BRITAIN'S HIGHEST BOG: CAN WE UNLOCK ITS SECRETS?

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SUMMARY

The Glenfeshie Mòine Mhór (Great Moss) is Britain's highest bog, the largest bog in the Cairngorm Mountains (Scotland) and a water source area for the River Spey. The area was managed primarily for sport hunting for about two centuries, but deer numbers have been heavily reduced in the last decade to allow regeneration of natural woodland and the return to more natural condition of all ecosystems including peatland. However, it may not be realistic to expect spontaneous improvement in peatland condition and ecosystem services provision in the harsh environment of the Mòine Mhór, which retains snow cover for more than half the year and differs floristically from lower-altitude bogs. To understand whether and where management intervention may be required, we need first to understand how the system works at scales ranging from microform to macrotope, and from sub-catchment to whole-system level. Multi-disciplinary condition and process studies (involving various collaborators) are in progress, with a current emphasis on streamflow generation and fluvial carbon loads. This presentation develops two sub-themes. First, ground survey and GIS analysis are used to address the questions: what are the special features of this bog; what is the nature and extent of degradation; and what are the implications for water delivered to the outflow streams? Secondly, a striking feature is the bare peat patches which were favourite resting places for deer on warm, dry summer days. The occurrence of seasonally extreme surface conditions seems a likely factor in preventing their recolonisation by bog plants now. Information about these conditions that cannot readily be accessed through direct observation, originating from temperature sensors and delivered at 60-minute intervals *via* a low power internet link, is explored in this context. Finally, we discuss aspects of the suitability of our investigation methods for remote and intermittently accessible field sites such as the Mòine Mhór.

KEY WORDS: bare peat, Cairngorms, environmental sensor network, Internet of Things, vegetation

INTRODUCTION

The Glenfeshie Mòine Mhór ('Great Moss' in the Gaelic language) occupies a plateau of siliceous Dalradian country rock (Thomas *et al*. 2004), about 3 km across, at the south-western corner of the Cairngorm Mountains in Scotland. It has been described as the largest expanse of peatland in the Cairngorms National Park and the highest ('raised') bog in Britain (900–950 m a.s.l.). Located within the privately owned Glenfeshie Estate, the centre of the plateau (57° 01′ 58″ N, 03° 48′ 51″ W) lies approximately 600 m above and 5.5 km distant from the Estate office at Carnachuin on the left bank of the River Feshie (Figure 1). It is usually snow-covered for half of the year (November to May), with snow patches often persisting through June. Access at any time of year is constrained by the logistics of fording the notoriously flashy River Feshie and most of the plateau is in mobile phone shadow. The site has considerable interest for nature conservation, being included within the Cairngorms Site of Special Scientific Interest (SSSI) (SNH 2016) and Special Area of Conservation (SAC) (JNCC 2016).

Glenfeshie was managed for sport hunting - primarily stalking of Red Deer (*Cervus elaphus*) - from the early 19th century, and deer stocking levels of 35–40 km^{-2} were usual until 2006. Since then the density of deer has been substantially reduced, to ~1 km^{-2}, to promote the return of native woodland and more natural ecosystems in general. After two centuries of heavy use by deer in summer, the most striking features of the Mòine Mhór are the expanses of bare peat dissected by an extensive system of erosion channels feeding into headwaters of the Feshie, which is in turn a tributary of the River Spey. It is not immediately clear how severely ecosystem services such as water quality maintenance, carbon cycling and support of wildlife have been impaired, or whether it is realistic to expect spontaneous improvements in condition of the peatland without further management intervention.

Here we report some early results from ongoing studies that aim to inform future management of the Mòine Mhór. At macro scale we make first estimates of the extent of peatland on the plateau and how much of it still retains vegetation cover, in the context of the implications for river water quality. At micro scale we investigate the environment of the bare peat surfaces with a view to assessing their suitability for recolonisation by plants. For this site, the unpredictability of access poses a major risk to successful implementation of field-based investigations, making efficient use of fieldwork time a priority and remote observation techniques highly attractive. We conclude with some comments about the effectiveness of our methods in this context.

