Forest Research

# A Strategic Assessment of the Afforested Peat Resource in Wales

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The Research Agency of the Forestry Commission

# A Strategic Assessment of Afforested Peat Resources in Wales

## *and the biodiversity, GHG flux and hydrological implications of various management approaches for targeting peatland restoration.*

Report by Forest Research staff for Forestry Commission Wales Project, with Reference No 480.CY.00075 (T), October 2012.

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# Executive Summary

*Rationale: peatland ecosystems and forestry in Wales*

Peatland in pristine or good condition provides a range of critical ecosystem services, including biodiversity, carbon storage and sequestration, regulation of stream base flows, water runoff and downstream flood peaks and nutrient regulation and retention. Peatlands are also sinks and sources of several natural greenhouse gases, particularly carbon dioxide ($CO_2$) and methane ($CH_4$). More than 75% of deep peat soils in Wales are covered in semi-natural vegetation. Most of this is upland blanket bog, with significant amounts of fen and flush and, locally, lowland raised bog. These are all UK Biodiversity Action Plan priority habitats with UK and Welsh targets for habitat management and restoration. In this project it has been estimated that there are 18,092 ha of woodlands established on deep peats in Wales (soils in which the organic content of the surface horizon is > 80% and the peat depth is >40 cm[1]). Of this area 11,232 ha remains under coniferous tree cover. The Welsh Government owns 11,038 ha of the afforested blanket bog and deep peat resource which are managed by Forestry Commission Wales (FCW). In order to deliver the habitat restoration targets set out in the Wales Environment Strategy, there is a need to progressively restore semi-natural habitat on these areas. Restoration measures should seek to better integrate the key objectives of nature conservation, soil carbon protection, carbon sequestration and water quality.

*Report contents*

This report provides a strategic assessment of the afforested peatland resource in Wales. The report:

- assesses the distribution of the Welsh peatlands, based on best available spatial information on the extent and location of peat soil and peatlands.
- delivers an improved distribution map of the upland blanket peat and deep peat soils resource at the highest resolution.
- includes an improved map of the distribution of afforested deep peats in Wales and ownership of forested land in Wales.
- provides an overview of the likely impacts of peat forming factors and afforested peatland restoration and management on the biodiversity, hydrology and greenhouse gas (GHG) benefits.
- develops *national* and *field based assessment schemes* based on rule based criteria, proxy factors and thresholds for the assessment of afforested peatland in Wales viable for restoration.
- carries out a national GIS assessment identifying potential restoration areas in Wales.
- tests the *field-based assessment* by ground truthing a number of sites in Wales.
- provides relative costs of afforested peat restoration

[1] Note the UKFS defines deep peat as >50cm depth. Use of 40cm depth is, therefore, precautionary.

*Mapping peatlands in Wales*

Reconciling the various descriptions and classifications within available spatial datasets to provide a unified picture of the deep peat distribution in Wales is a significant challenge. Spatial datasets of soils, geology and vegetation were assessed and combined to produce the definite improved map of peat resources in Wales. These include the National Soil Survey of England and Wales (NSRI survey), British Geological Survey dataset (BGS) and Habitat Phase 1 datasets for Wales. Based on these estimates peatlands cover 116,400 ha which is approximately 5.6% of Wales's total land area. The intact deep peat resource accounts for almost 3% of these UK peatland areas. The most extensive areas of peatland habitat are the upland blanket bogs (23,400 ha) mostly in North Wales and the substantial area of wet modified bog (22,600 ha) mostly in the uplands of central Wales.

The Forestry Commission Mapping and Geodata Unit (M&G) have recently digitised the soil mapping for Welsh forests from the original Forestry Commission soil survey records and these data were made available for this project. The new dataset is a significant improvement on the soil information that was previously stored in the FC sub-compartment database. The spatial dataset provides a more accurate and detailed record of the soils, at the time they were surveyed usually, prior to the original tree planting. The extent of available FC soil survey information across Wales is in total 74,985 ha that have been surveyed.

To assess the reliability of the Welsh Peatlands Map the peat classification of the national map was compared with a peat classification scheme based on the FC soil survey data in a case study in Gwydyr forest. The area of deep peat mapped in the Gwydyr forest by the FC soil surveyors (688.5 ha) is 12% smaller than that in the national map (784.6 ha). However, across Wales the area of deep peat soils identified by the FC soil surveyors is just 175 ha (1.6%) less, than the area of deep peat identified in the national map. As in the Gwydyr forest, the classification of mineral soils is more robust than the organic soils and the greatest shifts in the estimate of the peat resource arise due to the reclassification of the shallow peaty soil types. This illustrates the importance of accurate mapping, based on observation in the field, when trying to identify and assess the potential of afforested sites for restoration.

The Welsh Peatland Map was also compared with peat depth probe readings from a number of projects (e.g. ECOSSE Plynlimon survey, Welsh wind farm projects). In general the peat probe survey data and the areas mapped as deep peat show reasonably good agreement. However, several surveys appear to have concentrated on the margins of the area mapped as deep peat and in these surveys the number of discrepancies is greater.

The total afforested deep peat area in Wales is estimated as 18,092 ha. Using available data sources (e.g. FC legal boundary, FC woodland grant schemes), it was possible to identify the owners of over 85% of the afforested peat. The greater portion of the land is in public ownership, the extent and distribution of the Welsh Government Woodland Estate afforested deep peat is 11,038 ha, of which 6,592 ha are under coniferous forests in addition to 1,687 ha of young stands and 2,018 felled. Other public authorities are responsible for 16.6 ha. There are 4,845 ha owned by private individuals and businesses, and 59 ha owned by voluntary organisations.

*Benefits from afforested peatland restoration: appraisal of the literature*

A comprehensive review was carried out of the available literature and lessons learnt from existing afforested peatland restoration projects, examining the factors affecting peat formation and the impacts of restoration and management on the biodiversity, hydrology and greenhouse gas (GHG) benefits. It was not always possible to use reported evidence from open peatland restoration projects to predict the likely outcomes of afforested bog restoration. Neither was it always possible to apply reported outcomes from other countries to Welsh sites.

In addition, an appraisal of the scientific literature and reviews available on different management approaches to improving the condition of afforested blanket peat and deep peat soils was included. The likely outcomes of a range of management practices are provided but it is very important to include monitoring and reporting of the outcome of such efforts on the medium and long term success of any restoration project to provide evidence to inform future decisions.

The speed of delivery of benefits was also considered and the likely short and long term impacts of afforested peatland restoration on the provision of the main ecosystem services is summarised. There is a paucity of evidence from medium to long term afforested peatland restoration projects. For example, the lack of research and monitoring of non-C GHG emissions from previously-afforested peatland areas needs to be addressed before conclusions can be made on the likely GHG implications of restoration.

*National and field based assessments of restoration potential in Wales*

Based on the appraisal of the available literature and the research team's expert judgement; *national and field based schemes* for the assessment of the potential for restoration of an afforested peat site have been developed using rule-based criteria, factors and thresholds.

The *national assessment scheme* applies GIS and spatial datasets to assess five *issues*: a) current status of the peat; b) hydrological integrity of the site; c) consequence of restoration in terms of greenhouse gas emissions; d) ecological integrity of the site and e) climatic integrity of the site. The rule-based criteria score a site's potential for restoration so that the sites with good potential to become peat forming habitats have higher scores than those which will merely retain the existing peat. Each criteria is classed into three categories in which the lowest score (**no score**) ≡ has the least advantageous, neutral or potentially detrimental consequences of restoration; a medium score (**value of 1**) ≡ advantageous consequences of restoration and the highest score (**value of 2**) ≡ most beneficial consequences of restoration.

At national level, each issue has been assessed and mapped separately (peat condition, hydrology, GHG balance, biodiversity, and climate integrity). The five issues are then combined using the weighting factors to determine the final score for each site and produce the national map.
The results of the *national assessment* reveal that the best opportunities for restoration on the WGWE are in the Snowdonia National Park, Tywi forest and Coed y Mynydd regions.

Once a site has been identified as potentially restorable by the *national assessment scheme*, a follow up *field assessment* will be required to validate the desk-based national assessment. A *field-based assessment* was developed based on field observations. The *field-based assessment* proved to be very reliable when tested by ground truthing a number of afforested peat sites in Wales.

A *Field Assessment Tool* has been developed and is intended to be used by FC Wales staff (e.g. forest planners or conservation managers) responsible for the strategic planning of an afforested peat site e.g. during the revision of the Forest Design plan or identification of sites for compensatory restoration action within the WGWE Wind Energy Programme.

Overall, this project is a significant step in collating spatial data, evaluating available knowledge and developing and testing *national* and *field* based assessments in order to improve information on the distribution of Welsh peatlands and strategically assess the restoration potential of afforested peat in Wales. Moreover, it also demonstrates an approach to integrating consideration of biodiversity, climate change and water policy.

*Cost of afforested peat restoration*

The report includes an initial exploration of the likely costs of restoration of afforested peatlands, based on previous work, and the relative costs of different management options assessed.

# Crynodeb Gweithredol

*Sail resymegol: ecosystemau mawndir a choedwigaeth yng Nghymru*

Mae mawndir mewn cyflwr dilychwin neu dda yn darparu llawer o wahanol wasanaethau ecosystem hollbwysig, gan gynnwys bioamrywiaeth, dal a storio carbon, rheoli llif gwaelodol nentydd, dŵr ffo ac anterth llifogydd i lawr yr afon, a rheoli a chadw maetholion. Mae mawndiroedd hefyd yn ddalfeydd, ac yn ffynhonnell llawer o nwyon tŷ gwydr naturiol, yn enwedig carbon deuocsid ($CO_2$) a methan ($CH_4$). Mae mwy na 75% o'r priddoedd mawn dwfn yng Nghymru wedi eu gorchuddio â llystyfiant lled-naturiol. Mae'r rhan fwyaf o hwn yn orgors ar dir uchel, â llawer iawn o ffeniau a llaciau ynghyd â chyforgors iseldir mewn rhai mannau. Mae'r rhain i gyd yn gynefinoedd â blaenoriaeth yng Nghynllun Gweithredu'r DU ar Fioamrywiaeth, ac mae ganddynt dargedau ar lefel y Deyrnas Unedig a Chymru ar gyfer rheoli ac adfer cynefinoedd. Yn y prosiect hwn, amcangyfrifwyd bod 18,092 ha o goetir wedi ei sefydlu ar fawn dwfn yng Nghymru (priddoedd lle mae cynnwys organig o derfynlin arwyneb yn fwy nag 80% a dyfnder y mawn yn fwy na 40 cm[2]). O'r cyfanswm hwn, mae 11,232 ha yn dal wedi'i orchuddio â choed conwydd. Mae Llywodraeth Cymru'n berchen ar 11,038 ha o'r adnodd gorgors a mawn dwfn wedi'i goedwigo sy'n cael ei reoli gan Gomisiwn Coedwigaeth Cymru. Er mwyn cyflawni'r targedau ar gyfer adfer cynefinoedd sydd yn Strategaeth Amgylcheddol Cymru, mae angen adfer cynefinoedd lled-naturiol fesul tipyn yn yr ardaloedd hyn. Dylai camau adfer geisio integreiddio amcanion cadwraeth gwarchod natur, diogelu carbon pridd, dal a storio carbon ac ansawdd dŵr yn well.

*Cynnwys yr adroddiad*

Mae'r adroddiad hwn yn cynnwys asesiad strategol o'r adnodd mawndir wedi'i goedwigo sydd yng Nghymru. Mae'r adroddiad yn:

- asesu dosbarthiad mawndiroedd Cymru, ar sail yr wybodaeth ofodol orau sydd ar gael am faint a lleoliad pridd mawnog a mawndiroedd.
- darparu map gwell yn dangos dosbarthiad adnodd gorgors fawnog yr ucheldir a phriddoedd mawn dwfn yn y cydraniad uchaf.
- cynnwys map gwell yn dangos dosbarthiad mawn dwfn wedi'i goedwigo yng Nghymru a pherchnogaeth tir wedi'i goedwigo yng Nghymru.
- darparu trosolwg o effeithiau tebygol ffactorau ffurfio mawn ac adfer mawndir wedi'i goedwigo a rheoli er budd bioamrywiaeth, hydroleg a nwyon tŷ gwydr.
- datblygu *cynlluniau asesu cenedlaethol a maes* wedi'u seilio ar feini prawf sy'n seiliedig ar reolau, ffactorau dirprwyol a throthwyon ar gyfer asesu mawndir wedi'i goedwigo yng Nghymru sy'n hyfyw ar gyfer ei adfer.
- cynnal asesiad GIS cenedlaethol sy'n nodi ardaloedd adfer posibl yng Nghymru.

[2] Sylwer bod Safon Coedwigaeth y Deyrnas Unedig (UKFS) yn diffinio mawn dwfn fel >50cm o ddyfnder. Defnyddiwyd dyfnder o 40cm, felly, er mwyn bod yn ofalus.

- profi'r *offeryn asesiad maes* drwy wneud gwaith maes ar nifer o safleoedd yng Nghymru i gadarnhau ffeithiau.
- darparu costau cymharol adfer mawn sydd wedi'i goedwigo

*Mapio mawndiroedd yng Nghymru*

Mae cysoni'r gwahanol ddisgrifiadau a dosbarthiadau sydd yn y setiau data gofodol sydd ar gael er mwyn darparu darlun unedig o ddosbarthiad mawn dwfn yng Nghymru'n dipyn o her. Cafodd setiau data gofodol o briddoedd, daeareg a llystyfiant eu hasesu a'u cyfuno er mwyn cynhyrchu'r map penodol gwell o adnoddau mawn yng Nghymru. Mae'r rhain yn cynnwys Arolwg Pridd Cenedlaethol Cymru a Lloegr (arolwg NSRI), set ddata Arolwg Daearegol Prydain (BGS) a setiau data Cynefin Rhan 1 ar gyfer Cymru. Ar sail yr amcangyfrifon hyn mae mawndiroedd yn gorchuddio 116,400 ha, sef tua 5.6% o holl arwynebedd tir Cymru. Mae'r adnodd mawn dwfn cyfan yn cyfateb i bron i 3% o'r ardaloedd mawndir hyn yn y DU. Yr ardaloedd helaethaf o gynefin mawndir yw gorgorsydd yr ucheldir (23,400 ha), yng Ngogledd Cymru yn bennaf, a'r ardal sylweddol o gors wlyb wedi'i haddasu (22,600 ha), yn ucheldiroedd canolbarth Cymru yn bennaf.

