoral Sediment
Montane Habitats
Rough grassland
Saltmarsh
Saltwater
Suburban
Supra-littoral Rock
Supra-littoral Sediment
Urban
0 5 10
kms
N
Land use in selected area (%)
Urban
Supra-littoral Sediment
Supra-littoral Rock
Suburban
Saltwater
Saltmarsh
Rough grassland
Montane Habitats
Littoral Sediment
Littoral Rock
Inland Rock
Improved grassland
Heather grassland
Heather
Freshwater
Fen, Marsh and Swamp
Coniferous
Broadleaved
Bog
Arable and horticulture
Acid grassland
0 20 40 60 80 100
% of area


IACS simple classes 2008 and LCM 2007 with woodland inventory
Loch Lomond and Trossachs National Park
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_improved_and_temporary
Heather
Heather grassland
Inland Rock
Littoral Rock
Littoral Sediment
Montane Habitats
Rough grassland
Saltmarsh
Saltwater
Suburban
Supra-littoral Rock
Supra-littoral Sediment
Urban
0 5 10
kms
N
Land use in selected area (%)
% of area
0 20 40 60 80 100

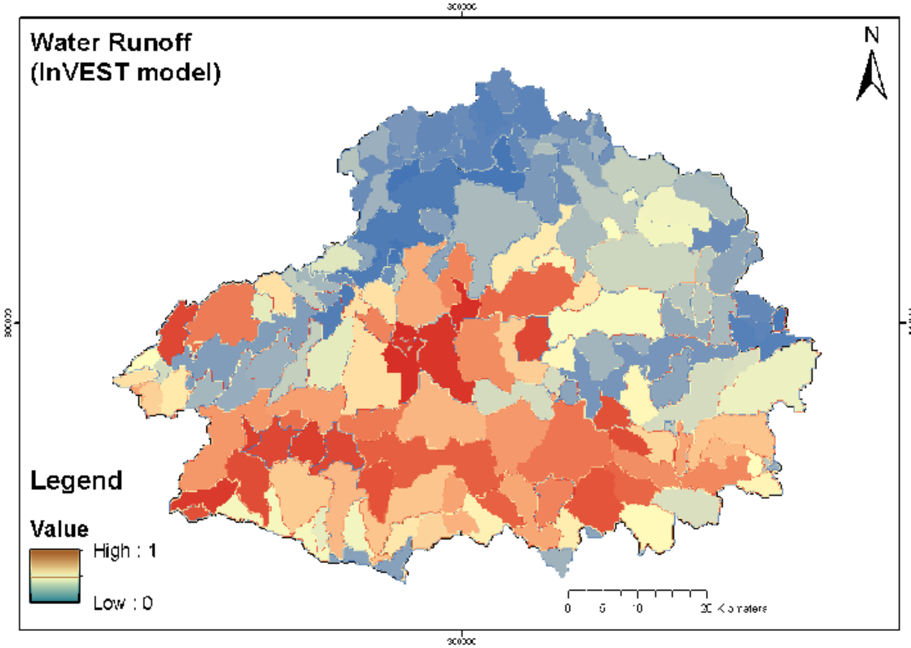

IACS simple classes 2010 and LCM 2007 with woodland inventory
Loch Lomond and Trossachs National Park
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_improved_and_temporary
Heather
Heather grassland
Inland Rock
Littoral Rock
Littoral Sediment
Montane Habitats
Rough grassland
Saltmarsh
Saltwater
Suburban
Supra-littoral Rock
Supra-littoral Sediment
Urban
0 5 10
kms
N
Land use in selected area (%)
% of area
0 20 40 60 80 100

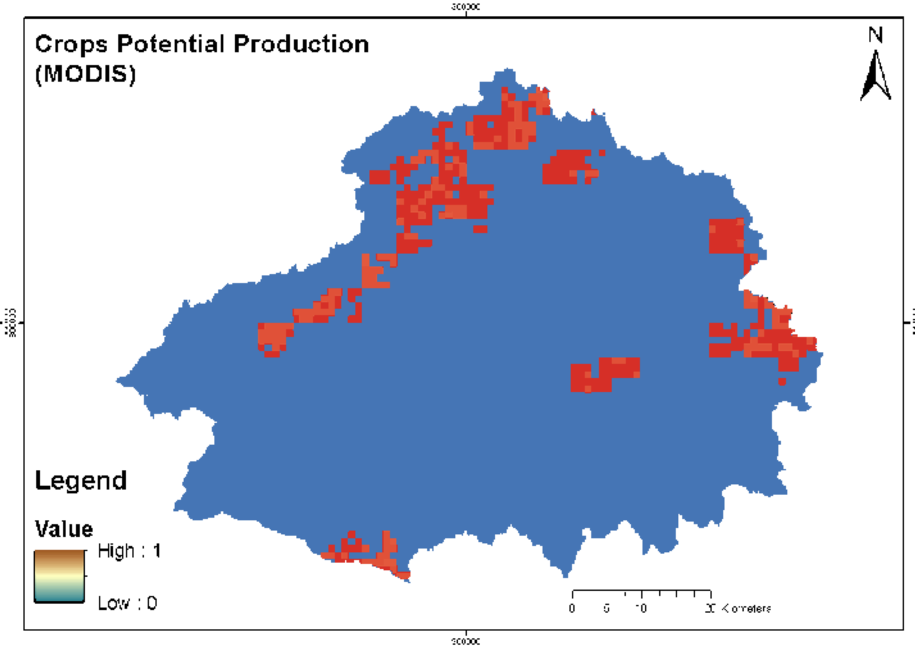

IACS simple classes 2015 and LCM 2007 with woodland inventory
Loch Lomond and Trossachs National Park
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_improved_and_temporary
Heather
Heather grassland
Inland Rock
Littoral Rock
Littoral Sediment
Montane Habitats
Rough grassland
Saltmarsh
Saltwater
Suburban
Supra-littoral Rock
Supra-littoral Sediment
Urban
0 5 10
kms
Land use in selected area (%)
Urban
Supra-littoral Sediment
Supra-littoral Rock
Suburban
Saltwater
Saltmarsh
Rough grassland
Montane Habitats
Littoral Sediment
Littoral Rock
Inland Rock
Heather grassland
Heather
improved_and_temporary
Freshwater
Fen, Marsh and Swamp
Coniferous woodland
Broadleaved woodland
Bog
Arable unspecified
Acid grassland
0 20 40 60 80 100
% of area
N

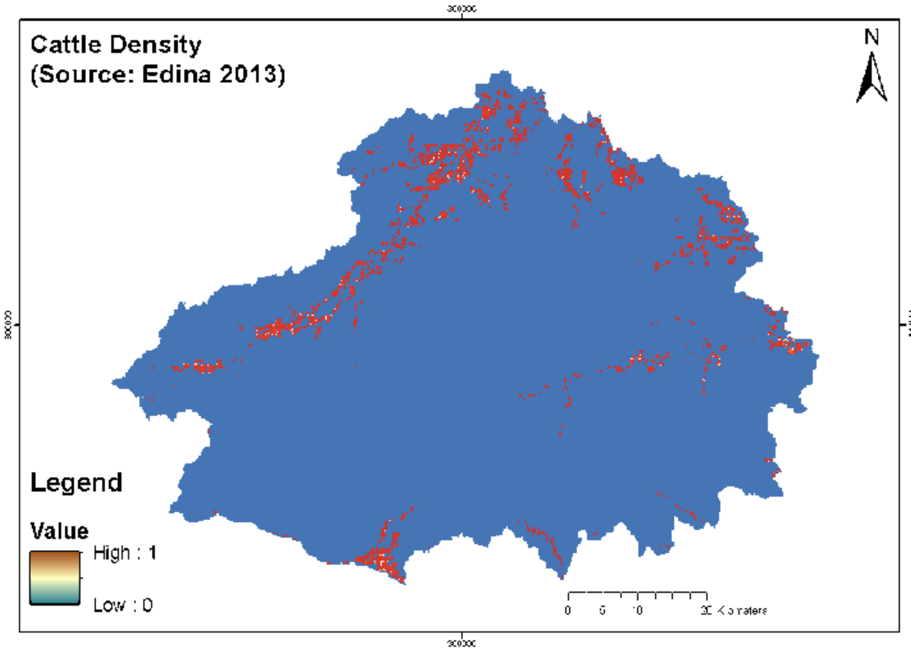

IACS extended classes 2010 and LCM 2007 with woodland inventory
Loch Lomond and Trossachs National Park
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_unspecified
Heather
Heather grassland
Improved grassland
Inland Rock
Littoral Rock
Littoral Sediment
Montane Habitats
Rape
Rough grassland
Saltmarsh
Saltwater
Spring barley
Suburban
Supra-littoral Rock
Supra-littoral Sediment
Temporary grassland
Urban
Winter barley
0 5 10
kms
Land use in selected area (%)
Winter barley
Urban
Temporary grassland
Supra-littoral Sediment
Supra-littoral Rock
Suburban
Spring barley
Saltwater
Saltmarsh
Rough grassland
Rape
Montane Habitats
Littoral Sediment
Littoral Rock
Inland Rock
Improved grassland
Heather grassland
Heather
Grassland_unspecified
Freshwater
Fen, Marsh and Swamp
Coniferous woodland
Broadleaved woodland
Bog
Arable unspecified
Acid grassland
0
20
40
60
80
100
% of area
N

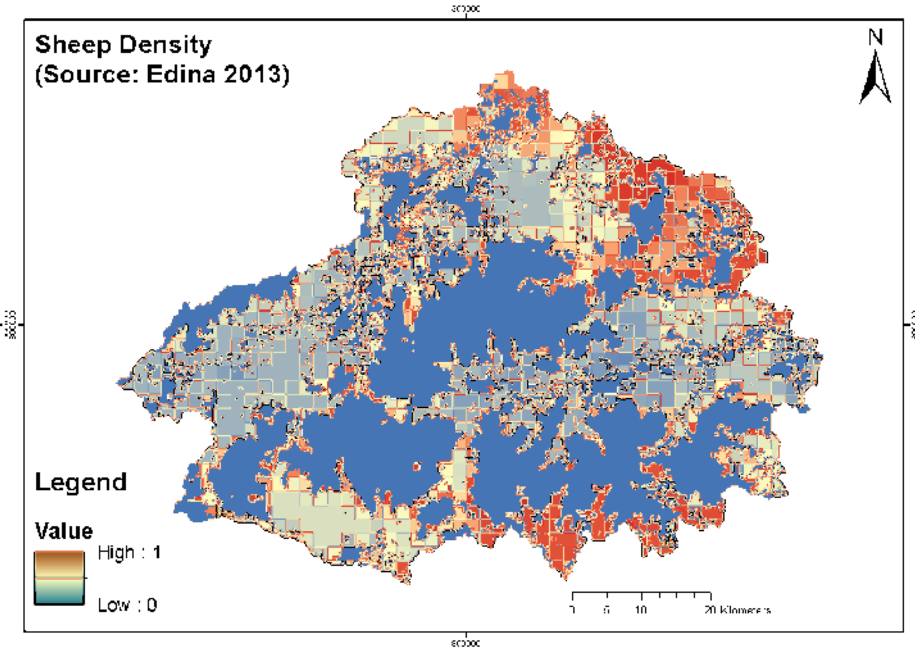

IACS extended classes 2015 and LCM 2007 with woodland inventory
Loch Lomond and Trossachs National Park
Acid grassland
Arable unspecified
Bog
Broadleaved woodland
Coniferous woodland
Fen, Marsh and Swamp
Freshwater
Grassland_unspecified
Heather
Heather grassland
Improved grassland
Inland Rock
Littoral Rock
Littoral Sediment
Montane Habitats
Oats
Rape
Rough grassland
Saltmarsh
Saltwater
Spring barley
Suburban
Supra-littoral Rock
Supra-littoral Sediment
Temporary grassland
Urban
0 5 10
kms
Land use in selected area (%)
Urban
Temporary grassland
Supra-littoral Sediment
Supra-littoral Rock
Suburban
Spring barley
Saltwater
Saltmarsh
Rough grassland
Rape
Oats
Montane Habitats
Littoral Sediment
Littoral Rock
Inland Rock
Improved grassland
Heather grassland
Heather
Grassland_unspecified
Freshwater
Fen, Marsh and Swamp
Coniferous woodland
Broadleaved woodland
Bog
Arable unspecified
Acid grassland
0
20
40
60
80
100
% of area
N