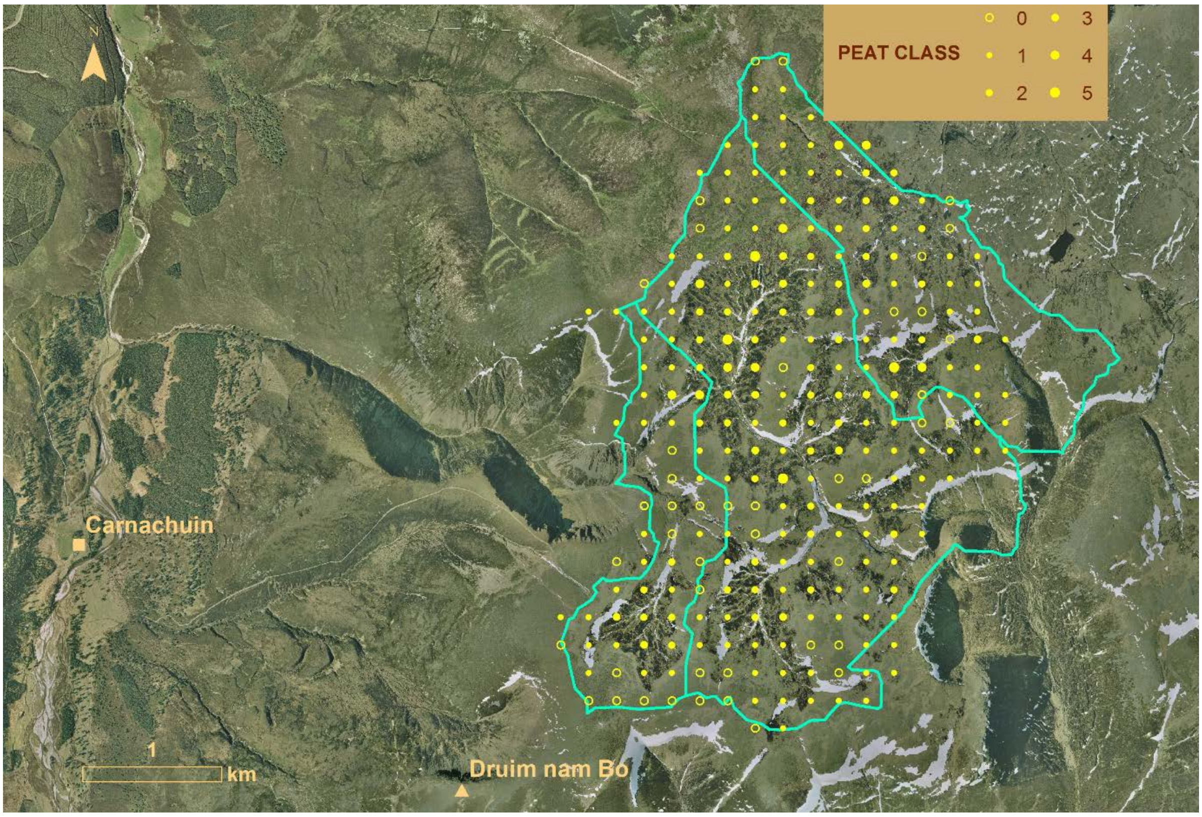

Figure 1. Aerial view of the Mòine Mhór plateau and River Feshie (flowing south–north at left side of image). Cyan polygons divide the plateau between three stream catchments, namely (from west to east) Allt Garbhlach, Coachan Dubh and Allt Sgairnich. Locations of survey quadrats are indicated by yellow points whose sizes reflect peat thickness (key to classes: 0 = no peat, 1 = 1–30 cm, 2 = 31–60 cm, 3 = 61–90 cm, 4 = 91–120 cm, 5 = 121–150 cm). The locations of Carnachuin and Druim nam Bo are also shown. Aerial imagery: Ordnance Survey, Licence No. 100030994. Catchment boundaries derived from OS Terrain 5 DTM [ASC geospatial data], Scale 1:10000, Tiles: nn89ne, nn89se, nn99sw, nn99nw, Updated: 24 March 2015, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: 2015-08-04 21:44:16.33.

METHODS

A 200 m × 200 m grid of waypoints (defined in six-figure British National Grid co-ordinates, i.e. to 1 m precision) covering the approximate area of the Mòine Mhór plateau and catchment was generated in Microsoft Excel and uploaded to a hand-held GPS with integral camera (Garmin GPSMAP® 62sc). In the field, an observer navigated to each waypoint in turn. At each location a 0.5 × 0.5 m quadrat was laid on the ground, a geotagged vertical photograph of the quadrat was captured using the GPS and, if the observer had botanical knowledge (219/279 quadrats), a list of plant species occurring within the quadrat was recorded. A soil auger or metal probe was then used to determine the thickness of peat (defined as soft organic sediment ≥ 1 cm thick) at the centre of the quadrat. The field data were transcribed into an Excel spreadsheet, then converted to an ArcGIS feature class to which the geotagged quadrat photographs were spatially joined. This facilitated viewing of individual quadrat photographs in conjunction with a base map or aerial photograph, i.e. in their spatial context within the site. The quadrat photographs could then be reviewed and attributed with additional information as required. For present purposes the pertinent attributes are peat thickness and whether more than 50 % of the quadrat was occupied by bare peat.

