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USING MULTISPECTRAL SATELLITE IMAGERY TO IDENTIFY AREAS OF ERODED PEATLAND

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ABSTRACT

After decades of neglect and failed management, peatlands are now recognised for the important role they play in carbon storage, flood prevention and freshwater availability, but also as a habitat for wildlife. Governments, public and private sector organisations are putting in practice a wide scale policy of preservation and restoration of peatlands. In Wales, as part of the Welsh Government's National Peatland Action Programme, Bannau Brycheiniog National Park Authority is carrying out restoration work on areas of peatland that have suffered damage through wildfires, ov[redacted]ting and cutting.

Monitoring and surveying are critical factors in these restoration efforts, as they inform the decision-making process and guide the available resources towards areas most in need of attention. Aerial photography and remote sensing are becoming widely used in various environmental protection and restoration programmes, because they offer clear advantages compared to traditional monitoring and surveying methods. Earth observation data sources are now freely available, and together with software that can analyse and present this data, this technology has become indispensable in informing, guiding and implementing environmental policies.

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1. INTRODUCTION

1.1. Peatlands in UK

Peatlands are waterlogged landscapes made up of dead and decaying vegetation. Joosten and Clarke (2002) define peatlands as areas with or without vegetation, containing material accumulated naturally and consisting of at least 30% (dry mass) of dead organic material. The waterlogged conditions usually found in these wetland ecosystems prevent plant material from fully decomposing, hence the production of organic material is larger than the decomposition. Over thousands of years, these processes lead to a net accumulation of peat layers up to 15m deep (International Peatland Society IPS 2024, Northumberland national Park 2019). In the Northern Hemisphere the natural vegetation found in peatlands is mainly mosses, sedges and shrubs. The tropics peatlands they are naturally forested (UK Centre for Ecology and Hydrology 2024).

In UK peatlands occupy around 10 -12% of the land surface, an estimated area between 46,000 - 47,000km² (Bain et al. 2011, UK Centre for Ecology and Hydrology 2024). carbon-rich ecosystems have a net cooling effect on the global climate, reduce the risk of flooding, and support biodiversity (IUCN 2024). Healthy peatlands play an important role in the mitigation of flood risks, by retaining precipitation water and slowing its flow from the uplands towards low lying regions. Lowland bogs, fens and mires supplement the flood prevention contribution peatlands make, by providing floodplain storage capacity in periods of heavy rainfall (UK Centre for Ecology and Hydrology 2024).

From a biodiversity viewpoint, areas of peatlands are nesting and feeding grounds for many species of birds, as well as critical habitats for rare insects and plants (Rydin et al. 2013, Witt and Short 2020). Blanket bogs and raised bogs support specialist species adapted to the acidic and nutrient-poor conditions. UK has 13 species of carnivorous plant recorded and all are found in bog habitats: sundews (Drosera spp.), butterworts (Pinguicula spp.) and bladderworts (Utricularia spp.) (Littlewood et al. 2010). They are able to capture and absorb nutrients from their invertebrate prey, a special adaptation which allows them to thrive in nutrient-poor environments (Millet et al. 2015). Sphagnum mosses are also adapted to grow best in acidic, low-nutrient conditions and they are a key species in the formation of peat (Malmer et al. 1994, Rydin et al. 2006). Another peatland specialist is the bog hoverfly (Eristalis cryptarum). Despite wide distribution across Europe, Siberia and Mongolia, the bog hoverfly finds itself critically endangered in the UK, present only on a few sites in Dartmoor National Park (IUCN 2024). The white-faced darter (Leucorrhinia dubia), a small dragonfly species, has seen a significant decline in the UK due to the loss of the lowland bog pools, vital for their breeding (IUCN 2024). One of Europe's rarest butterflies can be found on the edges of bogs and fens: The Marsh Fritillary (Euphydryas aurinia) is a UK native butterfly

which has become increasingly scarce. Small areas of South Wales hold one of the last remaining strong populations in Britain [18] [19] lin Bog - Swansea, Cross Hands-Carmarthenshire) (Marsh Fritillary Proje[illegible]4, European Commission 2023).

UK peatlands are also home to a variety of bird species which are specially adapted to the unique conditions found in these habitats. Golden Plover (Pluvialis apricaria), Red Grouse (Lagopus lagopus scotica), Nightjar (Caprimulgus europaeus), Curlew (Numenius arquata), Black-tailed Godwit (Limosa limosa). Dunlin (Calidris alpina), Snipe (Gallinago gallinago), Merlin (Falco columbarius), Hen Harrier (Circus cyaneus), Skylark (Alauda arvensis), Whimbrel (Numenius phaeopus). M[illegible]f them have UK or European conservation designations and legal protection (Littlewood et al. 2010). [20]

Peatlands are vitally important in the global carbon cycle and UK greenhouse gas budgets. They represent the single most important terrestrial carbon store in the UK, with peat bogs containing over 3,2 billion tonnes of carbon, approximately twenty times more than UK forests (Worrall et al. 2010), (IUCN UK 2011). A 5% loss of UK peatland would have the same climatic effect as the total annual UK anthropogenic greenhouse gas emissions (IUCN UK 2011).

[21] rimary driver of contemporary climate change is the increased concentration of greenhouse gases (GHGs) in the atmosphere, in particular carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). [22] hese gases trap heat from the sun, leading to the greenhouse effect and war[illegible]e Earth's surface (IPCC 2024). The degradation of peatlands can significantly contribute to climate change through two main mechanisms [23] [illegible] 2016):

- Release of carbon dioxide (CO_2): Peatlands store vast amounts of organic carbon accumulated over thousands of years. When peatlands are degraded the stored carbon can be exposed to decomposition, leading to the release of CO_2 into the atmosphere.
- Methane emissions: In addition to CO_2, degraded peatlands can also emit methane (CH_4), a potent greenhouse gas. When peatlands are drained or disturbed, anaerobic conditions conducive to methane production can develop. Methane emissions from degraded peatlands further intensify the greenhouse effect and contribute to global warming.

[24] Onl[illegible]ximately 20% of UK peatlands remain in a natural state, 80% having been degraded as a result of past and present management (IUCN UK 2024). The post-World War II period saw largely unsuccessful efforts to drain them for agricultural use and commercial forestry. Burning and grazing was also used as peatland management. Over time these practices have caused severe degradation of habitat and erosion of peat soil (IUCN UK 2024). Many areas of peatlands have a long history of being used as grazing for sheep and high stocking densities has led to overgrazing and trampling, made worse on some sites by high populations of wild deer (Haigh 2006). Burning is still and accepted and ongoing moorland management practice, mainly in areas of grouse and livestock production. Frequent repeat burning can destroy bog habitat, leading to a decline or loss of key [25]

species of plants and animals, reducing structural diversity and allowing typical heath species to become dominant (Ramchunder 2009). Localised extraction for fuel and gardening continues in some areas, particularly in the Scottish Isles and in Northern Ireland (IUCN 2024)6. New threats to these already vulnerable habitats include upland development such as tracks and renewable energy schemes. Poorly designed, built and located developments with associated drainage and excavation of peat can also result in peatland degradation and habitat loss (IUCN 2024).

Peatland restoration plays a crucial role in combating climate change by addressing the degradation of peatlands and maximising their potential as carbon sinks (Leifeld 2018). Peatland restoration is gaining recognition as a climate change mitigation strategy, with many countries including it in their national climate action plans. Additionally, international agreements such as the Paris Agreement emphasize the importance of conserving and restoring ecosystems, including peatlands, to achieve global climate goals (Joosten 2016).

"*Restoration of peatlands is a low hanging fruit, and among the most cost-effective options for mitigating climate change*." (Achim Steiner, UN Under-Secretary General and Executive Director UN Environment Programme UNEP)

In Wales, peatland is estimated to cover over 90,000 hectares, which is approximately 4.3% of Wales's total land area (NRW 2024). At present these areas are managed predominantly for agriculture and forestry and show the degradation signs associated with modern forestry practices and the increased focus on more profitable agriculture (Jenkins 2022). The Welsh Government's policy towards conservation and restoration of peatlands is disseminated through various pieces of legislation, the most important and up-to-date being The National Peatland Action Programme 2023 (IUCN 2024). Launched in March 2023 and managed by Natural Resources Wales, it offers grants to applicants with a plan ready to action peatland restoration (NRW 2023). Other notable policy documents are:

- Sustainable Management of Natural Resources (SMNR) Strategy
- Environment (Wales) Act 2016
- National Natural Resources Policy (NNRP)
- Regional Land Use Partnerships (RLUPs)

1.2. Aim of the Study

The Bannau Brycheiniog National Park has 16,000 hectares of upland peat bogs. Raised bogs, such as those found in the South Wales area, represent considerable carbon stores, but are particularly susceptible to the effects of climate warming, due to their southerly location within the UK (Carless et al. 2021). Sadly, a lot of it is already in a badly degraded state, so severely eroded in places that it emits more carbon than it a[illegible] (Chartered Institute of Water and Environmental Management CIWEM 2023).