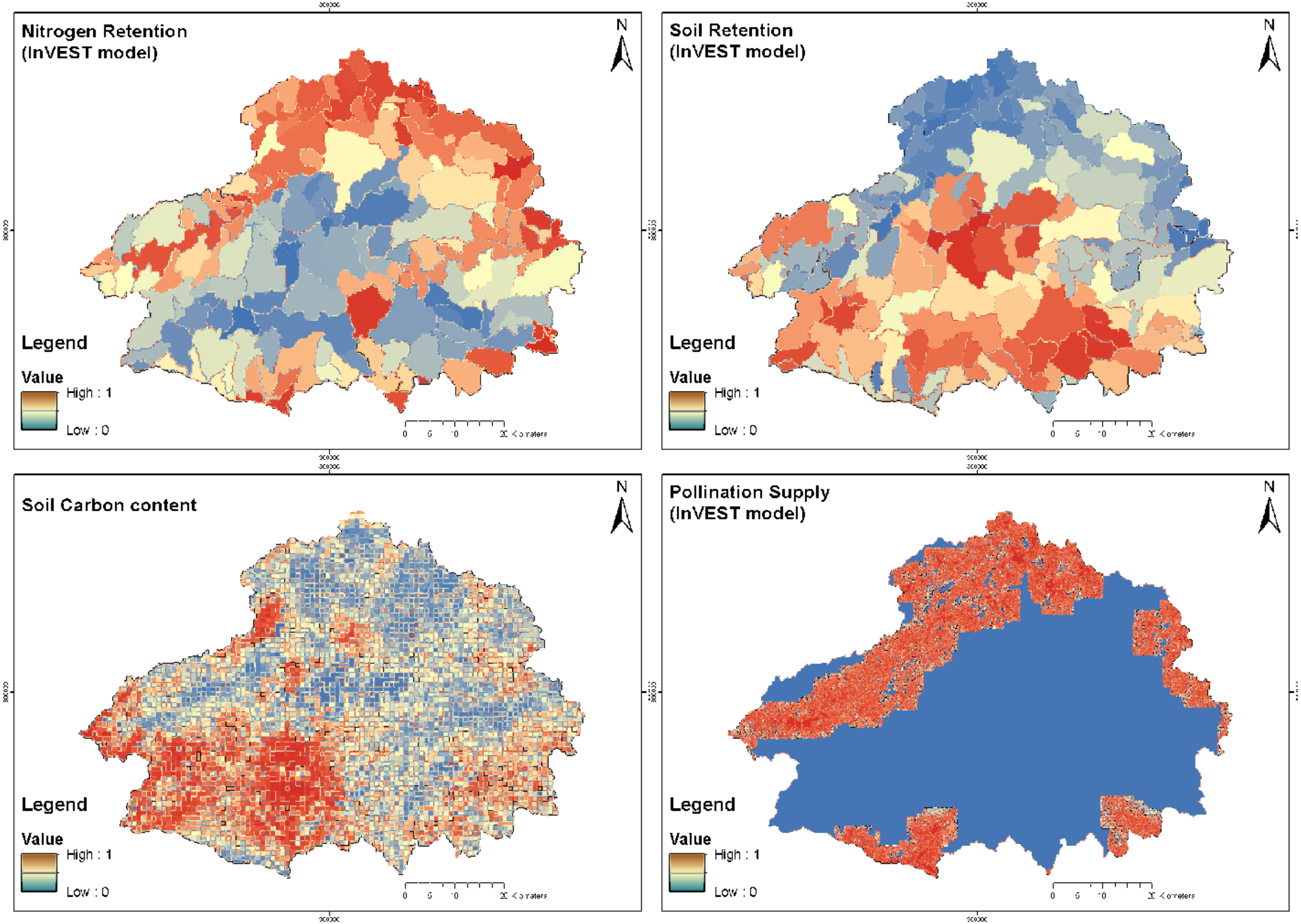
Appendix 2: Maps of ecosystems services


Water Runoff
(InVEST model)
N
Legend
Value
High : 1
Low : 0

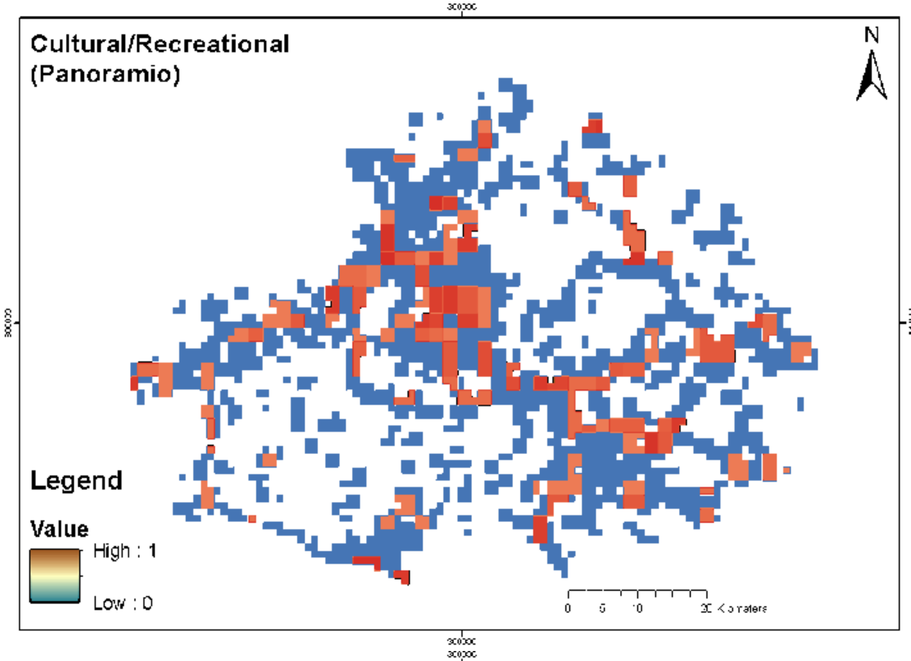

Crops Potential Production
(MODIS)
N
Legend
Value
High : 1
Low : 0

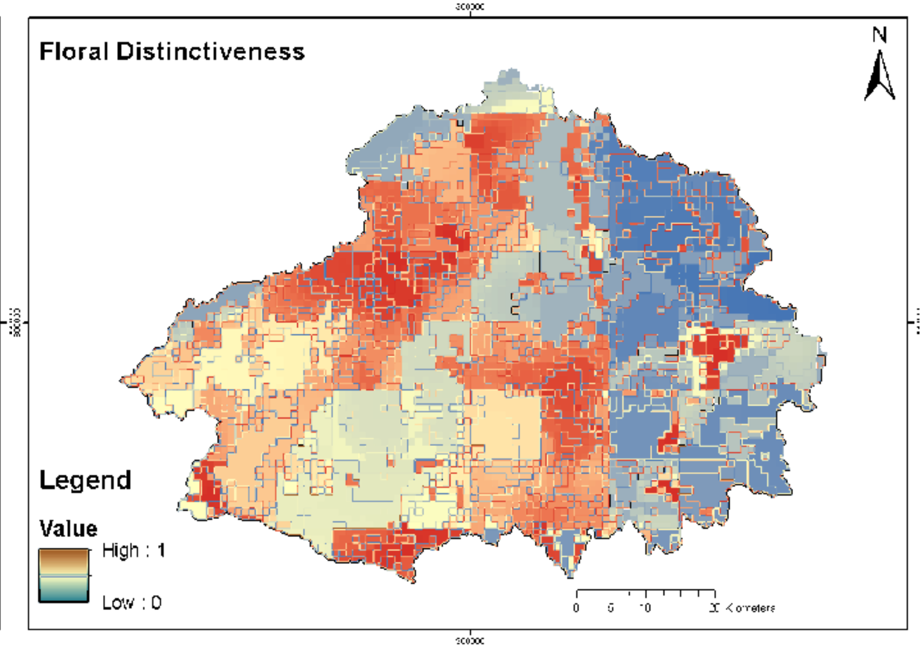

Cattle Density
(Source: Edina 2013)
N
Legend
Value
High : 1
Low : 0

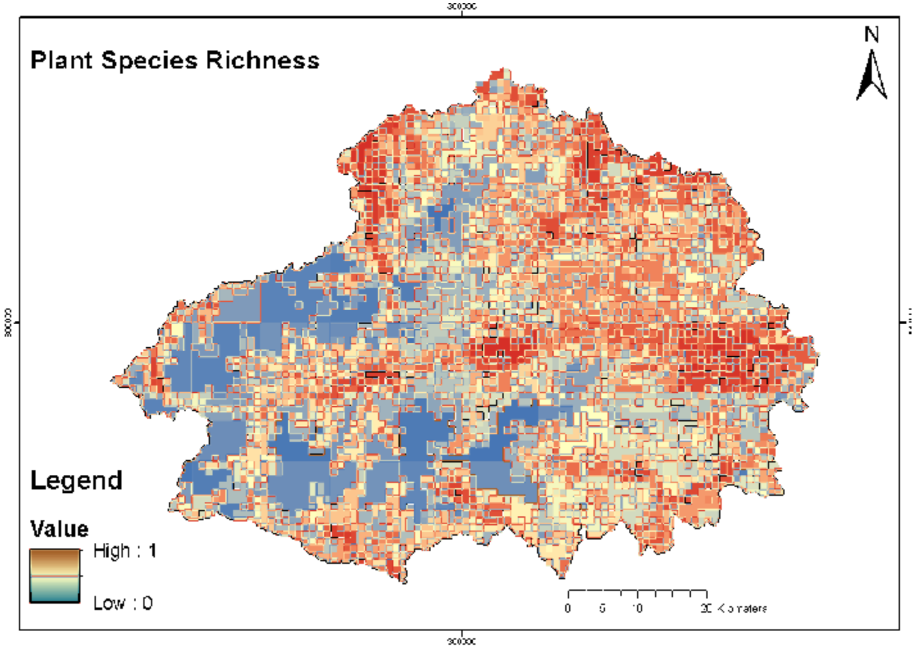

Sheep Density
(Source: Edina 2013)
N
Legend
Value
High : 1
Low : 0

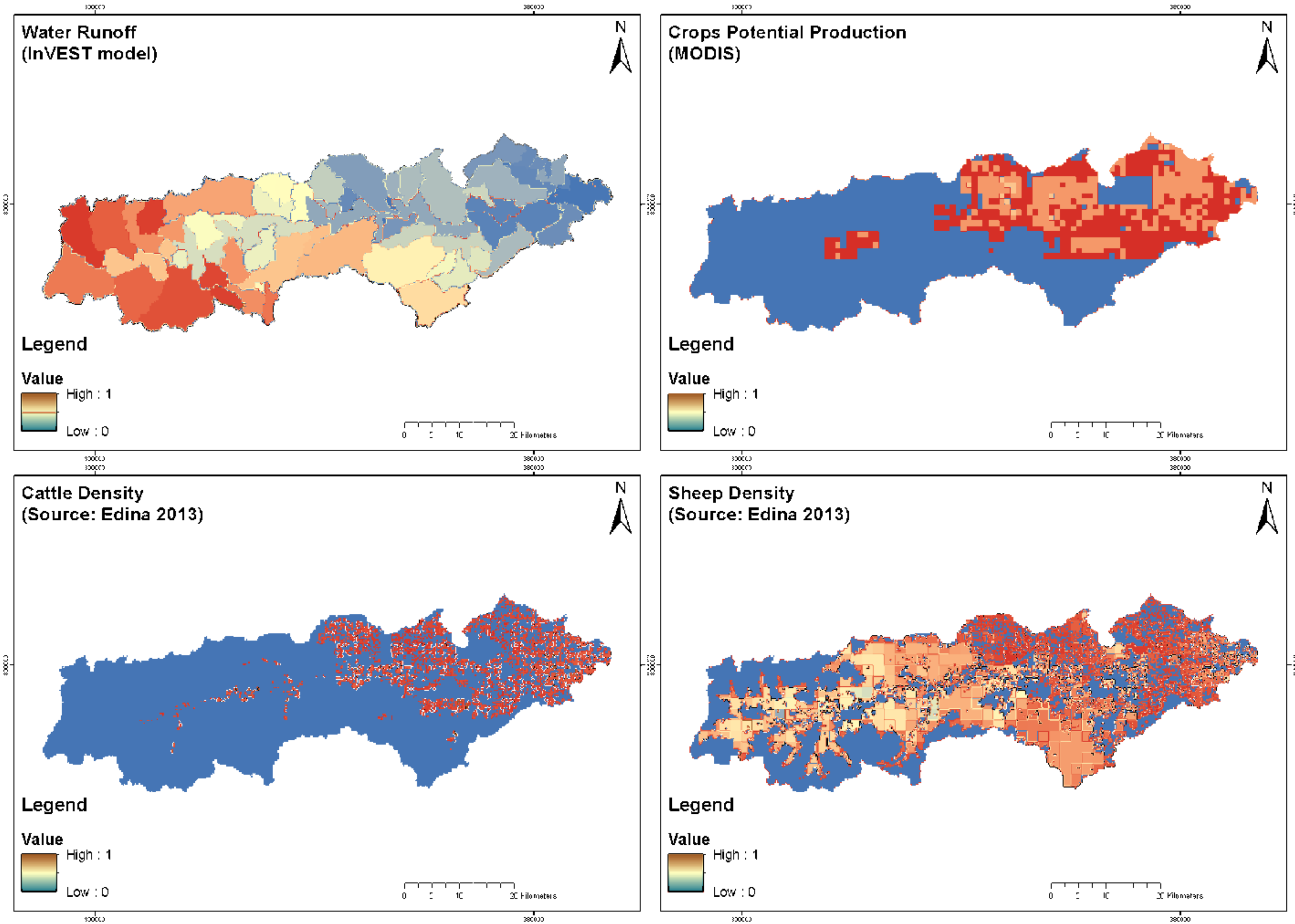


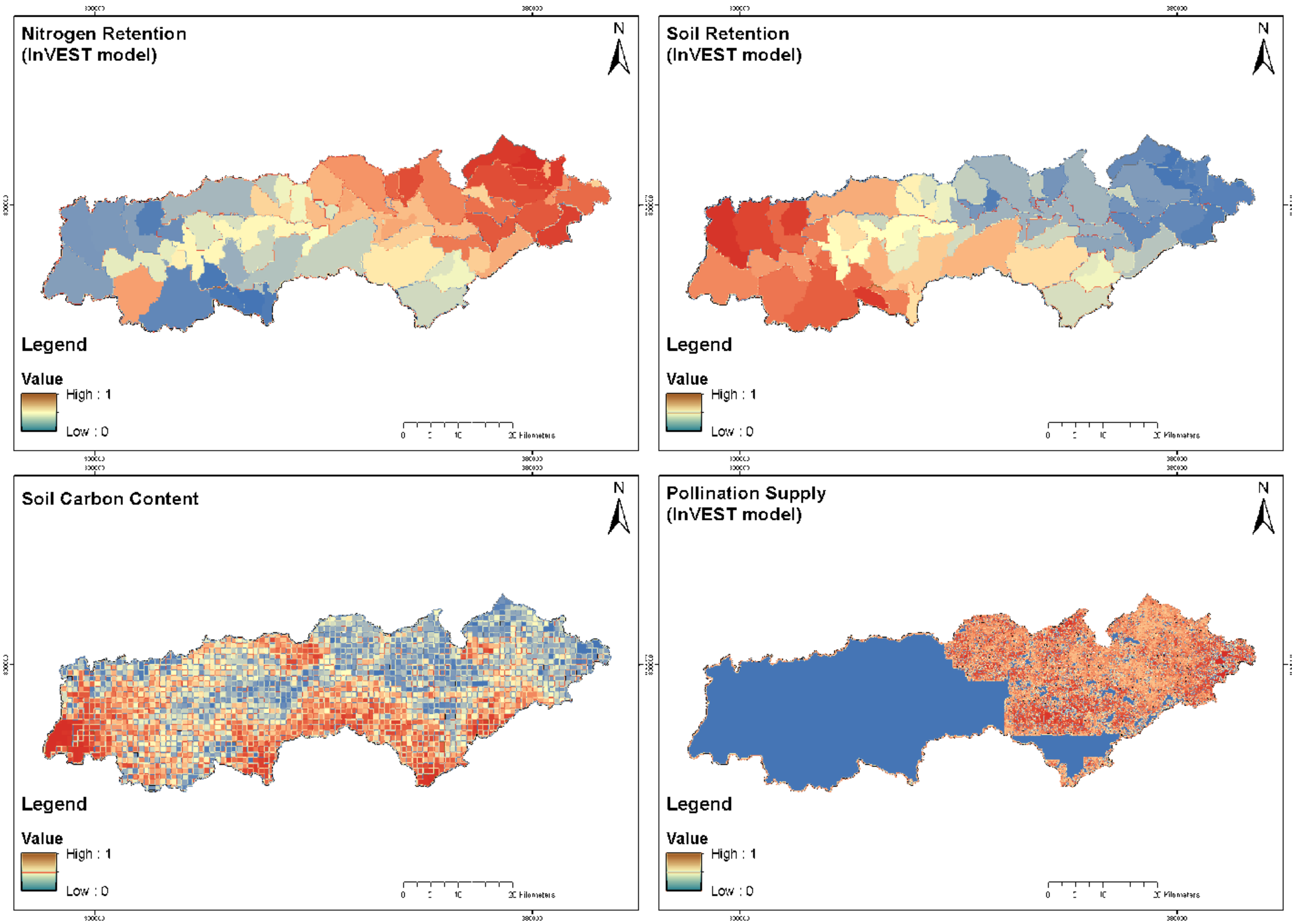
Nitrogen Retention
(InVEST model)
N
Legend
Value
High : 1
Low : 0
Soil Retention
(InVEST model)
N
Legend
Value
High : 1
Low : 0
Soil Carbon content
N
Legend
Value
High : 1
Low : 0
Pollination Supply
(InVEST model)
N
Legend
Value
High : 1
Low : 0

