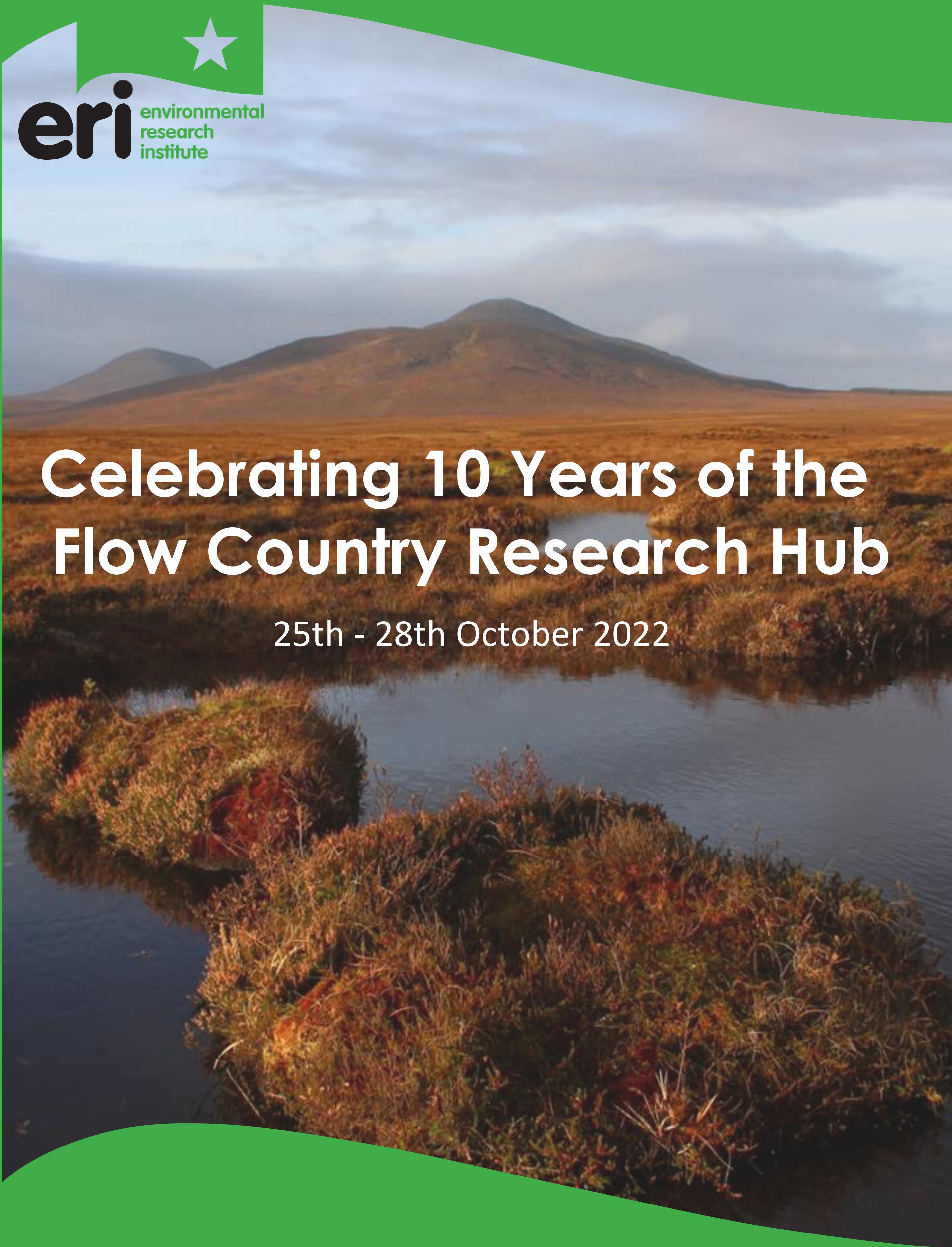

# Celebrating 10 Years of the Flow Country Research Hub

25th - 28th October 2022

# Thanks to our partners and sponsors

*Editing:* *Aimée Houghton, Mascha Bischoff and Chris Marshall*
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# Welcome to the 7th Flow Country Research Conference:
## Celebrating 10 years of the Flow Country Research Hub!

It is with great pleasure that we welcome you all once again in Thurso for a celebration of a decade of exciting collaborative science in the Flow Country! We are humbled and immensely grateful by your response to this first in person post-lockdown event, and thankful to our sponsors and funders for their support.

It is hard to believe that a decade has already passed since October 2012, when a small group of researchers, students and stakeholders gathered in Thurso for a conference dedicated to research in the Flow Country peatlands. Back then, the group agreed that a new collaborative and coordinated approach was needed to ensure the Flow Country could take a centre-stage in UK peatland research. The "Flow Country Research Hub" was launched, with the aim not only to facilitate research in the Flow Country and support the critical infrastructure that underpins it, but also to actively engage in outreach and knowledge transfer.

A decade later, the Flow Country Research Hub has supported more than 40 collaborative research projects including 20 PhD students, many of whom have since progressed with peaty careers of their own. We have hosted many visits from international collaborators and world leading peatland experts, artists in residence, undergraduate interns from far and wide, and quite a few media production teams. We have helped with workshops, demonstration events, field courses, and much more. A decade later, a bid for UNESCO World Heritage Site is about to be submitted, making the Flow Country the first and only peatland in the world at that stage of the process. For all these successes, we can only say "Thank you" – thank you for your confidence and your trust, thank you for believing in this approach and embracing it, and thank you for your enthusiasm and unfailing support over the years. You made this happen!

Yet, a decade later, the Flow Country has also been through at least two droughts (2018, 2021) and a "megafire" (2019), reminding us that our coordinated and collaborative approach is perhaps more important now than ever. Robust evidence, solid datasets and excellent science are all essential if we are to convince policy makers and the public that global protection and restoration of peatlands need to be ramped up alongside increased efforts to reduce our consumption of fossil fuels. We must pull up our sleeves and look ahead to another decade during which we can generate ideas, build knowledge and evidence and produce more amazing peatland science together.

But, for now, we hope that you will enjoy the programme and the local hospitality, remember good times with old friends and make new contacts, and celebrate the inspiring work that continues to take place in this incredible landscape.

Have a good conference!

# Celebrating 10 years of the Flow Country Research Hub
## Thurso, Caithness – 25th- 28th October 2022
# Programme

| Tuesday 25th October | |
|---|---|
| 16:45 - 19:00 | Icebreaker and registration at UHI North Highland, Thurso Campus (drinks and nibbles provided) |
| 19:00 - | Dinner in town (not provided) |

| Wednesday 26th October | |
|---|---|
| 8:30 | Arrival and registration at Thurso Merlin Cinema |
| 8:45 | Opening and Welcome address – Stuart Gibb |
| **SESSION 1 Peatlands: the big picture – from local to global**<br>Chair: Amy Pickard | |
| 9:05 | From local to global: 20 years of monitoring and modelling peatland condition and their contributions to greenhouse gas budgets – Rebekka Artz |
| 9:30 | The Scottish Flux Tower Network – Mhairi Coyle |
| 9:45 | Near-natural and restored peatland monitoring using remotely sensed radar data: Forsinard Flows case study – Linda Toca |
| 10:00 | PeatPic Project: Understanding peatland green leaf phenology using smartphones and community science – Scott Davidson |
| 10:15 | The Forth-ERA peatland monitoring platform – Jens Arne Subke |
| 10:30 | Break (30 min) |
| **SESSION 2 It's all in the details: small-scale peatland monitoring**<br>Chair: Jens Arne Subke | |
| 11:00 | Monitoring peatland health below the surface – Nicholle Bell |
| 11:25 | The effect of drainage on the physicochemical and microbial characteristics of peat – Ezra Kitson |
| 11:40 | Linking microbial traits with carbon flux in degraded and restored peatlands – Will Pallier |
| 11:55 | Functional trait variability in three Flow Country *Sphagnum* species and the influence of precipitation and altitude – Callum Thompson |
| 12:10 | Local Adaption in Plant Populations and its Role in Peatland Ecosystem Responses to Climate Change – Tom Parker |
| 12:30 | Lunch (85 min) |
| **SESSION 3 10 years and beyond – modelling peatlands of the future**<br>Chair: David Large | |
| 13:55 | Modelling the Influence of Mechanical-Ecohydrological Feedback on the Nonlinear Dynamics of Peatland – Adilan W. Mahdiyasa |
| 14:10 | Machine Learning and Deep Learning for Multi-Temporal-Spatial Assessment of Anthropogenic Stressors on Peatlands – A Case Study of Ireland – Wahaj Habib |
| 14:25 | Peat and Whisky – Mike Billett |
| 15:15 | Transfer to main college for poster session (at Thurso Campus, ETEC building walking distance) |
| **16:00** | **The Bog Blanket – a dance performance by Julia McGhee followed by a discussion with the artist** (at Thurso Campus, 30 min) |
| **16:00 - 18:45** | **Poster session (drinks and nibbles provided)** |
| 18:45 - 19:00 | Transfer to conference dinner (in walking distance) |
| **19:00 - 21:00** | **Conference dinner at the Pentland Hotel** |
| 21:00 - late | Drinks at the Commercial (not provided) |