Catchment boundaries were generated from Ordnance Survey Terrain 5 DTM (digital terrain model) data using the Spatial Analyst 'Hydrology' tools in ArcGIS 10.2.2. After removing small imperfections such as isolated 'sinks' from the data using the 'Fill' tool, flow direction and flow accumulation rasters were generated. Pour point features were placed near the lowest point of each focus stream, then located accurately as pixels in the flow accumulation raster using the 'Snap Pour Point' tool. The generated pour point raster was used in conjunction with the flow direction raster to derive catchment (Watershed) rasters which were then converted to polygons.

Peat temperatures were measured on an expanse of bare peat in the southern (upstream) part of the Allt Garbhlach catchment (Figure 1) using ten temperature sensors (1-Wire DS18B20 digital thermometer; Maxim Integrated Products, San Jose, CA, USA). Five of the sensors (Cluster 106B) were installed horizontally, supported by a strip of plastic mesh, at 10 cm depth intervals in the wall of a 5 cm × 5 cm pit excavated in a small degraded peat hagg using a Malcolm peat sampler (Cuttle & Malcolm 1979), after which the excavated peat was carefully re-packed around them. The remaining sensors (Cluster 106A) were pushed vertically into the ground (to a depth of approximately 1 cm) at intervals of ~20 cm along a transect starting in, and running perpendicular to, a shallow runoff channel on the bare peat surface. The two sensor clusters form part of an environmental sensor network (ESN; Hart & Martinez 2006) that covers the south-western part of the Mòine Mhór plateau. Each sensor cluster is wired to a MSP430-based node running the Contiki operating system (Dunkels *et al*. 2004). The captured data are stored in flash memory, encoded using protocol buffers to save space. They are fetched hourly *via* an 868 MHz low-power (20 mW) radio network (G.M. Bragg *et al*. in press) which uses 6LowPAN and CoAP. Once on the micro-PC (border router) at Carnachuin, they are sent *via* the Estate's internet connection to the database server where they are unpacked and loaded into a database for previewing and export for analysis.

RESULTS

In total, quadrats were recorded at 279 GPS waypoints. Of these, 184 (66 %) were on vegetated peat, 51 (18 %) were on bare peat and 44 (16 %) had no peat. Where present, the thickness of the peat layer ranged from > 0 to 143 cm (mean 30 cm) (Table 1). The average peat thickness across all quadrats was 25 cm. Rather than accommodating a single expanse of peatland, the Mòine Mhór plateau turned out to consist of a series of knolls topped with *Racomitrium lanuginosum* heath on extremely shallow mineral soils and flanked by *Nardus stricta* grassland. It is probably above the altitude limit for *Calluna vulgaris* but other dwarf shrubs (e.g. *Empetrum* and *Vaccinium* species) were found, as well as *Rubus chamaemorus* growing on isolated *Sphagnum fuscum* cushions. Peatland is more or less confined to basins between the knolls which together form the headwater catchments of three streams, namely Allt Garbhlach (1.64 km^2), Coachan Dubh (5.98 km^2) and Allt Sgairnich (2.88 km^2) (Figure 1). The total number of quadrats recorded within the three stream basins was 237. When assigned to their respective catchments, the data for the 237 quadrats indicated that the relative extents of non-peatland (12–14 %) and vegetated peat (65–68 %) were similar for Coachan Dubh and Allt Sgairnich, whereas 31 % of the Allt Garbhlach catchment had no peat layer and only 55 % was covered by vegetated peat. Whilst 20–21 % of the Allt Garbhlach and Allt Sgairnich peatland had no plant cover, 26 % of the Coachan Dubh peat layer lacked vegetation. Overall, the fraction of bare peat cover *per* catchment was 14 % for Allt Garbhlach, 18 % for Allt Sgairnich and 23 % for Coachan Dubh (Table 1). These figures might provide a first basis for prioritisation of different parts of the plateau for any management intervention driven by peat erosion / water quality considerations.

