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Detection of peatland drainage with remote sensing – a scoping study

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Background

Knowledge of the location and extent of drainage in Scottish peatlands is now recognised as valuable information for prioritisation of peatland restoration. In addition, proposed amendments to the implementation of the Kyoto Protocol suggest that reporting of spatially explicit information of drainage in peatlands may be required.

As the original records from grant-in-aid schemes for drainage implemented since the 1920's until 1990 have been lost, the only ways forward involve mapping of individual drains over an area that may exceed 1 million hectares in Scotland.

Manual or automated mapping of such an extensive area is a very substantial task, and this scoping study was developed to ascertain whether the presence of drainage could be modelled using remote sensing data.

Key Points

- Drainage of peatland can be detected and mapped using manual mapping of very high resolution remote sensing imagery (aerial photography), and various spatial statistics derived from this.
- High and moderate resolution remote sensing imagery (Landsat & MODIS) shows the capacity to detect drainage and estimate its spatial density, but accuracy is restricted and methods using this imagery are limited by insufficient data.
- A total of 338 sites were selected on peat soils across Scotland, and classified as to whether they contained artificial drainage in a 500 x 500 metre block at each site. Of these, 93 had some level of artificial drainage (27.5%), with 45 being estimated as fully drained within the 500 metre block.
- It is estimated that information on 300 additional drained sites would be required in order to provide adequate data for developing automated remote sensing-based approaches with Landsat or MODIS data.

Introduction

Under the United Nations Framework Convention on Climate Change (UNFCCC), ratified by the UK in December 1993, countries that are Parties to the Convention are required to submit annual national greenhouse gas (GHG) inventories to the Climate Change secretariat. These are included in the UK National Inventory Report (NIR). The UNFCCC is based on general obligations for all parties to develop and annually update national inventories of GHG emissions and removals as well as implement programmes to mitigate climate change. The UK publishes these annually in the UK National Inventory Report (NIR). Emissions of GHG from, and removals by, Scottish peatlands are reported within the Agriculture, Forestry and Other Land Use (AFOLU) sector submission.

Until 2013, almost all areas on peat soil (with the exception of small areas where peat is extracted) have been accounted for in the NIR under either forest land, where afforested, or otherwise under the grassland category. The recent publication of the "2013 Supplement to the 2006 Guidelines: Wetlands" (hereafter called the 2013 Wetlands Supplement; IPCC, 2013a), published by the Intergovernmental Panel on Climate Change (IPCC), addresses the emissions and removals from drained and rewetted organic soils in a more comprehensive manner than the 2006 Guidelines.

In 1997, the Kyoto Protocol (KP) was concluded under which industrialized countries committed to reducing their collective emissions of six greenhouse gases. The KP is a legally distinct treaty under the UNFCCC with separate and additional obligations for KP parties. It contains quantified emission reductions targets for the parties in Annex B, as well as corresponding enhanced rules on accounting and reporting. Countries can be party to UNFCCC but not the KP, and present examples include the US and Canada. Since 2010, the UK is required to provide annual reports to both the EU and the UNFCCC on its progress towards its Kyoto Protocol targets within the National Greenhouse Gas Inventory. Whereas UNFCCC reporting includes changes in emissions between different land use sectors, Kyoto Protocol reporting includes changes in activity in certain management activities.

Until 2013, the only mandatory KP reporting category was Afforestation, Reforestation, and Deforestation. The 2013 KP Supplement now also adds the optional Article 3.4 activity of wetland drainage and rewetting (WDR), which can be elected for the second commitment period (2013-2020) amongst other optional activities such as Cropland Management and Grazing Land Management. The Conference of the Parties (COP) in Doha adopted an amendment to the KP, which contains quantified mitigation commitments for 38 parties for a second commitment period covering 2013 to 2020. In order to enter into force, this amendment (http://unfccc.int/kyoto_protocol/doha_amendment/items/7362.php) must be ratified by at least 144 KP parties. As of April 2016, this requirement had not been fulfilled and the Doha amendment has not yet entered into force. Thus, the decision on whether or not WDR will be adopted as a reporting category is still pending, although it is believed to be imminent (https://www.gov.uk/government/publications/eu-no12015-euiceland-second-commitment-period-of-the-kyoto-protocol-to-the-united-nations-framework-convention-on-climate-change).