| Thursday 27th October | |
|---|---|
| 8:30 | Arrival and registration for day 2 |
| 9:00 | Welcome to day 2 |
| **SESSION 4 Reflections on peatland restoration in the Flow Country**<br>Chair: Neil Cowie | |
| 9:05 | Reflections on 35 years in the Flows – celebrating our progress, and highlighting some key themes – Mark Hancock |
| 9:30 | Afforestation and bird assemblage changes in the Flow Country – Rob Hughes |
| 9:45 | Restoration Trajectories from Forest to Bog Restoration using Satellite Radar Derived Peat Surface Motion – Chris Marshall |
| 10:00 | Forest to Bog: lessons captured and developing approaches– Ian Mckee (TBC) |
| 10:20 | Break (30 min) |
| **SESSION 5 There's something in the water – exploring peatland hydrology**<br>Chair: Renée Kerkvliet-Hermans | |
| 11:00 | Waters draining the Flows: insights into land use, restoration and climate effects on water quality – Amy Pickard |
| 11:25 | Diurnal variations in greenhouse gas fluxes from peatland pools – John King |
| 11:40 | Historic peatland drainage density has a greater impact on water quality than time since restoration in a Flow Country catchment – Liam Godwin |
| 11:55 | Carbon dynamics of surface water pools and *Sphagnum* in Blanket peatlands – Jasper Newman |
| 12:10 | Lunch (70 min) |
| **13:20** | **The Wet Desert – a play by George Gunn, Act 1** |
| 14:30 | UNESCO World Heritage Session with Steven Andrews |
| 15:20 | **Richard Payne Student Prizes** followed by conference close |
| 15:30 | Stay for tea (30 mins) |
| 16:00 | Departure for 16:32 train |
| 16:20 | Meet for walk to Wolfburn Distillery tour and whisky tasting |
| 18:30 - | Dinner in town (not provided), later, informal drinks in town |

| Friday 28th October | |
|---|---|
| 9:00 | Meet for field trip to Camster Cairns (at Thurso Campus) |
| 13:00 | Lunch (provided) at Camster Cairns |
| 15:00 | Return to Thurso |

# Keynote speakers

## Rebekka Artz

Rebekka is a Senior Research Scientist at the James Hutton Institute. She has more than 17 years of research experience in the ecology and ecosystem functions of peatland ecosystems and more than a decade of experience of providing links between science and policy, delivering land management decision support tools, policy briefings and expert opinions on Soils and Climate Change mitigation policy matters to Scottish and UK Governments. She has been an expert reviewer on the carbon benefits of peatland management to the UK and Scottish Governments as well as for various nature conservation agencies in the UK.

## Nicholle Bell

Nicholle is an Organic Chemist working at the University of Edinburgh. She is interested in using a combination of next-generation sequencing and high-resolution NMR and MS spectroscopy to link molecular-level metrics with peatland health status. Nicholle has been working on peatland chemistry for more than 7 years including receiving a prestigious NERC independent research fellowship in 2019. She now leads efforts in the School of Chemistry, University of Edinburgh to understand the synergies between the molecules and microbes in promoting healthy peatlands.

## Russell Anderson

Russell is an Ecologist with Forest Research. Russell leads research to support forest policy and practice relating to afforested peatlands. This covers the impacts of peatland afforestation and restoration on key ecosystem services. It includes testing techniques for peatland restoration and trialling alternative types of land management that may in some places give greater overall benefits. Russell joined Forest Research in 1978 and has undertaken research on soils, hydrology, peatlands and ecology. He studied for an MSc in Forest Science at Edinburgh in 2000-2003. He is a member of the Land Use and Ecosystem Services (LUES) team and co-ordinates the Evidence and Knowledge

## Mark Hancock

Royal Society for the Protection of Birds (RSPB)

Mark is a Senior Conservation Scientist with RSPB. His work is focussed in the forests and hills of Cairngorms Connect, the UK's largest habitat restoration project; and in the peatlands, rivers and lochs of the Flow Country. Through this work he provides the science foundation that supports large-scale restoration of key ecosystems in northern Scotland, and the species associated with them. Mark has worked on peatland research for more than 30 years including works on the monitoring of Common Scoter in the Flow country, the impact of forestry plantations on ground nesting birds and numerous collaborations with peatland partners from a range of disciplines.

## Dr Amy Pickard

UK Centre for Ecology and Hydrology, Edinburgh

Amy is an Aquatic Biogeochemist working at the UK Centre for Ecology & Hydrology. She is interested in the cycling of carbon, nutrients and greenhouse gases in freshwaters, particularly within peatlands and their drainage systems. Amy has been conducting research surrounding these themes in Scottish peatlands for > 8 years and is currently involved in a number of projects concerned with the effects of changing land use, climate and extreme events on the mobilisation of carbon from land to water.

# SESSION 1: Peatlands: the big picture – from local to global

**Keynote** – Rebecca Artz

## From local to global: 20 years of monitoring and modelling peatland condition and their contributions to greenhouse gas budgets

In the talk, I will give an overview of the historic beginnings of greenhouse gas emission and condition modelling research on peatlands in Scotland, from its' humble beginning with manual chamber measurements at small-scale degraded sites in the North East of Scotland and later in the Flow Country, to the current and rapidly growing network of long-term, eddy covariance-based, research stations across the country. Many of these locations have also served as ground observation training data for the modelling of peatland condition via remote sensing. I will show some of the highlights from this research and how we are now integrating our improving understanding of the drivers of carbon dynamics into regional, continental and global modelling efforts. Along the way, I will showcase the instrumental work of the many PhD students, research assistants and senior researchers, who collectively contribute to this constantly evolving and world class scientific research community.

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## Scotland's Flux Tower Network

Mhairi Coyle[1]*

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Scotland contains a large area of peatlands which have developed since the ice sheet and glaciers retreated 14-20k years ago, including the Flow Country in Caithness and Sutherland, the single largest area of blanket in the world. Much of Scotland's peatland was left undisturbed by human activity, other than some domestic fuel extraction, limited drainage and rough grazing until the 20th century when industrialised extraction, drainage and forestry rapidly expanded. With the realisation that this is harming these environments, in terms of biodiversity, subsidence and net emissions of soil carbon, legislation and programmes have been put in place to restore significant areas. As part of the restoration effort and need to expand our scientific understanding of carbon exchange over different types of peatlands, a network of eddy-covariance towers is being established. The eddy-covariance method is well established as the standard for observing gas exchange, giving the net-ecosystem exchange over a footprint of 10s to 100s of metres around the measurement tower, depending on the topography and installation height. The network incorporates existing sites, such as those on the RSPB Forsinard Reserve, and new sites to give coverage of different land uses. Our network monitors the exchange of carbon dioxide and water vapour, and at most sites also methane, alongside important micrometeorological variables that determine their dynamics. Some additional "low-cost" techniques are also being trialled at some sites to improve our ability to monitor and classify the condition of any peatland. The current status of the network and an overview of the data obtained to date are presented here. These measurements should give us a unique perspective on the effectiveness of restoration.

## Near natural and restored peatland monitoring using remotely sensed radar data: Forsinard Flows case study

Linda Toca[1]*, Rebecca Artz[1], Keith Morrison[2], Alessandro Gimona[1], Tristan Quaife[2]

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Peatlands in their natural state are effective long-term sequestrators and substantial stores of carbon. In the past, ineffective land management schemes have left many peatlands around the world degraded, and even such remote areas as Forsinard Flows have experienced peatlands being turned from carbon sinks into CO2 emission sources. Luckily in the past years, we have seen a significant increase in northern peatland protection and restoration projects.