In line with the Welsh Government's policy to preserve and restore peatland, the National Park Authority is actively involved in restoration projects across the P[illegible]

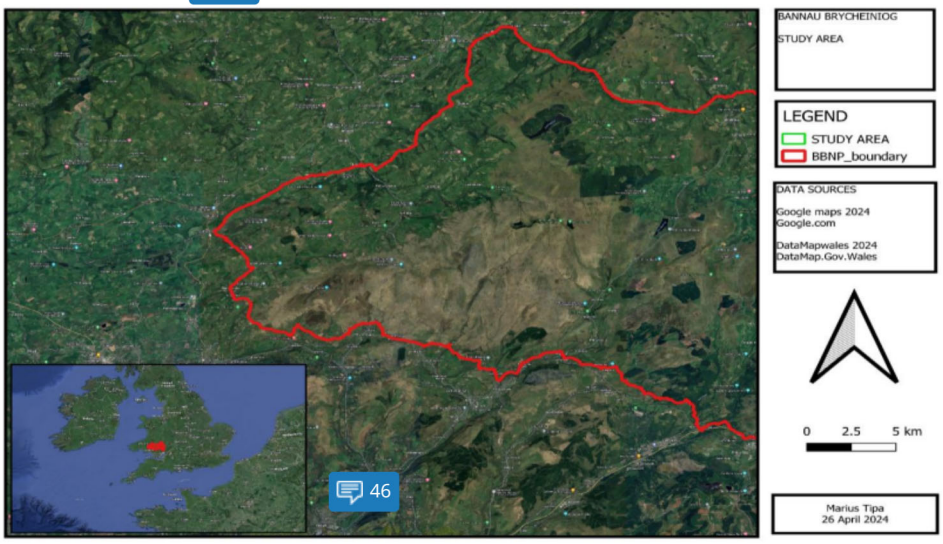
Beacons. Research and monitoring are an integral part of this effort, as it leads to informed decisions on what areas must be tackled first and what methods are best used in a particular location.

The aim of this study is to explore the use of cost-free satellite imagery in identifying areas of severe peatland erosion in the Bannau Brycheiniog National Park. Using Planet multispectral satellite imagery, the study analyses the spectral signatures of eroded peatland and three other types of land cover present in the research area (vegetated peat, rock scree and heather), with the intention of creating a map of eroded peat areas.

1.3. Research Location

The site represents a polygon of approximately 8.5 square miles located a mile to the west of Mo Road Car Park (Herbert's Quarry), in the Black Mo area of the western Brecon Beacons (Fig 1). At an elevation of approximately 1600ft, the area is formed of a relatively flat plateau with a slight NE incline, and a zone with a more pronounced SE slope on the southern section of the study area. The location was chosen for its mixture of representative upland vegetation and geological features (grasses, heather, moss, rocky outcrops, scree), and because of the presence of typical erosion indicators in the area (bare peat, gullies, hags). The location forms part of the Mynydd Du SSSI (Site of Special Scientific Interest) and the n Herbert's Quarry is a Registered Landscape of Outstanding Historic Interest in Wales, thanks to the industrial remains documenting the rise and decline of limestone extraction and the lime-burning industry on the Mountain (CALCH 2024).

Fig 1 – Location map



2. LITERATURE REVIEW

2.1. Peatland Monitoring

Monitoring plays an essential role in peatland management by providing data and information to assess the health of peatland ecosystems, track changes over time, and guide conservation and restoration efforts. It provides the information and insights needed to conserve, restore, and sustainably manage these critical ecosystems in the face of environmental change and human impacts (Monteverde 2022, Bhomia 2021). In view of its significance as carbon store and the increased threat climate change presents to peatland, accurate estimates of peatlands extent, thickness and condition has a wider importance. Not only peatland degradation can cause climate feedbacks if these carbon stores are released into the atmosphere, but it can also impact on other ecosystem services that peatlands provide: wildlife habitat, flood prevention, water filtration, freshwater supplies (Carless et al. 2021).

In the UK, traditional monitoring methodologies have been field based surveys such as the Phase 1 habitat surveys, Heather Trust and Scottish Natural Heritage peat condition surveys and JNCC's Common Standards Monitoring (CSM) (Bonnett et al. 2009). "Dipwells" are used to observe ground water levels and "subsidence poles" are hammered into the ground to show the depth (Ordnance Survey 2021). Surveys employing traditional methods are difficult to carry out given the terrain and prevalent weather conditions in peatland areas. The process also requires considerable staff resources which are usually not available. On-foot surveys can also cause damage to vegetation and fauna through trampling and disturbance of ground nesting birds (Artz et al. 2019).

Minasny et. al 2019 suggest that the current global knowledge and mapping of peatlands is quite poor, and the global estimates for peatland extent and sequestrated carbon are vague (between 113 and 612 billion tonnes C). The same study attributes this uncertainty to the coarse spatial scale of global soil maps and the use of outdated data. Carless et. al 2021 notes that peatland carbon stocks are often estimated using generalis values for peat thi and carbon content. Their study stresses the need for reliable mapping and quantifying of site-specific carbon stocks and makes the argument for the use of GPR (ground penetrating radar) and LiDAR (light detection and ranging) as appropriate methods of mapping peat distribution and thickness.

The increased availability of satellite observation technology has led to Earth observation (EO) becoming a widely used data source for understanding of the Earth and its environment (Zhao et al. 2022). Increasingly, peatland research is also moving towards using remote surveying to assist in peatland monitoring strategies (Trippier et al. 2020). Further research by ewski and Szuminska 2021 also concludes that the last decade saw a marked uptake in the use of remote sensing methods for peatland research, as a result of increased availability of new remote sensing data sets (Sentinel 1&2, Landsat 8, SPOT 6&7), coupled with the fast development of open-source software (QGIS, ArcGIS, ESA SNAP, SAGA GIS). Artz et al (2019) argues that the increased spatial and temporal resolution of satellite

data now freely available is providing new po[51]es f[52]e reliable, detailed and frequent peat assessments. Minasny et. al 2019 supports this conclusion and suggests that the increased availability of satellite data in an open-access format, together with availability of open-source machine learning algorithms and high-performance computing facilities could greatly improve the accuracy and cost-effectiveness of peatland mapping.

[53]2016 research from the James Hutton Institute reinforced the opinion that the data available on the national state of peatland condition was very limited and suggested that remote sensing techniques, in combination with modelling, could be potentially the right tools to assess peatland condition at a national scale (Artz and Chapman 2016).[54]

Earth observation (EO) offers several advantages over traditional surveying methods:

- **Coverage**: Remote sensing allows for the collection of data over large areas in a relatively short amount of time (ESA 2021). This is particularly beneficial for monitoring expansive peatland ecosystems.
- **Spatial Resolution**: Remote sensing techniques can capture imagery at various spatial resolutions, from coarse resolution satellite imagery covering entire landscapes to high-resolution aerial imagery providing detailed information about specific areas of interest (Sarelli 2023). This flexibility allows for the detection of both broad-scale patterns and fine-scale features within peatlands.
- **Temporal Resolution**: Remote sensing platforms can collect data repeatedly over time, allowing for the monitoring of changes in peatland ecosystems on a regular basis (ESA 2021). Traditional surveying methods may not be able to provide this temporal resolution, limiting the ability to capture dynamic processes such as seasonal variations and long-term trends.
- **Accessibility**: Remote sensing data can be easily accessed and analysed using various software tools and techniques (Gomes et al. 2020). This accessibility facilitates data sharing, collaboration, and integration with other sources of information, enhancing the overall understanding of peatland dynamics and ecosystem function.
- **Safety and Cost-effectiveness**: Remote sensing eliminates the need for extensive fieldwork in remote or hazardous environments,[55] reducing risks to personnel and equipment. Additionally, while there are costs associated with acquiring and processing remote sensing data, these costs are often lower compared to traditional surveying methods, especially for large-scale monitoring projects (Kopp et al. 2019).
- **Multi-spectral and Hyperspectral Capabilities**: Remote sensing platforms can capture imagery across multiple wavelengths of the electromagnetic spectrum, allowing for the detection of various environmental parameters such as vegetation health, moisture content, and land cover types (Vali et al. 2020). This multi-spectral and hyperspectral capability provides valuable information for assessing the health and condition of peatland ecosystems.