Mae Uned Mapio a Geodata y Comisiwn Coedwigaeth wedi digideiddio'r mapiau pridd ar gyfer coedwigoedd Cymru yn ddiweddar o gofnodion arolygon pridd gwreiddiol y Comisiwn Coedwigaeth, a darparwyd y data hyn ar gyfer y prosiect hwn. Mae'r set ddata newydd yn llawer gwell na'r wybodaeth am bridd a oedd yn cael ei storio cyn hyn yng nghronfa ddata isadrannau'r Comisiwn Coedwigaeth. Mae'r set ddata ofodol yn darparu cofnod mwy manwl a chywir o'r priddoedd, ar yr adeg y cawsant eu harolygu fel arfer, cyn y gwaith gwreiddiol o blannu'r coed. Mae'r wybodaeth o arolygon pridd y Comisiwn Coedwigaeth sydd ar gael yn ymwneud â chyfanswm o 74,985 ha sydd wedi cael eu harolygu.

Er mwyn asesu dibynadwyedd Map Mawndiroedd Cymru cymharwyd dosbarthiad mawn y map cenedlaethol â chynllun dosbarthiad mawn yn seiliedig ar ddata arolygon pridd y Comisiwn Coedwigaeth mewn astudiaeth achos yn fforest Gwydyr. Mae arwynebedd y mawn dwfn sydd wedi'i fapio yn fforest Gwydyr gan arolygwyr pridd y Comisiwn Coedwigaeth (688.5 ha) 12% yn llai na'r arwynebedd yn y map cenedlaethol (784.6 ha). Fodd bynnag, drwy Gymru gyfan, dim ond 175 ha (1.6%) yn llai yw'r arwynebedd priddoedd mawn dwfn a ddynodwyd gan arolygwyr pridd y Comisiwn Coedwigaeth, na'r arwynebedd mawn dwfn a nodwyd yn y map cenedlaethol. Fel yn fforest Gwydyr, mae dosbarthiad priddoedd mwnol yn gadarnach na'r priddoedd organig ac mae'r newidiadau mwyaf yn yr amcangyfrif o'r adnodd mawn yn digwydd o ganlyniad i ailddosbarthu'r mathau o bridd mawn bas. Mae hyn yn dangos pwysigrwydd mapio cywir, ar sail arsylwadau yn y maes, wrth geisio nodi ac asesu'r potensial i adfer safleoedd sydd wedi eu coedwigo.

Cymharwyd Map Mawndir Cymru hefyd â darlleniadau profi dyfnder mawn o nifer o brosiectau (e.e. arolwg ECOSSE Pumlumon, prosiectau ffermydd gwynt yng Nghymru). Yn gyffredinol, mae data'r arolygon profi mawn a'r ardaloedd a fapiwyd fel mawn dwfn yn cytuno'n bur dda. Er hyn, ymddengys bod llawer o arolygon wedi canolbwyntio ar ymylon yr ardal a fapiwyd fel mawn dwfn, ac mae mwy o anghysonderau i'w gweld yn yr arolygon hyn.

Amcangyfrifir bod cyfanswm yr arwynebedd mawn dwfn wedi'i goedwigo yng Nghymru yn 18,092 ha. Gan ddefnyddio'r ffynonellau data sydd ar gael (e.e. terfynau cyfreithiol y Comisiwn Coedwigaeth, cynlluniau grant coetir y Comisiwn Coedwigaeth), roedd modd darganfod perchnogion dros 85% o'r mawn wedi'i goedwigo. Mae'r rhan fwyaf o'r tir yn eiddo cyhoeddus. Mae'r mawn dwfn wedi'i goedwigo sy'n eiddo i Ystâd Goed Llywodraeth Cymru yn 11,038 ha. O'r cyfanswm hwn, 6,592 ha dan goed conwydd, ac mae 1,687 ha yn cynnwys coed ifanc a 2,018 ha yn cynnwys coed wedi eu torri. Mae awdurdodau cyhoeddus eraill yn gyfrifol am 16.6 ha. Mae 4,845 ha yn eiddo i unigolion a busnesau preifat, a 59 ha yn eiddo i fudiadau gwirfoddol.

*Budd o adfer mawndir wedi'i goedwigo: gwerthusiad o ddeunydd ysgrifenedig*

Cynhaliwyd adolygiad cynhwysfawr o'r deunydd ysgrifenedig sydd ar gael a'r gwersi a ddysgwyd o brosiectau adfer mawndir wedi'i goedwigo sy'n cael eu cynnal yn barod, gan edrych ar y ffactorau sy'n effeithio ar ffurfiad mawn ac effeithiau adfer a rheoli ar fioamrywiaeth, hydroleg a budd sy'n gysylltiedig â nwyon tŷ gwydr. Nid oedd modd defnyddio tystiolaeth yn deillio o brosiectau adfer mawndir agored bob amser i ragfynegi canlyniadau tebygol adfer corsydd wedi'u coedwigo. Yn ychwanegol at hyn, nid oedd yn bosibl cymhwyso canlyniadau yr adroddwyd amdanynt mewn gwledydd eraill i safleoedd yng Nghymru.

Cynhwyswyd gwerthusiad hefyd o'r dogfennau a'r adolygiadau gwyddonol a oedd ar gael am wahanol ddulliau rheoli er mwyn gwella cyflwr gorgors fawnog a phriddoedd mawn dwfn wedi'u coedwigo. Darperir canlyniadau tebygol gwahanol arferion rheoli ond mae'n bwysig iawn cynnwys gwaith monitro ac adrodd am ganlyniad ymdrechion o'r fath ar lwyddiant unrhyw brosiect adfer yn y tymor canolig ac yn yr hirdymor er mwyn darparu tystiolaeth fel sail i benderfyniadau yn y dyfodol.

Ystyriwyd hefyd pa mor gyflym y byddai'r budd i'w weld a cheir crynodeb o effeithiau tebygol adfer mawndir wedi'i goedwigo ar ddarparu'r prif wasanaethau ecosystem yn y tymor byr ac yn yr hirdymor. Nid oes llawer o dystiolaeth o brosiectau tymor canolig a hirdymor sy'n ymwneud ag adfer mawndir wedi'i goedwigo. Er enghraifft, mae angen rhoi sylw i'r prinder gwaith ymchwil a gwaith i fonitro allyriadau nwyon tŷ gwydr di-garbon o ardaloedd mawndir a oedd yn arfer bod wedi'u coedwigo cyn y gellir gwneud casgliadau ynglŷn â'r goblygiadau adfer tebygol o safbwynt nwyon tŷ gwydr.

*Asesiadau cenedlaethol a maes o'r potensial ar gyfer adfer yng Nghymru*

Ar sail y gwerthusiad o'r dogfennau sydd ar gael a barn arbenigol y tîm ymchwil; datblygwyd *cynlluniau cenedlaethol a maes* i asesu'r potensial ar gyfer adfer safle mawn wedi'i goedwigo gan ddefnyddio meini prawf, ffactorau a throthwyon sy'n seiliedig ar reolau.

Mae'r *cynllun asesu cenedlaethol* yn cymhwyso GIS a setiau data gofodol i asesu pum *agwedd*: a) statws presennol y mawn; b) cyfanrwydd hydrolegol y safle; c) canlyniad adfer o ran allyriadau nwyon tŷ gwydr; ch) cyfanrwydd ecolegol y safle a d) cyfanrwydd hinsoddol y safle. Mae'r meini prawf sy'n seiliedig ar reolau'n rhoi sgôr i botensial safle i gael ei adfer fel bod y safleoedd sydd â photensial da i ddod yn gynefinoedd ffurfio mawn yn cael sgorau uwch na'r rhai hynny a fydd ddim ond yn cadw'r mawn sydd yno'n barod. Dosberthir pob maen prawf i dri chategori lle mae'r sgôr isaf (**dim sgôr**) ≡ y canlyniadau adfer lleiaf manteisiol, niwtral neu niweidiol o bosibl; sgôr canolig (**gwerth o 1**) ≡ canlyniadau adfer manteisiol, a'r sgôr uchaf (**gwerth o 2**) ≡ y canlyniadau adfer mwyaf buddiol.

Ar lefel genedlaethol, mae pob agwedd wedi cael ei hasesu a'i mapio ar wahân (cyflwr y mawn, hydroleg, cydbwysedd nwyon tŷ gwydr, bioamrywiaeth, a chyfanrwydd hinsoddol). Yna, cyfunir y pum agwedd gan ddefnyddio'r ffactorau pwysoli i benderfynu ynglŷn â'r sgôr derfynol ar gyfer pob safle a llunio'r map cenedlaethol.

Mae canlyniadau'r *asesiad cenedlaethol* yn dangos bod y cyfleoedd gorau ar gyfer adfer ar Ystâd Goed Llywodraeth Cymru yn ardaloedd Parc Cenedlaethol Eryri, Coedwig Tywi a Choed y Mynydd.

Ar ôl i safle gael ei ddynodi fel safle sydd â'r potensial i'w adfer gan y *cynllun asesu cenedlaethol*, bydd angen *asesiad maes* dilynol er mwyn dilysu'r asesiad desg cenedlaethol. Datblygwyd *asesiad maes* wedi'i seilio ar arsylwadau maes. Gwelwyd bod yr *asesiad maes* yn ddibynadwy iawn pan brofwyd ef drwy wneud gwaith maes ar nifer o safleoedd mawn wedi'u coedwigo yng Nghymru i gadarnhau ffeithiau.

Datblygwyd Offeryn Asesiad Maes a'r bwriad yw iddo gael ei ddefnyddio gan staff Comisiwn Coedwigaeth Cymru (e.e. cynllunwyr coedwigoedd neu reolwyr cadwraeth) sy'n gyfrifol am gynllunio strategol safle mawn wedi'i goedwigo e.e. wrth adolygu'r cynllun Dylunio Coedwigoedd neu wrth nodi safleoedd ar gyfer gwaith adfer cydbwyso yn Rhaglen Ynni Gwynt Ystâd Goed Llywodraeth Cymru.

Yn gyffredinol, mae'r prosiect hwn yn gam pwysig yn y broses o goladu data gofodol, gwerthuso'r wybodaeth sydd ar gael a datblygu a phrofi asesiadau *cenedlaethol* a *maes* er mwyn gwella gwybodaeth am ddosbarthiad mawndiroedd Cymru a gwneud asesiad strategol o'r potensial ar gyfer adfer mawn wedi'i goedwigo yng Nghymru. Mae hefyd yn dangos dull o integreiddio ystyriaeth o fioamrywiaeth, newid yn yr hinsawdd a pholisi dŵr.

*Cost adfer mawn wedi'i goedwigo*

Mae’r adroddiad yn cynnwys archwiliad cychwynnol o gostau tebygol adfer mawndiroedd wedi’u coedwigo, ar sail gwaith blaenorol, a chostau cymharol gwahanol ddewisiadau rheoli a aseswyd.

# 1. Introduction

Peatland in pristine or good condition performs a range of critical ecosystem services, including biodiversity, carbon storage and sequestration, regulation of base flows, water runoff and downstream flood-peaks and nutrient regulation and retention. It is important to recognise that peatlands can act as both sinks and sources of greenhouse gases, depending on their aerobic or anaerobic status which is controlled by hydrological condition, particularly influenced by climate and the extent of drainage and nitrogen deposition. Peatland supports a critically important biodiversity resource, including four UK BAP priority habitats (blanket bog, upland fen, lowland fen, and lowland raised bog) and a wide range of priority species dependent on these habitats. During the 20th Century a significant proportion of Welsh peatland has been drained for afforestation or conversion to pasture or arable and farmland (Blackstock et al., 2010).

Blanket bog is the main peat type in Great Britain (GB, comprising England, Scotland and Wales), accounting for 92% of the total peatland area covering around 2330,000 ha (10% of GB land area), and is located almost exclusively in the uplands. It is the single largest terrestrial carbon store in GB, accounting for ca. 50% of the total carbon stock (Milne & Brown 1997). However, many of these areas have been degraded due to drainage, air pollution, rotational burning and wildfires, plantation forestry and overgrazing (Ramchunder et al. 2009). Restoration efforts are underway to block drains (Armstrong et al. 2009), re-vegetate areas of bare peat (Evans et al. 2006), change fire management (Davies et al. 2008) and reduce air pollution (RoTAP, 2011).

Organic matter accumulates in peat because of low decomposition rates (due to waterlogging) rather than high plant productivity (Freeman et al., 2001; Toberman et al., 2008. Blanket peat vegetation is adapted to these saturated conditions, and is highly sensitive to changes in water availability (Bragg and Tallis 2001). In these ombrotrophic systems, high water tables are maintained by precipitation and poor drainage due to impermeable underlying deposits (Taylor 1983), coupled with the hydraulic properties of the peat itself. The reliance on precipitation makes blanket peat highly sensitive to climate changes that affect the net water balance (precipitation – actual evapotranspiration), as this alters the balance between decomposition and primary production (Hughes and Heathwaite, 1995).

Blanket bog is a habitat requiring persistently wet and cool climate conditions to support the characteristic mixed flora of ericoids, graminoids and bryophytes, including Sphagna.  A wide range of species contribute to peat formation and this is only possible under and stable water table regimes. The acidic, waterlogged environment ensures plant decomposition rates are low, resulting in peat formation and long term carbon storage (Lindsay, 2011). The process is slow, often no more than 1 mm per year, but over the last 10,000 to 20,000 years, approximately 455 Gt of carbon have accumulated in temperate peatlands that would otherwise be held in the atmosphere (Bragg, 2002; Charman 2002; Minkkinen et *al.,* 2002; Moore, 2002). Britain holds 13 per cent of the world's blanket bog habitat, where the deep peat (over 45 cm deep, definition follows Kennedy (2002)) contains an estimated 4523 MtC (Cannell, 1999; Chapman et *al.,* 2001). This warfs the 162 MtC contained within British forests (trees only, Morison et al., 2011) and is equivalent to the amount of carbon that would be emitted over nearly 30 years, if the UK continued to burn fossil fuels at current rates of 131 MtC per year.

In recent years, peatland restoration has received considerable attention as interest in conservation has grown and the peat industry has become concerned with peatland degradation (Wheeler et *al.,* 1995; Parkyn et *al.,* 1997; Gorham and Rochefort, 2003). Research suggests that after the reestablishment of an appropriate hydrological regime, a highly disturbed peatland has considerable potential for regeneration (Lavoie et *al.,* 2001; Girard et *al.,* 2002; Smoulders et *al.,* 2002). Conservation organisations are primarily concerned with restoring the unique assemblage of bog flora and fauna, in line with the aims and targets set out in the UK's Biodiversity Action Plan (UKBAP, revised targets, 2006). But recently there has also been an assumption that restoring degraded blanket bog will have a positive impact on carbon storage, by restoring the carbon sink capacity of the peat (M. Harley Pers. Comm., 2004; Caithness and Sutherland Peatland Management Strategy, 2005).