Example segments of the peat temperature data delivered by Sensor Clusters 106A and 106B are shown graphically in the upper two panels of Figure 2; the lower two panels show concurrent data from an independently operating Campbell CR1000 automatic weather station (Campbell Scientific, Shepshed, UK) located on the Druim nam Bo ridge (Figure 1) that delivers data by conventional telemetry. The data period chosen runs for 21 days from 00:00 hrs on 07 November 2015, and illustrates the transition from autumn to winter conditions on the plateau. A further point of interest is that the first two Atlantic storms to be named (Abigail and Barney) by British Isles meteorologists passed over the UK during this time, and the example record ends as the third (Clodagh) was approaching (Met Office 2016). Up to and including 12 November, peat surface temperature was above 0 °C and followed the more or less diurnal fluctuations in air temperature. The coincident drop in barometric pressure and peak in air temperature that day can be linked to Storm Abigail, which delivered the heaviest rainfall of the period as well as the first dusting of snow on the summits (visible in webcam images of Druim nam Bo captured from Carnachuin around 10:00 hrs on the 13th). Thereafter, the temperature of surface peat fell to ~ 0 °C and the diurnal fluctuations ceased, presumably due to presence of snow and/or ice. The peak in air temperature that preceded Storm Barney during the 15th/16th was mirrored (only) at the three surface peat sensors located highest in the microtopography, suggesting that concave parts of the bare peat surface remained frozen. The next warming event

Table 1. Summary characteristics of the peat layer of the Mòine Mhór plateau and catchments, as indicated by the quadrat data (see text for details).

		Allt Garbhlach	Coachan Dubh	Allt Sgairnich	All quadrats
catchment	area (m^2)	1643277	5984334	2878267	
	number of quadrats	36	145	56	279
	% without peat	31	12	14	16
	% with vegetated peat	55	65	68	66
	% with bare peat	14	23	18	18
peat	mean thickness (cm ± SD)	29 ± 32	30 ± 30	32 ± 34	30 ± 31
	maximum thickness (cm)	105	143	128	143
	% of peat area bare	20	26	21	22