The methods for gathering data through remote sensing can be categorised as long-range (satellites), medium-range (aerial photography) and close-range (drones). Satellites offer the advantage of cyclicality, which ensures good temporal resolution, with the same

area of the Earth's surface being covered at regular intervals (1-16 days). The medium and close-range alternatives offer a greater spatial resolution, with some drones being capable of very high resolution images (1-10cm) (Czapiewski and Szuminska 2021).

Peatland research methods using remote sensing often involve analyses of land cover classification employing machine learning (Melton 2022, Sencaki 2020). However, many studies tend to use popular vegetation indices and soil moisture indices like NDVI, NDWI, VARI, TGI (Montero et al. 2023, Planet), as they are simple and effective algorithms for qualitative and quantitative evaluations of vegetation cover, growth dynamics and vigour (Xue 2017, Khunrattanasiri 2023).

2.2. The History of Remote Surveying

Remote sensing, according to its simplest definition, is the acquiring of information from a distance (NASA 2024). In the early stages remote sensing used only aerial photography to ascertain physical properties of distant objects (Moore 1979). Since then, several remote sensing techniques have emerged that can be used monitor and survey peatlands (Minasny et al., 2019). These include satellite remote sensing, drone-based surveys, airborne geophysical surveys, and ground geophysics (O'Leary 2023).

The beginnings of other types of remote sensing can be followed back to the Second World War, following the invention of radar, sonar, and thermal infrared detection systems (Hudson & Hudson 1975). In the 1960s, sensors were designed to operate in virtually across the entire electromagnetic spectrum (Elachi & Van Zyl 2021). Remote sensing was re-defined to include the use of electromagnetic energy to ascertain the physical properties of distant objects (USGS 2024).

For almost half a century, researchers have been testing innovative ways of using earth observation (EO) data to establish the extent and condition of peatlands. In the 1980s, worked carried out for the Irish Peat Board tried to determine certain physical characteristics of peat by using satellite remote sensing. The research concluded that Landsat Thematic Mapper imagery (NASA) could be used for identifying parameters linked to peat depth (McGovern et al 2000). The constraints and a lack of sufficient ground-proofing to confirm the hypothesis meant that their findings couldn't be certain.

In 1986 Betts et al used SPOT imagery (European Space Agency) to analyse its potential for the classification of peatlands in Northern Ireland. The study's conclusion was that mapping extensive areas of peatland could be carried out with far greater speed and consistency compared to conventional techniques. The methodology also offered reasonable accuracy (Betts et al 1986). However, other research looked at the use of both SPOT and Landsat TM imagery for monitoring changes in Northern Ireland peatlands and reached the conclusion that the demarcation of peatland boundary was difficult. (Cruickshank and Tomlinson 1994). The study recommended that satellite data should be used in combination with aerial photography.

Reid et al. (1994) used Landsat Thematic Mapper multispectral imagery to survey peatlands on the islands of Lewis and Harris, Scotland. Reinforcing previous studies, the conclusion was that satellite imagery could quantify and map large expanses of blanket bog. Poulin et al (2002) used Landsat 7/ETM+ (Enhanced Thematic Mapper Plus) data to map 13 peatland habitats in southern Quebec, Canada. This study was one of the first to create a high-resolution map of peatland habitats using satellite imagery, showing that it was possible to map peatland habitats using Landsat 7/ETM+ data and to achieve a level of accuracy comparable with regional investigation and compatible with conservation objectives.

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Another study used MODIS data to successfully identify healthy areas of peatland in Scotland (Artz et al. 2019). Moderate Resolution Imaging Spectroradiometer (MODIS) is operated by NASA and consists of a satellite-based sensor used for earth and climate measurements. Two MODIS sensors currently orbit the Earth: one launched in 1999 on board the Terra satellite, and a second one on board the Aqua satellite, launched in 2002 (NASA 2024).

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Harris and Bryant 2009 noted that peatland hydrology controls the rate at which the carbon in the atmosphere is absorbed and released from the peat (Dise et al. 1993, Moore & Roulet 1993), and investigated a multi-scale remote sensing technique for assessing the link between Sphagnum mosses, the near-surface hydrology of peatlands and their condition. According to Rydin et al. 2006, sphagnum is a good proxy indicator of peatland in favourable condition, as the links between the species' traits and ecosystem functions in peatlands are very strong. Other studies have also shown that a drop in the water table depth is a primary driver of the rate of greenhouse gas (GHG) fluxes from managed peatland systems (Koch et al. 2023, Evans 2021). Applying a Convolutional Neural Network model to aerial imagery, Robb et al. 2023 developed a methodology for automated object detection and mapped drainage ditches in the Flow Country, Caithness, as part of an effort to guide attempts at raising the water table in peatland areas. The field validation data showed the technique had an accuracy of 79% (Robb et al.2023).

Rasanen et al. 2022 researched monitoring peatland water table depth with optical and radar satellite imagery. The study looked at 50 sites across Finland, a mixture of restored and undrained natural peatland areas, and concluded that there is no one-size-fits-all approach for detecting water table depth and soil moisture in peatlands, and the methodology must be adapted to the peatland habitat type. It also confirmed earlier research that show that water table depth and soil moisture estimations models work better in open areas, without tree cover (Burdun et al., 2020, Millard and Richardson 2018).

In 2021 researchers from Nottingham University developed a new technique that uses satellite radar data to measure the rising and falling of peatland, in response to changes of water and gas content (bog breathing). The study suggests this surface motion of peatland could be an indicator of peat condition: a net uplift would show mass gain, therefore healthy peatland, whereby a net fall would indicate the peat drying out (IUCN 2021, Terra Motion 2023). The same year, the Ordnance Survey, Space4Climate, Assimila and Durham University started work on a peatland observatory, with the stated goal of using satellite

imagery to monitor large areas of peatland, at regular intervals, multiple times a year and at low cost (Ordnance Survey 2021). The organisation developed a Peatland Health Index which rates every 1km² of peatland in the UK, scoring it from 0-100. Multiple layers of satellite imagery – temperature, vegetation and albedo- were used to create the index (Ordnance Survey 2021).

Blake and Frake (2020)[29] suggest that Sentinel-2 imagery could be used to quantify the extent of bare peatland in an area. However, the resulting maps would be relatively coarse, given the 10m spatial resolution of the sensor installed on Sentinel 2. This is likely to miss small patches of exposed peat, leading to an underestimate.

Other research projects have used high-resolution aerial photography to monitor peatland condition and detect fine scale changes in the landscape. Williamson et al. (2018) used high-resolution aerial images to detect bare peat zones, then trained a Random Forest Regression model to derive the bare peat coverage from Sentinel-2 multispectral imagery. This technique accurately estimated the proportion of bare peat within a pixel.

Trippier et al. (2020) investigated if Very High Resolution imagery from Aerial Photography GB and Pleiades satellite data could be employed to develop a methodology for detecting bare peat areas the Peak District. Aerial photography showed a significant divergence between areas of vegetated and bare peat, and the authors created fine-scale maps of bare peat through the use of derived indices as thresholds (NDVI, Brightness, Red/Green and Red/Blue ratios). The second part of the study looked into extrapolating the bare peat model derived from VHR imagery to predict bare peat zones over extensive areas using low resolution Sentinel-2 imagery (10m). Classified pixels from VHR were added to inform the bare peat percentage cover of 10m Sentinel-2 pixels, and using regression modelling, the authors successfully scaled up the predictions to wider areas.

November 2015 saw the creation of the Earth Observation Centre of Excellence, placed under the auspices of DEFRA and bringing together expertise from the related departments and public bodies. The aim was the delivery of an EO roadmap, in partnership with the UK Space Agency's Space for Smarter Government Programme, which would ensure cheaper, more effective, more customer-focused delivery of EO data across policy areas (Joint Nature Conservation Committee JNCC 2015). In 2016/17 one of the early projects focussed on the use of EO to monitor peatlands. It was jointly funded by DEFRA and the Scottish Government, and it researched how Earth observation could provide a low-cost method for large-scale assessment of peatland condition (Robinson 2021). The study resulted in a report published by JNCC in 2019, which describes the potential of freely available EO data to map and monitor the condition of the UK's peatlands (Artz et al. 2019).