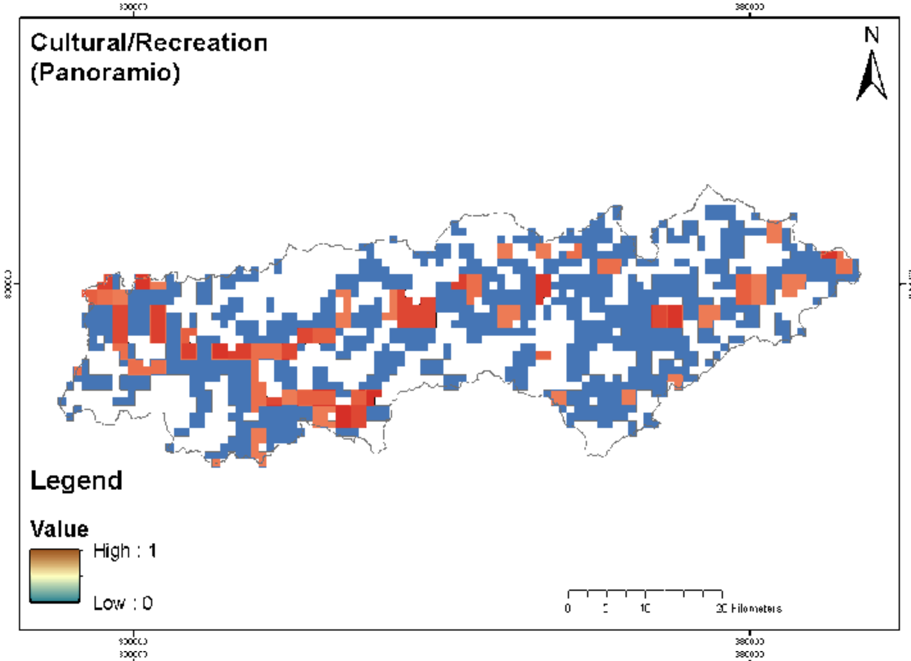

Cultural/Recreational
(Panoramio)
N
Legend
Value
High : 1
Low : 0

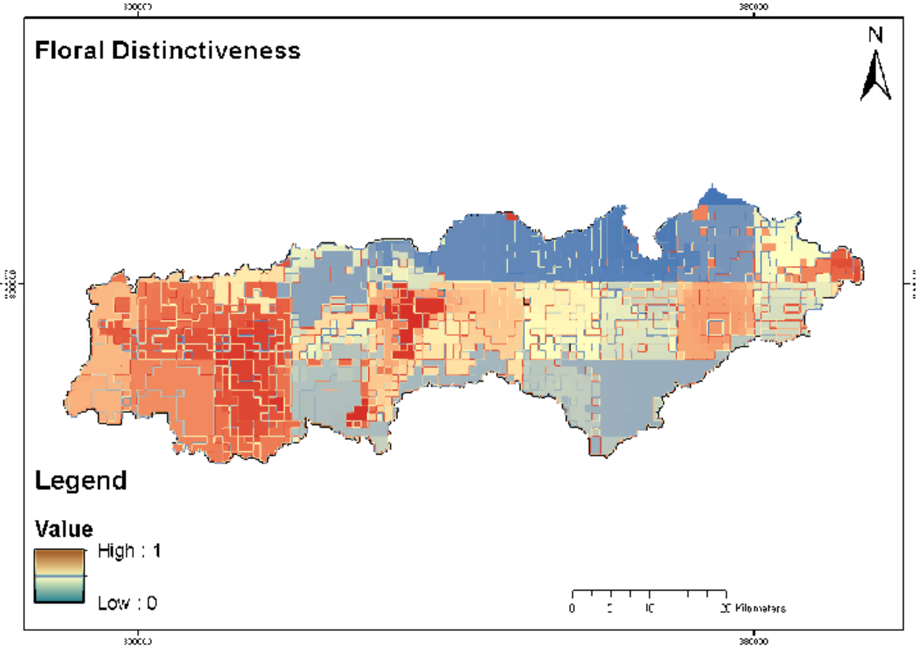

Floral Distinctiveness
N
Legend
Value
High : 1
Low : 0

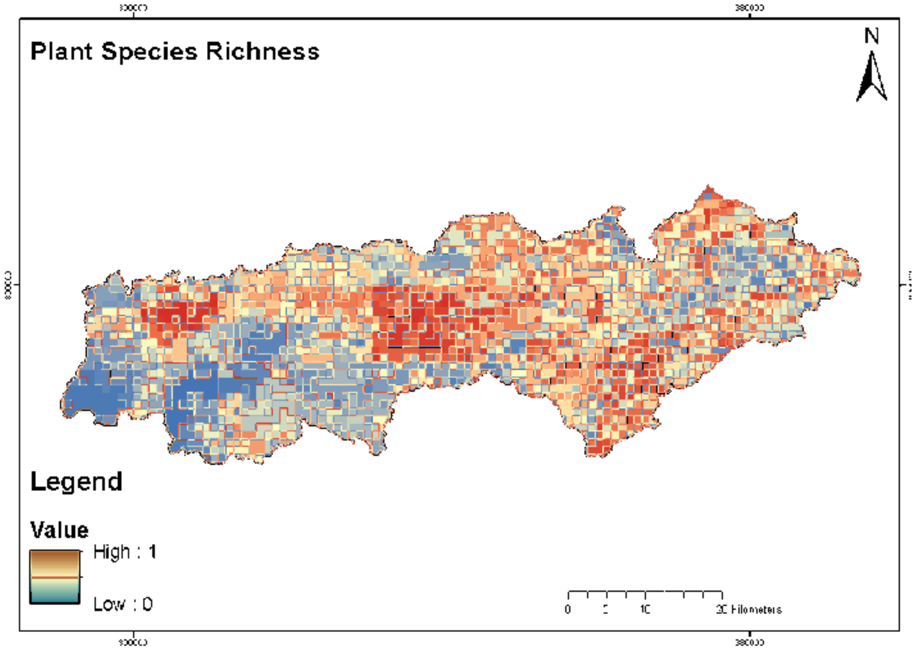

Plant Species Richness
N
Legend
Value
High : 1
Low : 0

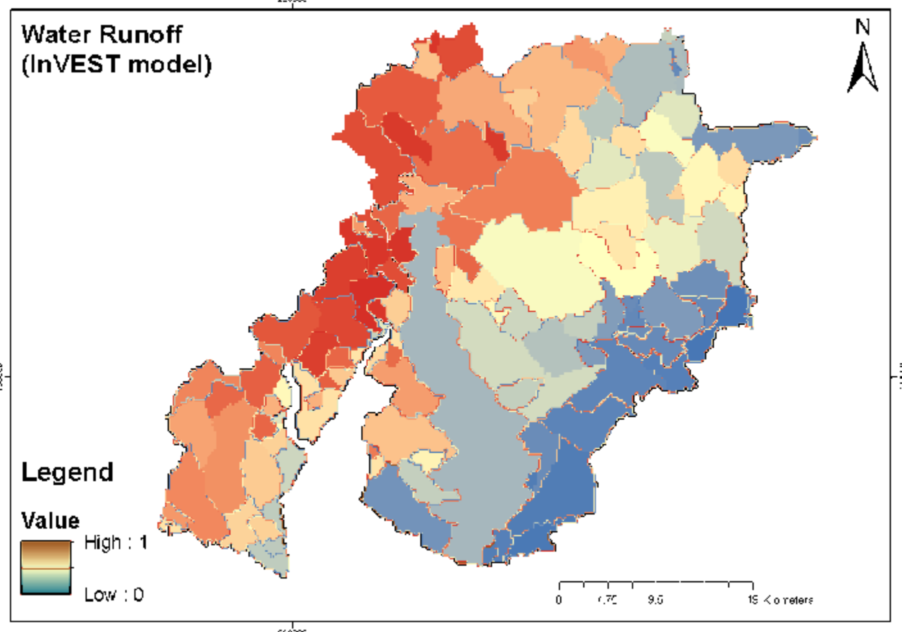

Water Runoff
(InVEST model)
N
Legend
Value
High : 1
Low : 0
Crops Potential Production
(MODIS)
N
Legend
Value
High : 1
Low : 0
Cattle Density
(Source: Edina 2013)
N
Legend
Value
High : 1
Low : 0
Sheep Density
(Source: Edina 2013)
N
Legend
Value
High : 1
Low : 0

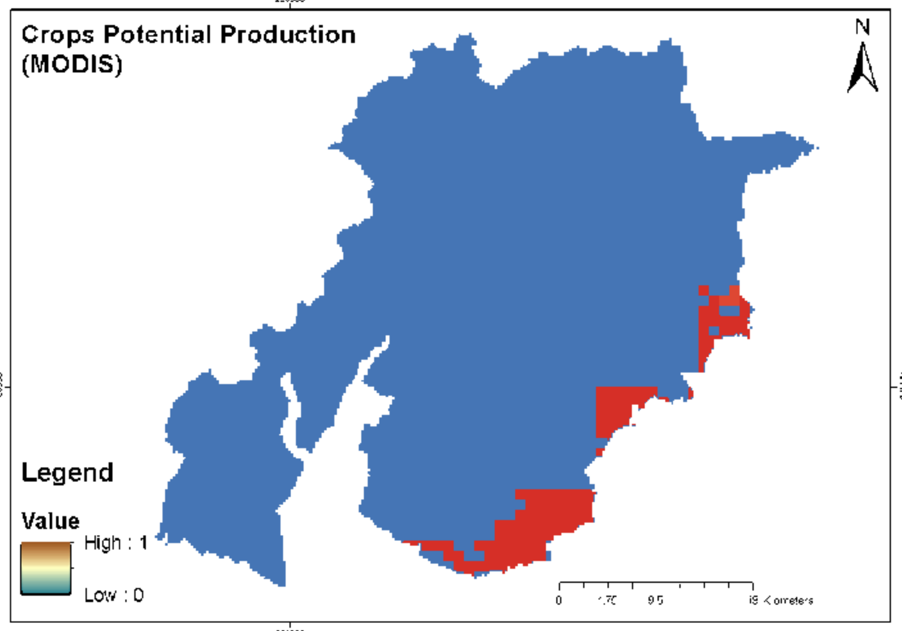

Nitrogen Retention
(InVEST model)
N
Legend
Value
High : 1
Low : 0
Kilometers
Soil Retention
(InVEST model)
N
Legend
Value
High : 1
Low : 0
Kilometers
Soil Carbon Content
N
Legend
Value
High : 1
Low : 0
Kilometers
Pollination Supply
(InVEST model)
N
Legend
Value
High : 1
Low : 0
Kilometers