More than 75% of deep peat soils in Wales are covered in semi-natural vegetation. Most of this is upland blanket bog, with significant amounts of fen and flush and, locally, lowland raised bog. These are all UK Biodiversity Action Plan priority habitats with UK and Welsh targets for habitat management and restoration, and under the Wales Environment Strategy (WES), the management and restoration targets for Welsh peatland are currently under review but the broad ambition is to ensure favourable condition of all UKBAP species and habitats by 2026 (WBP, 2010). It was estimated previously (Van Velzen and Joss, 2009) that 12,400 ha of established woodland occurs on peat over 1m deep and the majority of it (9,995 ha) is coniferous woodland. In order to deliver the habitat restoration targets, set out in the WES, there will be a need to progressively restore semi-natural habitat on these areas. Restoration measures should seek to better integrate the key objectives of nature conservation, carbon storage and water quality.

Despite only covering 5.6% of the land area of Wales, deep peat soils are estimated to contain approximately 30% of the countries total soil C carbon stock. Protection of this peatland resource is increasingly recognised as critical to climate change mitigation in the land-use sector. While in total there is more carbon within Welsh mineral soils, it is necessary to target actions on peat soils, especially as there are clear synergies with the need to meet BAP habitat restoration targets. The estimated 121 MtC within Welsh deep peat soils is almost 10 times the total net annual emissions from Wales. Within the WG Climate Change Strategy, soil carbon conservation has been recognised as one of the big challenges for the land-use sector.

Aside from biodiversity and carbon storage, another important driver for protecting peatlands is their role in regulating water flows and water quality. Peat performs a complex role in the regulation of runoff to headwater streams. In a saturated state, peat sheds surface runoff relatively quickly but forms a large water store that can help to sustain low flows during dry periods. Artificial drainage can increase peak flows downstream by providing routes for the rapid transmission of rain water but can also enhance base flows by increasing the soil hydraulic gradient (Robinson et al. 1998). Ditch blocking has been shown to have mixed effects, sometimes reducing peak flows while in other cases having no detectable impact (McGrath and Smith, 2006). Lowland mires perform an analogous function, but because of their topographic context also offer the potential for flood water storage. There is a need for more research to understand the hydrological effects of grip blocking and to establish if certain guiding principles emerge. Peatland afforestation can promote surface drying and peat shrinkage due to the greater water use of forest crops, especially conifer (Nisbet, 2005). The drying effect can extend to adjacent areas, requiring consideration to be given to the management of upslope forest stands. Prioritisation of any restoration work should assess the hydrological impacts of proposed restorative management options.

Degraded peat is a potentially potent source of dissolved organic carbon, which aside from carbon loss, can contribute to water colour and cause problems for water supplies. There is good evidence that restoration work, particularly gulley and ditch blocking, can help to reduce losses and benefit water quality (Labadz et al, 2010). Temperature, water table depth, pH and atmospheric deposition have all been implicated as causal agents of DOC release (Labadz et al, 2010). Lowland wetlands in particular offer significant potential for nutrient retention, though this must be balanced against the ecological and conservation consequences of eutrophication. Understanding the relative potential of peatland restoration to improve water resource and water quality management is an important element of this study.

Welsh Government’s strategy for woodlands and trees recognises the importance of managing woodlands for biodiversity and the need to restore priority open habitats on the Assembly Government Woodland Estate, as well as more widely. It states that when the environmental benefits from open habitat restoration are clear there should be permanent deforestation, with the loss of woodland being offset by woodland creation elsewhere. It sets out the case to modify the nature, character and management of non-native plantations through a variety of techniques, all designed to optimise the range of ecosystem service benefits. The strategy notes the need for further guidance on managing habitat restoration on deep peat soils, especially on identifying those types or areas of woodland where restoration is likely to be most viable and provide the greatest benefits in terms of carbon, biodiversity gain and water resources and water quality. The Strategy’s Action Plan suggests that the Wales Biodiversity Partnership Woodland Ecosystem Group is best placed to lead the identification of sites for permanent woodland removal for priority habitat restoration. This study was established to inform targets to be advised upon and implemented by the members of this group (Cariss, 2011).

# 2. The objectives of the project

a) Provide an improved distribution map of the upland blanket peat and deep peat soils resource at the highest resolution available for two purposes: firstly for use in Glastir Woodland Creation Grant map viewer and scheme processing and secondly to allow a strategic assessment of the afforested peatland resource. There is also a need for assessment of the coverage of available FC soils maps and extent of their digitisation. A subsidiary objective is to identify any remaining FC soils maps within the project scope which remain to be digitised. Where the afforested deep peat falls outside of the Welsh Government Woodland Estate (WGWE), details of ownership will need to be obtained.

b) Provide an appraisal of the scientific literature and reviews available on different management approaches to improving the condition of afforested blanket peat and deep peat soils. In particular the literature review should evaluate:

- the impact of projected climate change on peatland distribution;
- the potential for reducing net GHG emissions over the next 40 years;
- the viability of restoring priority habitats;
- the potential hydrological (base flow, water quality, flood management at the catchment scale) benefits that restoration on deep peat soils would deliver from different management approaches; and,
- In addition to published material the appraisal should include a brief survey of anecdotal lessons learnt from existing restoration projects including the 'live' approaches under development as part of the AGWE Wind Energy Programme. The review to include management measures relating to blanket bog in favourable condition (in effect as a 'control') to appraise the benefits of restoration.

c) Categorise the afforested peatland resource. Undertake a GIS-based assessment of selected areas of the known afforested deep peat areas of Wales to identify rule-based criteria for the identification of areas (or types):

- of woodland where restoration is most viable and will provide the most benefit in terms of carbon, hydrological and biodiversity gain;
- where improved management of existing degraded semi-natural communities within a woodland holding, such as Molinia-dominated bog, should be focused to deliver more effective blanket bog restoration;
- where it may not be viable to re-establish blanket bog, such that the protection of the existing soil and peat resource would be best

served by retention of tree cover such as upland native woodland or mixed woodland; and,
- where it may not be viable to re-establish blanket bog, such that the protection of the existing soil and peat resource would be best served by creation of another open habitat type such as wet heath or marshy grassland.

d) Identify and cost the management options available within discrete sites by application of the rule-based criteria identified in (c) to assess the extent of applicability of different management prescriptions as outlined in (b) across the whole of the afforested deep peat areas of Wales. This will provide a means of determining an appropriate management regime at a site level including but not restricted to:

- no action - retain existing tree cover and leave site undisturbed
- retain existing tree cover and manage with low impact woodland management
- retain tree cover but change tree species composition favouring native woodland species
- careful mixture of management systems to encourage native woodland & open space
- remove tree cover permanently, actively restore bog habitat and maintain open habitat

e) Appraise the assessment at (d) and prioritise the action according to economic effectiveness, technological feasibility and ecological potential across the whole of the afforested deep peat areas of Wales. A 'ground truthing' element should be included for selected areas which are sufficiently representative across the range of site types and recommended management options. It is suggested the assessment should include anecdotal lessons learnt from existing restoration projects including the 'live' approaches under development as part of the AGWE Wind Energy Programme. This element should include an assessment of the speed of implementation, consideration of the impact of management intervention and disturbance, and the implications of ongoing maintenance regimes.

f) Final written report and spatial data provision (IPR to be granted to project partners) agreed and approved by project partners.

# 3. GIS assessment and mapping

**(Samantha Broadmeadow)**

## *3.1. The (upland blanket peat and) deep peat resource in Wales*

### 3.1.1 Mapping methodology using national datasets

Peatland is defined by many as those soil types where the surface horizon contains >25% organic matter and is >40 cm deep, these soils are often described as deep peats. This corresponds with the definition used within the Soil survey of England and Wales; however in Scotland peat soils are defined as >50 cm deep, as is the definition under the UK Forest Standard. The situation is complicated further by the Forestry Commission soil classification (Kennedy, 2002, see also Appendix 2) which makes a division between *shallow peaty soils* (organic matter depth <45 cm) and *deep peats* (organic matter depth >45 cm).

The initial map of the extent of deep peat in Wales was prepared using the same method adopted by Natural England in their recent England's Peatlands project (NE, 2010). That project identified three types of peatland soil types based on their general characteristics (JNCC 2011):

- **Deep Peaty Soils**: areas covered with a majority (>80%) of peat >40 cm deep often referred to as PEAT
- **Shallow Peaty Soils**: areas with extensive (>50%) of soils with peat 10 - 40 cm deep also referred to as ORGANO MINERAL SOILS
- **Soils with Peaty Pockets**: areas of mostly non-peat or shallow peaty soils, supporting significant smaller pockets of deep peat (such as flushes or exposures of buried peat) too small to map at a national scale.

The NE mapping team used spatial data on soil, geology and vegetation communities combined according to the rules set out in Table 1 to create a detailed map of peatlands in England (Shepherd, 2008).

**Table 1** Peat and peaty soil classes as defined by the JNCC and used by Natural England to map English peatland, Shepherd (2008). The Map Unit codes of the National Soil Research Institute (NSRI) soil associations are listed under each classification, fuller details of these soil associations are provided in Appendix 1.

| Deep Peaty Soils - PEAT | Shallow Peaty Soils – Organo Mineral soils | Soils with Peaty Pockets (non peaty soils or shallow organic soils with pockets of deeper peat) | Other, mineral soils |
|---|---|---|---|
| KEY PEATY SOIL ASSOCIATIONS [1013a, 1013b, 1022a, 1024a, | INTERMEDIATE PEATY SOIL ASSOCIATIONS [311a, 311b, | OTHER ORGANIC SOIL ASSOCIATIONS [541o, 612a, | All other soil types |

| | | | |
|---|---|---|---|
| 1024b]<br><br>*plus*<br><br>BGS peat polygons<br><br>*plus*<br><br>Blanket Bog - [equivalent Welsh peatland data from Phase 1 habitat survey for all mire habitats] | 311e, 651b, 652, 654a, 654b, 654c, 721a, 721c, 721d, 721e]<br><br>*excluding*<br><br>All areas identified as **Deep Peaty Soils** using method in column 1 | 631a, 713c, 713e, 813a, 871a]<br><br>*excluding*<br><br>All areas identified as **Deep Peaty soils** using method in column 1 | |

**SOILS:** Details of Shepherd's classification, of the NSRI soil associations found in Wales, are provided in Appendix 1. There are 695 km$^2$ of the five key peaty soil associations; an extensive area, 380200 ha of intermediate peaty soil associations and a further 81100 ha of other organic soil associations.

**GEOLOGY:** Additional areas of deep peat outside the key peaty soil associations were identified using the BGS superficial geology data. The data held by the BGS in DiGMapGB50 has been generalised from data captured by field surveyors, between 1883 and 2010, using 1:10560 or more latterly 1:10000 scale topographical data coupled with sampling to 1.2 m depth via an auger and/or boreholes. Since the geology maps were first prepared, the significance attached to peat has increased; initially as a potential fuel or soil resource, subsequently as a potential target for drainage, forestry and agricultural improvement and most recently as a threatened and increasingly rare ecosystem (R. Lawley, personal communication). So although the maps are largely conceptual, the boundaries being defined through landscape interpretation or modelling, the peat data are generally considered to reliably represent deep peat.

According to the BGS scheme, a map unit is defined as peat if it is:

- an organic deposit (i.e.) predominantly non-mineral
- its margin can be readily identified at the landscape scale during the survey (typically by vegetation/soil/topographical change)
- where the unit can be augured and shown to be >1 m thick

The peat resource was identified by selecting all polygons in the DiGMapGB50 with the rock code description of "PEAT"; the other lexicon descriptors included in the NE map ("PEAT AND SILT" and "PEAT, ORGANIC MUD AND CALCAREOUS MUD") do not occur in Wales. There are currently gaps in the BGS drift geology spatial data, three tiles/paper sheets have not yet been digitised which means that data is unavailable for 123,800 ha of Wales (6%). Across the area of Wales currently covered by the BGS digital mapping there is 30,100 ha of Peat identified by the drift geology data, which is additional to the area of deep peat identified by the NSRI key peaty soil associations. Over 90% of this additional deep peat was located within intermediate peaty soil associations.

**HABITATS:** The location and extent of additional areas of deep peat, often too small to be mapped at a national scale, can be identified from spatial data for peatland habitats. For the NE peatland project Shepherd (2008) included all areas mapped as BAP blanket bog as being reliably deep peat but rejected the BAP fen maps and the NPRI raised bog peat maps as being unreliable sources of soils data after consultation with local NE staff.

In Wales, the best equivalent information for areas of deep peat is the peat-forming mire habitats in the Habitats of Wales dataset (1997). The Phase I methodology, upon which the Habitats of Wales dataset is based, is a habitat classification scheme based on a combination of floristic and hydrotrophic criteria rather than a scheme based on the classification of the vegetation-community. Mire and swamp habitat types are difficult to define but some details of typical substrate type are provided in Appendix 6, of the Habitats of Wales (Blackstock et al., 2010) and this information was used to select which habitats are most likely to represent areas of deep and modified deep peat. The Habitats of Wales Mires dataset was re-classed according to substrate (PEAT – deep peat; PEAT-M – modified deep peat; P/M - mixed predominantly peaty; M/P - mixed predominantly mineral), Table 2.

**Table 2** The extent of deep peat and modified deep peat mire habitats from the Habitats of Wales dataset. Classification of the peat type is based on substrate information provided in Appendix 6 of the Phase 1 classification of Mires. For areas of land with an intricate mosaic of habitats, for which more than one habitat code is listed in the attribute table of the spatial data, only the principal habitat (code 1) is used in this estimation.

| Code | Habitat | Area (ha) |
|---|---|---|
| Deep peat habitat | | |
| E.1.6.1, E.1.6.2, E.3.1, E.3.2 | Blanket bog, Raised bog, Valley mire, Basin mire | 23,417.2 |
| Modified peat habitat | | |
| E.1.7, E.1.8, E3.1.2, E.3.2.2, E.4 | Wet modified bog, Dry modified bog, Modified valley mire, Modified basin mire, Bare peat | 22,665.9 |
| Habitats of predominantly peaty soils | | |
| E.2.1, E.2.2, E.2.3, E.3.3 | Acid/neutral Flush, Basic Flush, Bryophyte-dominated Spring, Fen and Floodplain mires | 15,774.9 |
| Habitats of predominantly mineral soils[*1] | | |
| F.1, F.2.2 | Swamps, Indundation Vegetation | 2,055.9 |

[*1]some locations mapped as swamp support deep peat – key examples are Crymlyn Bog and Anglesey Fens

The most extensive areas of peatland habitat (Table 2, Figure 3) are the upland blanket bogs of North Wales and the substantial area of wet modified bog in the uplands of central Wales. The additional peat of the acid/neutral flush habitats scattered across the country also contributes a significant area.