3. METHODOLOGY

3.1. On-site survey of land cover

Observations: The initial on-site survey was carried out in March 2024, after a prolonged period of rain. The vegetation cover in the study area presented as dominated by

grasses and low-growing shrubs, in a dormant state, with dark brown, brown or yellow leaves (Fig 3). The ground conditions varied from moist to wet and water-logged, and the exposed areas of soil presented as dark-grey or brown in colour. Areas of bare peat were moist or waterlogged and dark brown to black in colour, with protruding rock scree on the margins. (Fig 5) Another widespread land cover type is represented by zones of lose limestone, formed of a combination of boulders, rocks and scree, which look grey-light grey in colour and can present as totally void of vegetation or can be mixed with sparse vegetation like moss, grasses or heather. The heather is present either in large blocks or small clumps, with a height of between 10-20 cm and brown in colour (dormant).

Fig 2 – Rock scree

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Fig 3 Grasses



Fig 4 Heather



78 are peat



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a). Prior to the on-site work, a desktop survey of the area of interest was undertaken to scope out the prevalent types of land cover in the area. Using Google Earth imagery, four

different types of presumed land cover were identified: bare peat (dark brown), vegetated peat (grey-brown to green), rock scree (light-grey), and heather (dark-brown). Using QGIS, some preliminary mapping was done by digitising polygons representative of the land cover types and saving them as layers.

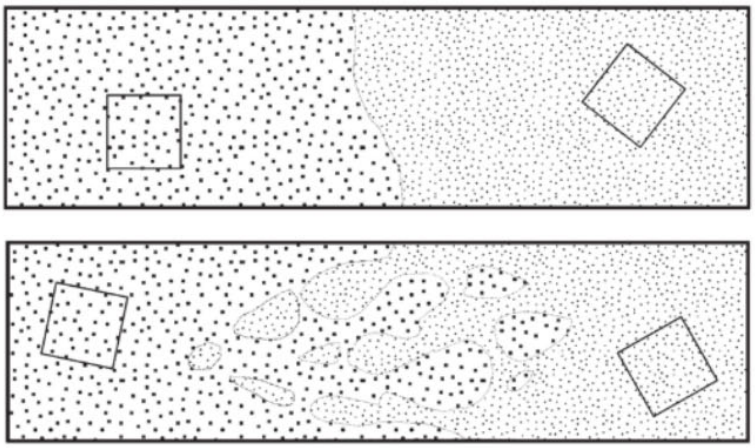
Carry 80 a desktop identification of these pre-defined polygons was done to hedge against time-on-site limitations and adverse weather conditions. The process maximised the efficiency of the operation while on the ground, but also minimised the risk of not finding the areas with the presumed land covers, due to possible reduced visibility in poor weather. The remote location and prevalent bad weather conditions were the main challenges of the project. These factors didn't allow for extensive ground surveys to identify and subcategorise land cover types.

b). In QGIS, with the land cover layers uploaded, a field survey project was created using the Mergin maps plugin; the field project was then synced to the field device (tablet). The attributes to be collected were GPS coordinates for the centre of each polygon, date, primary/secondary/tertiary land cover and their percentages, aspect, photo and notes.

c). The field device GPS was used to navigate to the pre-determined polygons locations, followed by a rapid site walk-over to confirm the types of land cover; the presumed cover was proved correct on all surveyed polygons.

d). 2mx2m quadrants were over imposed on blocks of uniform stands of land cover within each of the 4 different types of polygons; this size is the recommended quadrant for short herbaceous vegetation dwarf-shrub heaths (Rodwell 2006). The positioning of the quadrants avoided obvious boundaries between land covers. (Fig 6)

Fig 6 – Quadrant placement



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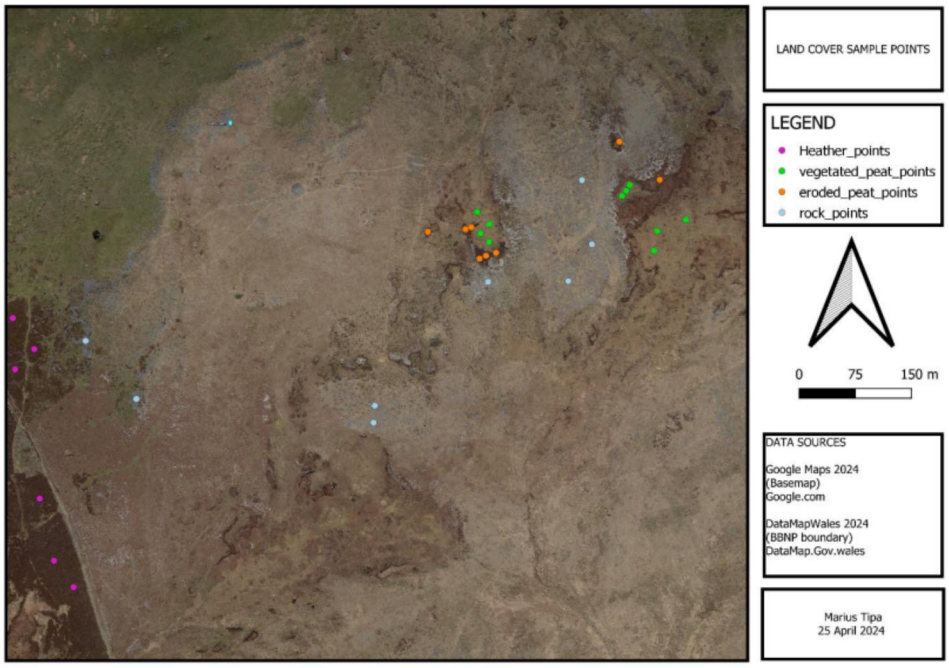
e). Using a DOMIN scale pre-configured in the Mergin Maps field project, the survey recorded attributes for each polygon: primary, secondary and tertiary land cover, together with an estimated percentage for each. Other information recorded:

- GPS coordinates for the sample point in each polygon
- Date
- Aspect
- Ground condition
- Photo

DOMIN Scale is a classification tool used by the National Vegetation Classification (NVC) methodology and also recommended by NRW's Peatlands Survey Manual. For percentage estimations, the quadrant is imaginarily split into a 5 x 5 grid, each grid representing 4%; the land cover in question is then grouped into a corner and cover is estimated depending on how many grid squares it fills (Rodwell 2006).

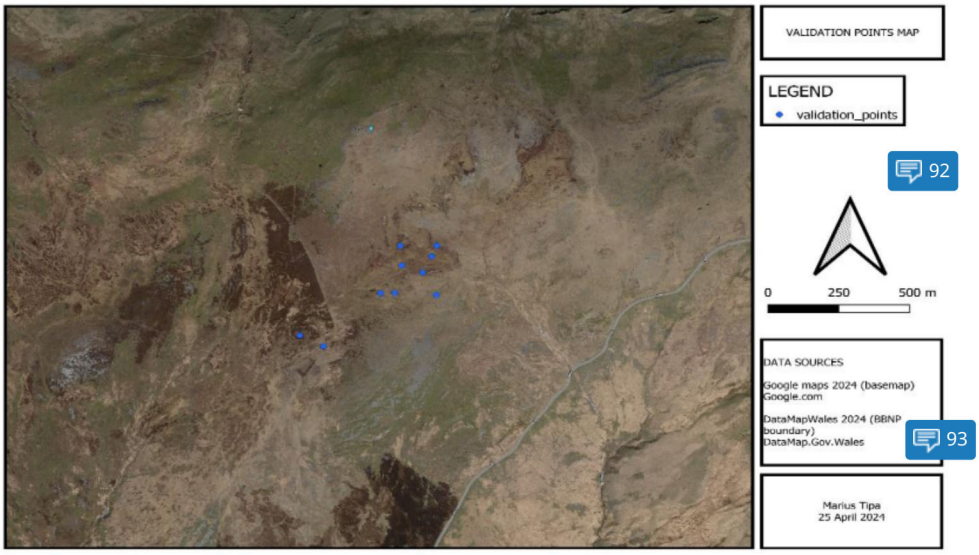
d). A total of 40 sampling points were surveyed, 10 for each type of land cover: vegetated peat, eroded peat, rock scree, heather. On completion, the field survey was synced to QGIS in the form of attribute tables linked to specific layers, and the data became available for analysis. The sample points representative of the eroded peat zones were then digitised and saved as a layer in QGIS. (Fig 7)

Fig 7 – Sample points



e). A validation area was chosen situated within the boundaries of the known peatland extent in the area (Peatland Map W[illegible]22), exhibiting the same four principal land cover types and located approximately 700m SW from the initial eroded peat sample points. A batch of 10 sample points were identified during a second field trip, selected as representative of eroded peat zones in the area. GPS coordinates for the point samples were collected and used to digitise a QGIS layer (Validation points, Fig 8).