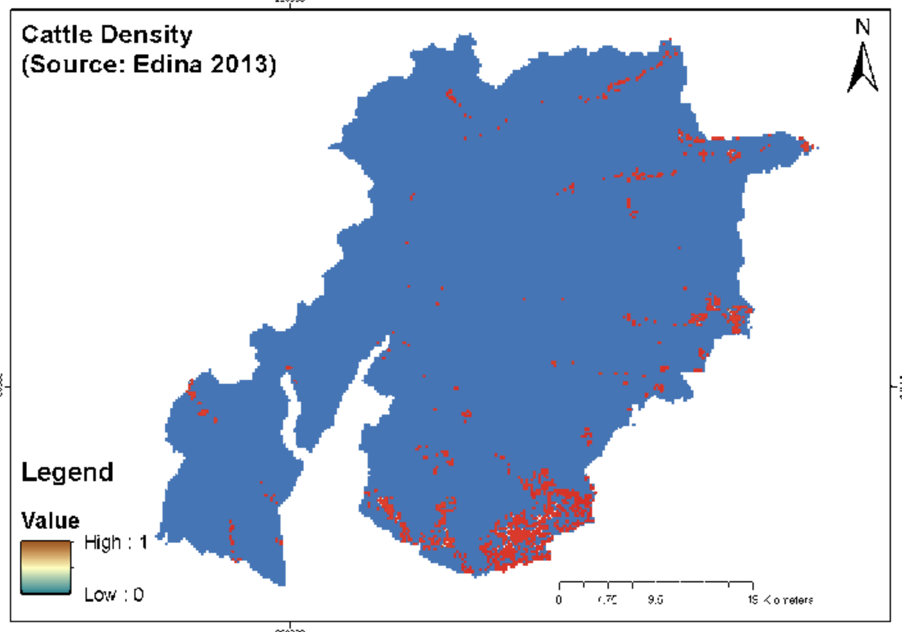

Cultural/Recreation
(Panoramio)
N
Legend
Value
High : 1
Low : 0
Kilometers

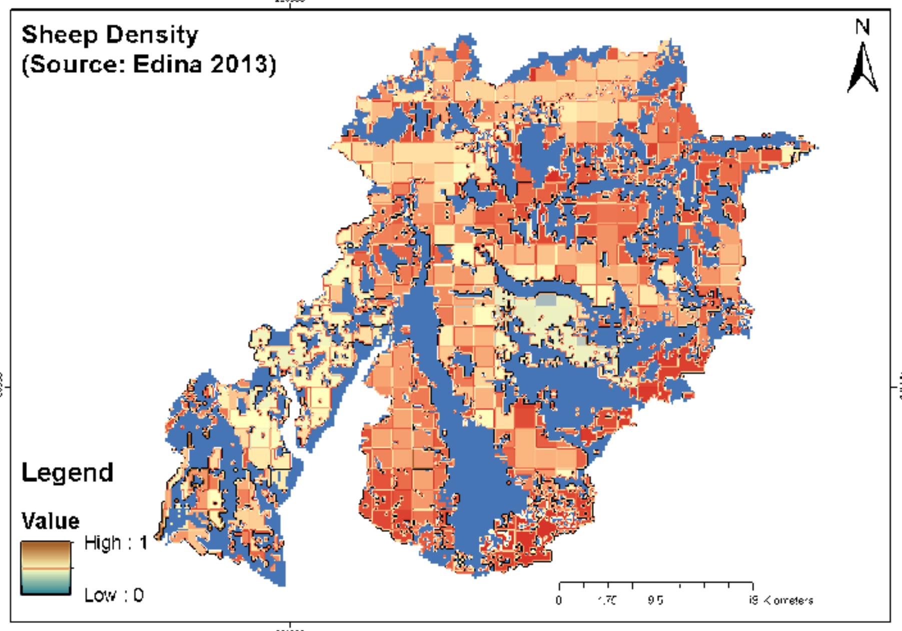

Floral Distinctiveness
N
Legend
Value
High : 1
Low : 0
Kilometers

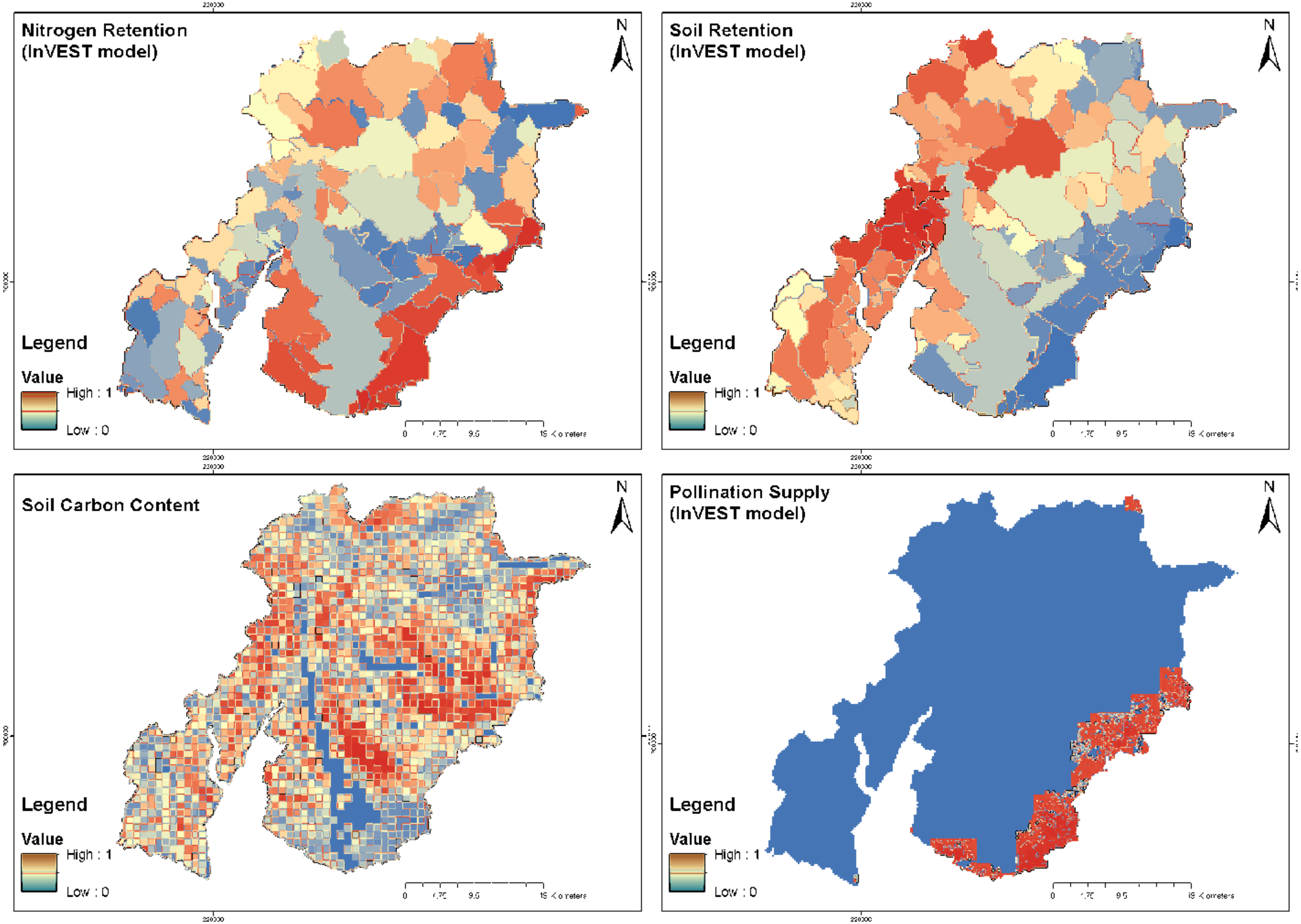

Plant Species Richness
N
Legend
Value
High : 1
Low : 0
Kilometers


Water Runoff
(InVEST model)
N
Legend
Value
High : 1
Low : 0

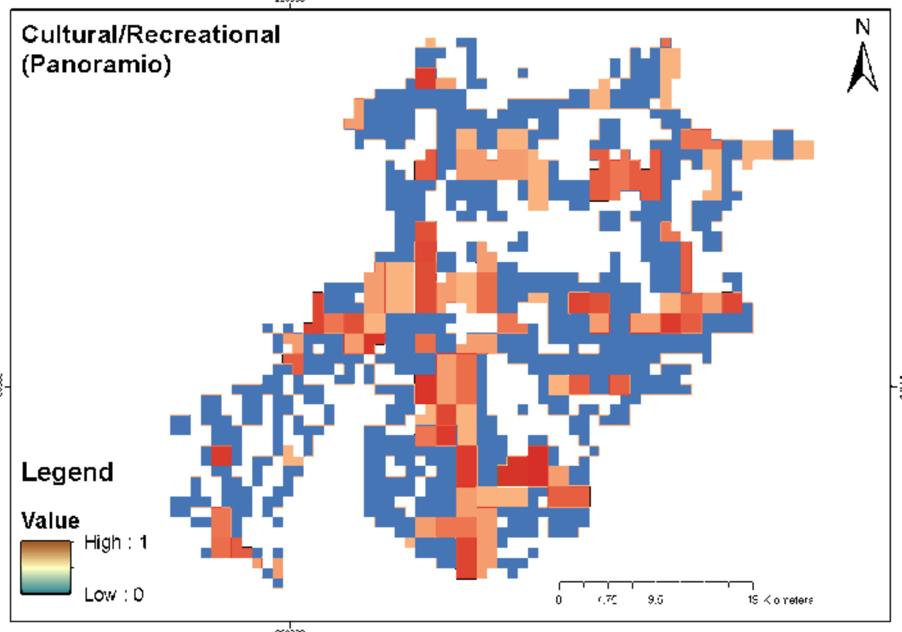

Crops Potential Production
(MODIS)
N
Legend
Value
High : 1
Low : 0

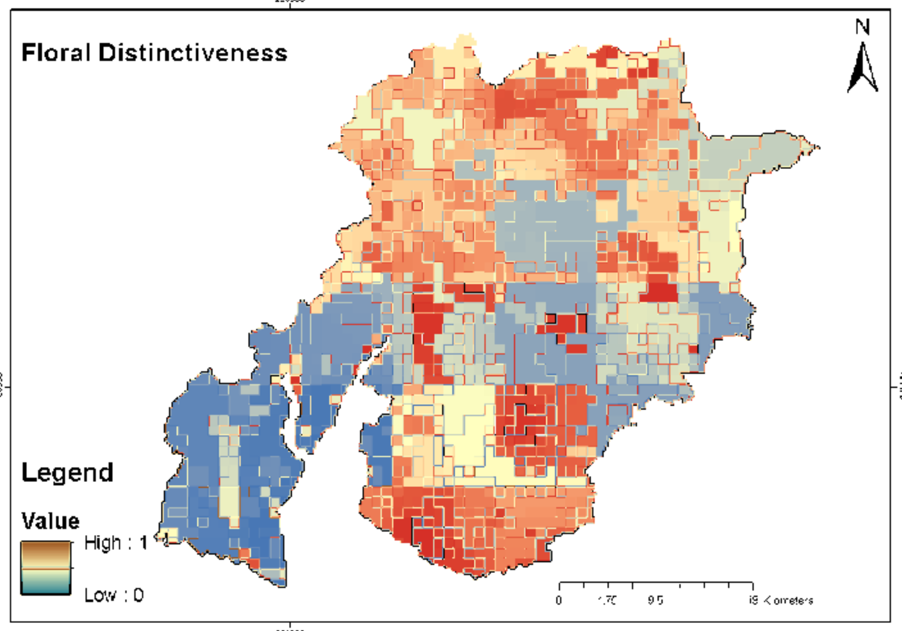

Cattle Density
(Source: Edina 2013)
N
Legend
Value
High : 1
Low : 0

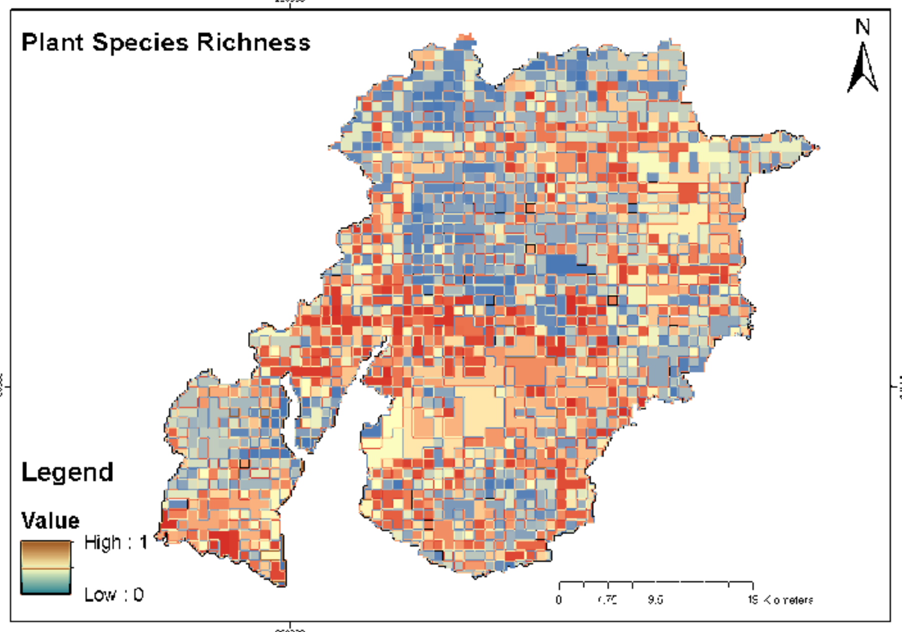

Sheep Density
(Source: Edina 2013)
N
Legend
Value
High : 1
Low : 0



Nitrogen Retention
(InVEST model)
N
Legend
Value
High : 1
Low : 0
Soil Retention
(InVEST model)
N
Legend
Value
High : 1
Low : 0
Soil Carbon Content
N
Legend
Value
High : 1
Low : 0
Pollination Supply
(InVEST model)
N
Legend
Value
High : 1
Low : 0


Cultural/Recreational
(Panoramio)
N
Legend
Value
High : 1
Low : 0


Floral Distinctiveness
N
Legend
Value
High : 1
Low : 0


Plant Species Richness
N
Legend
Value
High : 1
Low : 0

Appendix 3: Supporting tables for processing of Integrated Administration and Control System (IACS) data

Appendix 3.1: Aggregated classes and IACS Field codes used for classification for the IACS predominant land use dataset, simple crops classification

Code	Aggregate land class	Land Use Codes (IACS database)
	Arable	[AGRI] + [AMCP] + [ARTC] + [ASPG] + [ASSF] + [BEAN] + [BEAN_E] + [BFLO] + [BFLO_E] + [BKB] + [BLB] + [BLR] + [BLR_OPEN] + [BLR_POLY] + [BLU_GLS] + [BLU_OPEN] + [BLU_POLY] + [BOR] + [BPP] + [BSFS] + [BSP] + [BW] + [BW_E] + [CABB] + [CALA] + [CANS] + [CANS_E] + [CARR] + [CAUL] + [CMIX] + [CRB] + [DW] + [DW_E] + [ENG_BEET] + [FB] + [FFS] + [FFS_E] + [GCM] + [GSB] + [HS] + [HS_E] + [HZL] + [LEEK] + [LETT] + [LGB] + [LIN] + [LIN_E] + [MAIZ] + [MAIZ_E] + [MC] + [MC_E] + [MIL] + [MIL_E] + [MLB] + [NF_BOR] + [NF_CRBE] + [NF_HEAR] + [NF_IB] + [NF_IHS] + [NF_ILIN] + [NF_IO] + [NF_IOSR] + [NF_IOTH] + [NF_IPOT] + [NF_IS] + [NF_IW] + [NF_OPL] + [NS_BF] + [NS_MU] + [NS_OL] + [NS_P] + [NS_WBC] + [NU_FS] + [NU_RRS] + [NU_SH] + [NURS] + [OCS] + [OCS_B] + [OCS_K] + [ONU] + [OSFRT] + [OTH] + [OVEG] + [OVEG_E] + [PEAS] + [PEAS_E] + [PP] + [PSTS] + [RASP] + [RASP_GLS] + [RASP_OPEN] + [RASP_POLY] + [RAST] + [RHB] + [RRC] + [RYE] + [RYE_E] + [SAAP_A] + [SAAP_F] + [SAAP_PROT] + [SB] + [SB_E] + [SC] + [SC_E] + [SFRT] + [SFRT_E] + [SL] + [SO] + [SO_E] + [SOR] + [SOR_E] + [SOSR] + [SOSR_E] + [SPOT] + [SPOT_E] + [STRB] + [STRB_GLS] + [STRB_OPEN] + [STRB_POLY] + [STS] + [STS_E] + [SW] + [SW_E] + [TFRT] + [TFRT_E] + [TRIT] + [TRIT_E] + [TSWS] + [TURF] + [WB] + [WB_E] + [WBS] + [WCC] + [WO] + [WO_E] + [WOSR] + [WOSR_E] + [WPOT] + [WPOT_E] + [WRC] + [WW] + [WW_E]
	Temporary Grassland	[TGRS]
	Improved Grassland	[MSC] + [MSC_E] + [NS_G] + [NS_GCM] + [PGRS] + [RCG] + [RCG_E]
	Semi-Natural areas	[COMM] + [FALW] + [FALW_5] + [LIEM] + [NS_NRC] + [NS_NRO] + [NS_SAS_W] + [PEM] + [RGR] + [SHAR] + [SS_EH]
	Woodland	[ALMS] + [EX_SS] + [NEWTRS] + [NF_SRC] + [NF_TSB] + [NS_5S_FWS] + [NS_5S_WGS] + [NU_OT] + [SRC] + [SRC_E] + [SS_WP] + [SS_X5] + [TSB] + [WAF] + [WAFF] + [WAFF_LMCMS] + [WDG] + [WLN]
	Water	[PRSL]
	Inland Rock	[SCR]
	Urban	[RYB]
	Unclassified	[NS_OWN] + [UCL]
	Land Let Out (LLO)	Total parcel area – Total claims
	No Claim	Total parcel area = 0

Appendix 3.2: Aggregated classes and IACS Field codes used for classification for the IACS predominant land use dataset, extended crops classification

Code	**Aggregate land class**	**Land Use Codes (IACS database)**
	Winter Wheat	[WW] + [WW_E]
	Spring Barley	[SB] + [SB_E]
	Winter Barley	[WB] + [WB_E]
	Oats	[WO] + [WO_E] + [SO] + [SO_E] + [NF_IO]
	Potatoes	[WPOT] + [WPOT_E] + [SPOT] + [SPOT_E] + [NF_IPOT]