Water table depth along with soil moisture are predominant factors driving biogeochemical processes in peatlands, with excessive lowering of water level leading to peat subsidence, oxidation, and carbon release back into the atmosphere. Both restored and near-natural peatland ecosystems require long-term continuous hydrological monitoring and remotely sensed radar data has the potential to both meet the demand of regular continuous monitoring and cover vast areas. As radar signal is sensitive to both geometric and water (dielectric) content of vegetation and soil, can cover large areas, penetrate clouds and has a high temporal revisit time over northern peatlands, the Sentinel-1 synthetic aperture radar (SAR) data can be expected to offer valuable information on peatland ecosystem condition.

A laboratory experiment conducted by the authors confirmed a firm linear relationship existing between radar backscatter and peat hydrological characteristics with $R2>0.9$ when other factors influencing radar backscattering were controlled for. A model was then developed to predict water table depth in peatlands using Sentinel-1 backscatter data. Eleven representative areas from near-natural and restored sites were chosen from peatland sites in the Forsinard Flows based on the availability of historical water level monitoring sites. Both simple linear regression (SLR) and multiple linear regression (MLR) models were built and applied. When tested for the chosen peatland sites, the Sentinel-1 model demonstrated SAR backscatter sensitivity to peatland hydrological conditions, but the relationships varied between peatland condition classes and individual sites. The model performance reached up to an adjusted R2 of 0.62 for all sites together, and up to 0.67 when used per site individually. It was concluded that the inclusion of the radar image acquisition time (year and season) in the model can improve the WTD prediction as the WTD-backscatter relationship has seasonal trends. The analysis demonstrated the radar backscatter to be sensitive to hydrological patterns in the peatbog ecosystem and supported the notion that Sentinel-1 data could support peatland condition monitoring over northern unforested peatlands, however, further improvements, such as addressing the high heterogeneity between peatland sites, are necessary.

## PeatPic Project: Understanding peatland green leaf phenology using smartphones and community science

Scott J. Davidson[1,2]* and Avni Malhotra[3]

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Peatlands store one-third of the world's soil carbon and these carbon dynamics are partly driven by understory vegetation such as sedges, mosses, and dwarf shrubs. The phenology of these small-statured plants is difficult to capture with remote sensing proxies. Furthermore, the relationship between leaf phenology and peatland carbon cycling is not fully explored. We leveraged our previous work developing smartphone-based methods for quantifying peatland phenology to initiate a peatland community-based (#PeatTwitter) project called PeatPic. PeatPic provides a platform for smartphone images that can be used to calculate leaf greenness proxies. To date PeatPic has had submissions from 27 sites, with images submitted every 1-2 weeks across the growing season. We will present within- and across-site variation in leaf greenness across a variety of peatland types globally. Future goals include identifying environmental predictors of green leaf phenology and linking phenology to carbon fluxes. We hope to maintain this database as a long-term, adaptable community resource that can improve understanding and modelling of peatland carbon cycling processes.

## The Forth-ERA peatland monitoring platform

Jens-Arne Subke*, Matthew Blake, Benjamin Roberts, Edward Salakpi, Peter Hunter

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The Forth Environmental Resilience Array (Forth-ERA) has the ambition to become the first regional environmental recovery monitoring platform. It aims to provide real-time data from environmental monitoring equipment across the Forth catchment to support a regional transition towards better environmental management and sustainable decision making. Forth-Era is funded as part of Scotland's Environment Centre, established as part of the Stirling and Clackmannanshire City Region Deal through an investment of £17m from the Scottish Government and £5m from the UK Government, with additional funding leveraged through private and match-funded investment.

A key component of this approach is the monitoring of peatland restoration progress. We will develop, test, and apply methods for the assessment and monitoring of peatland restoration projects by combining data from wireless sensor networks and satellite-based remote sensing. We collaborate with Peatland Action and NatureScot to make data available in (near) real-time through a bespoke web-based platform. The approach will be initially piloted using restoration sites within the Forth catchment, but with a view to these being upscaled nationally during future project phases.

The project will specifically address the following research questions:

- What are the most appropriate remote sensing-based indicators of peatland condition and trajectories of change at the ecosystem scale?
- How can optical and radar remote sensing be used synergistically to quantify the success of peatland restoration projects?
- To what extent are remote sensing approaches to peatland monitoring transferable across space and time and what factors affect their applicability?

The project was initiated in 2021, and we are in the process of deploying equipment such as automated monitoring soil chambers and an eddy covariance tower alongside environmental peat and meteorological sensors at five peatland sites. The poster will introduce the Forth-ERA peatland project and latest progress

# SESSION 2: It's all in the details: small-scale peatland monitoring

**Keynote** – Nicholle Bell

## Monitoring peatland health below the surface

Rewetting peatlands by installing dams is one of the most common methods for restoration. While we know rewetting can bring back the waterlogged conditions, the question remains whether rewetting successfully restores peatlands to their full health. To answer this question, we need to know what is happening below the surface and examine the roles of key players in peat formation and carbon cycling, namely the microbes, the enzymes and the carbon containing molecules. It is not clear which of these players is more important, or how do they depend on each other. To address this question, we are using the latest technologies (DNA/RNA sequencing, NMR spectroscopy and FT-ICR mass spectrometry) to uncover who they are, how they interact and how they are impacted by drainage and rewetting. In this presentation, I will provide a brief overview of what insights such technologies provide below the surface of our Flow Country field sites. I will also describe a method that may prove to be a simpler tool for monitoring peat health on a molecular level.

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## The effect of drainage on the physicochemical and microbial characteristics of peat

Ezra Kitson*, Andrew Free, Nicholle Bell

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Over the last century we have acquired substantial evidence that water table regime is a fundamental determinant of peatland health. Peatland health refers to the ability of a peatland to perform essential ecosystem functions for humanity, including but not limited to, carbon sequestration, water filtration, flooding prevention and sustenance of high biodiversity. Undrained peatlands perform these services better than drained peatlands. The question is, why?

Peatland drainage changes the physicochemical and microbial characteristics of peat. These characteristics are linked and likely interact through feedback mechanisms, although the precise nature of these interactions is not known. The result of these changes is to create peat that no longer performs the essential ecosystem functions listed above. The consequences for humanity are serious: carbon release driving global warming, flooding, fresh water pollution and loss of biodiversity.

The primary aim of my work is to develop a better deterministic understanding of how peatland drainage changes the physicochemical and microbial characteristics of peat, and in turn how these changes result in loss of ecosystem functions. To this end I have analysed peat cores taken from drained, undrained, and rewetted regions at four UK blanket bogs using a variety of chemical and biological techniques. In this presentation I will discuss findings from high resolution mass spectrometry, 16S RNA and DNA sequencing and physiochemical assays including phenol concentration and enzyme activity.

## Linking microbial traits with carbon flux in degraded and restored peatlands

Will Pallier[1] *, Rebekka Artz[2], Roxane Andersen[3], Nicholle Bell[4], Ashish Malik[1]

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A major focus of peatland research for the past 20 years has been to assess the effectiveness of peatland restoration in restoring peatlands to their "natural" state. This research has up to this point been largely focussed on ecosystem functioning of peatlands, mainly greenhouse gas emissions and the environmental factors that drive these changes e.g. vegetation and water table depth. Microbes play a key role in biogeochemical cycling in peatlands, they dictate whether the plant organic matter is mineralised and released as CO2 or stabilised and stored as organic matter.

Despite their key role the majority of microbial research in peatlands has up to this point been mainly focused upon taxonomic classification, as such the microbial functioning in peatland and how these changes with drainage and restoration remains unknown. A mechanistic understanding of microbial processes is required to both predict and manage carbon cycling processes in peatlands in a changing climate.

Here we will present how peatland degradation and subsequent restoration impacts microbial physiological processes and their consequences on peatland carbon transformations. We have sampled 7 peatlands sites across the UK, each containing near natural, degraded and restored areas. The goal has been to assess microbial carbon cycling functions like growth rate, carbon use efficiency, resource breakdown and uptake, maintenance and stress tolerance. These community traits have been quantified using a combination of shotgun metagenomics and stable isotope analysis, in order to link microbial traits from genes and phenotypes to rates of carbon cycling.