Fig 8 – Validation points



3.2. Data sources

a). Planet multispectral satellite imagery was obtained and uploaded into QGIS; four sets of images were chosen, to take into consideration any potential seasonal variations in [illegible]l profiles: January, April, June and November.

[illegible] data was chosen as it offers a higher spatial resolution than Sentinel data (3m pixels, compared to 10m pixels for Sentinel), making it more suitable for the identification of small [illegible]s of land cover; Planet data can be specified as 4 band or 8 band spectral resolution. The Planet satellites orbit the earth at an altitude of approximately 500 km and have a swath width of 25km. They provide daily images at a spatial resolution of between 3-6.5 m pixels. These images are widely us[illegible]vironment monitoring, agriculture, disaster management, urban planning,etc. (Planet.com 2024)

b). Peatlands of Wales Map, released by DataMap Wales in April 2022, was used to identify areas of interest and choose the study location. The Peatlands of Wales map series provides an up-to-date distribution of Welsh Peatlands (to 2022) based on currently existing

evidence sources. The data layers were created at a 50m grid resolution, with the extent and thickness of peat being derived from a variety of sources for each 50m grid cell across Wales. The level of confidence in the presence of peat in any given grid cell is defined on a scale of 1-10, with every cell over 2 captured in the Peatlands of Wales peat distribution map (DataMapWales).

c). Google Maps Hybrid was used as the base layer in QGIS; Google Maps primarily utilises satellite imagery, aerial photography, road network data and landmark labels to create 3D maps (McQuire 2019). It provides good geographical information, and it puts the study area in local context. The combination of aerial photography and satellite imagery offers a very good spatial resolution, making possible the identification of small topographic features.

d). Google Earth provided the aerial imagery and the image manipulation tools required for the identification of various types of land cover in the research area; the combination of aerial photography and satellite imagery gives it very good spatial resolution, and the tilt/rotate/ground view functions make possible the identification of various topographic features (distinguishing shadows from gullies, for example).

Google Earth was also used to create an Area of Interest of approximately 8.5 square miles which was uploaded to QGIS and used to ensure uniform satellite imagery overlay onto the area of study.

3.3. Data storage and manipulation

Both field-collected data and downloaded digital data were stored in a QGIS project, with the additional use of the Mergin Maps plugin for the field data collection element. The field survey used an Android tablet and a Mergin Map account linked to the main QGIS project. The device GPS automatically recorded the coordinates of each sample point from the various land cover types. The same device was used to capture and temporarily store photos.

Once uploaded to the main QGIS project, the field data was structured in various layers and attribute tables. Some of the attributes tables were transferred to Excel for calculations and analysis. Minimum and maximum values for each type of polygon were calculated, together with the average values for each type of land cover. The tabulated data was used to produce charts which helped visualise the differences in spectral signature between the 4 types of land cover, across 8 spectral bands.

The minimum and maximum values for eroded peat polygons across the 8 spectral bands of the satellite imagery were used as thresholds in the raster calculator function of QGIS, to derive zones of land cover within the area of study with the required pixel values. The same process was repeated to calculate the predicted eroded peat areas using several indices as thresholds: NDVI, NDWI, Brightness Average, SAVI, R/G Ratio, R/B Ratio.

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4. RESULTS

111 The various types of land cover that make up the surface of the Earth absorb, reflect and transmit different amounts of electromagnetic energy (NASA 1999). A spectral profile, spectral signature or spectral response pattern of a surface refers to the unique way this surface interacts with light across multiple wavelengths (Environmental Systems Research Institute ESRI 2024). The spectral profile can be determined by quantifying the intensity of light reflected, emitted or transmitted by a surface across a range of wavelengths (Klein et al. 2008). The spectral response pattern is influenced by various factors related to the surface's physical, chemical, and biological properties, as well as environmental conditions (Soriano-Disla 2014).

Remote sensing utilises variations in spectral profiles to study and classify different types of land cover, such as vegetation, geological formations, water bodies and urban areas (Pandey et al. 2021). Spectral variations are easy to distinguish between broad classes of land covers (vegetation and soil), but become more difficult to distinguish within broad classes, like differentiating between types of vegetation (NASA 2021).

During the initial desktop visual survey carried out using Google Earth imagery (Fig 9), a clear distinction could be observed between vegetated peat, rock scree and heather. The vegetated peat areas presented as 112 own or grey-green in colour, while rocks and heather looked light-grey and dark-brown respectively. However, some eroded peat polygons and the heather polygons (especially small clumps of heather) looked a very similar dark brown in colour and presented a similar raised topographic profile when viewed using the ground level function in Google Earth Pro, making it difficult to distinguish between the two.

Fig 9 – Study 113 ogle Maps view)



Due to its surface properties and the biochemical composition of its tissues, vegetation has a complex interaction with light. Vegetation typically reflects more green light and less red and blue light, so it appears green in the visible spectrum. Vegetation absorbs red and blue light primarily due to the presence of pigments, particularly chlorophyll, which are essential for photosynthesis (Ustin and Jacquemoud 2020). Chlorophyll is the main pigment responsible for capturing light energy during photosynthesis. It absorbs light most efficiently in the blue and red regions of the spectrum (Ramus 1981). Vegetation also strongly reflects Near-infrared (NIR) light, compared to other types of land cover (Price 1992), hence healthy vegetation looks bright red when viewed through an infrared sensor.

In order to identify areas of eroded peatland, it was necessary to isolate the spectral values of this type of land cover, across the 8 bands of the Planet imagery. The QGIS sampling tool was used to derive these values and save then under the form of an attribute table (Table 1).

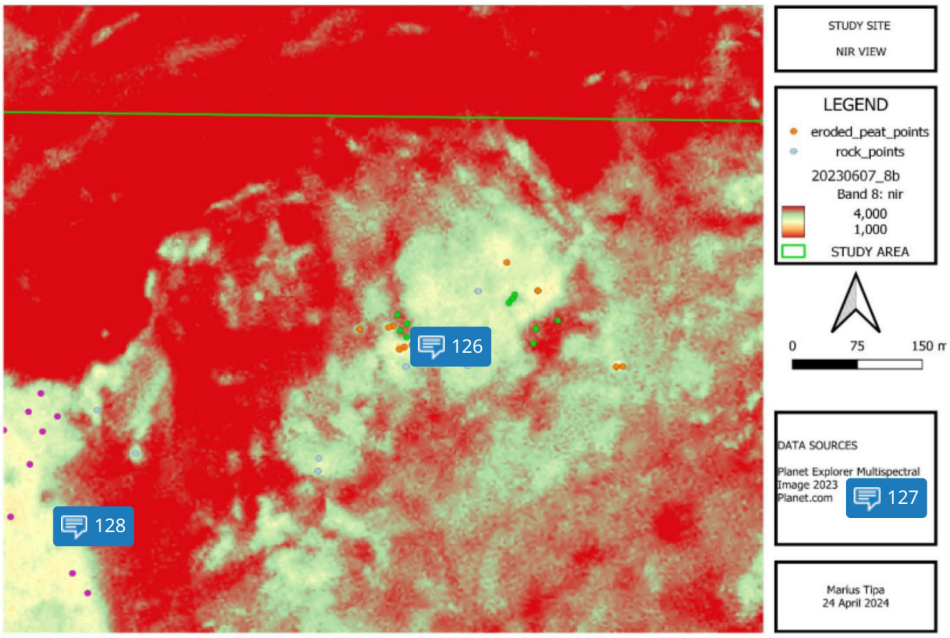
Table 1 – eroded peat values

SAMPLE POINT	COASTAL	BLUE	GREEN-I	GREEN	YELLOW	RED-EDGE	RED	NIR
1	388	489	586	668	719	702	1031	2169
2	429	482	607	700	763	696	1173	2396
3	382	544	628	695	737	727	1120	2245
4	305	444	614	699	763	752	1327	2864
5	373	460	557	677	694	720	1241	2865
6	362	371	570	700	691	678	1328	3316
7	333	421	480	646	698	692	1187	2401
8	348	417	540	669	668	650	1151	2727
9	505	543	651	733	809	891	1266	2422
10	545	642	729	861	911	877	1359	2617

Multispectral images of the study site showed a distinction between the spectral signatures of four different types of land cover, particularly when the imagery obtained in June 2023 was used, and more so when using the Red, Green and Blue bands. In the NIR band, there was a marked difference between vegetated peat on one side, where the values were high, and bare peat, rock scree and heather on the other hand, where the NIR values were lower (Fig 10). Sparsely vegetated areas with thin soil, usually found at the periphery of eroded peat zones, were also showing NIR values within the same minimum and maximum limits as bare peat and rock scree. The NIR profiles for the 10 eroded peat sample points are

spread between 2169 and 3316, reflecting the diverse nature of these erosion features. Seen in the image below as the bright zones, these values are overlaping with both the heather (2255-2915) and the rock scree values (2617-3157), which makes it difficult to differentiate between them. The vegetated points sampled at between 3205 and 3898, which is generally higher than other land cover types but still overlapping with the upper end of the eroded peat readings. This indicates that NIR alone wasn't sufficient to isolate 3 out of 4 land covers.