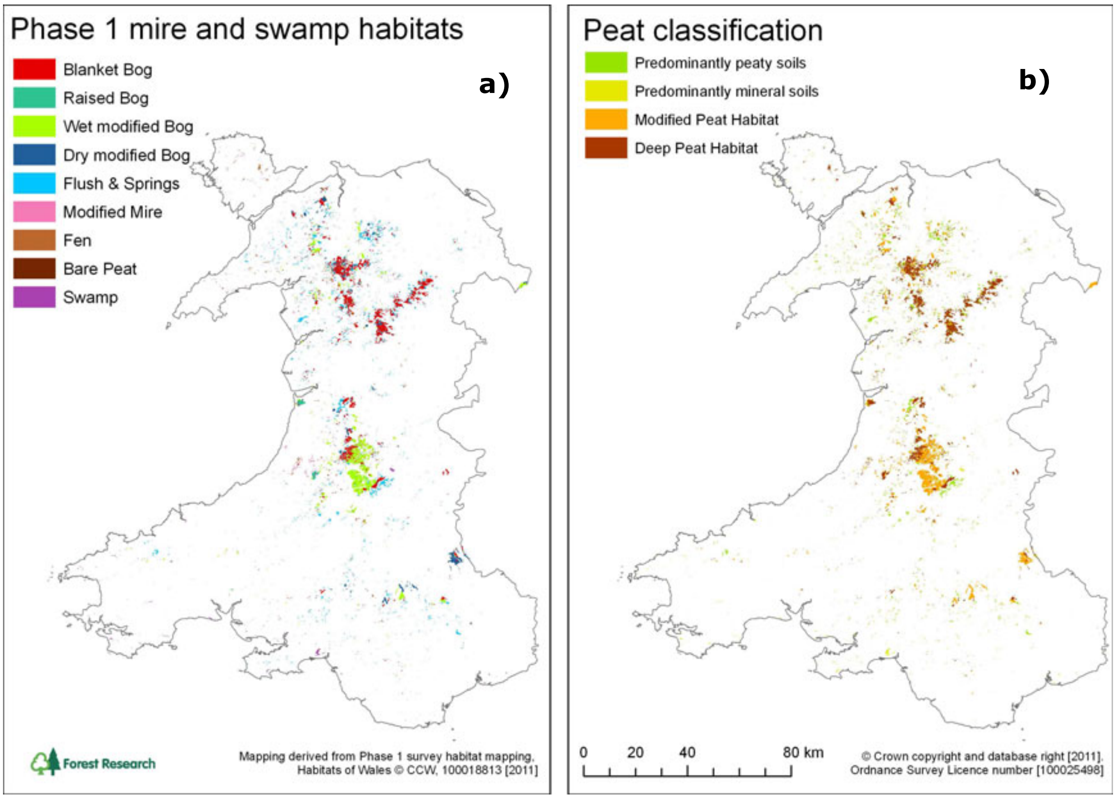


**Figure 1** The Habitats of Wales (a) Phase 1 classification of mire and swamp habitats and (b) peat soil classification based on the peatland substrate.

The extent and distribution of peatland habitats in Wales are shown in Figure 1(a); Figure 1 (b) illustrates the extent of deep peat based on the probably substrate of the peatland communities. The peat and modified peat habitats were combined with the soil and geology data to complete the identification of areas of **Deep Peaty Soils** according to Shepherd's methodology (Figure 3).

### 3.1.2 Results

Data were merged on the basis of Shepherd's three peaty soil classes (Deep Peaty Soils, Shallow Peaty Soils and Soils with Peaty Pockets) then exploded to produce multiple polygons each of which may have been derived from one or more data source. The extent and distribution of each peat soil class in Wales are presented in Table 3 and shown in Figure 1.

**Table 3** Area (ha) of different peat soil classes in Wales, derived using spatial data for soil, geology and habitat maps.

| Deep Peaty Soils | Shallow Peaty Soils | Peaty Pockets | Other, mineral soils |
|---|---|---|---|

| | | | |
|---|---|---|---|
| 116,385 (93,932 Peat and 22,453 Modified Peat) | 343,820 | 79,211 | 1,526,800 |

Based on this estimate peatlands make up around 5.6% of Wales's total land area. The intact deep peat resource, 93,932 ha, accounts for almost 3% of the total UK peatland area (JNCC, 2011). The area of deep peat soils is less than the first published estimate of 158,800 ha of peat deposits in Wales, Taylor and Tucker (1968).

The proportional scale of the additional areas of deep peat, identified using the drift geology and habitat cover data are illustrated in Figure 2, together they extend the area identified and mapped as deep peat beyond that defined in the recent ECOSSE (2007) project which estimated that there was 70,600 ha of soil associations dominated by peat in Wales and a further 359,200 ha of organo-mineral soils.

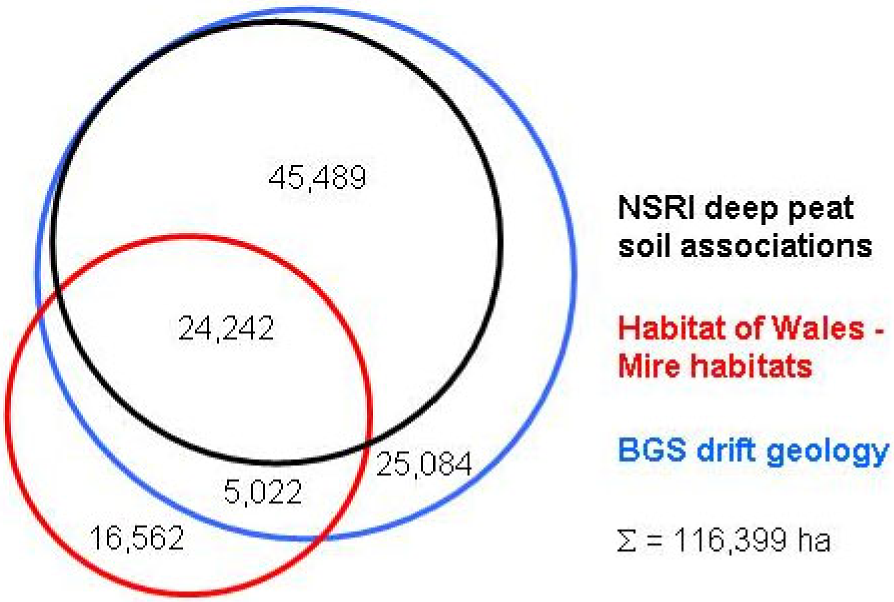


**Figure 2** An illustration of the relative contribution to the total area of deep peat in Wales from the three data sources. All figures are area (ha).

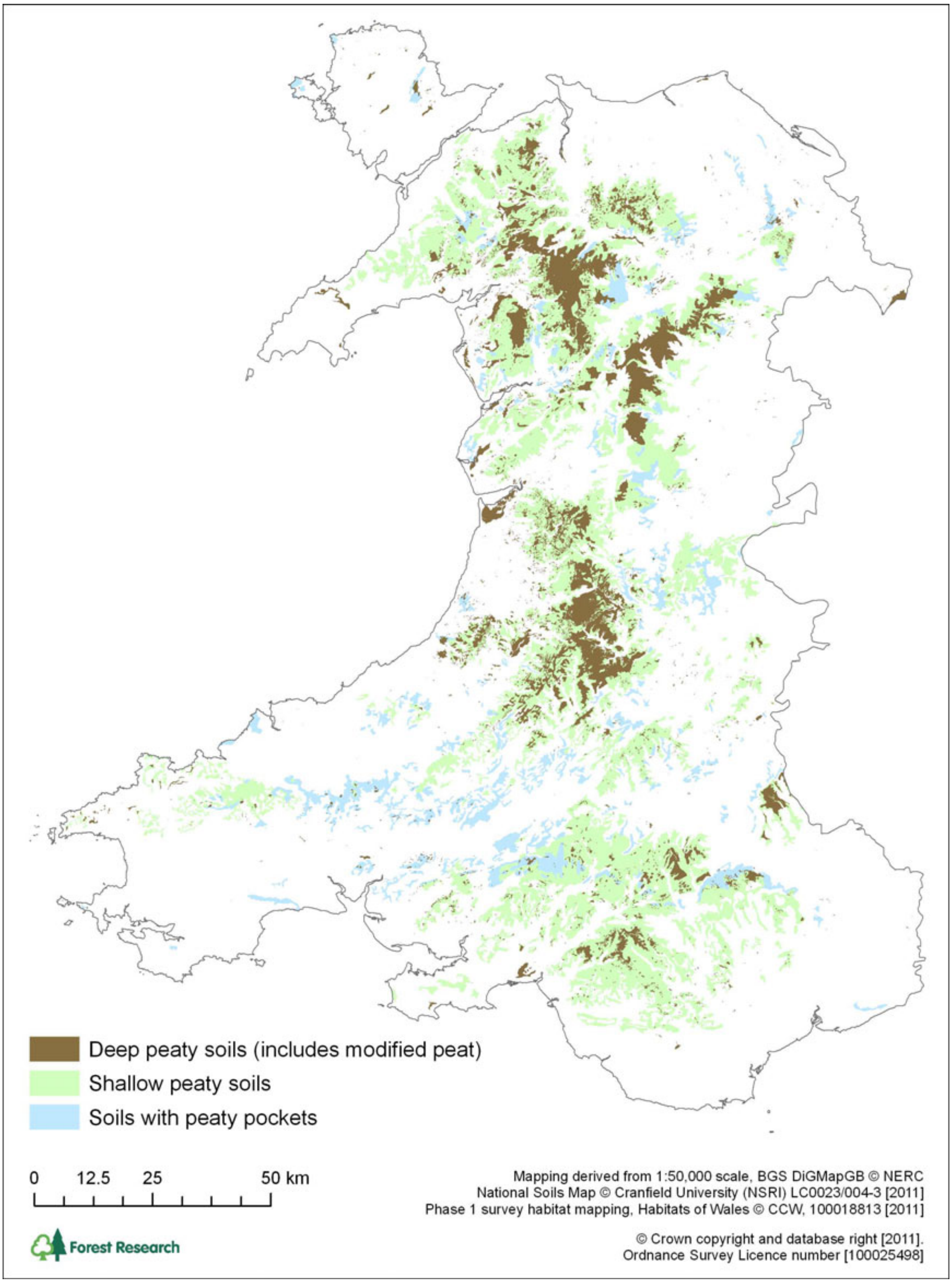


**Figure 3** The national peat map for Wales. The map shows the total extent of deep peat based on soil (NSRI), drift geology (BGS) and peatland habitat mapping (CCW Phase I survey), with the latter being taken as evidence of deep peat when NSRI/BGS are lacking.

### 3.1.3 The potential to improve the national peat map using FC soil survey data

The protection of the soil resource is a fundamental concept in sustainable forest management and prior to afforestation or subsequent management decisions large tracts of the FC estate were surveyed by foresters using the Forestry Commission's soil classification system. Under this system soils are divided into 15 soil groups, with various types and phases used to record local variation. The importance of peat and peaty soils in UK forestry is reflected by the inclusion of 5 deep peat soil groups. The FC soil classification system distinguishes between sites on the basis of the nutrient status of the peat.

#### 3.1.3.1 Forestry Soil Mapping

The Forestry Commission Mapping and Geodata Unit (M&G) have recently digitised the soil mapping for Welsh forests from the original Forestry Commission soil survey records. The paper maps have been scanned and rectified and the accompanying report used to create spatial data. The new dataset is a significant improvement on the soil information that was previously stored in the FC sub-compartment database. The spatial dataset provides an accurate and detailed record of the soils, at the time they were surveyed usually, prior to the original tree planting.

The extent of available FC soil survey information across Wales is illustrated in Figure 4. In total 74,985 ha have been surveyed.

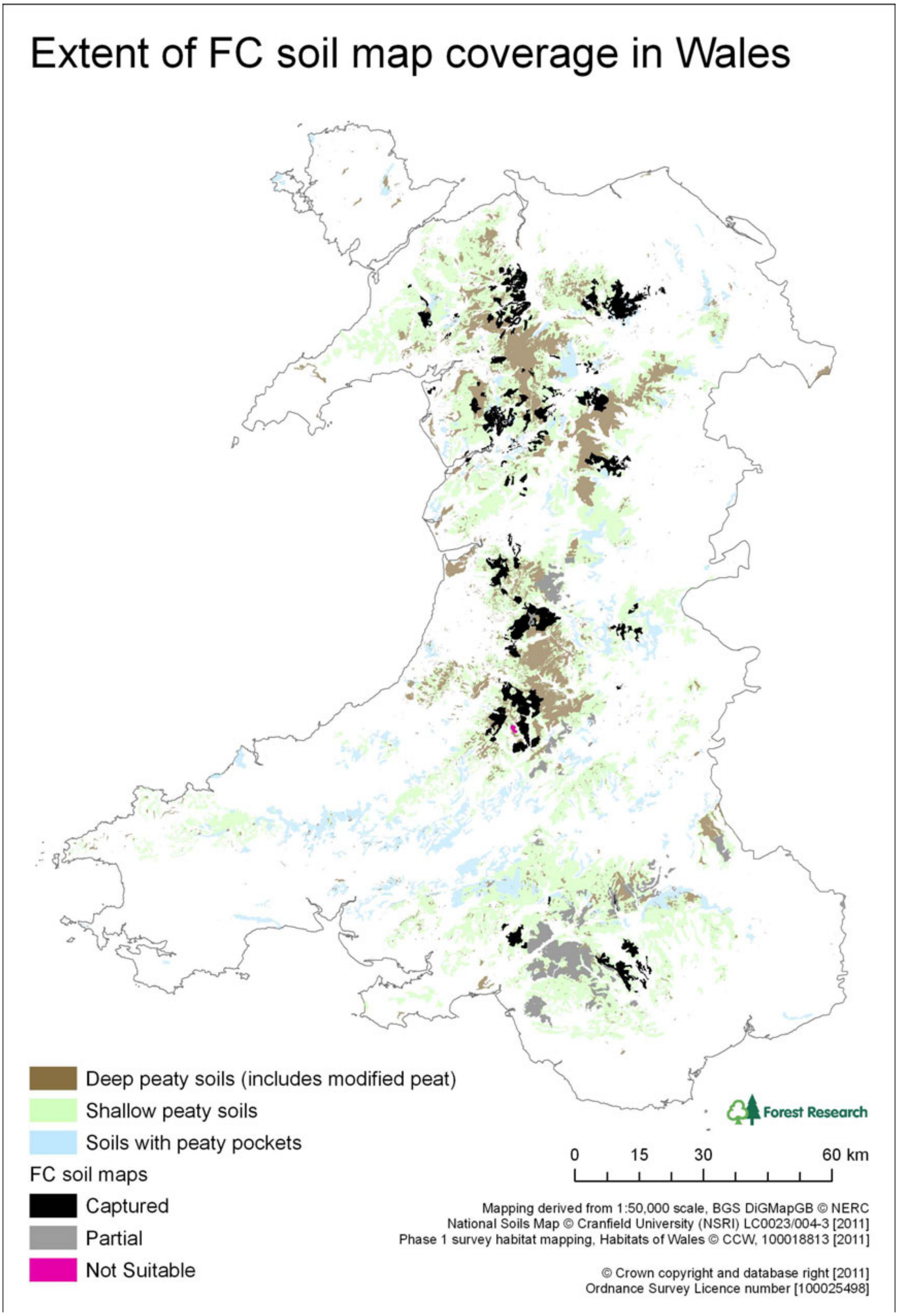


**Figure 4** Map illustrating the extent of FC soil survey mapping in Wales.

To illustrate the difference in the extent of deep peat soils identified using the NSRI national soil map classification system and the Forestry commission soil classification system a detailed assessment of the soils of the Gwydyr Forest Block (approx. 5,800 ha) has been included as a case study.