However, even if WDR is not adopted, the practices of drainage and rewetting on former peatlands must still be reported under the Doha Agreement. Such emissions would have to be reported under the categories of Forest Land, Cropland, and Grazing Land. At the moment, there is an automatic assumption that such land uses on peat soil are all drained, however previous work indicated that a sizeable proportion of the Grazing Land reporting category includes areas that are not drained at all (such as near natural peatlands). In addition, the UK Department of Energy and Climate Change (DECC) have commissioned a study to 'take(ing) account of the updated methodologies set out in the recently published 2013 IPCC Wetland Supplement particularly the reporting of emissions and removals from wetland drainage and rewetting and to provide information to support the UK's decision making on whether to elect to include this activity in carbon accounting under the EU LULUCF Decision' (DECC tender TRN860/07/2014, project period 2014-2016). The project team is currently assembling information on potential activity data and Tier 2 emission factors for UK peatlands, and specifically is looking into ways to better represent the wide variety of areas currently classified as grassland on peat soils under UNFCCC. It is likely that there is a distinction possible between emissions from former peatlands that have been converted to Grazing land (intensive and extensive grassland) and those that have been converted to a less degree (drained moorlands on deep peat) or even remain in a semi-natural state.

A very obvious gap in knowledge is lack of digital information on drainage ditches on former peatlands in Scotland. Farm drainage, including drainage of upland and lowland peatlands, was subsidised through various government grant-in-aid schemes since the 1920's and has resulted in the UK overall being possibly the most extensively drained country in the world (Robinson, 1980). Unfortunately, the existing drainage records held by the then Ministry for Agriculture, Fisheries and Food (MAFF), the Department of Agriculture and Fisheries for Scotland (DAFS) and other subsequent government bodies, have been lost, and so there is no consistent knowledge of drainage across the country. Robinson (1980) estimated that in Scotland alone, nearly 1.8 Mha of moorland were drained in the period 1921-81.

Mapping of peatland drainage in Scotland is also important in order to allow us to identify and target future peatland restoration measures. Similarly, although restoration activities that aim to restore the habitat value of these ecosystems have been carried out for more than a decade in Scotland, these have not yet been captured in a ready to report format. Grip blocking, in particular, forms regular new water bodies along the line of the former drainage channel, and these features can be readily seen in high resolution aerial imagery.

Given the highly distributed nature of drainage channels, remote sensing was considered a potentially useful tool for mapping the amount of drainage (and potentially restoration efforts) spatially across Scotland. A number of different remote sensing data sources are available, with their own specific characteristics. In this work, we investigated methods appropriate to three different spatial resolutions of remote sensing imagery, and evaluated them in terms of ease of application, effectiveness and data requirements.

Methods

Peatland site selection

In order to provide an unbiased representation of peat sites in Scotland, a selection was made of 338 locations known to be on peat soils, using the Scottish Soils 1:250,000 spatial dataset. For each of these locations, a square block 500 metres across was delineated and used to produce a GIS layer, with the coordinates of the location at the centre of the block. These polygons were overlain on 0.25m aerial photography acquired between 2009 and 2015, to allow both rapid visual examination and more detailed later drainage channel mapping (see below).

The first visual examination was used to identify those sites for which drainage was visible within the 500 metre block. Even old and overgrown drainage channels are easily visible and identifiable at this spatial resolution and with a small amount of practice, the discrimination between drained/non-drained blocks was achieved rapidly and accurately. For the blocks identified as having drainage, further visual examination by two researchers was carried out to determine the level of drainage on a three-point scale (slight, moderate, fully drained) that was based on the area of the block that contained drains and the spatial density of the drains visible.