	Rape	[WOSR] + [WOSR_E] + [NF_HEAR] + [NF_IOSR] + [SOSR] + [SOSR_E] + [RAST]
	Other Arable	[AGRI] + [AMCP] + [ARTC] + [ASPG] + [BEAN] + [BEAN_E] + [BFLO] + [BFLO_E] + [BKB] + [BLB] + [BLR] + [BOR] + [BPP] + [BSFS] + [BSP] + [BW] + [BW_E] + [CABB] + [CALA] + [CANS] + [CANS_E] + [CARR] + [CAUL] + [CMIX] + [CRB] + [DW] + [DW_E] + [FB] + [FFS] + [FFS_E] + [GCM] + [GSB] + [HS] + [HS_E] + [HZL] + [LEEK] + [LETT] + [LGB] + [LIN] + [LIN_E] + [MAIZ] + [MAIZ_E] + [MC] + [MC_E] + [MIL] + [MIL_E] + [MLB] + [NF_BOR] + [NF_CRBE] + [NF_IB] + [NF_IHS] + [NF_ILIN] + [NF_IOTH] + [NF_IS] + [NF_IW] + [NF_OPL] + [NS_BF] + [NS_MU] + [NS_OL] + [NS_P] + [NS_WBC] + [NU_FS] + [NU_RRS] + [NU_SH] + [NURS] + [OCS] + [OCS_B] + [OCS_K] + [ONU] + [OSFRT] + [OTH] + [OVEG] + [OVEG_E] + [PEAS] + [PEAS_E] + [PP] + [PSTS] + [RASP] + [RHB] + [RRC] + [RYE] + [RYE_E] + [SAAP_A] + [SAAP_F] + [SAAP_PROT] + [SC] + [SC_E] + [SFRT] + [SFRT_E] + [SL] + [SOR] + [SOR_E] + [STRB] + [STS] + [STS_E] + [SW] + [SW_E] + [TFRT] + [TFRT_E] + [TRIT] + [TRIT_E] + [TSWS] + [TURF] + [WBS] + [WCC] + [WRC]
	Temporary Grassland	[TGRS]
	Improved Grassland	[MSC_E] + [NS_G] + [NS_GCM] + [PGRS] + [RCG_E]
	Semi Natural	[COMM] + [FALW] + [LIEM] + [NS_NRC] + [NS_NRO] + [NS_SAS_W] + [PEM] + [RGR] + [SHAR] + [SS_EH]
	Woodland	[ALMS] + [EX_SS] + [NF_SRC] + [NF_TSB] + [NS_5S_FWS] + [NS_5S_WGS] + [NU_OT] + [SRC] + [SRC_E] + [SS_WP] + [SS_X5] + [TSB] + [WAF] + [WAFF] + [WAFF_LMCMS] + [WDG] + [WLN]
	Water	[PRSL]
	Inland Rock	[SCR]
	Urban	[RYB]
	Unclassified	[NS_OWN] + [UCL]
	Land Let Out (LLO)	Total parcel area – Total claims
	No Claim	Total parcel area = 0

Appendix 3.3: IACS full categories, land use codes, and grouped category used for IACS predominant land use 2008-15 map series.

NB. 2007 codes relate to the 2008 map, 2009 codes to the 2010 map, and 2014 codes to the 2015 map.

Land Use Short Code	Decode	Grouped Category (DGM v2)	2007	2009	2014
AGRI	SFPS BEING CLAIMED ON AGRI-ENVIRONMENTAL OPTIONS	Arable	AGRI	AGRI	
ALMS	ALMONDS	Woodland	ALMS	ALMS	ALMS
AMCP	AROMATIC, MEDICAL AND CULINARY PLANTS	Arable	AMCP	AMCP	AMCP
ARTC	ARTICHOKES	Arable	ARTC	ARTC	ARTC
ASPG	ASPARAGUS	Arable	ASPG	ASPG	ASPG
ASSF	ARABLE SILAGE FOR STOCK FEED	Arable	ASSF		ASSF
BEAN	BEANS FOR HUMAN CONSUMPTION	Arable	BEAN	BEAN	BEAN
BEAN_E	BEANS FOR HUMAN CONSUMPTION ENERGY	Arable	BEAN_E	BEAN_E	
BFLO	BULBS FLOWERS	Arable	BFLO	BFLO	BFLO
BFLO_E	BULBS FLOWERS ENERGY	Arable	BFLO_E	BFLO_E	
BKB	BLACKBERRIES	Arable	BKB	BKB	BKB
BLB	BILBERRIES (AND OTHER FRUITS OF THE GENUS VACCINIUM)	Arable	BLB	BLB	BLB
BLR	BLACKCURRANTS	Arable	BLR	BLR	
BLR_OPEN	BLACKCURRANTS GROWN IN THE OPEN	Arable	BLR_OPEN		
BLR_POLY	BLACKCURRANTS GROWN IN OPEN SOIL UNDER TEMPORARY WALK-IN STRUCTURES	Arable	BLR_POLY		
BLROPEN	BLACKCURRANTS GROWN IN THE OPEN	Arable			BLROPEN
BLRPOLY	BLACKCURRANTS GROWN IN OPEN SOIL UNDER TEMPORARY WALK-IN STRUCTURES	Arable			BLRPOLY
BLU_GLS	Blueberries - Grown under glass	Arable	BLU_GLS		
BLU_OPEN	Blueberries - Grown in the open	Arable	BLU_OPEN		
BLU_POLY	Blueberries - Grown in open soil under temporary walk-in structures	Arable	BLU_POLY		
BLUOPEN	Blueberries - Grown in the open	Arable			BLUOPEN
BLUPOLY	Blueberries - Grown in open soil under temporary walk-in structures	Arable			BLUPOLY
BOR	BORAGE	Arable	BOR	BOR	
BPP	BEDDING AND POT PLANTS	Arable	BPP	BPP	BPP
BSFS	FLOWER BULBS AND CUT FLOWERS	Arable	BSFS	BSFS	
BSP	BRUSSEL SPROUTS	Arable	BSP	BSP	BSP
BW	BUCKWHEAT	Arable	BW	BW	BW
BW_E	BUCKWHEAT ENERGY	Arable	BW_E	BW_E	
CABB	CABBAGES	Arable	CABB	CABB	CABB
CALA	CALABRESE	Arable	CALA	CALA	CALA
CANS	CANARY SEED	Arable	CANS	CANS	CANS
CANS_E	CANARY SEED ENERGY	Arable	CANS_E	CANS_E	
CARR	CARROTS	Arable	CARR	CARR	CARR
CAUL	CAULIFLOWER	Arable	CAUL	CAUL	CAUL
CMIX	ARABLE SILAGE FOR STOCK FEED	Arable	CMIX	CMIX	

COMM	COMMON GRAZING	Semi-Natural	COMM	COMM	COMM
CRB	CRANBERRIES	Arable	CRB	CRB	
DW	DURUM WHEAT	Arable	DW	DW	
DW_E	DURUM WHEAT ENERGY	Arable	DW_E	DW_E	
ENG_BEET	ENERGY BEET	Arable	ENG_BEET		
EX_SS	EX STRUCTURAL SET-ASIDE (AFFORESTED LAND ELIGIBLE FOR SFPS)	Woodland	EX_SS	EX_SS	
EXSS	EX STRUCTURAL SET-ASIDE (AFFORESTED LAND ELIGIBLE FOR SFPS)	Woodland			EXSS
FALW	FALLOW	Semi-Natural	FALW	FALW	FALW
FALW_5	FALLOW LAND FOR MORE THAN 5 YEARS	Semi-Natural	FALW_5		
FALW5	FALLOW LAND FOR MORE THAN 5 YEARS	Semi-Natural			FALW5
FB	FIELD BEANS	Arable	FB	FB	FB
FFS	FIBRE FLAX	Arable	FFS	FFS	
FFS_E	FIBRE FLAX ENERGY	Arable	FFS_E	FFS_E	
GCM	GREEN COVER MIXTURE	Arable	GCM	GCM	GCM
GSB	GOOSEBERRIES	Arable	GSB	GSB	GSB
HS	HEMP	Arable	HS	HS	
HS_E	HEMP ENERGY	Arable	HS_E	HS_E	
HZL	HAZELNUTS	Arable	HZL	HZL	
LEEK	LEEKS	Arable	LEEK	LEEK	LEEK
LETT	LETTUCE	Arable	LETT	LETT	LETT
LGB	LOGANBERRIES	Arable	LGB	LGB	LGB
LIEM	LFASS INELIGIBLE ENVIRONMENTAL MANAGEMENT	Semi-Natural	LIEM	LIEM	LIEM
LIN	LINSEED	Arable	LIN	LIN	LIN
LIN_E	LINSEED ENERGY	Arable	LIN_E	LIN_E	
LLO	LAND LET OUT TO OTHERS	Arable			LLO
MAIZ	MAIZE	Arable	MAIZ	MAIZ	MAIZ
MAIZ_E	MAIZE ENERGY	Arable	MAIZ_E	MAIZ_E	
MC	MIXED CEREALS	Arable	MC	MC	MC
MC_E	MIXED CEREALS ENERGY	Arable	MC_E	MC_E	
MIL	MILLET	Arable	MIL	MIL	
MIL_E	MILLET ENERGY	Arable	MIL_E	MIL_E	
MLB	MULBERRIES	Arable	MLB	MLB	
MSC	MISCANTHUS	Improved Grassland	MSC		MSC
MSC_E	MISCANTHUS ENERGY	Improved Grassland	MSC_E	MSC_E	
NEWTRS	NEW WOODLAND (ELIGIBLE FOR SFPS)	Woodland	NEWTRS		NEWTRS
NF_BOR	NON-FOOD SETASIDE – BORAGE	Arable	NF_BOR	NF_BOR	
NF_CRBE	NON-FOOD SETASIDE - CRAMBE FOR INDUSTRIAL USE	Arable	NF_CRBE	NF_CRBE	
NF_HEAR	NON-FOOD SETASIDE - HIGH ERUCIC ACID RAPESEED	Arable	NF_HEAR	NF_HEAR	
NF_IB	NON-FOOD SETASIDE - BARLEY FOR INDUSTRIAL USE	Arable	NF_IB	NF_IB	
NF_IHS	NON-FOOD SETASIDE - HEMP	Arable	NF_IHS	NF_IHS	
NF_ILIN	NON-FOOD SETASIDE - LINSEED FOR INDUSTRIAL USE	Arable	NF_ILIN	NF_ILIN	
NF_IO	NON-FOOD SETASIDE - OATS FOR INDUSTRIAL USE	Arable	NF_IO	NF_IO	

NF_IOSR	NON-FOOD SETASIDE - OILSEED RAPE FOR INDUSTRIAL USE	Arable	NF_IOSR	NF_IOSR	
NF_IOTH	NON-FOOD SETASIDE - OTHER CROPS FOR INDUSTRIAL USE	Arable	NF_IOTH	NF_IOTH	
NF_IPOT	NON-FOOD SETASIDE - POTATOES FOR INDUSTRIAL USE	Arable	NF_IPOT	NF_IPOT	
NF_IS	NON-FOOD SETASIDE - SOYA FOR INDUSTRIAL USE	Arable	NF_IS	NF_IS	
NF_IW	NON-FOOD SETASIDE - WHEAT FOR INDUSTRIAL USE	Arable	NF_IW	NF_IW	
NF_OPL	NON-FOOD SETASIDE - OUTDOOR PLANTS	Arable	NF_OPL	NF_OPL	
NF_SRC	NON-FOOD SETASIDE - FOREST TREES SHORT CYCLE	Woodland	NF_SRC	NF_SRC	
NF_TSB	NON-FOOD SETASIDE - TREES SHRUBS AND BUSHES	Woodland	NF_TSB	NF_TSB	
NS_5S_FWS	NORMAL SETASIDE - 5 YEAR UNDER FWS	Woodland	NS_5S_FWS	NS_5S_FWS	
NS_5S_WGS	NORMAL SETASIDE - 5 YEAR UNDER WGS	Woodland	NS_5S_WGS	NS_5S_WGS	
NS_BF	NORMAL SETASIDE - BARE FALLOW	Arable	NS_BF	NS_BF	
NS_G	NORMAL SETASIDE - SOWN GRASS COVER	Improved Grassland	NS_G	NS_G	
NS_GCM	NORMAL SETASIDE - GREEN COVER MIXTURE	Improved Grassland	NS_GCM	NS_GCM	
NS_MU	NORMAL SETASIDE - MUSTARD	Arable	NS_MU	NS_MU	
NS_NRC	NORMAL SETASIDE - NAT REGEN (AFTER CEREALS)	Semi-Natural	NS_NRC	NS_NRC	
NS_NRO	NORMAL SETASIDE - NAT REGEN (AFTER OTHER CROPS)	Semi-Natural	NS_NRO	NS_NRO	
NS_OL	NORMAL SETASIDE - ORGANIC LEGUMES	Arable	NS_OL	NS_OL	
NS_OWN	NORMAL SETASIDE - OWN MANAGEMENT PLAN	Unclassified	NS_OWN	NS_OWN	
NS_P	NORMAL SETASIDE - PHACELIA	Arable	NS_P	NS_P	
NS_SAS_W	NORMAL SETASIDE - NEXT TO WATERCOURSES,HEDGES,WOODS,DYKES AND SSSIs	Semi-Natural	NS_SAS_W	NS_SAS_W	
NS_WBC	NORMAL SETASIDE - WILD BIRD COVER	Arable	NS_WBC	NS_WBC	
NU_FS	NURSERY - FRUIT STOCK	Arable	NU_FS	NU_FS	
NU_OT	NURSERY - ORNAMENTAL TREES	Woodland	NU_OT	NU_OT	
NU_RRS	NURSERY - ROSES AND ROSE STOCK	Arable	NU_RRS	NU_RRS	
NU_SH	NURSERY - SHRUBS	Arable	NU_SH	NU_SH	
NUFS	NURSERY - FRUIT STOCK	Arable			NUFS
NUOT	NURSERY - ORNAMENTAL TREES	Woodland			NUOT
NURRS	NURSERY - ROSES AND ROSE STOCK	Arable			NURRS
NURS	NURSERIES	Arable	NURS	NURS	NURS
NUSH	NURSERY - SHRUBS	Arable			NUSH
OCS	OTHER CROPS FOR STOCK FEED	Arable	OCS	OCS	OCS
OCS_B	FODDER BEET	Arable	OCS_B	OCS_B	
OCS_K	KALE AND CABBAGES FOR STOCKFEED	Arable	OCS_K	OCS_K	
OCSB	FODDER BEET	Arable			OCSB
OCSK	KALE AND CABBAGES FOR STOCKFEED	Arable			OCSK
ONU	OTHER NURSERY STOCKS	Arable	ONU	ONU	ONU
OSFRT	OTHER SOFT FRUIT	Arable	OSFRT	OSFRT	OSFRT
OTH	OTHER LAND	Arable	OTH	OTH	OTH
OVEG	OTHER VEGETABLES	Arable	OVEG	OVEG	OVEG
OVEG_E	OTHER VEGETABLES ENERGY	Arable	OVEG_E	OVEG_E	
PEAS	PEAS FOR HUMAN CONSUMPTION	Arable	PEAS	PEAS	PEAS