Details of the Forestry Commission soil classification system are provided in Appendix 2. The boundaries of each discrete area of soil is mapped as a single map unit and assigned a code that records the general soil type and phase description. In variable terrain a map unit may be assigned 2 or 3 codes to indicate a mosaic of soil types. For this exercise the individual map units were assigned one of four peat classes:

- Deep peat: >50% Deep Peats [soils Appendix 2, Table 2]
- Shallow peaty soil: >50% peaty soils [soils from Appendix 2, Table 1] with no deep peat present
- Peaty soils with peat pockets: > 50% peaty soils + localised areas of deep peat soils
- Mineral: >50% mineral soils

### 3.1.3.2 Case Study - the Gwydyr Forest Block

The Gwydyr Forest Block is a large area of forest surrounding Betws-y-coed in the Snowdonia National Park, North Wales. The soils (Figure 5a) are typically shallow and peaty, but there is also a significant area of amorphous deep peat. The FC soil surveyors recorded the boundaries and defined the soil units in terms of soil type (details provided in Appendix 2), plus several additional key features of the landscape which may be relevant to an assessment of the peat restoration potential such as the location of springs, large agricultural drains, flushes and small unmapped streams.

To assess the reliability of the peat mapping derived from national datasets, the peat classification based on the national map was compared with a peat classification scheme based on the FC soil survey, Figure 5. The areas classed as deep peat soils are shown in red in the two figures. The improved resolution of the mapping in Figure 5b reflects the spatial scale of the FC soil survey and illustrates the value of the FC soil survey data to the improved understanding of the exact location and character of afforested deep peat in Wales.

Table 4 summarizes the land areas classed as having deep peat and peaty soils in Gwydyr Forest according to the two peat classification schemes. The area of deep peat soils identified by the FC soil surveyors in the FC forest block is 12% smaller than the area of deep peat soils mapped in the national map (688.5 ha Gwydyr, 784.6 ha national map). In general terms, over 90% (2360 ha) of the soil classed as mineral in the national map was also classed as mineral soil by the FC soil surveyors; however, the classification of the organic soils in the national map was less robust. The area of soil classed as deep peat in the national map, was spilt in roughly equal parts between mineral soils (28.5%) shallow peaty soil types [16.7% & 17.2%] and deep peat soils [37.6%] by the FC soil surveyors. The reduction in the area of deep peat soils of, 490 ha is in part compensated for by gains in the area of deep peat from soils that had previously been classed as shallow peat soils (328 ha) and mineral soils (65 ha).

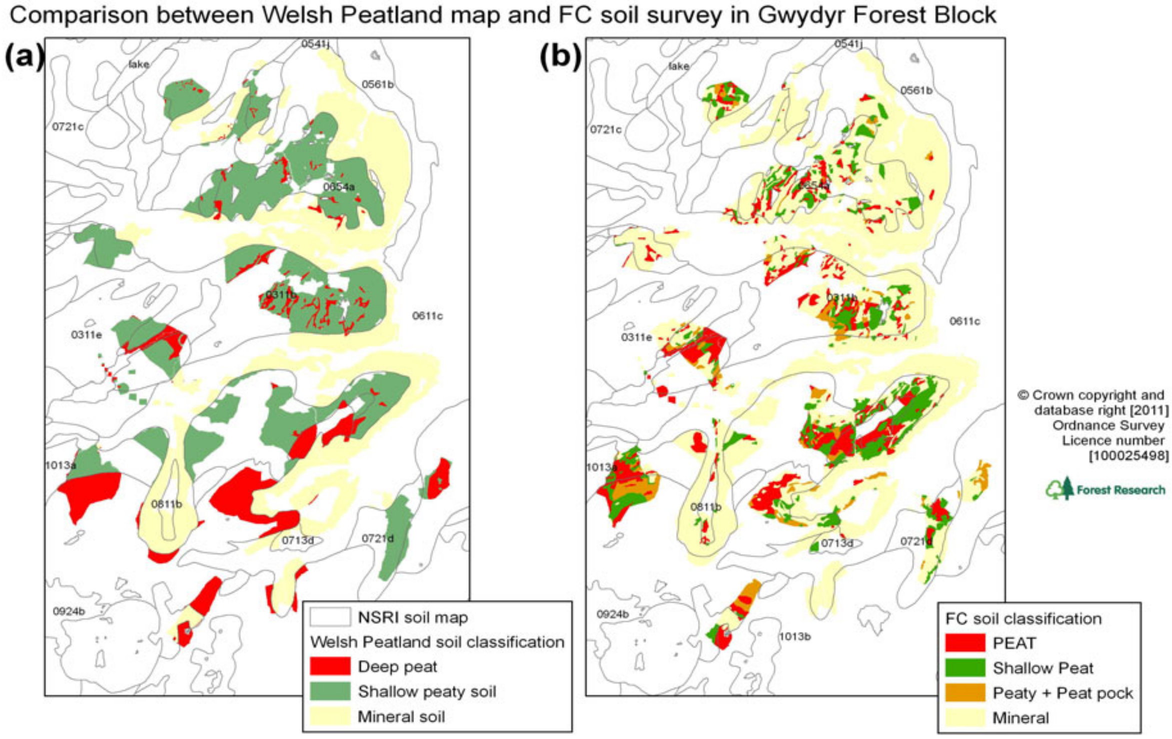


**Figure 5** Map of the peat soil classifications for Gwydyr forest block, comparing (a) soil classification based on the criteria used to create the national peat map, Figure 3, [NSRI soil association, BGS drift geology and CCW peatland habitat datasets] and (b) soil classification based on field survey of soils by FC soil surveyors.

**Table 4** Area (ha) of different soil peat classes in the Gwydyr Forest block. The rows represent the distribution using the national peat map classification, while the columns reflect the FC peat classification information. The percentages in blue indicate the proportion of each national peat-soil class that **remained unchanged** or was *reclassified* in the FC soil survey mapping.

| Welsh peatlands map - peat class | | Forestry Commission soil classification - peat class | | | |
|---|---|---|---|---|---|
| | | Mineral 4,181 ha | Shallow peaty soil 667 ha | Peaty soils + peat pockets 270 ha | Deep Peat 689 ha |
| | | 72% | 11% | 5% | 12% |
| Mineral 2,553 ha | 44% | 2,360 **[92%]** | 97 *[4%]* | 31 *[1.5%]* | 65 *[2.5%]* |
| Shallow peaty soil 2,464 ha | 42% | 1,594 *[65%]* | 438 **[18%]** | 105 *[1.5%]* | 328 *[2.5%]* |

| | | | | | |
|---|---|---|---|---|---|
| Deep peat (+modified peat) 785 ha | 14% | 224 *[28.5%]* | 131 *[17%]* | 135 *[17%]* | 295 **[37.5%]** |

N.B. The 'Soils with peaty pockets' class is absent from the Welsh peatlands classification as none of the soil associations mapped in the forest block fell into this category.

The discrepancies between the two schemes are also illustrated in Figure 6. It is clear that some soil associations are more likely to be reclassified than others. In particular a large proportion of land mapped as the humic rankers and stagnopodzols in the national map were identified as having a mineral rather than peaty top soil by the FC soil surveyors and pockets of deeper peat within these series were identified and recorded. Similarly the small scale variation in peat depth within the areas mapped as oligo-amorphous peat is recorded in the FC soil survey and a significant area is therefore classed as a peaty surface water gleys rather than deep peat.

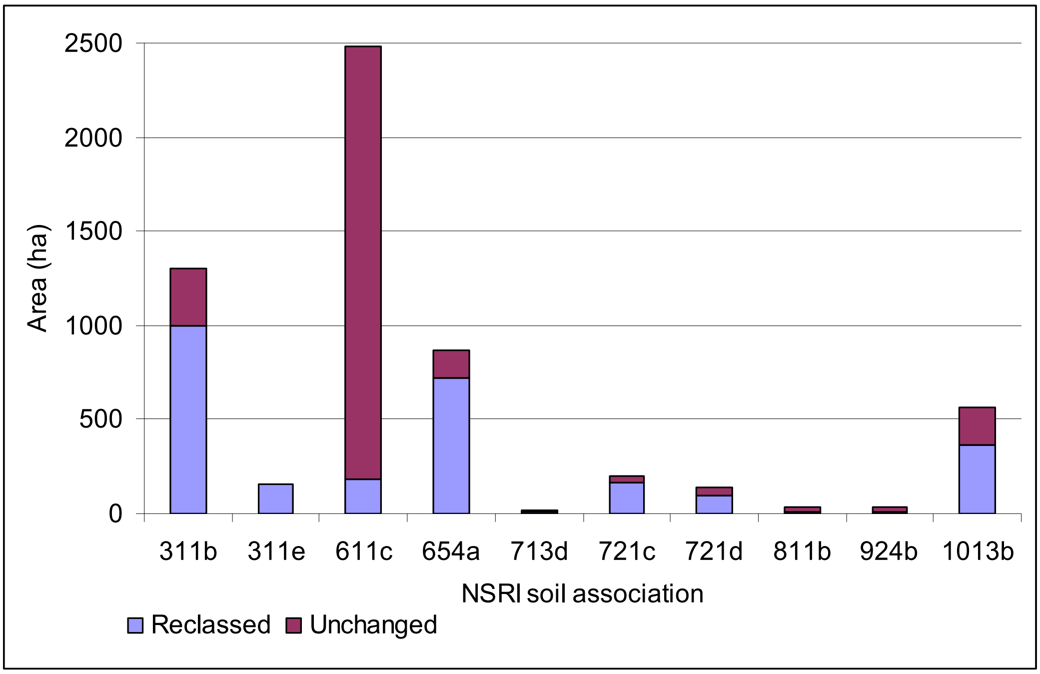


**Figure 6** Histogram comparing the peat soil classification of the NSRI soil associations across the Gwydyr Forest block, using the national peat mapping methodology and FC peat classification systems. The blue bar in the graph illustrates the proportion of each NSRI soil association which is assigned a different peat soil classification in the FC soil survey to that in the national peat map. (The NSRI soil classification: 311x peaty rankers; 611 podzol, 654 peaty podzol; 713 surface water gley; 721x peaty surface water gley soils; 811 alluvial gley soil; 924 mining spoil and 1013 deep peat).

### 3.1.3.3 Peat classification in the Forestry Commission Soil Mapping

Table 5 summarizes the land areas classed as deep peat and peaty soil types, in the two peat classification schemes; for the complete Forestry Commission soil survey dataset for Wales.

**Table 5** Comparison of the area (ha) of different soil peat classes for the land included in the FC soil survey dataset for Wales. The rows represent the distribution using the national peat map classification, while the columns reflect the FC peat classification information. The percentages in blue indicate the proportion of each national peat-soil class that **remained unchanged** or was *reclassified* in the FC soil survey mapping.

| Welsh peatlands map - peat class | | Forestry Commission soil classification- peat class | | | |
|---|---|---|---|---|---|
| | | Mineral 49,293 ha | Shallow peaty soil 14,789 ha | Peaty soils + peat pockets 4,313 ha | Deep Peat 10,995 ha |
| | | 62.2% | 18.6% | 5.4% | 13.8% |
| Mineral 24,196 ha | 30.5% | 22,639 **[93.5%]** | 949 *[4%]* | 324 *[1.3%]* | 283 *[1.2%]* |
| Shallow peaty soil 41,784 ha | 52.6% | 23,124 *[55.4%]* | 10,629 **[25.4%]** | 3,264 *[7.8%]* | 4,771 *[11.4%]* |
| Other organic soils 2,241 ha | 2.8% | 1,596 *[71.2%]* | 467 *[20.8%]* | 46 **[2%]** | 132 *[6%]* |
| Deep peat (+ modified peat) 11,170 ha | 12.3% | 1,935 *[17%]* | 2,747 *[25%]* | 680 *[6%]* | 5,808 **[52%]** |

Across Wales the area of deep peat soils identified by the FC soil surveyors is just 175 ha (1.6%) less, than the area of deep peat in the national map. As in the Gwydyr forest, the classification of mineral soils is more robust than the organic soils and the greatest shifts in the estimate of the peat resource arise due to the reclassification of the shallow peaty soil types. Although roughly equal in extent the gains and losses in the area of deep peat between the two maps are significant, almost half the deep peat soils in the national map are re-classed by the FC soil surveyors. This illustrates the importance of accurate mapping, based on observation in the field, when trying to identifying and assess the potential of afforested sites for restoration (see section 2.2). The extent and distribution of each peat soil class in Wales including the FC soil survey dataset is shown in Table 6.

**Table 6** Area (ha) of different peat soil classes in Wales, derived using spatial data for soil, geology, peatland habitats and the FC soil survey.

| | Deep Peaty Soils | Shallow Peaty Soils | Peaty Pockets | Other, mineral soils |
|---|---|---|---|---|
| Including FC soil survey data | 116,205 | 316,893 | 81,300 | 1,552,247 |
| Excluding FC data ≡ Table 3 | 116,385 | 343,820 | 79,211 | 1,526,800 |
| Difference | -0.2% | -0.9% | +2.7% | +1.6% |

The 12% discrepancy in the area of deep peat between the two peat classification systems for the Gwydyr forest is similar in scale to that found in previous comparisons of national and FC soil surveys. In a case study of two afforested Scottish sites (Meallmore and Craik) differences of

11% and 14% in the area of deep peat were reported when FC and national mapping were compared (Morison et al, 2010). These values are also comparable to an 8% error estimated for the Glensaugh catchment with predominately peats soils, in North East Scotland, when comparing measured soil C stocks with a National Soil Map (NatMap) UK soil database, reported by Frogbrook et al. (2009).