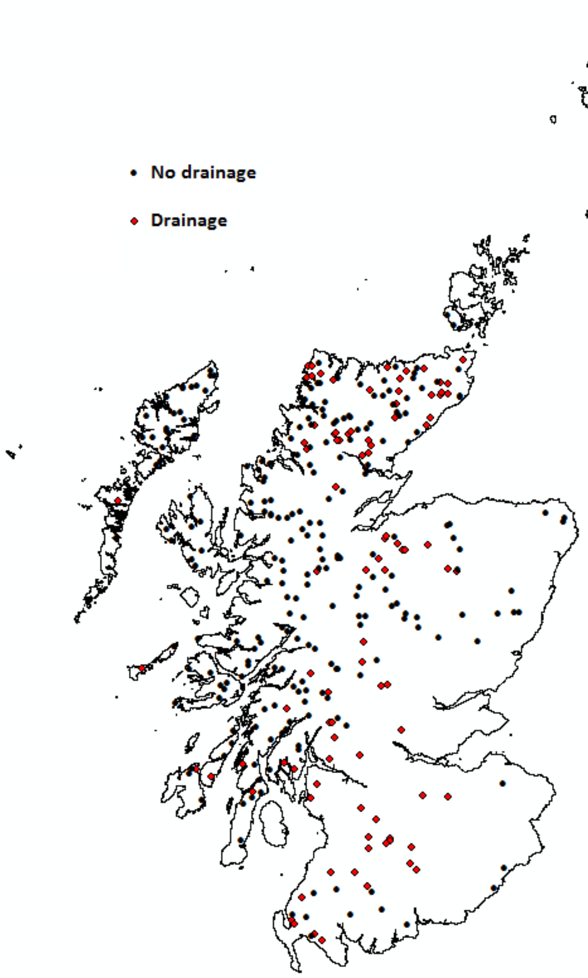

Figure 1. Distribution of selected peatland sites across Scotland.

Very high resolution aerial photography

The 500 metre blocks of imagery that contained drains were used to produce delineated polygon layers, identifying the edges of each drain visible. This was a manual process that took time and considerable attention to detail, and required the person involved to be able to discriminate each potential drainage channel from other landscape features (fences, paths, animal tracks etc.). Using GIS-based analysis, measurements were made of several relevant parameters for the delineated drains:

- Total length of drains visible

- Average width of drains
- Total area of drains

High resolution satellite imagery (Landsat)

Landsat 8 imagery for Scotland was acquired from the USGS download service, with all imagery from 2015. This type of imagery is known to produce useful information for peat and land cover discrimination (e.g. Aitkenhead & Aalders, 2008; Brown et al., 2007). However, one of the issues with Landsat data is that clouds often create gaps in the imagery (particularly for Scotland), and so a larger number of scenes (each approximately 180x180 km) were acquired that provided overlapping and duplicate imagery for Scotland. This was used to produce a single, almost entirely cloud-free image for the country using a customised and automated image analysis approach. The resulting composite image was used to provide data for the 500 metre blocks of peatland described above.

Each pixel's data contained reflectance for a number of wavelength ranges, and was used to calculate NDVI (from Red and NIR) and soil temperature (from mid-infrared). Soil temperature was assumed to act as a proxy for moisture content, and was further evaluated to reduce elevation effects and local weather conditions by measuring the local soil temperature anomaly value for each pixel. This is calculated by subtracting the local average soil temperature (within a distance of 900m) from the temperature at each pixel. Soils that are wetter than the local norm will show be colder, while drier soils will be warmer. Elevation was also used as an input parameter.

Landsat imagery is approximately 30 metre resolution, and so approximately 250 pixels were obtained for each block. This was used on a pixel-by-pixel basis and also with averaged values over each block, to train a neural network model that estimated drainage either on a yes/no basis, or by the level of drainage using the three-point scale. The method used was similar to that applied in Aitkenhead et al. (2015) and Aitkenhead et al. (2013). Statistical evaluation of the results from the Landsat-based model was carried out using kappa statistic and commission/omission errors.