PEAS_E	PEAS FOR HUMAN CONSUMPTION ENERGY	Arable	PEAS_E	PEAS_E	
PEM	POSITIVE ENVIRONMENTAL MANAGEMENT	Semi-Natural	PEM	PEM	PEM
PGRS	GRASS OVER 5 YEARS	Improved Grassland	PGRS	PGRS	PGRS
PP	PROTEIN PEAS	Arable	PP	PP	PP
PRSL	PONDS, RIVERS, STREAMS OR LOCHS	Water	PRSL	PRSL	PRSL
PSTS	PISTACHIOS	Arable	PSTS	PSTS	
RASP	RASPBERRIES	Arable	RASP	RASP	RASP
RASP_GLS	RASPBERRIES-GROWN UNDER GLASS	Arable	RASP_GLS		
RASP_OPEN	RASPBERRIES GROWN IN THE OPEN	Arable	RASP_OPEN		
RASP_POLY	RASPBERRIES GROWN IN OPEN SOIL UNDER TEMPORARY WALK-IN STRUCTURES	Arable	RASP_POLY		
RASPOPEN	RASPBERRIES GROWN IN THE OPEN	Arable			RASPOPEN
RASPPOLY	RASPBERRIES GROWN IN OPEN SOIL UNDER TEMPORARY WALK-IN STRUCTURES	Arable			RASPPOLY
RAST	RAPE FOR STOCK FEED	Arable	RAST	RAST	RAST
RCG	REED CANARY GRASS	Improved Grassland	RCG		RCG
RCG_E	REED CANARY GRASS ENERGY	Improved Grassland	RCG_E	RCG_E	
RGR	ROUGH GRAZING	Semi-Natural	RGR	RGR	RGR
RHB	RHUBARB	Arable	RHB	RHB	RHB
RRC	REDCURRANTS	Arable	RRC	RRC	RRC
RYB	ROADS, YARDS OR BUILDINGS	Urban	RYB	RYB	RYB
RYE	RYE	Arable	RYE	RYE	RYE
RYE_E	RYE ENERGY	Arable	RYE_E	RYE_E	
SAAP_A	SETASIDE AGRICULTURAL PRODUCTION - ARABLE	Arable	SAAP_A	SAAP_A	
SAAP_F	SETASIDE AGRICULTURAL PRODUCTION - FORAGE	Arable	SAAP_F	SAAP_F	
SAAP_PROT	SETASIDE AGRICULTURAL PRODUCTION - PROTEINS	Arable	SAAP_PROT	SAAP_PROT	
SB	SPRING BARLEY	Arable	SB	SB	SB
SB_E	SPRING BARLEY ENERGY	Arable	SB_E	SB_E	
SC	SWEETCORN	Arable	SC	SC	
SC_E	SWEETCORN ENERGY	Arable	SC_E	SC_E	
SCR	SCREE OR SCRUB	Inland Rock	SCR	SCR	SCR
SFRT	SOFT FRUIT	Arable	SFRT	SFRT	
SFRT_E	SOFT FRUIT ENERGY	Arable	SFRT_E	SFRT_E	
SHAR	SHARED GRAZING	Semi-Natural	SHAR	SHAR	
SL	SWEET LUPINS	Arable	SL	SL	SL
SO	SPRING OATS	Arable	SO	SO	SO
SO_E	SPRING OATS ENERGY	Arable	SO_E	SO_E	
SOR	SORGHUM	Arable	SOR	SOR	SOR
SOR_E	SORGHUM ENERGY	Arable	SOR_E	SOR_E	
SOSR	SPRING OILSEED RAPE	Arable	SOSR	SOSR	SOSR
SOSR_E	SPRING OILSEED RAPE ENERGY	Arable	SOSR_E	SOSR_E	
SPOT	SEED POTATOES	Arable	SPOT	SPOT	SPOT
SPOT_E	SEED POTATOES ENERGY	Arable	SPOT_E	SPOT_E	
SRC	SHORT ROTATION COPPICE	Woodland	SRC	SRC	SRC

SRC_E	SHORT ROTATION COPPICE ENERGY	Woodland	SRC_E	SRC_E	
SS_EH	STRUCTURAL SETASIDE - ELIGIBLE HABITATS	Semi-Natural	SS_EH	SS_EH	
SS_WP	STRUCTURAL SETASIDE - WGS, FWPS OR SFGS	Woodland	SS_WP	SS_WP	
SS_X5	STRUCTURAL SETASIDE - EX 5 YEAR STILL IN FWS	Woodland	SS_X5	SS_X5	
STRB	STRAWBERRIES	Arable	STRB	STRB	STRB
STRB_GLS	STRAWBERRIES-GROWN UNDER GLASS	Arable	STRB_GLS		
STRB_OPEN	STRAWBERRIES GROWN IN THE OPEN	Arable	STRB_OPEN		
STRB_POLY	STRAWBERRIES GROWN IN OPEN SOIL UNDER TEMPORARY WALK-IN STRUCTURES	Arable	STRB_POLY		
STRBGLS	STRAWBERRIES-GROWN UNDER GLASS	Arable			STRBGLS
STRBOPEN	STRAWBERRIES GROWN IN THE OPEN	Arable			STRBOPEN
STRBPOLY	STRAWBERRIES GROWN IN OPEN SOIL UNDER TEMPORARY WALK-IN STRUCTURES	Arable			STRBPOLY
STS	SHOPPING TURNIPS SWEDES	Arable	STS	STS	STS
STS_E	SHOPPING TURNIPS SWEDES ENERGY	Arable	STS_E	STS_E	
SW	SPRING WHEAT	Arable	SW	SW	SW
SW_E	SPRING WHEAT ENERGY	Arable	SW_E	SW_E	
TFRT	TOP FRUIT	Arable	TFRT	TFRT	TFRT
TFRT_E	TOP FRUIT ENERGY	Arable	TFRT_E	TFRT_E	
TGRS	GRASS UNDER 5 YEARS	Temporary Grassland	TGRS	TGRS	TGRS
TRIT	TRITICALE	Arable	TRIT	TRIT	TRIT
TRIT_E	TRITICALE ENERGY	Arable	TRIT_E	TRIT_E	
TSB	TREES SHRUBS & BUSHES	Woodland	TSB	TSB	TSB
TSWS	TURNIPS SWEDES FOR STOCK FEED	Arable	TSWS	TSWS	TSWS
TURF	TURF PRODUCTION	Arable	TURF	TURF	TURF
UCL	UNCLAIMED LAND	Unclassified	UCL	UCL	
WAF	WOODLAND AND FORESTRY	Woodland	WAF	WAF	WAF
WAFF	WOODLAND FORESTRY WITH UNIQUE FIELD IDENTIFIER	Woodland	WAFF	WAFF	
WAFF_LMCMS	WOODLAND FORESTRY WITH UNIQUE FIELD IDENTIFIER	Woodland	WAFF_LMCMS	WAFF_LMCMS	
WB	WINTER BARLEY	Arable	WB	WB	WB
WB_E	WINTER BARLEY ENERGY	Arable	WB_E	WB_E	
WBS	WILD BIRD SEED	Arable	WBS	WBS	WBS
WCC	WHOLE CROP CEREALS	Arable	WCC	WCC	WCC
WDG	OPEN WOODLAND(GRAZED)	Woodland	WDG	WDG	WDG
WLN	WALNUTS	Woodland	WLN	WLN	
WO	WINTER OATS	Arable	WO	WO	WO
WO_E	WINTER OATS ENERGY	Arable	WO_E	WO_E	
WOSR	WINTER OILSEED RAPE	Arable	WOSR	WOSR	WOSR
WOSR_E	WINTER OILSEED RAPE ENERGY	Arable	WOSR_E	WOSR_E	
WPOT	WARE POTATOES	Arable	WPOT	WPOT	WPOT
WPOT_E	WARE POTATOES ENERGY	Arable	WPOT_E	WPOT_E	
WRC	WHITECURRANTS	Arable	WRC	WRC	
WW	WINTER WHEAT	Arable	WW	WW	WW
WW_E	WINTER WHEAT ENERGY	Arable	WW_E	WW_E	

Appendix 4: Supporting data on errors and limitations in Integrated Administration and Control System (IACS) data

Appendix 4.1: Mapping errors in IACS data

Initial investigations carried out on receiving these data revealed some problems with polygon geometry namely overlapping polygons i.e. overlapping parcels of agricultural land. Since, in the real world, field boundaries do not overlap, these polygon overlaps are errors. Since the IACS database is in a continuous process of correction, recent editions suffer from these problems to a much lesser extent than earlier editions (Figure 2).