### 3.1.3.4 Additional field survey peat depth data from the (a) ECOSSE Plynlimon survey and (b) Welsh wind farm project soil maps

In addition to the Forestry Commission soil maps, field survey data from other projects in areas of deep peat soils were kindly provided by the project partners. Spatial data of peat depth across Plynlimon was provided by CEH from the ECOSSE project; and FC soil survey data and peat depth probe records from the Wind Energy Programme were provided by FC Wales. This included digital soil data from three project areas: Clocaenog Forest, Dyfnant Forest and Nant y Moch, which together covered an area of 105200 ha, and peat depth probe data from Nant y Moch, the hills surrounding a wind farm at Trannon in the Afon Cledan catchment and an extensive survey of Pen y Cymoedd. These data were used to assess the accuracy of the national peat map.

### 3.1.3.5 ECOSSE Plynlimon peat depth survey

The field survey was carried out across three, adjacent 1 $km^2$ squares sampled on a 200 m grid providing 96 samples (Frogbrook *et al.,* 2009). At every sample point the soil profile was sampled three times using a rectangular corer and depth of the organic/peat horizon recorded. An organic horizon covered much of the surveyed area with some patches of deeper peat up to 175 cm depth. Figure 7 illustrates the mean peat depth at each sample point and compares the distribution of observed peat depth with the mapped (national peat map) areas of deep peaty soils. The map identifies areas of deep peat soils in each of the three 1-$km^2$ squares surveyed, which correctly matches the recorded peat depth in 65% of the sample points. However, In the area mapped as deep peat in the north west block three quarters of the peat probe observations were measured as shallow peat and there is also a significant area of deep peat which has not been mapped, illustrated by the bold pink line in Figure 7.

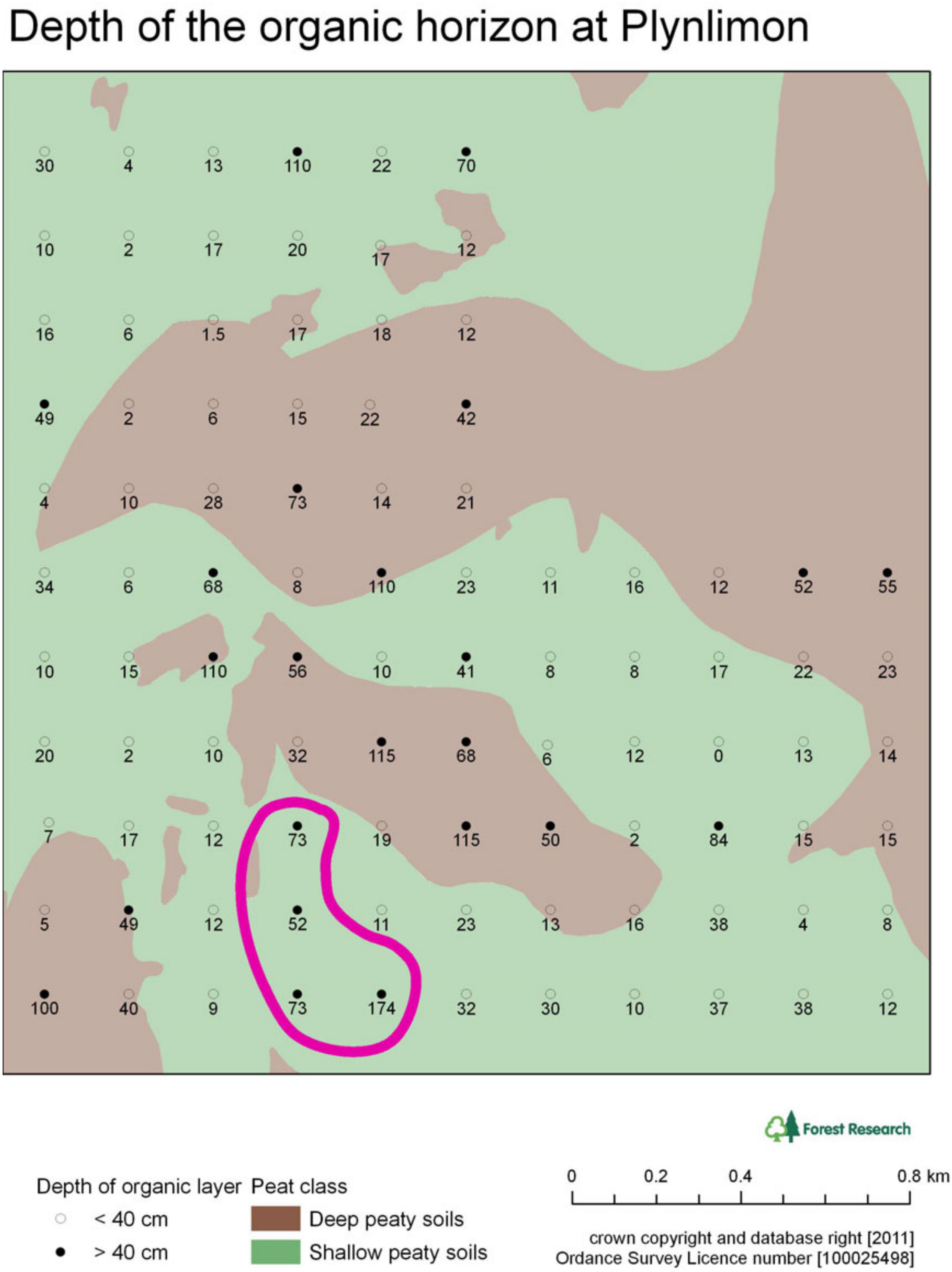


**Figure 7** Map illustrating the depth of the organic soil horizon at Plynlimon, comparing peat probe survey data with the national peat map.

### 3.1.3.6 Welsh wind farm project - soil mapping for Clocaenog Forest, Dyfnant Forest and Nant y Moch

The peat classification of these three areas is compared in the same way as had been done in the Gwydwr Forest block. The differences in mapped spatial distribution of deep peat between the two schemes for the three wind farms are shown in Figure 8.

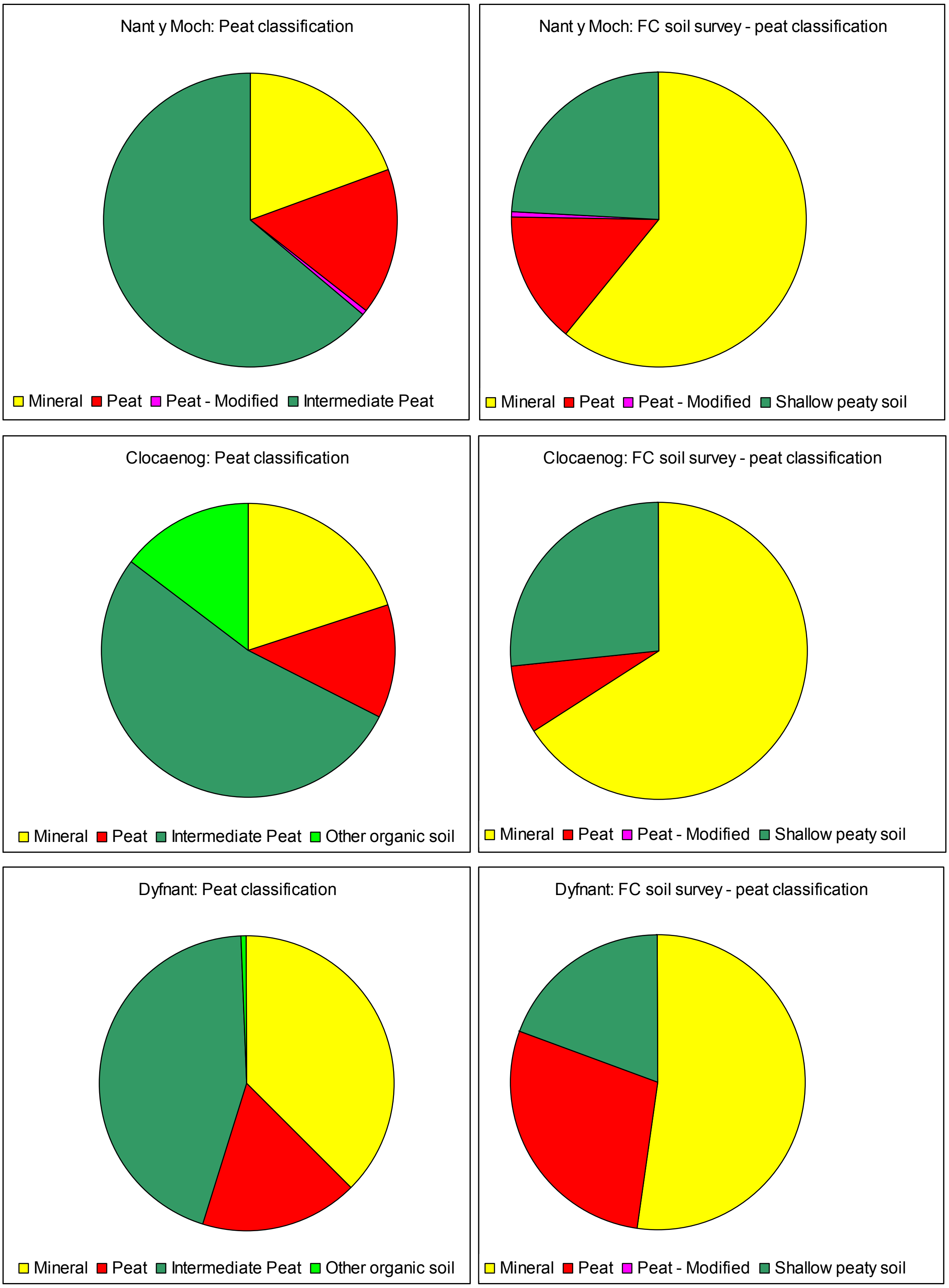


**Figure 8** Pie charts comparing the peat soil classification at three Welsh wind farm project sites in the national peat map and FC soil survey mapping.

## 3.1.3.7 Welsh wind farm - peat depth probe data from Nant y Moch, Trannon and Pen y Cymoedd

Peat depth probe data from EIA investigations undertaken on behalf of windfarm developers is available for three sites; one site, Pen y Cymoedd, appears to have been surveyed twice. The number of observations at each site varies from 41 observations across three hill tops surrounding the Trannon wind farm to > 2500 observations from within the forest at the Pen y Cymoedd site. It is apparent from the spatial distribution of the readings that the survey was not random, with most of the measurements being taken from around the perimeter of recorded areas of deep peat.
Areas mapped as having mineral soils appear to have been largely avoided.

To determine how well the national peat map agrees with the probed peat depth the observations were classed as 'no peat': 0 cm, 'shallow peat': <40 cm depth and 'deep peat': >40 cm depth. Figure 9 compares the proportion of observations mapped as either deep peat or shallow peat soils. It can be seen that most of the peat depth observations are taken from areas mapped as deep peat soils (therefore represented by the red bar). An even higher proportion of the observed deep peat (>40 cm) had been mapped as a deep peat soil (red bar). At Nant y Moch most of the peat-depth readings recorded no organic horizon; these observations tended to be from areas mapped as peat by the BGS superficial geology data. At Trannon many peat depth readings also failed to record an organic horizon, with most of the measurements taken on the hill tops in semi improved and marshy grassland along the mapped boundary between 1013a and 654a soil series.

Two data sets are available from Pen y Cymoedd. These show reasonably good agreement between the peat probe readings and the mapped area of deep peat (mapped as 1013a and 1013b soil series plus an area of BGS superficial peat deposit), although there was a significant number of mismatches. The latter is perhaps to be expected considering the extensive nature of the area involved. The smaller of the two surveys appears to show less agreement with the peat map, possibly reflecting the greater proportion of the peat depth readings taken at the edge of the mapped area of deep peat.

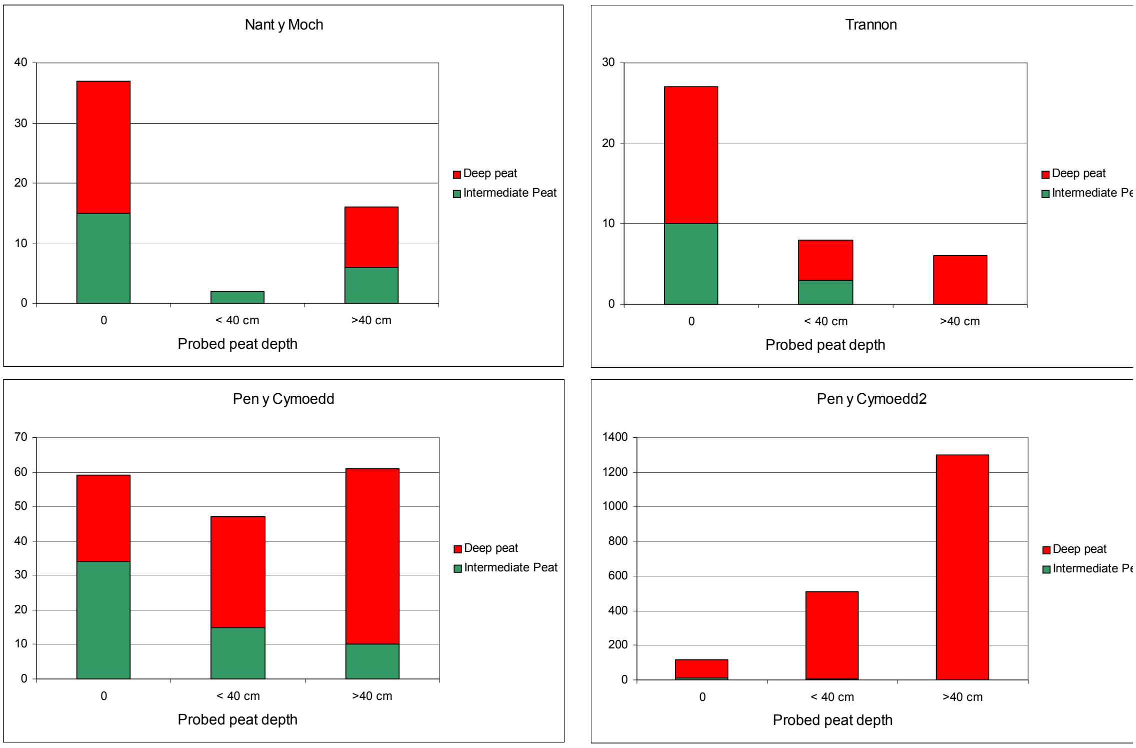


**Figure 9** Histogram of the number of peat probe observations at three Welsh wind farm project sites mapped as either deep peat (red section of the bar) or an intermediate peaty soil (green section of the bar) in the national peat map. Note the variable scales of the y axis which shows the number of observations.

## *3.2 Afforested upland blanket peat and deep peat resource in Wales*

### 3.2.1 Extent and distribution:

The spatial data for the national inventory of woodland for Wales map was used to determine the area of afforested deep peat in Wales (Table 7). In Wales, a digital map of all woodland was derived from 40 cm per pixel orthorectified digital imagery flown in 2006 provided by the Welsh Government. OS MasterMap features were used where the woodland boundary was coincident with or within 10 m of the perceived woodland edge. The individual woodland polygons were then differentiated into Interpreted Forest Types (IFT's) of 0.5 ha and over.