Moderate resolution satellite imagery (MODIS)

Modis data were donwloaded for 12 years (2000-2011), clouds gaps were filled using the method described in Poggio et al (2012). In this exercise the median of the 12 years was used. Generalised Additive Model geostatistical approach was fitted to the available data MODIS data for Scotland, exploiting the values of neighbouring pixels (Wood, 2006). This approach has been successfully applied to different soil and environmental point data (Poggio et al, 2010, 2013, 2014,2015). The model was fitted using downscaled data at 100 metre resolution, for binary drained/not drained discrimination and also interpolated organic matter content determined using NSIS 1 & 2 (National Soil Inventory of Scotland) data points.

For MODIS data, no model could be fitted using the information about drainage classes on the three-point scale. This is probably due to the limited number of points available, especially in classes 1 and 2. In addition, the data currently available for use exclude the Shetland Islands, as MODIS coverage there has a lot of cloud and could not be used effectively.

Results

Detection Of Peatland Drainage With Remote Sensing – A Scoping Study

Using the manual delineation approach with 0.25 metre resolution aerial photography, it was agreed that the drainage channels were correctly identified and delineated. This approach allowed spatial statistics to be determined rapidly for each image block, but did take a significant amount of effort in the delineation process (varying from several minutes to over an hour per block depending on the number and complexity of drains in each image). An evaluation of the quick-look three-point scale drainage class estimation against the values determined for length of drains indicated that the quick-look evaluation was successful but that there was a lot of variation between the two.

The approach using Landsat data was able to correctly discriminate between drained and non-drained image blocks 58% of the time using single pixel-based models (10% of variance explained), and 69% of the time for models trained using pixel data averaged across a block (18% of variance explained). The percentage accuracy for correctly identifying drained and non-drained blocks was approximately equal. For models developed using the three-point scale, the variance explained was 12% for single pixels and 22% for averaged pixels. This was unexpected, as it had been anticipated that the models using the three-point scale would be less accurate than the binary yes/no models. We have checked that the model is not over-fitted using cross-validation, and reason that because the three-point scale allows data to be matched from partial drainage, these sites are less likely to be misclassified.

Classification accuracy was also assessed using a table of commission/omission errors and by calculating the kappa statistic for the Landsat-based drainage/no drainage model and averaged pixel data, which was 0.37.

The model developed using MODIS data for drained/not drained explained only 13% of the deviance in the data, which is considered very low. The significant variables were:

- COV1: Organic matter layer (from modelling of NSIS1/2 points)
- COV2: MODIS EVI median 2000-2011 downscaled at 100m
- COV3: MODIS information on snow patterns median 2000-2011 downscaled at 100m
- COV4: MODIS Land Surface temperature median 2000-2011 downscaled at 100m
- Smoother of x and y coordinates.

Discussion

The aerial photography manual interpretation approach provides accurate assessment and spatial delineation of the peatland drains. It is very labour-intensive however and requires experience in working with both aerial photography and GIS software. Of the 93 drained sites, only 45 were mapped due to time constraints using this approach. The two methods based on satellite remote sensing imagery are more rapid to implement and demonstrate the potential to detect and characterise peatland drainage, but more data is required in order to confirm the most suitable approach and develop it effectively.

Rapid assessment of drainage within the 500 metre blocks is considered useful to allow the yes/no identification of the presence of drainage features and to provide a broad assessment of the level of drainage present, but does not provide enough information for the construction of models that adequately represent the level of drainage rather than presence of drainage alone.

Recommendations

In order to confirm the most suitable approach, we would recommend further work, in particular to collect sufficient points for validation and fitting of more robust models. It is estimated that it would be necessary to collect a further 300 random points on drained peats. These would require only a quick expert-based estimation of presence of drainage in a 500 metre block, as described above, to identify these locations but would then require more detailed work to provide the spatial mapping of peat within the 500 metre blocks

The sampling of the points could be based on existing peatland distribution information (preferential sampling) following statistical criteria to select the locations. To improve the geostatistical modelling, the covariate space needs to be covered effectively, e.g. by conditioned Latin hypercube sampling (e.g. Minasny and McBratney, 2006).