We have found that water table level and vegetation community impact microbial physiology in particular their growth rate, stress tolerance and carbon acquisition strategies. This consequently affects the flux of greenhouse gases. We observe that restoration leads to substantial changes in the microbial community and processes, however even 10 years post restoration microbial processes still differ from near natural peatlands. There also exists high variation in microbial activity between sites suggest microbial processes and recovery following restoration is not uniform. These restored peatlands with novel microbial and ecosystem processes will be important to continue studying especially in regard to how the altered microbial functioning impacts long term carbon storage and resilience in restored peatlands.

**Functional trait variability in three Flow Country *Sphagnum* species and the influence of precipitation and altitude**

Callum Thompson[1]*, Mascha Bischoff[1], Rebecca Artz[2], Jens Arne Subke[3], Neil Cowie[4], Anna Sánchez de Mingo[1,5], Erin Stoll[1], Roxane Andersen[1].

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Flow Country blanket bog is characterised as acidic, anoxic, and nutrient-poor due in part to being ombrotrophic, but also because of the presence of peat mosses of the genus *Sphagnum*. These plants are a keystone species for the ecosystem, maintaining conditions by stabilising water levels and performing cation exchange. However, despite the essential role of this bryophyte genus, the extent of *Sphagnum* morphological and metabolic variability is not well understood. In the context of peatland conservation, it is worth considering how intra- and interspecific differences could influence the suitability of individual *Sphagnum* species for restoration. Some *Sphagnum* species may in fact be better at coping with stressors resulting from climate change, i.e. through resistance to droughts with greater internal water storing capacity, enhanced capillary action to draw the water table, and specialised metabolisms that allow survival and recovery from desiccation.  This study sought to establish the existence and extent of variation in functional traits that *Sphagnum* display in response to differences in precipitation and elevation. Local trait adaptations to drought would indicate potential resilience to future climate change.

We explored inter- and intra-specific trait variability in three species (*Sphagnum papillosum*, *S. capillifolium,* and *S. cuspidatum)* representing common bog microhabitats. Six sites (three precipitation regimes at two different elevations) located across the Flow Country were used to explore the influence of water availability on select functional traits in a fully factorial design. Sites were selected to take advantage of the West-East precipitation gradient across the Flow Country, dividing the area up into wet (>2000 mm/yearly average), medium (2000-1000 mm/yearly average), and dry (<1000 mm/yearly average) categories, combined with two elevation levels: high (>200 m.a.s.l) and low (<100 m.a.s.l). Due to the importance of water to *Sphagnum* survival because of a lack of a true vascular system or sophisticated transpiration regulation, we expected morphological differences unique to local populations of *Sphagnum* that allow them to survive in the drier east, with a more transitory region in the centre, with populations in the wet west being less adapted to water retention. The traits measured were the dimensions of *Sphagnum* growing density in situ, structural morphology (stem, leaf and capitulum) and photosynthetic pigment concentration.

Trait variation within species tended to overshadow the influence local experimental conditions at the site. Initial analyses did not reveal any significant trends in the traits explained by the precipitation gradient. Elevation appeared to influence the growing density of all species, with increased elevation correlated with denser growth. However, the considerable change in pigment concentrations over a 3-week period within one site showed that some traits can have an almost immediate response to changes in local climate. These fast-response traits may have greater importance for resisting stress than long-term structural adaptations to climatic conditions.

## Local Adaption in Plant Populations and its Role in Peatland Ecosystem Responses to Climate Change

Thomas C. Parker[1]*

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Carbon sequestration in peatland ecosystems depends on the balance between input into the system by plants and mosses and their eventual decomposition. In northern peatlands, these plants typically thrive in cool, wet environments where their growth strategy has been shaped since the last ice age. However, the environmental 'envelope' that peatland species are adapted to will rapidly shift in the coming century, leaving these fundamentally important, slow-growing plants vulnerable.

*Eriophorum vaginatum* (tussock cottongrass) is a key peatland species for ecosystems around the Northern Hemisphere, including the Boreal Forest and Arctic Tundra where it has been shown to be highly locally adapted and potentially slow to respond to climate change. I will present my work from Northern Alaska on locally adapted populations of *E. vaginatum* along a 550 km environmental gradient (five degrees of latitude), how they respond to simulated climate change and what the ecosystem implications are. I will examine the potential for genetic variation in *E. vaginatum* to determine ecosystem processes such as phenology (timing of seasonal events), greenhouse gas exchange and decomposition rates and how phenotypically plastic (responsive to change) these traits are. I will compare Alaskan/tundra ecosystems with those of Scottish peatlands and suggest how understanding can be translated across continents.

# SESSION 3: 10 years and beyond – modelling peatlands of the future

## Modelling the Influence of Mechanical-Ecohydrological Feedback on the Nonlinear Dynamics of Peatland

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Peatlands are complex systems that exhibit nonlinear dynamics due to internal and external feedback mechanisms. However, the mechanical processes that provide feedback on the peatland ecology and hydrology, and potentially influence peatland dynamics, are not well understood. Here, we analyse the consequences of mechanical and ecohydrological feedback on a non-equilibrium model of peatland dynamics through the coupling between plant functional type, fluid flow, and solid deformation by developing the MPeat model. In this formulation of MPeat, the peat systems prefer to exist in two possible states defined by two limit cycles, one corresponding to a wet and the other a dry attractor. These states can also coexist under the same net rainfall indicating bistability in which a crucial drying threshold leads to a tipping point and associated regime shift from soft wet to stiff dry states with related changes in rates of carbon storage. While the shift from wet to dry states constitutes a tipping point, to shift from the dry to wet states requires more sustained increases in net rainfall, indicating that dry state is the more stable attractor as peatland grows. As the model peatland evolves, the response of surface motion, carbon accumulation, and water table depth to the same external forcing becomes increasingly higher amplitude indicating that a degree of caution may be required when interpreting the paleorecord. Investigation of the behaviour of these states in response to seasonal variations in water budget suggests that the wet state will display high amplitude and later peak timing when compared to the dry state, something that is observed in measures of surface motion. Our study highlights the possible importance of mechanical-ecohydrological feedback in influencing the nonlinear behaviour of peatland and its resistance to change. Through this model, we are able to explore regime shifts and tipping points in the peatland system, consider the relationship between water budget and surface motion, and compare results to observations of this nonlinear behaviour.

**Machine Learning and Deep Learning for Multi-Temporal-Spatial Assessment of Anthropogenic Stressors on Peatlands – A Case Study of Ireland**

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Peatlands account for ~ 21 % of the land surface area in Ireland, yet they store up to 50 – 75 % of the total Soil Organic Carbon (SOC) stock of the country. However, less than a quarter of these ecosystems remain relatively intact. This is due to the degradation caused by anthropogenic stressors, which include, artificial drainage and subsequent industrial/domestic peat mining, afforestation, and agricultural activities. These activities negatively influence the functioning of the ecosystem which in turn affects the many ecosystem services provided by peatlands e.g., climate and water regulation. However, the extent of these management activities (land use) and resulting degradation is poorly known. It is vital to map the land use on peatland. This will not only aid in the understanding of degradation and its implications on C/GHG (Carbon/Green House Gas) emissions and removals but also be useful for rehabilitation/restoration and rewetting activities.

In this study, we use the medium to high spatial resolution satellite remote sensing imagery i.e., Landsat 5, 8 (30m) and Copernicus Sentinel-2 (10m) respectively. The data was accessed and processed in Google Earth Engine using machine learning techniques. Landsat archive was used to map the spatial extent and temporal trend (1990 to 2020) of four main land uses: industrial peat extraction, forestry, grassland, and residual peatland. Whereas the high spatial resolution of Sentinel-2 allowed detailed mapping of seven classes of land use: cutaway, cutover, afforestation, grassland, water bodies, built-up and remnant peatlands (high bog). Furthermore, a very high-resolution aerial imagery (.25m) combined with deep learning (semantic segmentation) techniques are being used to map the spatial extent of artificial drainage on raised bogs in Ireland. The results show an alarming extent and trend of management activities on Peatlands in Ireland with regional and global consequences.

## Bog to Bottle – the Story of Peat and Whisky

Mike Billett

Peatlands to many of us are places of beauty, complexity and wonder. They have a special place in the scientific world and in the fight against climate change – a vulnerable ecosystem, an important sink for atmospheric carbon dioxide, a hotspot of biodiversity.