The National Forest Inventory (NFI) definition of woodland is:

- Minimum area is 0.5 hectares (inc. young trees) with tree crown cover of >20% of the ground.
- Minimum width for a wood is 20 m
- Intervening land classes - metalled roads, rivers (>20m wide), power line wayleaves and railways are excluded from the woodland area; internal unmetalled tracks, rides and streams are included.
- Scrub vegetation is included within the survey where low woody growth seems to dominate a likely woodland site.

- Open areas <0.5 ha in extent and completely surrounded by woodland IFT's are included as woodland as occasional gaps in the canopy are considered to be integral elements of a wood.

Open Areas >20m wide and >0.5 ha completely surrounded by woodland are mapped as open of 12 open Landcover classes within the NFI.

The NFI was combined with the new soil mapping, the areas of afforested deep peat and peaty soils are provided in Table 7 and illustrated in Figure 10.

**Table 7** Area of afforested deep peat in Wales (ha). The figures include the area of woodland and assumed woodland in the NFI for Wales (2011) but do not include open land within woodland which has been removed from the assessment.

| Afforested Deep Peat | | Afforested Shallow Peaty Soils | Afforested Peaty Pockets |
|---|---|---|---|
| Peat | Modified peat | | |
| 17,833 | 157 | 46,208 | 11,393 |

### 3.2.2 Ownership of afforested upland blanket peat and deep peat resource in Wales.

The area of afforested deep peat owned by the Welsh Government was identified using the FC legal boundary (Figure 11). Ownership of other woodlands was determined as far as possible using information held on the spatial data repository for the FC's woodland grant schemes. These data sets include contact details of the owners and their agents for all woodland receiving grant aid under the FCW WGS2 and WGS3 schemes. Using these sources, it was possible to identify the owners of over 85% of the afforested peat. The greater portion of the land is in public ownership. The Welsh Government Woodland Estate covers 11,038 ha of deep peat, most of the land ~70% is covered by established conifers, there are significant ~13% additional areas of young trees and ~15% ha of has recently been felled (see section 3.3 for further details). Other public authorities are responsible for 16.6 ha. There are 4,845 ha owned by private individuals and businesses, and 59 ha owned by voluntary organisations. It was not possible to determine the ownership of the remaining woodland within the time available for this project. It is current forest policy in Wales for existing non-native woodlands to be restored to priority open habitats where there is a clear ecosystem service benefit. This policy may be realised on privately owned land through the targeting of financial incentives and grant aid.

The new Glastir Targeted Element scheme will target agri-environmental payments towards farm measures that meet specific environmental objectives. In the first two years of the scheme, the scoring process will be weighted in favour of farms with the potential to deliver improvements in carbon storage and water management. The WG has created spatial datasets for the ranked priority areas for each environmental objective. It is therefore possible to identify the owners of afforested deep peat within the key target areas for measures to improve carbon management, water quality and biodiversity in order to try and persuade them to apply for the scheme.

It is possible that woodland officers would be able to identify owners within their locality and additional information may be available from FC Grants & Licences; their assistance should be sought before resorting to the land registry.

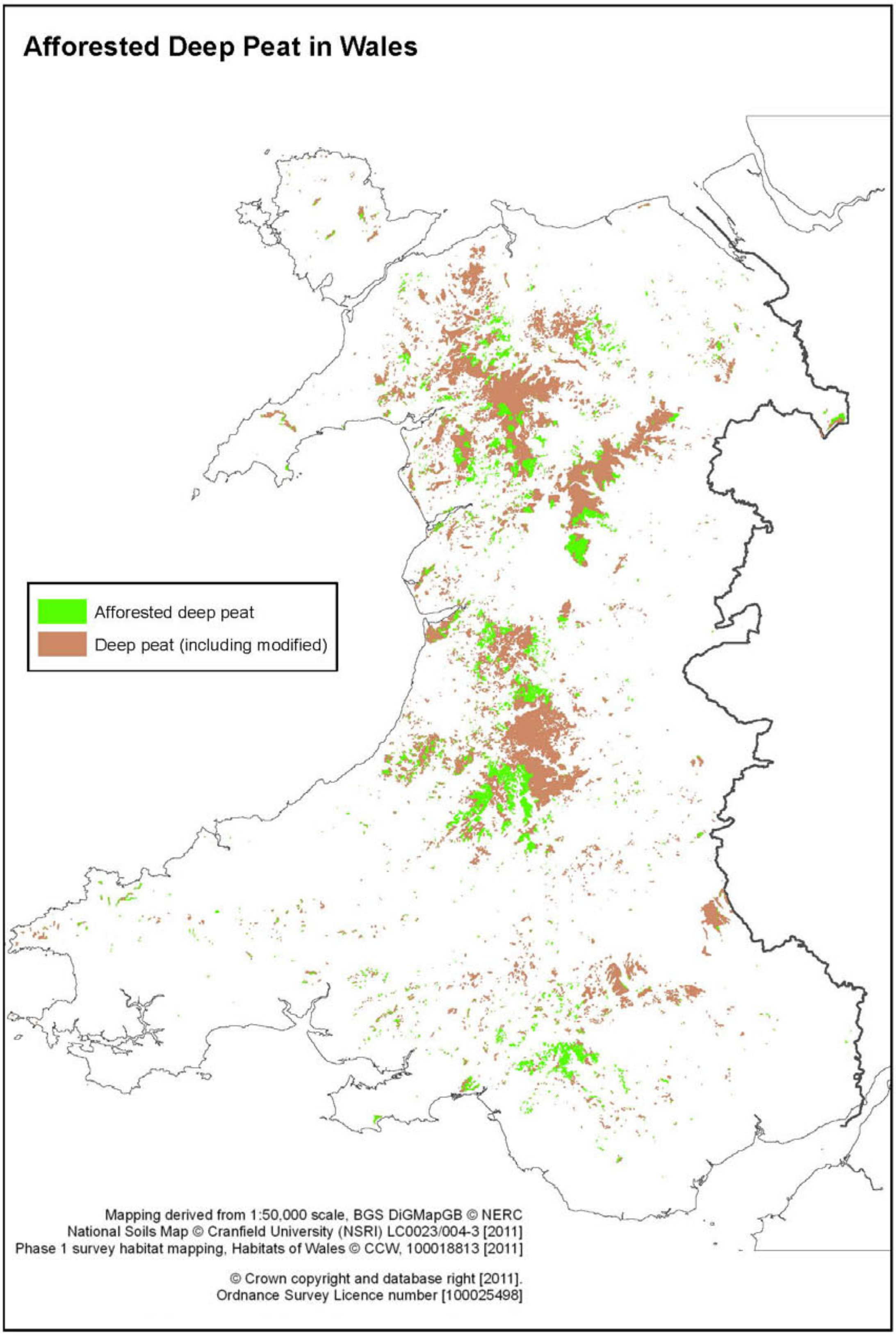


**Figure 10** Map of the afforested deep peat resource in Wales.

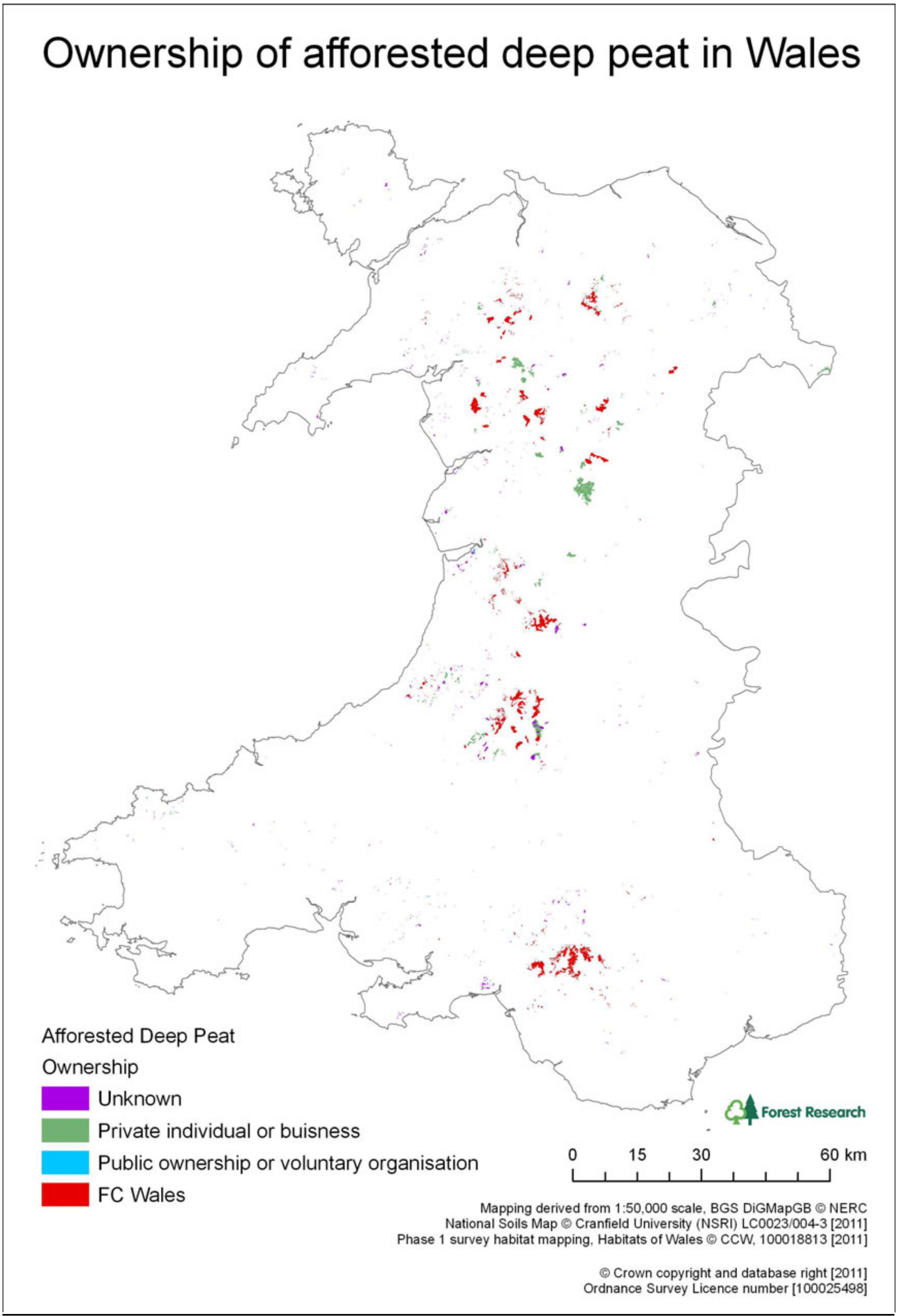


**Figure 11** Map of the known ownership of afforested deep peat resource in Wales.

## 3.3. The peat resource of the Welsh Government woodland estate

### 3.3.1 Extent and distribution

To determine the extent and forest cover of the afforested peat resource within the Welsh Government woodland estate the afforested peat spatial dataset was clipped using the spatial data for the FC legal boundary.

### 3.3.2 Results

The extent and distribution of the Welsh Government woodland estate on deep peat is illustrated in Figure 12 and the afforested areas on deep and shallow peat soils are shown in Table 8.

**Table 8** Area of afforested deep peat in Wales (ha) owned and managed by the Welsh Government Woodland Estate.

| | | NFI Interpreted forest type | | | | |
|---|---|---|---|---|---|---|
| | | Broadleaves | Conifer | New* Planting | Felled** | Open |
| Deep Peat: FC soil type | Deep peaty gley | 6 | 737 | 242 | 195 | 47 |
| | Basin bog | 16 | 955 | 223 | 203 | 128 |
| | Flushed blanket bog | 24 | 3,784 | 666 | 840 | 252 |
| | Flat or raised upland bog | 1 | 406 | 159 | 80 | 165 |
| | Unflushed blanket bog | 0 | 922 | 242 | 210 | 264 |
| | Eroded peat | 0.02 | 137 | 9 | 27 | 66 |
| | Not surveyed by FC staff | 4 | 580 | 127 | 173 | 0 |
| | ***Total*** | ***51*** | ***7,521*** | ***1,668*** | ***1,728*** | ***922*** |
| Shallow Peaty Soils | | 456 | 19,366 | 4,438 | 4,229 | 1,054 |
| Peaty Pockets | | 220 | 4,547 | 1,024 | 805 | 294 |
| Mineral soils | | 12,798 | 74,294 | 10,804 | 8,353 | 4,805 |

*maximum tree age for this category is 10 years-old
**felled area, includes ground prepared for planting

The information shown in Table 8 is a summary of the detailed soil information available in the FC soil survey record. The attribute table of the spatial data provides further details of the different phases of deep peat soils. The afforested basin bogs were predominantly the *Juncus effusus* type with a small area of *Juncus articulatus/acutiflorus* bog and a single hectare of true fen bog. There is a far greater extent of afforested flushed blanket bogs. The Tussocky *Molinia, Calluna* bog is the most common soil type of this group, but there is also an extensive area of afforested *Eriophorum vaginatum, Trichophorum* bog. The flat or raised bogs are entirely of the upland type and the unflushed blanket bogs are all of the *Calluna, Eriophorum vaginatum* type.

In addition to the survey derived soil mapping, for the Welsh Goverment woodland estate we also have detailed information on the current land cover, canopy tree species, age and yield class from the FC Forester database which will facilitate the identification of priority areas for peatland restoration (see section 5).