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Appendix A – Additional information

Table A1. Spatial statistics for 45 of the 500 metre blocks, derived from aerial photography.

Easting	**Northing**	**Total length (m)**	**Drain width (m)**	**Total area (m2)**	**Easting**	**Northing**	**Total length (m)**	**Drain width (m)**	**Total area (m2)**
258250	684250	3234	2	6468	264150	900550	3151	1	3151
278350	961750	4990	0.5	2495	260150	899050	4353	1.2	5224
291550	959350	5858	0.5	2929	224350	954950	962	0.6	577
304150	961150	1690	1	1690	230550	957050	4970	0.6	2982
315750	950650	5345	1.5	8018	239450	952250	2408	1.2	2889
320950	950350	3161	1.2	3793	218250	907750	3808	0.6	2285
331850	967050	7262	1.5	10893	102750	747050	1619	1	1619
315350	941950	3337	1.4	4671	309250	941750	7694	2	15388
316750	943350	3123	1	3123	286850	953150	3609	1.5	5413
321450	942550	4628	0.8	3703	236350	681750	5555	1	5555
265550	945850	7965	1.2	9558	237750	600750	9312	1.2	11175
284150	935550	4994	1.2	5993	294050	607450	1558	1.2	1869
221450	962950	2755	1.5	4133	227750	815750	3356	0.8	2685
225750	920150	3302	1.2	3963	321250	817750	1706	1	1706
240150	913750	5488	1	5488	211150	674450	567	1.5	850
241050	914650	7593	0.8	6074	290250	830850	2181	1.5	3272
223950	962850	2650	0.6	1590	264450	909550	438	1.5	657
308250	925450	9242	1	9242	240650	875750	1078	2	2157
450550	1195550	2144	0.6	1286	277250	840750	3507	2	7014
243350	909150	6851	0.8	5481	305550	920650	3913	1.6	6260
220650	954050	1009	0.6	606	320750	655150	10693	1.8	19247
220650	902950	1845	1.2	2215	286250	944750	4997	1.5	7496
266050	906050	2422	0.6	1453					

Table A2. Classification errors (commission and omission) for Landsat-based approach with averaged pixel values.

	0 (no drainage)	1 (drainage)	% correct
0 (no drainage)	170	75	69.4
1 (drainage)	31	62	66.7

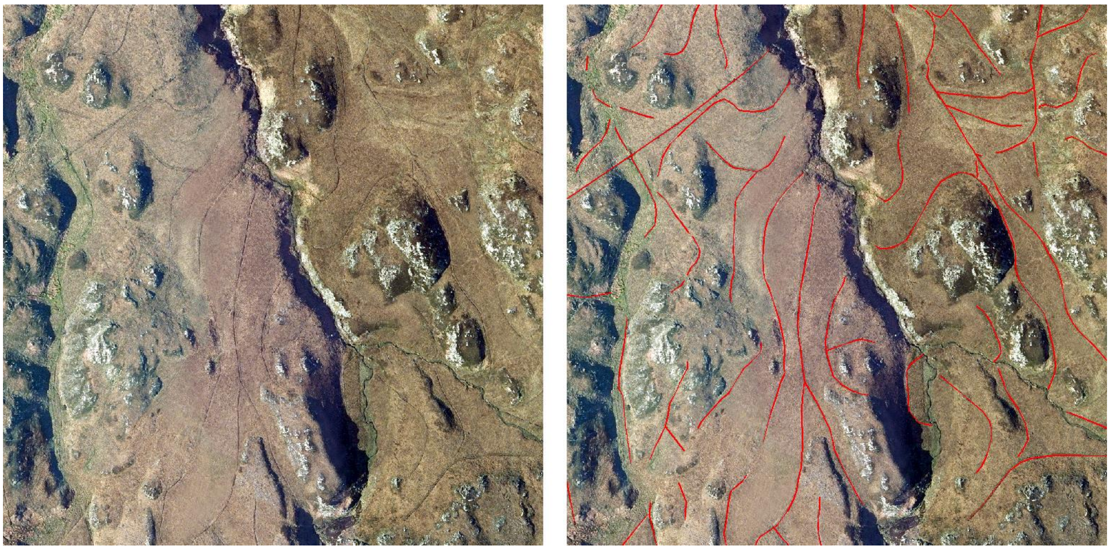

Figure A1. Example of 500 metre block of peatland, with raw imagery on the left and delineated drains overlain on the right. The image shows the complications of distinguishing man-made drains from natural drainage features such as streams, as can be seen in the lower right of the image.