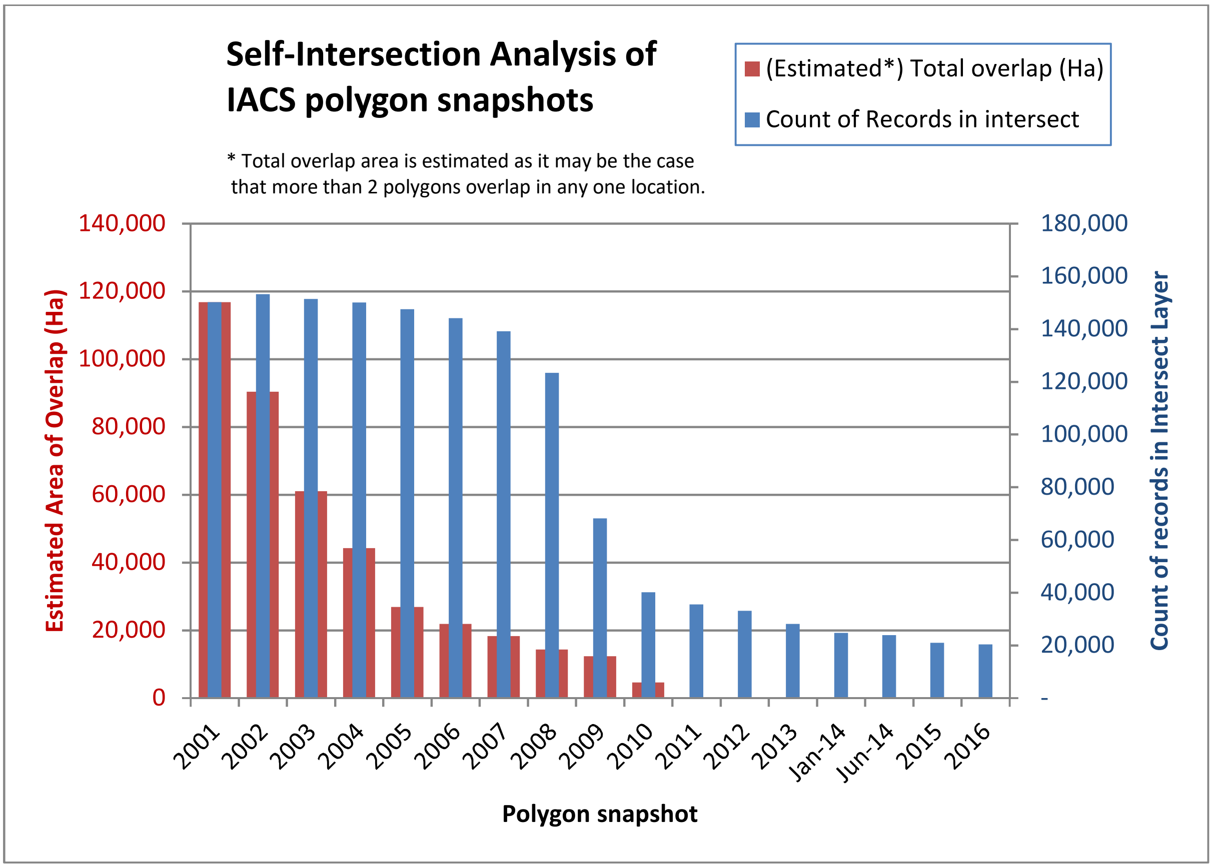
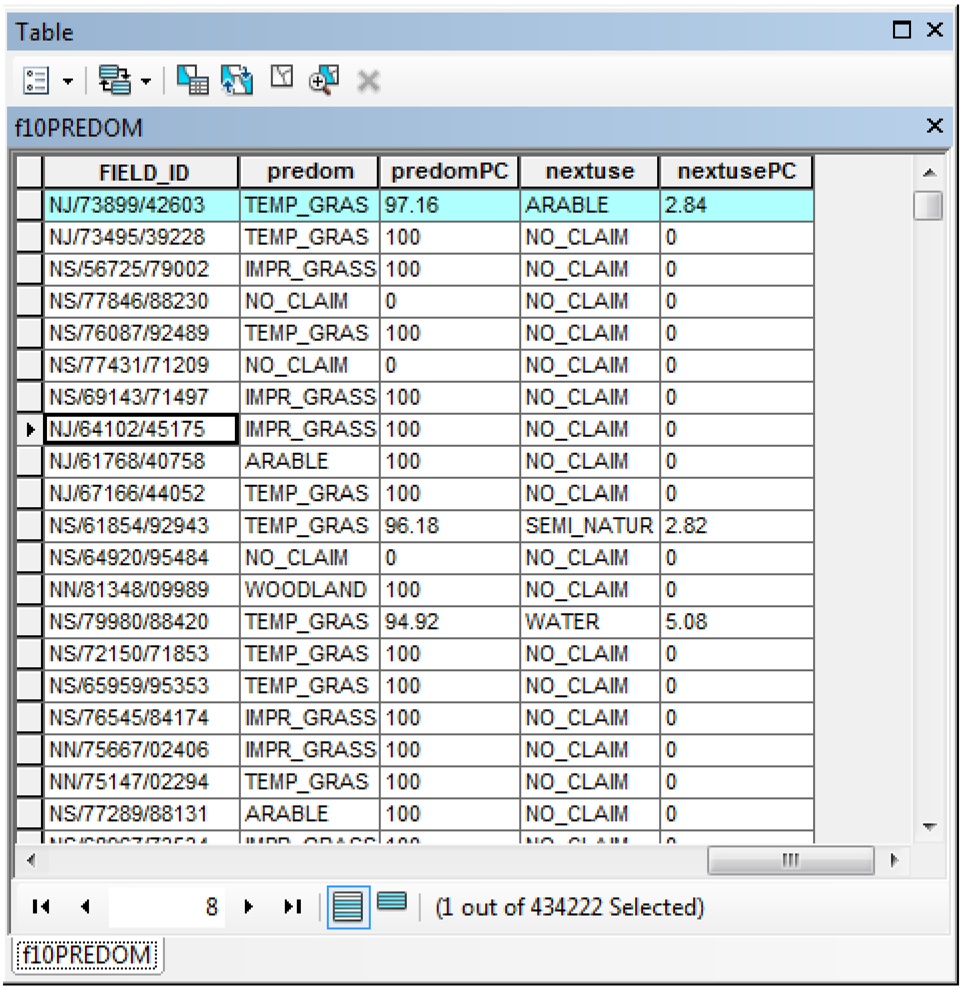


Figure 2: Self-intersection analysis results from annual IACS spatial datasets

Appendix 4.2: Assigning predominant land use to parcels containing multiple uses.

Since only a single land use can be assigned to each land parcel at a time, it was necessary to choose the predominant use (Field “predom”). The predominant land use was simply the land use having the largest area in a given parcel. This means that there is a potential to under or over-estimate land use, for example in a parcel of 10 ha, of which 4.5 ha are temporary grassland, 3.2 ha improved grassland, and 2.3 ha arable, would return a land use class of temporary grassland, since this is the predominant land use category in the parcel. To mitigate this problem, a separate field was created in the database and the secondary land use class was also recorded (Field “nextuse”). Additional fields were also created to record the percentage of each parcel occupied by predominant land use (Field “predomPC”) and likewise for the secondary land use (Field “nextusePC”). See Fig 1 (below).



Table

f10PREDOM

FIELD_ID	predom	predomPC	nextuse	nextusePC
NJ/73899/42603	TEMP_GRAS	97.16	ARABLE	2.84
NJ/73495/39228	TEMP_GRAS	100	NO_CLAIM	0
NS/56725/79002	IMPR_GRASS	100	NO_CLAIM	0
NS/77846/88230	NO_CLAIM	0	NO_CLAIM	0
NS/76087/92489	TEMP_GRAS	100	NO_CLAIM	0
NS/77431/71209	NO_CLAIM	0	NO_CLAIM	0
NS/69143/71497	IMPR_GRASS	100	NO_CLAIM	0
NJ/64102/45175	IMPR_GRASS	100	NO_CLAIM	0
NJ/61768/40758	ARABLE	100	NO_CLAIM	0
NJ/67166/44052	TEMP_GRAS	100	NO_CLAIM	0
NS/61854/92943	TEMP_GRAS	96.18	SEMI_NATUR	2.82
NS/64920/95484	NO_CLAIM	0	NO_CLAIM	0
NN/81348/09989	WOODLAND	100	NO_CLAIM	0
NS/79980/88420	TEMP_GRAS	94.92	WATER	5.08
NS/72150/71853	TEMP_GRAS	100	NO_CLAIM	0
NS/65959/95353	TEMP_GRAS	100	NO_CLAIM	0
NS/76545/84174	IMPR_GRASS	100	NO_CLAIM	0
NN/75667/02406	IMPR_GRASS	100	NO_CLAIM	0
NN/75147/02294	TEMP_GRAS	100	NO_CLAIM	0
NS/77289/88131	ARABLE	100	NO_CLAIM	0

8 (1 out of 434222 Selected)

f10PREDOM

Figure 1: The attribute table for IACS predominant land use 2010

A check on the extent to which this was a problem was carried out by summing the total hectares of land for which a use is claimed that had been assigned to predominant, to secondary and to other, respectively. The results are reassuring, showing that 96.2% of all land claimed had been assigned to the predominant land use class, and only 2.86 % in the secondary land use class (field “nextuse”). Only 0.22% of all land use claimed did not appear either as a predominant or secondary land use class.

For smaller land parcels, like the arable fields in the east of Aberdeenshire, the use of this approach to assign a land category to the predominant class is not likely to cause major problems. However, in the case of larger land parcels, like the large expanses or semi-natural or grazing land in upland areas, it is possible that small changes in the claimed area across different dates may result in an apparent “switch” between land classes, as a formerly predominant land use passes to become a secondary land use. The extent to which this is a problem can be checked by comparing “predominant” and “nextuse” fields and their percentage statistics across time periods when undertaking interannual comparisons.

Appendix 5: Supporting tables for concordance between IACS and LCM datasets

Appendix 5.1: Cross tabulation results for IACS 2010 (rows) and LCM2007 (columns).

Scores are percentages of total area of each category under IACS. Not all categories are shown for reasons of space. Cells are coloured according to the percentage of the total area of each IACS category that falls into each LCM category.

IACS_all		3	4	5	6	8	9	10	11	12	13	14	16	101	102
LCM integrated forestry		**Arable and horticulture**	**Improved grassland**	**Rough grassland**	**Neutral grassland**	**Acid grassland**	**Fen, Marsh and Swamp**	**Heather**	**Heather grassland**	**Bog**	**Montane Habitats**	**Inland Rock**	**Freshwater**	**Broadleaved**	**Coniferous**
ARABLE	301	73	19	4	0	1	0	0	0	0	0	0	0	1	1
TEMP_GRASS	302	25	59	9	0	2	0	0	1	0	0	0	0	1	1
IMPR_GRASS	303	7	54	14	0	8	0	1	5	2	1	0	0	3	1
SEMI_NATUR	304	1	3	7	0	22	0	11	22	19	11	1	1	1	1
WOODLAND	305	3	5	5	0	7	0	6	8	2	3	0	0	13	46
WATER	306	11	21	11	0	5	3	3	2	0	0	2	11	12	4
INLD_ROCK	307	13	13	10	1	12	0	6	4	3	0	11	2	11	3
URBAN	308	35	25	8	1	4	0	1	4	0	0	6	0	6	4

Legend:		
	>	10%
	>	25%
	>	50%
	>	75%

Appendix 5.2: Cross tabulation results for LCM2007 (rows) and IACS 2010 (columns).

Scores are percentages of total area of each category under LCM2007. Cells are coloured according to the percentage of the total area of each LCM category that falls into each IACS category.

IACS_all	LCM integrated forestry	ARABLE	TEMP_GRASS	IMPR_GRASS	SEMI_NATUR	WOODLAND	WATER	INLD_ROCK	URBAN
		301	302	303	304	305	306	307	308
3	Arable and horticulture	68	16	11	3	1	0	0	0
4	Improved grassland	12	25	51	11	2	0	0	0
5	Rough grassland	5	9	28	55	4	0	0	0
6	Neutral grassland	9	11	40	37	3	0	0	0
7	Calcareous grassland	0	1	21	78	1	0	0	0
8	Acid grassland	0	1	8	88	3	0	0	0
9	Fen, Marsh and Swamp	1	5	30	61	1	1	0	0
10	Heather	0	0	3	92	5	0	0	0
11	Heather grassland	0	0	6	90	3	0	0	0
12	Bog	0	0	3	95	1	0	0	0
13	Montane Habitats	0	0	2	95	2	0	0	0
14	Inland Rock	5	3	5	85	2	0	0	0
15	Saltwater	1	3	18	71	3	1	2	0
16	Freshwater	1	1	5	89	5	0	0	0
17	Supra-littoral Rock	0	0	19	80	0	0	0	0
18	Supra-littoral Sediment	2	8	28	60	1	0	0	0
19	Littoral Rock	0	1	19	74	4	0	1	0
20	Littoral Sediment	2	4	30	61	2	0	1	0
21	Saltmarsh	2	2	37	53	3	2	0	0
22	Urban	30	13	25	21	10	0	1	1
23	Suburban	29	11	27	21	9	0	0	1
101	Broadleaved	4	4	22	37	32	0	0	0
102	Coniferous	2	2	6	19	71	0	0	0

Legend	
>	10
>	25
>	50
>	75
>	90