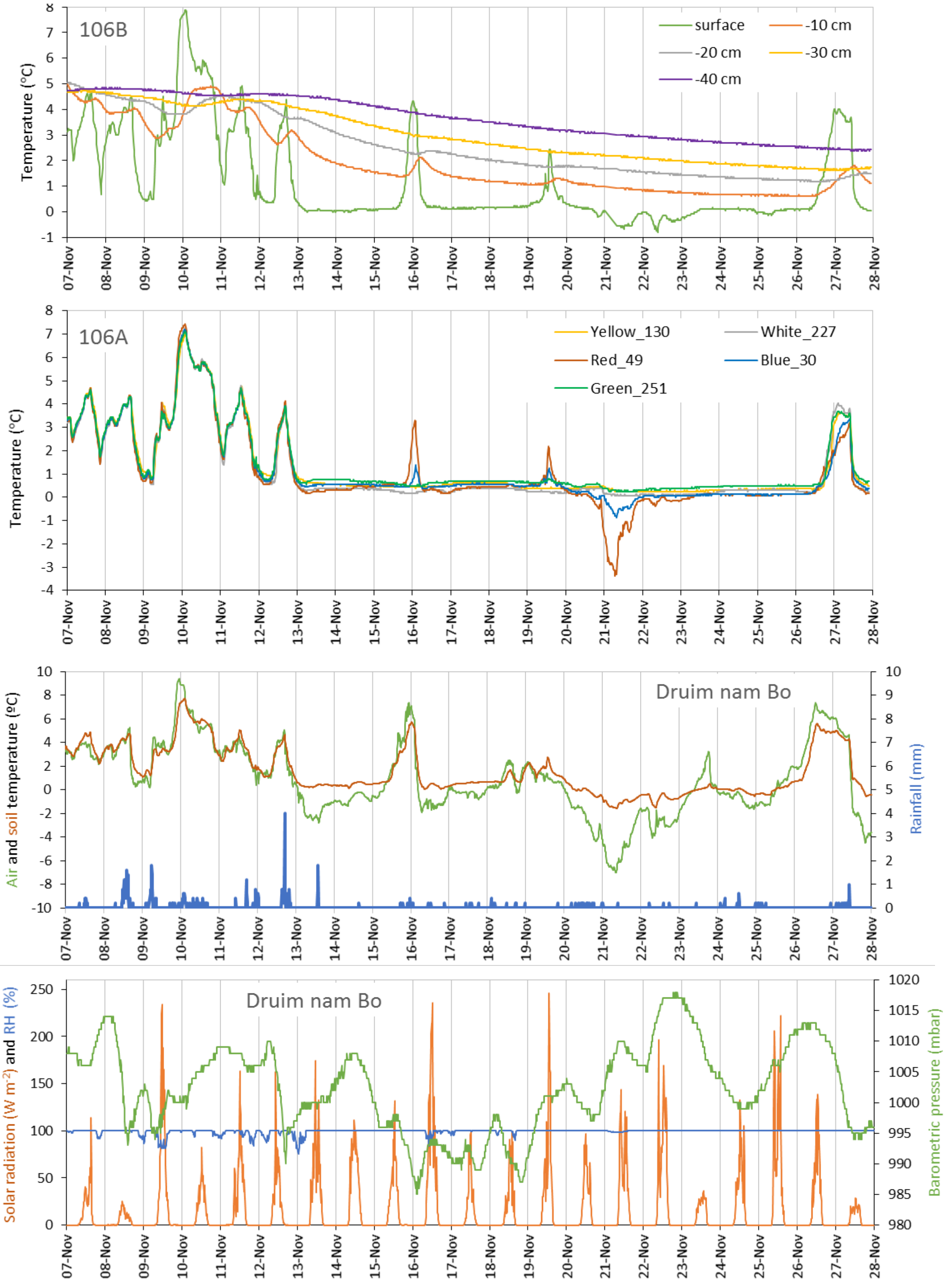

Figure 2. Environmental data for the 21-day period 07–27 November 2015 (the x-axes start at 00:00 hrs on 07 November). The data are peat temperatures from Sensor Clusters 106A and 106B (upper two panes; interval between consecutive records 20 minutes) and information gathered by the (telemetric) Wildland automatic weather station (Campbell CR1000) on Druim nam Bo (lower two panes; interval between consecutive records 15 minutes; RH = relative humidity). Notable weather events during this period were the UK's first two named storms, Abigail and Barney, which tracked over northern Scotland on 12–13 and 17–18 November, respectively, followed by Clodagh on 29 November (Met Office 2016). The sensors in Cluster 106A were positioned in surface peat along a transect (described in the text) in the following order: White_227 (lowest, in channel) - Yellow_130 - Green_251 - Blue_30 - Red_49 (highest, on the side of a peat hagg). The 'surface' sensor of Cluster 106B was located near the centre of a small degraded hagg.

detected on the peat may have been due to insolation on the 19th, as it hardly shows in the air temperature record. This time, four peat-surface sensors responded, perhaps indicating a lower thaw line than previously. Certainly, it appears that the sensor locations were differentially exposed to frosting in the early hours of the 21st as only three sensors indicated cooling. Conversely, when the next warm air mass arrived on the 26th, all surface sensors responded in a sequence that can be interpreted in terms of meltwater moving through the channel and snow at other levels requiring time to melt. The '106B' data indicate that subsurface peat cooled quite steadily from the 12th onwards, although the sensors at 10 cm and 20 cm depth showed some responses (with time lags) to warming events at the surface.

DISCUSSION AND CONCLUSIONS

The use of geotagged photographs was effective in expediting the peat/vegetation survey under circumstances of limited field time, species-poor plant communities and multiple observers with different skill levels; although there were instances where it was not easy to distinguish between graminaceous species in photographs that were not accompanied by field species lists. Nonetheless, the use of geotagging improves on the approach of e.g. Gilbert & Butt (2009) by removing the need for meticulous logging of photograph locations in the field. The intended even coverage of the stream catchments with sampling points was largely but not entirely achieved, firstly because some grid locations were too steep for observers to access safely, and secondly because the data and GIS resources needed to definitively generate the catchment boundaries were not in place before the seasonally determined time window for fieldwork. Now that the photographs have been captured there is potential to re-use them in interpretation of remotely sensed imagery of the site, which would effectively increase the fraction of ground sampled from $< 6.25 \times 10^{-4}$ % (0.25 m^2 *per* 40,000 m^2) to 100 %. The above consideration of just a segment of the peatland data captured *via* the ESN confirms the immense potential of this approach for remote data collection across inaccessible field sites in telemetry shadow under hostile conditions. It is difficult to imagine how such data could otherwise have been gathered on the Mòine Mhór through such a meteorologically eventful period. The environmental sensor network is ideal for investigations in locations like this where there is very limited mobile phone signal, as it allows the network to 'hop' from node to node to reach the field site and provides a 'live' data feed.

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