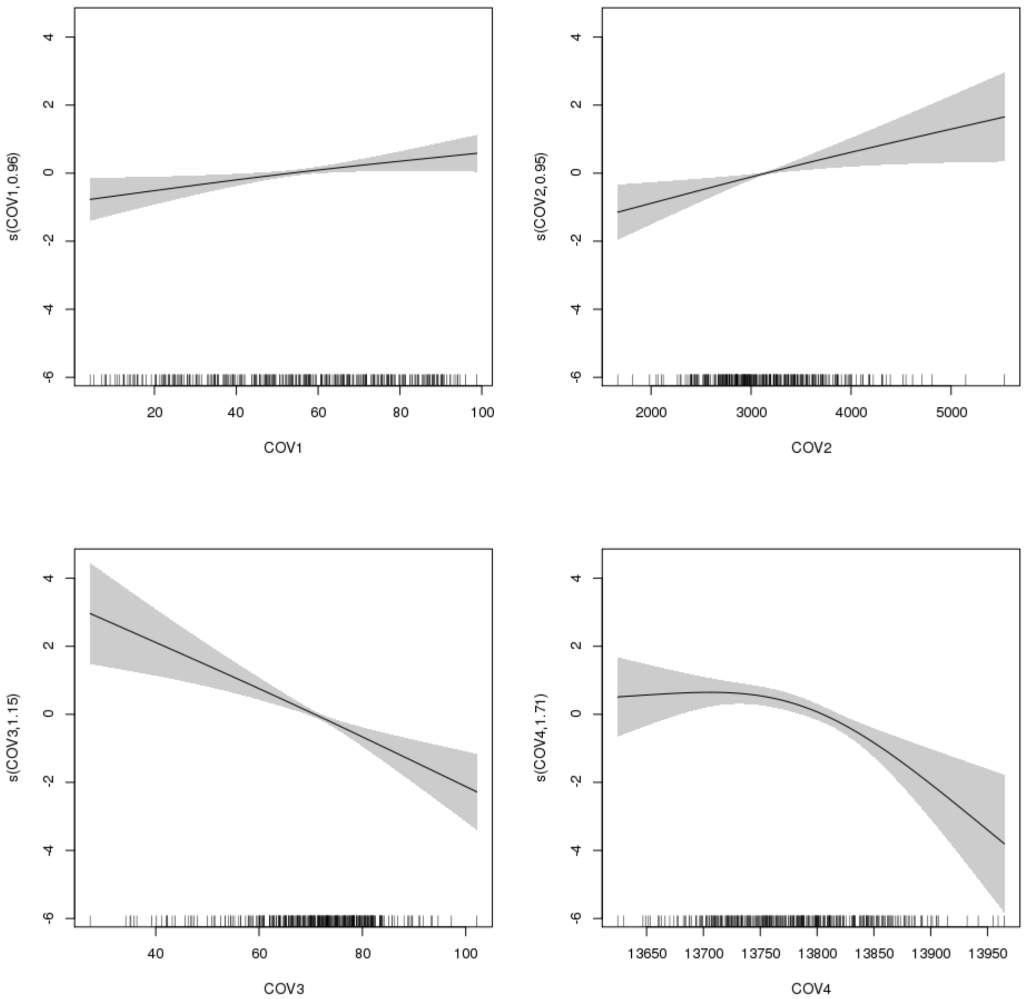

Figure A2. Representation of significant variables determined using the MODIS/GAM method.