Fig 10 – Study site/ Planet NIR view



Further analysis showed sufficient distinction between bare peat and rock scree across other wavelengths (R,G,B in particular), but a certain amount of overlap continued to be shown between bare peat and sparsely vegetated areas with thin soils situated at the transition point between eroded peat and rock scree.

Using QGIS and the raster calculator function, minimum and maximum values for bare peat were introduced as thresholds and a layer was derived, representing all the pixels in the Planet satellite imagery with values falling within the threshold limits. On a visual analysis using Google Earth images, the results of these calculations, in 4 bands and 8 bands, seem to contain both areas of bare peat and areas with thin vegetated soils overlaying rock. The 4 band derived images (R,G,B,NIR) showed more accurately the extent of eroded peat

areas, with 90% of the validation points falling within the predicted area (Fig 10), while the 8 band derived layer reduced the predicted extent considerably but also excluded 5 out of 10 validation points (Fig 11). On both layers the lack of distinction between degraded peat and thin soils persisted, but the 4 band layer contained less non-peat surfaces.

This lack of differentiation was witnessed again when derived NDVI, Brightness, R/B, R/G were used, with only 70% of the validation points contained within the predicted extent of eroded peat (Table 2). Additionally, this layer also contained the largest surface of non-peat land cover (Fig 12). A combination of derived indices (NDVI, Brightness, R/B, R/G) and 4 band thresholds (R,G,B,NIR) eliminated some non-peat surfaces but failed to improve the accuracy, again only 70% of the validation points being covered in the results (Fig 13). Also, a certain amount of overlap between eroded peat and thin soils remained.

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Fig 10 – 4 band derived layer

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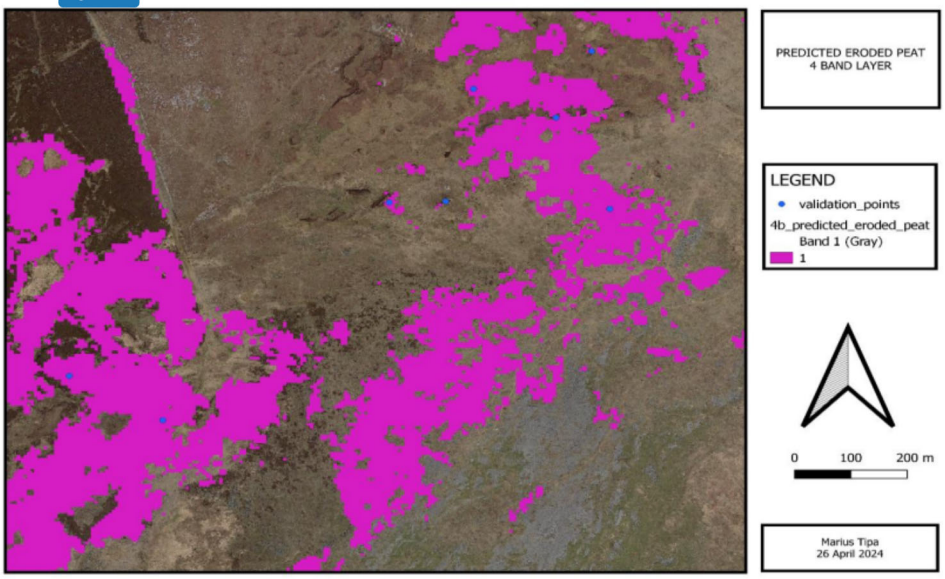