In the whisky world peat also has a special status and for the last 400 years there has been a deep connection between Scotland's lands of peat and the world of whisky. Peated, smoky spirit is part of Scotch - a drink both famous throughout the world and a symbol of the country of its birth. But the whisky world can often sound confused and unknowing about peat. Is it a fossil fuel like coal and oil, is it a renewable resource, is it rare, is it all the same? Misconceptions about peat are common and myths abound in the marketing of single malts and blends.

The story of peat and whisky started in smoke-filled bothies and small farm buildings in the Highlands and Islands. Peat fired the sma' stills and dried the malted barley, creating a premium product much sought-after across the UK and known throughout the world. "Peat reek" became part of the DNA of Scotch and although the connection loosened for a while as consumers developed a preference for blends and a lighter, largely unpeated style of whisky, in modern times peat and whisky have dramatically rediscovered their bond, developing an international cult following. At the beginning of the 21st century peated whisky, building on its roots in Scotland, is currently produced across all the continents of the world with the exception of Antarctic.

Although the connection between the peatlands of northern Scotland and its whisky is less obvious now, it is a still central to the aromatic, smoky flavour profile of Highland Park. The mainland distilleries of Old Pulteney, Wolfburn, Clynelish, Balblair and Glenmorangie all once used peat cut from the Flow Country, although now they are producers of unpeated malts. For more than 100 years the island of Eday in the north Orkneys was a major exporter of peat to distilleries throughout mainland Scotland, England and across the world to Australia. More recently Flow Country peat has been used to make Octomore, the "most peated whisky in the world" distilled in, of all places, Islay.

In his famous book, simply called *Whisky* published in 1930, Aeneas MacDonald wrote "the convenient proximity of a peat bog is an economic necessity for a Highland malt distillery". As large-scale industrial scale maltings replaced distillery floor maltings, the number of peat mosses (and the methods) used to extract distillery peat has changed dramatically. Sustainability, zero carbon, adaptation, mitigation and restoration are now more than just watchwords for the whisky industry and there is a growing awareness of the issues that surround peat use.

***End of Day 1***

# DAY 2

Photo credits: Rob McHenry

# SESSION 4: Reflections on peatland restoration in the Flow Country

**Keynote** – Mark Hancock

## Reflections on 35 years in the Flows – celebrating our progress, and highlighting some key themes

I will reflect on my work with RSPB in the Flow Country since 1987 – remembering the conflicts during afforestation in the 1980s, the challenges for a young research assistant new to the area, and our great progress since then. This includes establishing the largest RSPB reserve in the UK – Forsinard – at the heart of the Flows; working with an excellent academic partner – ERI – to build multiple valuable scientific collaborations; much better consensual working between land management sectors; and important progress towards World Heritage Site (WHS) status. I will bring out some of the themes, as they seem to me, that contribute towards the Flow Country's "outstanding universal value", and share some ideas about key topics and approaches that might inform our future science directions.

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## Afforestation and bird assemblage changes in the Flow Country

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Afforestation of the Flow Country has brought about changes in bird assemblages. This forestry has changed the biogeography of the area, creating insular 'island like' ecosystem areas. This talk describes the winner and losers of the habitat changes from bog to forestry. In the 1960's, pre-afforestation, the most abundant raptor species would have been Hen Harrier, Short-eared Owl and Merlin, now inter-specific competition comes from newly established forest breeding raptors such as Common Buzzard, Eurasian Sparrowhawk, Tawny and Long-eared Owl. Forest passerines such as Common Crossbill almost certainly would not exist as a breeding species in the Flow Country if it was not for the forestry. Some commoner breeding species that had their breeding habitat availability reduced, are declining in Scotland and are of conservation concern.

## Restoration Trajectories from Forest to Bog Restoration using Satellite Radar Derived Peat Surface Motion

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Forest to Bog Restoration at the RSPB Forsinard reserve has been extensive over the past 20 years in order to improve peatland condition and reduce carbon emissions. Techniques and treatments have evolved over this time from fell to waste to extractive techniques accompanied by an intensification of treatments from basic furrow blocking to reprofiling and mulching. This makes it an ideal place to test whether satellite radar-based approaches to measuring peatland surface motion can be used to determine whether peatlands subject to forest to bog restoration show clear trajectories towards peatland health over time. Using more than 600 forest blocks we measured three aspects of the motion of the peat surface: the long-term motion (whether the peat surface is subsiding or growing), the amplitude (the dynamism of the peat surface) and the peak timing (the response time of the peat surface to winter precipitation). We show that sites subject to fell to waste showed a delay of 8 years compared to more recent extractive techniques which we attribute to the requirement to revisit the site multiple times over the first 20 years post felling. Both fell to waste and extractive felling show a clear increase in dynamism post felling however fell to waste sites experience greater reduction in surface dynamism in the earlier phases of recovery. Peak timing appears to show no relationship with time since felling and appears to be an end point indicator controlled by landscape position and climate. This trend appears to be independent of intervention type providing evidence that peatland will naturally partition into wet and dry end members after restoration. These results indicate that peat surface motion based approaches to monitoring restored peatland provide a large scale means of quantifying progress towards restoration objectives potentially at the national scale.

# SESSION 5: There's something in the water – exploring peatland hydrology

## **Keynote** - Amy Pickard

## Waters draining the Flows: insights into land use, restoration and climate effects on water quality

The multiple and changing land management practices of the Flow Country, widely considered the world's largest tract of blanket bog, provides a unique environment to test the effects of land use on water quality. This talk will compile evidence from a series of UKCEH-led projects that have collected data from the Flow Country over the past decade as a means to better understand the flux of carbon from land-to-water and water-to-air, with specific reference to dissolved organic matter (DOM), and dissolved greenhouse gases (GHGs). Key findings include the notable effect of coniferous forestry on DOM, whereby forestry presence on peat increases dissolved organic carbon concentrations (DOC) in receiving waters by more than a third relative to undrained peat control sites. Climate extreme effects on DOM are also evaluated following the wildfire of May 2019, with evidence suggesting that drained peat is more vulnerable to deleterious fire-induced water quality effects than undrained peat. The effect of these pressures is considered in terms of improving resilience of our freshwaters under future climate change, and at varying scales, from the catchment scale, where drinking water supplies and aquatic ecosystem functioning are impacted by changing water quality, to the global scale, where it is increasingly important for us to understand and quantify the total flux moving between the land, ocean and atmospheric carbon pools.

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## Diurnal variations in greenhouse gas fluxes from Peatland pool

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Open freshwater pools are a characteristic feature of northern peatland environments, often forming large, complex systems of pools, with widely differing morphology. These freshwater peatland pools receive relatively large inputs of dissolved organic carbon (DOC) and, due to processes such as photodegradation and microbial activity breaking down the available aquatic carbon, have previously been found to be net emitters to the atmosphere of the greenhouse gases (GHGs), carbon dioxide ($CO_2$) and methane ($CH_4$). The fluxes of GHGs from the pools are known to vary over diurnal cycles, however the magnitude of these variations and the precise drivers behind them are poorly understood. Of the studies conducted on fluxes from peatland pools, many have been carried out during the middle of the day for practical purposes. Furthermore, many studies have focused on the summer season, again driven often by logistical necessity. This study examined diurnal variations in $CO_2$ and $CH_4$ fluxes from a selection of peatland pools in the blanket bog of the Flow Country, Northern Scotland with samples collected at 6-hour intervals through a full 24-hour cycle. Seasonality was also included, with repeat measurements conducted at the summer solstice, and again a month either side of the autumn equinox to primarily capture the impact of variable light conditions. The results suggest that there are notable differences in the GHG fluxes from peatland pools at different times of day and further variations are found based on the season (linked to water temperature and available daylight) as well as pool morphology (area, shape, depth). It is therefore important to factor diurnal changes into modelling of the carbon balance of peatlands as flux estimates informed by daytime-only measurement may over- or under-estimate the carbon storage potential of peatlands depending on the season and particular pool morphology in question.

## Historic peatland drainage density has a greater impact on water quality than time since restoration in a Flow Country catchment

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The Langwell river catchment on the southern reach of the Flow Country has undergone five peatland restoration schemes since 2015. This has resulted in large areas of formally drained peatland having drains blocked and surface smoothed. The Langwell river is one of the four Flow Country rivers that are Special Areas of Conservation due to their Atlantic Salmon populations and increasing peatland restoration in this region has made water quality a key concern. Reports of initial reductions to water quality following peatland restoration from other studies in other regions could mean the resident Atlantic Salmon (*Salmo salar*) populations are at risk. This study took measurements of the water quality of every tributary that flows into Langwell river, and every 2km of the river itself to monitor how catchment restoration and land use impacts the water quality of the tributaries and the impacts this has on the main water channel. We have found that there are greater changes to water quality based on previous drainage intensity compared to time-since-restoration, however many water quality changes are not above thresholds that are considered harmful to the aquatic wildlife and were comparable to values from undrained control streams. The study concludes that peatland restoration by drain blocking at these densities has not caused significant reduction in water quality, and greater drain blocking activities in the Flow Country should hold low risk to the aquatic environment, but monitoring remains recommended.