Fig 11- 8 band derived layer

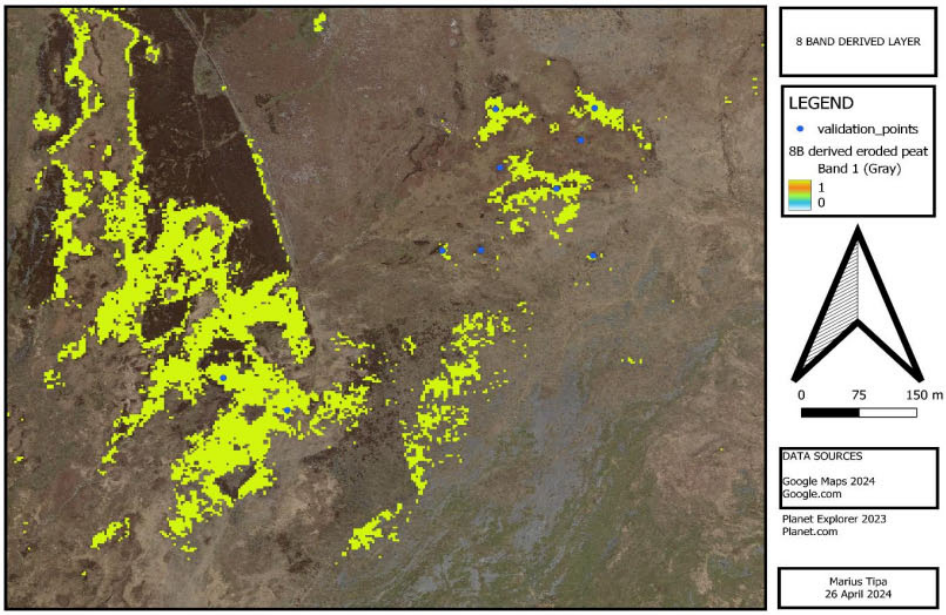


Fig 12- indices derived layer

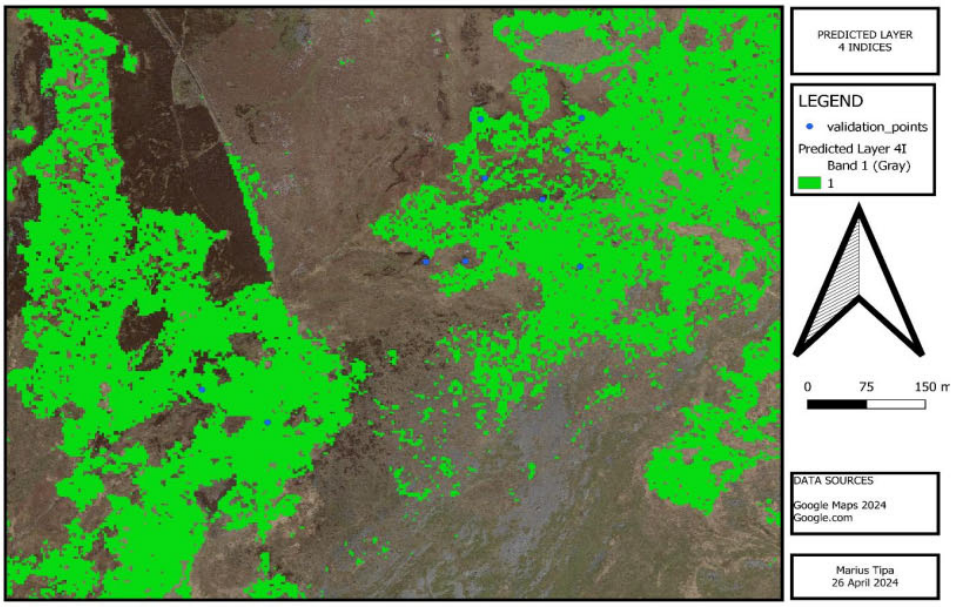


Fig 13 - 4 band+ indices derived layer

y

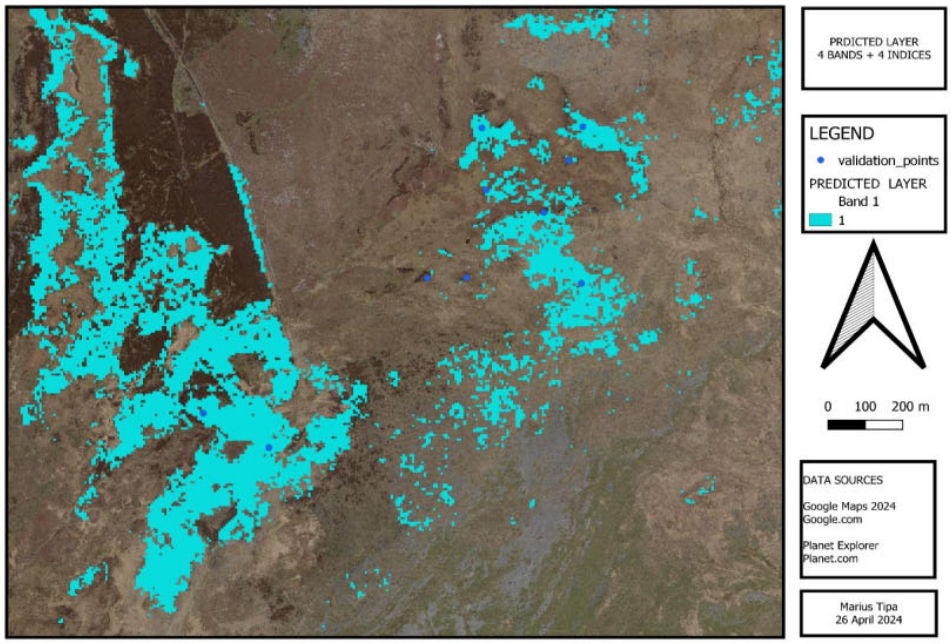


Table 2

THRESHOLDS	VALIDATION POINTS TOTAL	VALIDATION POINTS CONTAINED	ACCURACY
4 BANDS	10	9	90%
8 BANDS	10	5	50%
INDICES	10	7	70%
4 BANDS+INDICES	10	7	70%

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5. DISCUSSIONS AND CONCLUSIONS

Peatlands are waterlogged areas with or without vegetation, containing a naturally accumulated material of dead and decaying vegetation, consisting of at least 30% (dry mass) of dead organic material (Joosten and Clarke 2002). These ecosystems store large amounts of carbon and have a net cooling effect on climate (Worrall et al. 2010). Additionally, peatlands contribute to a reduction in flood risks, play an important role in freshwater availability and support biodiversity (IUCN 2024).

After a long period of neglect and failed management, governments together with public and private sector organisations have initiated a wide scale policy of preservation and restoration of peatlands. These efforts are hampered by the lack of sufficient data regarding the extent and condition of peatlands (Minasny et al. 2019).

Monitoring plays an important role in peatland management by providing data and information to assess the health of peatland ecosystems, track changes over time, and guide conservation and restoration efforts (Monteverde 2022, Bhomia 2021). The increased availability of satellite observation technology has led to Earth observation (EO) becoming a widely used data source for understanding of the Earth and its environment (Zhao et al. 2022). Peatland research is also moving towards using remote surveying to assist in peatland monitoring strategies (Trippier et al. 2020)19.

The raised bogs found in the South Wales area represent considerable carbon stores, but are particularly susceptible to the effects of climate warming, due to their southerly location within the UK (Carless et al. 2021). The Bannau Breichyniog National Park Authority is actively involved in restoration projects across the area they manage. Research and monitoring are an integral part of this effort, as it leads to informed decisions on what areas must be tackled first and what methods are best used in a particular location.

This study explores the use of multispectral satellite imagery in identifying areas of severe peatland erosion within the Bannau Breichyniog National Park. Using Planet satellite imagery, the research project analyses the spectral signatures of eroded peatland and three other types of land cover present in the research area (vegetated peatland, rock scree and heather), with the intention of producing a map of eroded peat areas. The study site was chosen on the basis of it containing representative land cover for the area and typical signs of peat erosion: bare peat, gullies, hags.

The methodology is based on the identification of spectral signatures for the different land cover types and QGIS thresholding to isolate areas of pre-determined pixel values. Various spectral band values, indices and combinations are used as thresholds: 8 band spectral images, 4 band spectral images, derived indices (NDVI, Brightness, R/B, R/G, NDWI, SAVI), and a combination of spectral bands values and derived indices values. Although there are a number of different land cover types in the area of study, the spectral response of these surfaces proved to be quite similar in some cases, requiring a finer categorisation of land cover. The vegetated polygons varied in their composition, from grass dominated in some

examples, to predominantly moss or heather in other cases. Similarly, the eroded peat zones are also quite diverse in their topography and composition (bare peat, hags, gullies), some with little vegetation and some with no vegetation at all. This factor would have influenced the spectral values extracted at different locations and it would have contributed to a certain overlap between the spectral values of distinct land cover types.

Four sets of spectral images were trialled, to allow for seasonal changes in land cover spectral profiles over a 12 month period (spring, summer, autumn, winter). Values were extracted from the same sampling points using the four images, in order to ascertain at what time in the year these values would best identify various land covers. Although the winter images showed good differentiation between vegetation and rock areas, especially when NDWI was derived (due to different water content), the Planet imagery dated June 2023 showed most differentiation and was chosen as the source of values for all the analysis carried out.

Due to its distinct interaction with vegetation, NIR values created a clear separation between bare peat and rock scree on one hand, and vegetated peat and heather areas on the other hand. However, the areas lacking in vegetation showed similar values and were difficult to distinguish in infra-red, hence bare peat and rock scree overlapped significantly.

Using the RGB values as further thresholds, the rock scree was largely eliminated from the predicted eroded peat areas and the resulting QGIS layer showed a reduced and more accurate extend of the erosion areas. An overlap persisted between the eroded peat areas and the sparsely vegetated thin soils usually found in the transition zones between peat and rock scree.

Further thresholds were introduced gradually, either as a single spectral band value, derived index value, or a combination of values and derived indices. In most cases the extra thresholding reduced the accuracy of the eroded peat extent prediction by dragging in other non-peat areas. The map of predicted peat erosion which contained the highest percentage of validation points was based on the use of R,G,B and NIR (90%). However, thin marginal soils, usually overlaying rock scree, continued to appear in the derived layer, although to a far less extent. Given the similar spectral profiles of eroded peat and sparsely vegetated thin soils, and their side-by-side presence in the same geographic locations, further research is necessary to establish the potential link between these two types of land cover. These thin soils overlaying rock or rock scree, often found in the transition zones between peat and rock scree, could themselves be an indicator of past or on-going peat erosion.

The study also indicates that splitting the different land cover types according to a finer scale would aid the more rigorous classification of spectral profiles and improve the accuracy of the map when it comes to predicting the exact extent of the erosion. A coarse land cover classification (eroded peat, vegetated peat, rock scree and heather) hasn't proved sufficient for producing a fine scale map, and some sparsely vegetated areas, in particular where heather was dominant, showed similar NIR values to eroded peatland. Furthermore, the different types of peat erosion (bare peat, hags, gullies), together with the percentage and type of vegetation still present in some of these eroded zones must be

taken into account. Vegetation cover, even if minimal, will influence the water retention rate of the peat substrate and influence the spectral signature.

Another limiting factor is the medium resolution spectral imagery used in the study (3m). Many of the erosion features are sub-3m and could form part of a pixel which has an allocated value corresponding to a neighbouring land cover type. The use of high-resolution images (<1m) would further reduce the possibility of different land covers being allocated similar spectral values. The lack of a Short Wave Infrared in the Planet imagery used further reduced the possibility of isolating out the thin soils. Further research would be necessary to explore the use of Lansdat SWIR images for this purpose. Landsat multispectral images are available through the Earth Explorer platform in spatial resolutions of 10m-100m, depending on the band required, and are taken 16 days apart (temporal resolution)(USGS 2024). SWIR images have a resolution of 30m and would produce relatively coarse maps, but short-infrared has the potential to eliminate the thin soils from the predicted peat results when larger scales are considered.