## Carbon dynamics of surface water pools and Sphagnum in blanket peatlands

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The surface water pools in blanket peatland are an important feature of the Flow Country due to their high dissolved greenhouse gas concentrations and large fluxes to the atmosphere. Peatland restoration efforts that create pools through ditch blocking further raises the need to better understand the local gas cycling processes. *Sphagnum* moss growing in and around peatland pools hosts microbes directly involved in producing carbon dioxide from dissolved organic carbon and methane. In this study, the methane cycling processes were investigated in pools with different restoration effects from a blanket bog in Dartmoor National Park. Stable carbon isotopes were used through an 18-month surface study to follow the signature methane signal from pools into *Sphagnum* tissue. *Sphagnum* has access to both atmospheric and biogenic dissolved carbon dioxide for growth. The balance of uptake routes in different environmental conditions is important for understanding the extent of atmospheric carbon dioxide sequestration and for managing restoration to best mitigate greenhouse gas release to the atmosphere. We observed high carbon dioxide concentrations in the peatland surface waters in the warmer months at all sites. We showed that this was predominately driven by methane oxidation. The water in the most recently formed pool, however, had distinctly lower contribution from $CH_4$ oxidation. This was evidenced by more 13C-enriched dissolved carbon dioxide. This low oxidation in the peat and pool water was compensated for by high methane oxidation in the water directly associated with the Sphagnum moss. This work highlights the value of *Sphagnum* as a support for symbiotic methane oxidising bacteria as a way of reducing greenhouse gas emissions when restoring peatland. When this dissolved methane is oxidised to carbon dioxide, it can be used for photosynthesis. Using carbon isotope ratios, it was shown that the carbon in *Sphagnum* is sourced in this way generally represents less than 5%. The methane derived carbon dioxide typically contributes a significantly lower proportion of the *Sphagnum* carbon than previous estimates of as much as 40%. Despite the high availability of dissolved carbon dioxide directly available to *Sphagnum* growing around peatland pools, slow diffusion of gasses in water means this carbon rich reservoir is largely bypassed and atmospheric sources dominate.

***End of Day 2***

# POSTERS

Photo credits: Liam Godwin

# Quantifying mammalian predator activity on active and abandoned roads in the Flow Country peatlands

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The global network of paved and unpaved roads has continued to expand rapidly into relatively undisturbed habitats to enable increasing resource extraction. Despite this, relatively little is known about their effect on the surrounding ecosystems or whether those effects can be reversed if roads are removed, and the affected land restored. A growing body of research indicates that artificial linear features can act as predator highways, enabling predators to travel faster and further into difficult terrain and accessing prey refugia that otherwise would be hard to reach. In the 1960-80s forestry plantations were established across previously intact peatland in the Flow Country. A large network of unpaved tracks was built to service these forestry plantations. In recent years, as forestry has been removed and peatland restored, these tracks have remained. It is hypothesised that forest associated mesopredators (e.g Foxes and Pine martens) are using these tracks to move further into difficult to navigate intact peatland to access ground nesting birds as supplementary prey. This project uses a combination of data from passive camera trap arrays, scat counts, and vegetation composition to compare the effect of abandoned revegetated roads on predator activity and the surrounding ecosystem to that on maintained forestry roads in the Flow Country. This knowledge will help inform the design and need for road removal and restoration to protect and restore the functioning of the peatland ecosystem in the future

## The Flow Country Green Finance Initiative

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The Flow Country, which is located in the north of Scotland, is the largest blanket peat bog in Europe. Its expanse of 400,000ha is an important wildlife habitat and stores 400 million tonnes of carbon – more than double the amount in all of Britain's woodlands. This makes it vital for both biodiversity conservation and climate change mitigation.

The remarkable ability of these peatlands to store carbon is only possible if the bogs are kept in healthy condition. Sadly, huge areas are degraded and in need of restoration.

Restoring our peatlands is one of the most important things we can do to fight climate change. But it's not always easy to set up projects to do this, especially not at scale.

The Flow Country Green Finance Initiative is a locally led Partnership which will raise money to restore peatlands at scale. The Partnership aims to establish a new model for peatland restoration which blends public and private finance in order to facilitate a just transition to benefit biodiversity, communities and the local economy.

We will formalise a not-for-profit - a Scottish Charitable Incorporated Organisation (SCIO) - which will enable us to aggregate multiple restoration projects across the Flow Country and raise significant funds to channel into restoration at scale. The not-for-profit vehicle will develop a set of ethical finance guidelines to help ensure that investment into the Flow Country's peatland retoration reflects local views on community and environment.

Moreover, the Flow Country Partnership SCIO will ensure profits accrued from investments, ecosystem services and carbon credits are locally beneficial by reinvesting this money into local community projects.

## Environmental factors affecting the moisture content of surface soils in the Flow Country Peatland

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Hourly time series for 19 variables including the surface soil moisture from the Copernicus Climate Data Store (ERA5_LAND_Hourly) were downloaded for the North of Scotland for year 2021 and analysed using ArcGIS and R Modelling.

The ArcGIS pro 3.0 tools such as Time Series Clustering, Local Outlier Analysis and Emerging Hot Spot analysis enabled to determine the natural boundaries for the flow country which is characterized by relatively high water content in soils compared to the rest of North Scotland.

Baseline linear models were developed using R Studio Cloud at 3 locations within the flow country. These models used normalized weather, vegetation and runoff variables for the prediction of soil surface moisture. In these models leaf area indexes had the highest coefficients, followed by total evaporation and other evaporation terms, temperature, rain fall and relative humidity. The higher coefficients suggested the higher environmental impact on the soil moisture for these variables.

A critical factor for the maintenance of wet peatlands is an adequate water supply. In the Flow Country which is in a natural state, this comes from surface water flooding and/or groundwater and both are influenced by climatic conditions which have seasonal differences. Losses were mainly by evaporation in 2021: evaporation from bare soil, evaporation from the top of canopy, snow evaporation and evaporation from vegetation transpiration.

Baseline linear models with R using the Copernicus Climate Data Store could be used for the management of Natural Peatlands in order to assess environmental factors affecting the most the moisture content of surface soils in the Flow Country Peatland. Indeed evaporation increases with increased temperatures due to climate change and the removal of vegetation.

## Molecular Tea Bag Index: Development of a simple and sustainable method for monitoring peatland health at the molecular level

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As peatland restoration and conservation efforts increase, there is a need in creating a simple, cost effective and minimally invasive method of determining and tracking the health of peatlands. Current peatland health monitoring approaches often use physical attributes such as water table and vegetation markers.[1] Whilst these do show changes in the health over time, we cannot relate them directly to the carbon storage mechanisms underground. This project aims to provide a tool to monitor peatland health condition on the molecular level.

Molecular level analysis may offer insight into the chemical processes that facilitate the essential ecological services that peatlands provide. This molecular viewpoint is important as it is believed that certain compounds are intrinsic to the carbon storage capabilities of the peat.[2] Peat is a deeply complex mixture, which hinders studies of its chemical composition. High resolution nuclear magnetic resonance (NMR) and Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR MS) are two of the most powerful tools for this task and these have successfully revealed key relationships between peat composition and health characteristics, such as hydrology.[3] However the analysis of peat composition requires taking peat cores. Our methodology offers a sustainable alternative: tea bags, which act as a proxy for peat organic matter. Tea bags are buried for 90 days and then removed for high resolution molecular-level studies. The change in composition of tea enables us to observe the natural processes occurring within the peat.

We present the results from the first study of tea bags buried at four peatland sites located within the Langwell Estate, Flow Country that are near-natural, drained, and at various stages of restoration by drain-blocking. From preliminary $^{1}H$ NMR studies we have been able to follow composition changes related to site, and identify possible molecular markers of health status.

## Investigating POC fluxes on an eroding upland blanket bog, Cairngorms National Park, Scotland

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Peat erosion and the subsequent flux of particulate organic matter (POC) in upland streams is a significant loss of carbon from degraded peatlands. Emissions factor estimates from this loss pathway vary enormously and need to be constrained to better estimate the overall carbon balance of degraded peatlands, and the emissions savings associated with peatland restoration.

Scotland stores the majority of the UK's peat yet understanding and estimates of POC losses from Scottish peatlands lags significantly behand the majority of the literature, particularly from English sites. We aim to measure erosion rates and POC fluxes on eroding upland blanket bog on the Cairngorms National Park, Aberdeenshire. Working adjacent to an eddy covariance tower (providing gaseous fluxes of carbon), we are deploying erosion pins, sediment traps and LiDAR surveys using a drone to combine and compare methods to estimate POC losses and gain a more complete carbon budget for this site and those like it. This work contributes more widely to the James Hutton Institute's Scottish Government-funded project 'Centrepeat'; large-scale remote sensing of erosion features will be used to make country-wide estimates of peatland loss and estimate the benefits of restoration.

# Photosynthetic pigment extraction in *Sphagnum* – is time of the essence?

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Plants possess a suite of functional traits, which are defined as those that influence growth, reproduction and survival. These traits can vary greatly depending on the environmental conditions the plant is growing in. Comparing individuals of a species from different sites gives insight into its so-called phenotypic plasticity, i.e. the range of changes in morphological and physiological traits in response to a specific environment. In the context of peatland resilience, functional traits and potential local adaptations of peat mosses of the genus Sphagnum might play a key role, but little is known about this to date.

The few existing studies on Sphagnum functional traits have explored anatomical and morphological traits as well as a range of primary and secondary metabolites. Photosynthetic pigment content was usually part of the suite of traits because the photosynthetic pigments chlorophyll A, chlorophyll B and total carotenoids are key for plant growth. However, a wide range of methodologies for photosynthetic pigment extraction and quantification can be found in the literature. A common feature of pigment extraction protocols is the processing of samples in the dark to prevent photochemical degradation. Further recommendations include cool storage of samples and processing of the plant material as soon as possible. However, no quantitative comparison of the effects of different extraction protocols on photosynthetic pigment yield in Sphagnum has been carried out to date. Exploring different methods to measure functional traits to test their robustness is as important as measuring the traits themselves. For this reason, we measured effects of different sample processing techniques on the degradation of the photosynthetic pigments chlorophyll A, chlorophyll B and total carotenoids in *Sphagnum papillosum* and *S. capillifolium* to determine if the time between the collection and processing of samples, light exposure during extraction, and different sample storage conditions had a significant effect on pigment yield. Pigment concentrations were quantified with UV/Vis spectrometry. The results indicate significant differences in pigment content depending on type of storage and light level during processing, as well as species-specific differences between *S. papillosum* and *S. capillifolium*. These findings allow us to make recommendations for best practice in the development of photosynthetic extraction protocols in Sphagnum.

## Brashly improving water quality

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Brash is the waste residue left over from harvesting trees, i.e., the tops of trees, branches, foliage. While commonly left on site to provide fertiliser for the next generation of trees, brash has also been shown to export dissolved organic carbon, phosphorous, nitrogen and potassium to freshwater environments around felled areas. This export creates diffuse pollution and can have negative effects on the environment, e.g., potentially causing eutrophication and oxygen loss in water bodies.

This PhD project seeks to assess how decomposing brash and different methods of brash management affect water quality. It will also consider whether it's possible to use brash biochar to improve water quality (by adsorbing pollutants), providing a circular approach to brash management. Forest-to-bog peatland restoration and its associated brash management is quickly evolving, with older methods now becoming obsolete. This work will compare novel methods of felling (like felling multiple drifts of trees into one, reducing the number of brash mats) to commonly used methods and understudied techniques like ground smoothing. Our research site is Forestry and Land Scotland's Benmore Forest, in Sutherland.

We will consider three paired commercially afforested sites of Sitka spruce (*Picea sitchensis*) and lodgepole pine (*Pinus contorta*) that are being restored to peatland. Three different tree felling methods will be employed; conventional felling, multiple drifts felled into one, and mulching. All six sites will then be ground smoothed. To study the impacts of brash management and decomposition, water samples will be taken every four weeks and analysed for various water quality parameters (such as suspended solids, turbidity, pH, conductivity, dissolved organic carbon, nitrogen, phosphorous, ammonium and macro and trace elements). Dipwells have been installed to monitor water table depth pre-, during and post-operations. Water table depth is an indicator of the health of a peatland. When in good condition, a fully functioning peatland has a high, stable, water table maintaining saturated conditions, which supresses carbon oxidation/degradation.

To obviate the impacts of brash decomposition, brash can be removed from site, but this is not always possible and can be uneconomical or may be undesirable (as works may damage underlying soil). An alternative option may be to create a biochar from brash waste, which could be an added value product itself, used on site as a carbon store, or used as a filter to remove pollutants (like excess nutrients) from watercourses. Biochar used to remove excess nutrients could also be spread back onto land as a slow-release fertiliser with benefits for carbon sequestration, creating a more circular economy. Such biochar will first be evaluated in the lab with experiments to assess pollutant adsorption capacity and its potential for leaching unwanted chemical components. It will then be tested within a mesocosm set-up, and if of potential benefit, ultimately trialled in the field.

The findings of this PhD will be brought together to create guidance for the forestry and peatland restoration industries on how to manage brash to enhance water quality.

## Analysis of net ecosystem exchange above a pristine Scottish blanket bog

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Peatland ecosystems contain 50% of Scotland's soil carbon and their $CO_2$ emissions overshadow the forest carbon sink. Understanding and reducing emissions from peatlands is therefore high on the agenda for our net zero commitments. Research has focused on understanding the driving variables of net $CO_2$ ecosystem exchange (NEE) for degraded peatlands, and peatland undergoing restoration, as they are large sources of atmospheric carbon. However, it is important to understand and quantify the fluxes from undisturbed peatlands as they are the 'benchmark' ecosystems that we are aiming for when implementing restoration. Furthermore, it is important to understand what variables drive $CO_2$ sequestration for natural peatlands, as we try to forecast emissions into a rapidly changing future climate.

We present eddy-covariance flux measurements of $CO_2$ across multiple years for a pristine peatland situated in the Forsinard area of the Flow Country. Through detailed analysis and comparisons with meteorological, hydrological and Earth observation measurements, we show how periods of climate extremes affect the NEE of a pristine peatland. Therefore, creating an understanding of how our natural peat bogs will respond to future climate change scenarios.

## The past and future climate of The Flow Country

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Globally peatlands have been sequestering carbon since the last glacial maximum. It is now understood that the processes that govern the amount of carbon sequestration are coupled with climatic inputs, such as precipitation and temperature. This would imply a global-scale, long-term feedback mechanism between peatland carbon storage, and emissions and the effect $CO_2$ has on climate. Therefore, understanding how peatlands will respond to localised climate change effects will be crucial to incorporating peatland contribution into general circulation models. Process-based peatland growth models, such as DigiBog and HPM, can be used to produce conceptualised peatland responses to climate change. These models focus on how specific processes and resulting feedbacks control peatlands growth. Encoded are a selection of the key eco-hydrological relationships, primarily focusing on GPP, decomposition rates, and water table depth, with all linked to climatic inputs. Here, the aim is to generate location specific climate reconstructions based on the current local climate parameters to be used as model inputs. Through analysis of observed precipitation data, three test sites have been chosen to generate climate series from. Both hourly precipitation and 12 hourly min/max temperature data were used in a stochastic weather generator, LARS-WG, to generate 8100 years of synthetic data. Alongside the baseline 8100 years of stochastic data, LARS-WG was used to generate climate projection series for the period 2081-2100 for RCP-26, RCP-45, and RCP-85 based off the results HadGEM2-ES model runs. Next, Holocene anomaly data, from the gridded EPOCH-2 database, was used with a univariate polynomial spline to create a smoothed, monthly anomaly series for each location. Both future projections and Holocene anomaly series were used with the baseline series to create the climatic model inputs. the Holocene anomaly series was suitable for simple monthly series (model input interval) modulation, while the future climate projection was interpolated to from the baseline. The initial takeaways from the 12 treatments (3 sites x 4 future climate scenarios) are that precipitation varies greatly inter-annually, > 200%, while the 50-year moving average has a variation of about 20% across the Holocene. Conversely, temperature shows the opposite trend, being highly modulated throughout the Holocene, ~ 2.5 °C, while inter-annual variability is minimal, ~ 0.5 °C.