The four types of land cover identified during the field survey and the sampling points were located using an Android GPS device with an accuracy of 5m, which again given the small extent of some of the erosion features could have a negative effect on the prediction results. An important observation was that even when a validation point was not within the predicted erosion extent, it was often in the next 3m pixel, which could point towards the reduced accuracy of the GPS as the possible cause of some of the missed points.

The layer of predicted erosion also contained areas that were not covered by the Peatland of Wales Map (DataMap.Gov.Wales) and which seemed to be outside the known peatland extent. Some of these areas formed part of the polygons mapped during the initial field survey and verified as peat at the time. This misalignment could be caused by the coarse resolution of the Peatland Map (50m pixels), which would exclude the small remnants of peatland usually associated with erosion.

The methodology used provided a good geographical indicator for the location of features associated with peatland erosion across the study area and the derived layer of predicted erosion contained 9 out of 10 validation points, with the missed point being in the adjacent pixel. Even with further adjustments in regards to GPS accuracy, higher resolution imagery and a finer categorisation of land cover types, the resulting QGIS layers could be used to identify potential erosion zones on a larger scale.

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Dissertation Final

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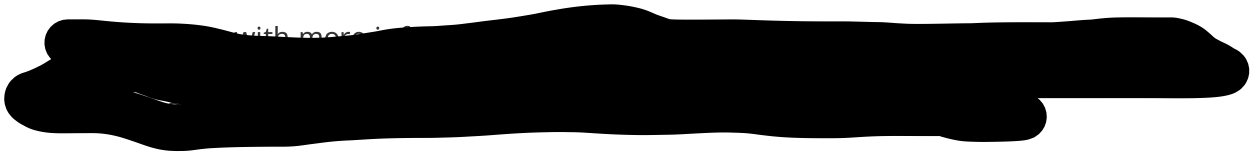
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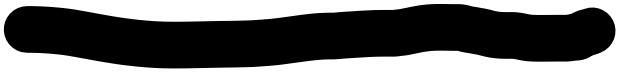
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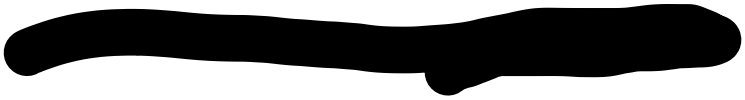
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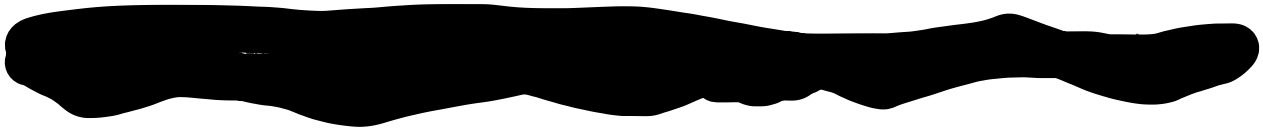
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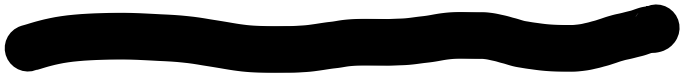
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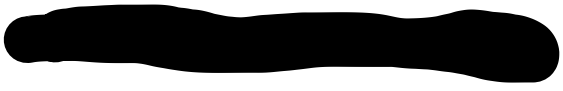
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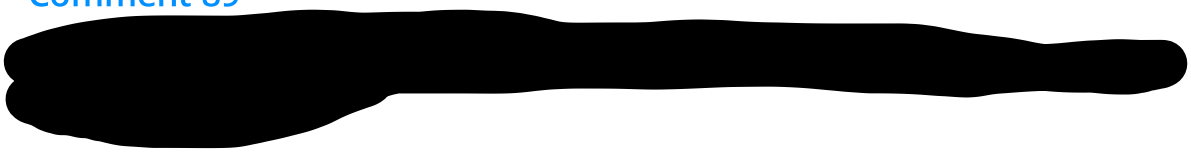
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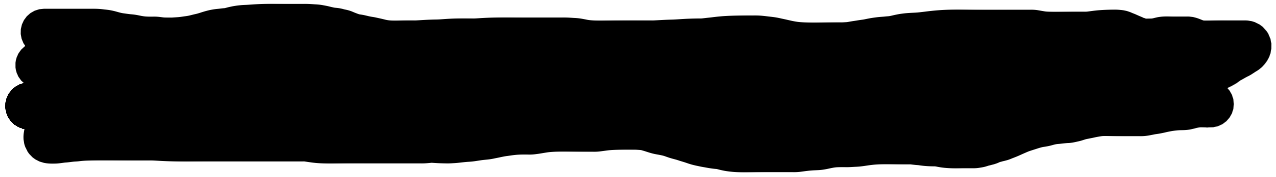
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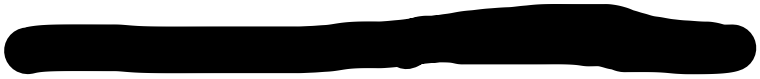
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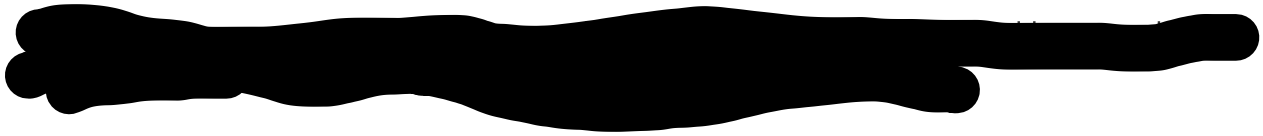
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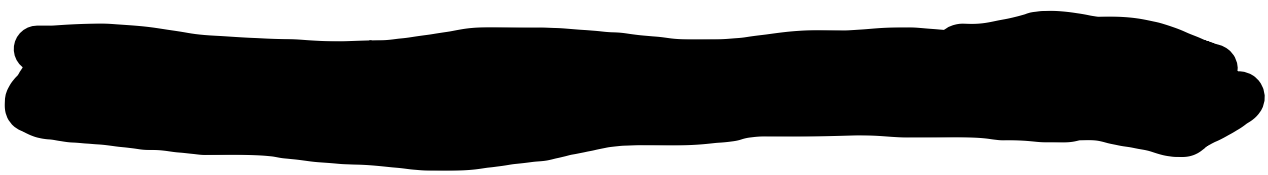
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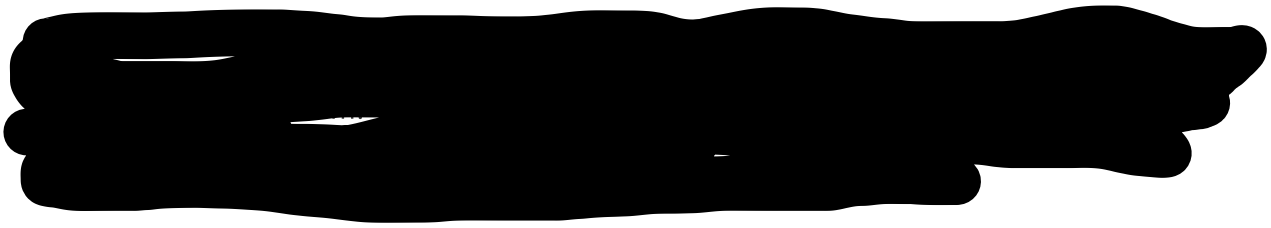
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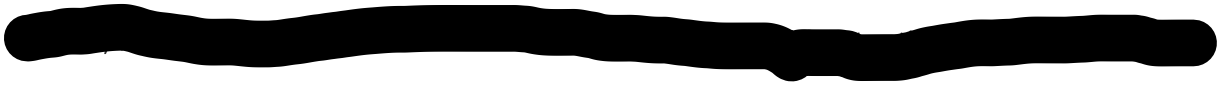
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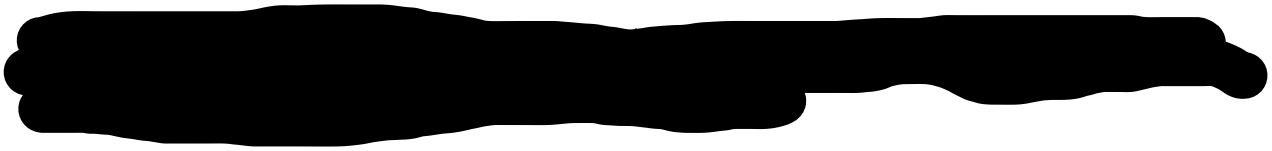


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