# Molecular-level characterisation of damaged and restored peat soils using molecular tagging and NMR spectroscopy

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The ecological and environmental importance of peat cannot be overstated; it represents the largest terrestrial carbon store worldwide, with up to four times the carbon stored in all the world's forests, and is a home to unique flora and fauna. Its damage threatens habitat destruction and release of this carbon into the atmosphere and natural waters. In order to restore damaged peatlands and protect those in near-natural condition, indicators of peat status and quality must be found. The most comprehensive indicator of peat quality is its molecular composition, but to date this remains elusive due to its nature as a complex mixture. The most viable analytical tool to achieve this endeavour is NMR spectroscopy, which is capable of assigning resonances to individual compounds. However, even using the most advanced NMR experiments at our disposal, full characterisation is hindered by the presence of thousands of similar molecules. Thanks to the narrow chemical shift range of the most commonly utilised nucleus in NMR, $^{1}H$, the resonances from these molecules overlap significantly, and the low relative abundance of $^{13}C$, the NMR-active nucleus of carbon, means that NMR signal from carbon is weak. For these reasons, techniques to enhance this signal are highly desirable.

One promising method to enable structure determination of individual molecules in NOM is molecular tagging: chemical modification of the predominant functional groups within the molecules of organic matter, inserting NMR-active nuclei to act as reporters on their chemical environment.[1] When combined with high-resolution NMR, these tags filter out the vast majority of signals of untagged molecules, allowing dramatic simplification of spectra. Here we present the first application of a previously reported molecular tagging method,[2,3] $^{13}C$-enriched methylation, to whole peat samples drawn from damaged, restored and near-natural peatlands, in order to reveal molecular markers of decomposition and assess the impact of ongoing restoration work. The use of 2D and 3D NMR experiments to identify the structures of these molecular markers is also reported. In addition, we compare with more traditional analytical techniques such as solid-state NMR to evaluate the benefits of the molecular tagging procedure.

## A burning question: how do wildfires impact water quality in peatland headwater streams?

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Carbon delivery to and processing within the freshwater continuum is an important part of the global C cycle. The role of peatlands in this carbon flux term, particularly for dissolve organic carbon (DOC) is disproportionately important given their global coverage is < 3 %. Extreme effects like wildfires might influence the export of carbon from peat to freshwaters.

Following a dry and warm spell in spring 2019, a large wildfire burnt approximately >60 km2 of blanket bog and wet heath within the Flow Country peatlands of Caithness and Sutherland, North Scotland. The area has been significantly altered in places by drainage and notably forestry and is now undergoing rapid and extensive restoration. The fire impacted a range of land-uses and occurred in an area actively used for research, providing an ideal opportunity to test the effect of wildfire on water quality in peatland headwaters.

Over the course of a year after the fire, monthly water sampling was undertaken from a total of 52 rivers and streams located in the Flow Country. Of these 52 sampling sites, a total of 42 had been included in previous studies of peatland water quality, which provided a large set of pre-fire data to use as reference to understand how water quality has changed during the fire and afterwards. Twenty of these sites were used as drained (n=10) and undrained (n=10) control sites. An additional ten sites were established specifically for the project to cover the area affected most by the wildfire. These additional sites were selected after site visits to the burned areas of the Flow Country. The selection of these sites was driven by the accessibility/safety, the characteristics of the channel, the flow and stratification of the river, and characteristics of the peat itself, in order to represent the burnt drained (n=5) and burnt undrained (n=5) peatland catchments in this area after the fire.

Dissolved organic carbon concentrations were on average 18.0 mg L in burned drained sites and 14.9 mg L in burned undrained sites: a difference of 3.1 mg L on average. While DOC concentrations were on average 12.2 mg L in the control drained sites compared to 12.9 mg L in control undrained sites. This shows that while DOC concentrations increased post-fire in streams receiving water from all burnt areas compared to unburnt ones, the changes were more pronounced in catchments with man-made drains. SUVA was also found to be 5.41 mg C m in burned drained sites compared to 5.31 mg C m in burned undrained sites. Overall, SUVA was higher in all burned sites than control sites and highest in burned drained sites.

This study suggests burned sites had higher DOC concentrations and more aromatic DOC than unburned areas and within the burned area the drained sites showed the largest response. In terms of water quality, DOC concentrations and aromaticity increased in response to the wildfire. This key finding highlights drained peatland is more vulnerable to wildfire impacts on water quality. Restoration is likely to increase wildfire resilience and reduce wildfire severity. When making management decisions at the landscape scale, intentional re-wetting around vulnerable areas may help reduce the risks of wildfires and help minimise the carbon losses associated with these events.

## A Hyperspectral Approach to Understand the Association Between PSM (as Measured by InSAR Data) and Vegetation Assemblage for a Scottish Peatland.

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Peatlands are vital ecosystems that store up to a third of terrestrial carbon despite covering 3 % of the land surface; it is therefore important to improve our understanding of these landscapes to enable continuous carbon sequestration as the climate changes. AVIRIS-NG hyperspectral data has the potential to add detail to current understanding from analysis of Peatland Surface Motion (PSM) from InSAR data. PSM is directly linked to vegetation assemblage, erosion rates and land use. Therefore four sites were chosen; one near natural, two undergoing restoration (starting a decade apart) and one that has been eroded.

Machine learning was used to predict Plant Functional Types (PFTs) at each site using fieldwork, satellite imagery and expert knowledge. Exploratory analysis demonstrated that the random forest classifier was better at predicting PFTs in the Flow Country than SVM analysis (using either linear or RBF kernels). The fieldwork was mainly focused on the first restoration site as this site overlapped most with the others and ten PFTs were determined for this location, with an additional three added from fieldwork at the erosion site. Train-test data was created for these 13 PFTs and random forest classifiers applied to the data, the first restoration site underwent additional analysis using the fieldwork-focused specific train-test data to classify the data. The fieldwork-focused classification was the most successful with a mean accuracy score of 0.789, with the other mean accuracies ranging from 0.722-0.728, demonstrating the benefits of conducting fieldwork. Within this analysis, the whole dataset was utilised as well as smaller spectral ranges to determine whether all hyperspectral bands (post pre-processing) need to be used; it was found that the outcomes using the whole dataset were more accurate than the smaller spectral ranges. Additionally, the data was transformed with the original wavelengths, first and second derivatives and continuum removal used to classify the data, with the original and derivative outcomes proving more accurate than continuum removal. Supervised machine learning was much more successful at locating PFTs than the unsupervised k-means cluster analysis; it was concluded that k-means is unsuitable to predict PFT locations.

The Peatland Surface Motion (PSM) data was analysed in conjunction with the PFT predictions for the first restoration site using a range of machine learning classification techniques (logistic regression, decision tree, random forest and SVM). Outcomes suggest that there is potential to use the hyperspectral analysis to increase understanding based on PSM outputs, however, further refinement of methods is required to achieve this.

## Lessons learnt from a decade of Forest to Bog Restoration

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Since 2014 Forestry and Land Scotland has been extensively involved in forest to bog restoration. We present an overview of our restoration work from the viewpoint of a practitioner during that time and lay out the lessons learnt and how this influenced our approach. Specifically, this presentation will talk about the guiding hypothesise and analysis we are using to improve our methods on the ground at sites across Scotland. By integrating real world experience we aim to make restoration more effective and efficient and help achieve the ambitious forest to bog restoration targets set out within the Forestry and Land Scotland Peatland Strategy.

## Caithness and Sutherland Important Plant Area: Globally important for wild plants

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- Important Plant Areas: the most important places in the world for wild plant and fungal diversity.
- They are identified using three internationally agreed criteria: threatened species, botanical richness and threatened habitats. Important Plant Areas have provided a framework for implementing target 5 of the Global Strategy for Plant Conservation.
- Caithness & Sutherlands qualifies under qualifies under Criterion C(i) (threatened habitats), and Criterion A(ii) (threatened species).
- The poster will display the boundary of the IPA, and will detail the qualifying features under criterion A and C. It will look at Plantlife's Munsary nature reserve as a centre for demonstration of peatland management, survey and research.
- Overall, the poster will highlight the international importance of the Caithness & Sutherland IPA for plant conservation, research and interpretation.