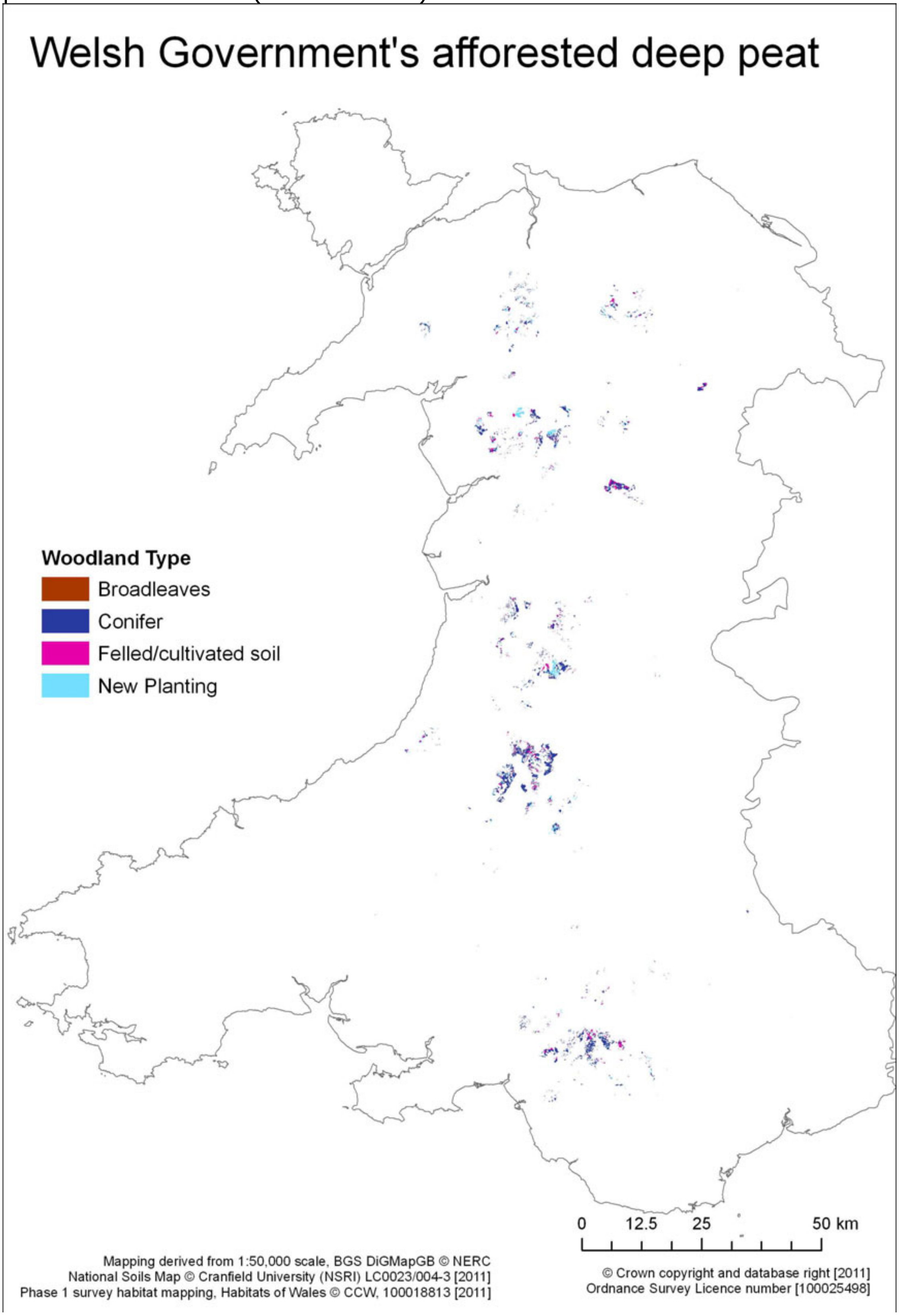


**Figure 12** Map of the Welsh Government's woodland estate - woodland cover on deep peat.

# 4. Potential impact of restoring afforested peatlands on biodiversity, hydrology and GHG balance

**(Elena Vanguelova, Russell Anderson, Samantha Broadmeadow, Sirwan Yamulki, Tim Randle)**

A desk-based assessment of existing information was carried out to summarise the main influencing factors on peat distribution in Wales and the potential impact of restoring afforested peatland, including post restoration management works on biodiversity, hydrology and GHG balance. The review includes the identification of relevant sources along with expert judgement of their strengths and weaknesses.

## *4.1 Key peer-review and grey literature sources.*

1. IUCN UK Peatland programme reports on:
   a) Peatland Biodiversity (Littlewood et al., 2010)
   b) Climate Change Mitigation & Adaptation Potential (Worrall et al, 2010)
   c) Peatland Hydrology (Labadz et al, 2010)
   d) Impacts of Peatland Restoration (Lunt et al, 2010)
   e) Commission of Inquiry on UK peatlands (Bain et al, 2011).

2. Peatlands and Climate Change: analysis of current evidence-base to inform policy development in peatland conservation and restoration in the context of climate change (Lindsay, 2010).

3. England's peatlands, carbon storage and greenhouse gases (Natural England report, 2010).

4. Towards an assessment of the state of UK peatlands (JNCC report 2011).

5. Assessing the probability of carbon and greenhouse gas benefit from the management of peat soils (Worrall et al, 2010).

6. A review of current evidence on carbon fluxes and greenhouse gas emissions from UK peatlands (Worrall et al, under review).

7. EA QUEST project outputs:
   a) Model inter-comparison between statistical and dynamic model assessments of the long-term stability of blanket peat in Great Britain (1940-2099) (Clark et al, 2010).
   b) Assessing the vulnerability of blanket peat to climate change using an ensemble of statistical bioclimatic envelope models. (Clark et al, 2010).

8. Managing open habitats in upland forests. Forestry Commission Practice Guide (Anderson, 2008).

9. Open ground in upland forests: a review of its potential as wildlife habitat and appropriate management methods (a review by Anderson, 2003, Forest Research).

10. Peat report for Forestry Commission Scotland (Morison et al, 2010).

11. Understanding the Carbon and Greenhouse Gas Balance of UK Forests (Morison et al, 2011).

12. United Utilities programme SCAMP which included drain blocking and peat restoration in the Peak District

13. Robinson et al 1998 report on hydrological impacts of upland afforestation at Coalburn.

14. FD2114 and EA update reports on role of land management in reducing flood risk.

## *4.2 Baseline factors affecting the distribution of peatlands in Wales.*

### 4.2.1 Topography

The altitude of the site, the angle of slope and concavity of the ground will all be given factors in the original potential accumulation of peat. If altitude is sufficient (> 300 m in most of Wales), the orographic rainfall will be sufficient to allow peat formation, as long as the ground slope is not too steep. In this case gravity in combination with rainfall intensity, will maintain skeletal soils. Where hollows have developed in the bedrock at high altitudes, which are not sufficiently deep to hold standing water, then peat formation should be expected, which may take the form of a raised bog development. Where runoff is high due to geology and slope then peat development may be limited to shallower blanket bog, or stream-side mires, with more through flowing water.

### 4.2.2 Rainfall and N deposition

Peat decomposition is a very important process because it is potentially a much faster process than the formation of new peat and so likely to be the main driver of overall carbon balance (Haines-Young et al, 2009). Evidence suggests that the relationship between diffuse pollution and peat decomposition is positive rather than negative, as had previously been assumed. Both nitrogen and sulphur deposition tend to reduce decomposition and therefore lead to increased C accumulation in soils (Evans et al. 2005 & 2006; Persson & Wiren, 1989; Sanger et al, 1994; Situala et al, 1995). However, N deposition does appear to be associated with the development of more strongly graminoid dominated (especially Molinia) vegetation and relatively minerotrophic Sphagna, neither of which are likely to achieve peat formation rates commensurate with mixed ericoid/graminoid/Sphagnum covers (Peter Jones, CCW, personal communication). In the case of sulphur deposition, for example, it appears that as upland ecosystems have recovered from the effects of acidification, levels of Dissolved Organic Carbon (DOC) in UK surface waters have risen by an average of 91 %. This suggests that past acidification was probably inhibiting carbon loss from catchments (Evans et al, 2006).

However, linking the nitrogen and sulphur in a single node for diffuse pollution needs to be considered carefully, because it is apparent that they show quite different temporal trends which may have tended to offset each other. While the deposition of reactive nitrogen compounds has increased markedly in recent years, now reaching levels of 40 kg N ha$^{-1}$ year$^{-1}$ over large areas of the UK (RoTap, 2011), acidic sulphur deposition has declined by about 60 % in the last two decades (RoTap, 2011).

The majority of bog habitats receive an average of 1000 - 1500mm rainfall per annum (Figure 13, left) (Hall et al, 2011). The rainfall range has been used as a modifying factor in calculating the most recent N critical loads values for protecting UK bog habitats (Table 9). They have been spatially mapped (Figure 14).

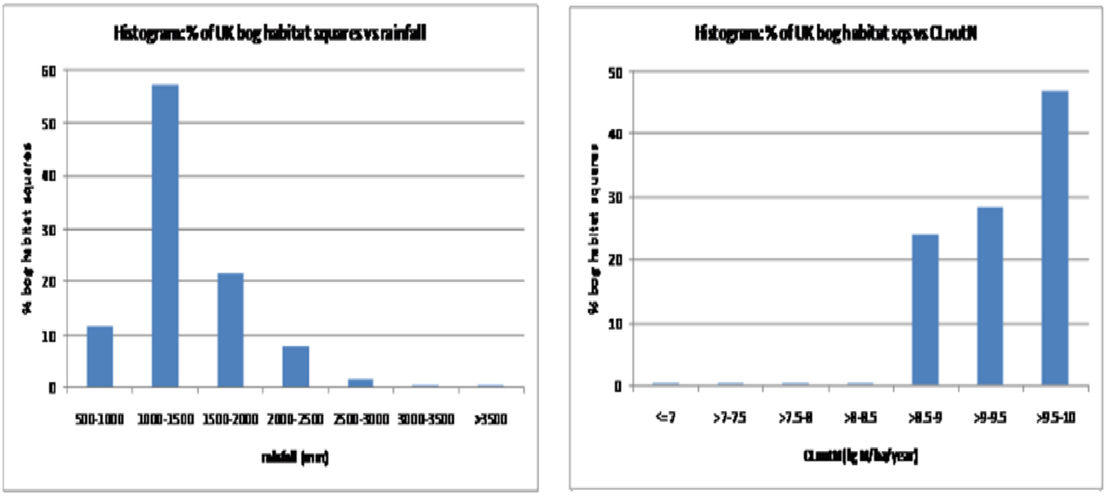


**Figure 13** Histogram of the number of bog 1x1km squares vs annual average rainfall (1961-90) categories (left) and histogram of the number of bog 1x1 km squares vs nitrogen critical load (right) (Hall et al, 2011). Calculated critical load for the majority of bog habitat squares would be above 8.5 kg N ha$^{-1}$ year$^{-1}$. The median critical load for all bog habitat squares using this approach is 9.5 kg N ha$^{-1}$ year$^{-1}$ (right).

There is no evidence of impact on indices of ecological function below deposition of 10 kg N ha$^{-1}$ year$^{-1}$ identified in new analyses in the UK by Emmett et al, (2011). However, the major change with the present era (post mid-1800s) is that of the increased human impacts, particularly those associated with the atmospheric deposition of nitrogen, which averages 17.5kg N h$^{-1}$ per annum (Lunt et al, 2010) and poses a risk to ecological integrity of peatlands. The recent Review and Revision of

Empirical Loads (Bobbink & Hettelingh, 2011) concludes that responses of bog vegetation in areas with N deposition of <10 kg N $ha^{-1}$ $yr^{-1}$ have been observed.

**Table 9** Most recent calculated rainfall ranges and their specified median nitrogen critical load values used in N deposition mapping for bog across the UK (Hall et al., 2011).

| Rainfall range (mm) | Median $CL_{nutN}$ (kg N $ha^{-1}$ $year^{-1}$) |
|---|---|
| 548 - 758 | 8 |
| 759 – 1,285 | 9 |
| >1,285 | 10 |

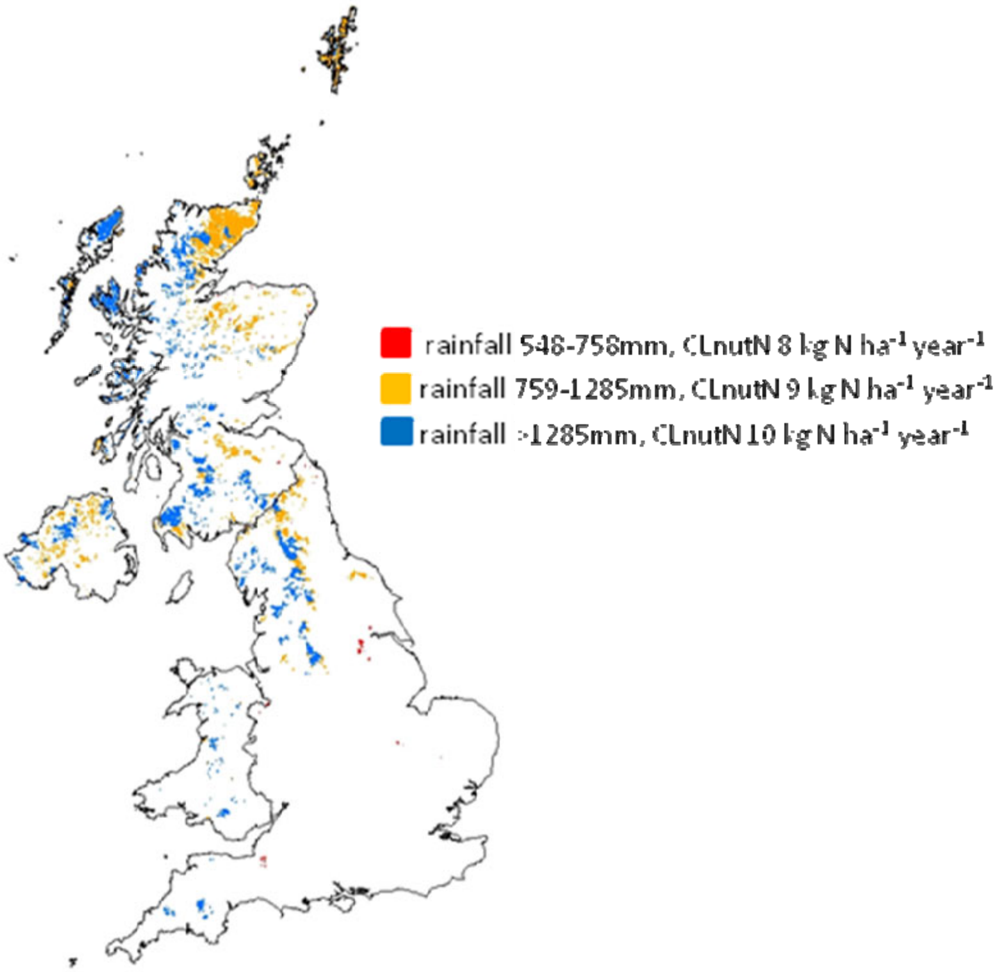


**Figure 14** Map of the annual rainfall (mm) and empirical nitrogen critical load value (kg N $ha^{-1}$ $yr^{-1}$) for the UK bog habitat (Hall, 2011).

### 4.2.3. Climate change impacts on peat distribution

Blanket peat formation is dependent on a positive water balance that is favoured by cool and wet conditions (Wieder and Vitt, 2006). Climate change could therefore provide a risk to the status of peatland ecosystems (Limpens et al, 2008), particularly in degraded areas that are already subject to stress.

Clark et al., (2010) have assessed the vulnerability of blanket peat to climate change in Great Britain using an ensemble of 8 bioclimatic envelope models. Models that included measures of both hydrological conditions and maximum temperature provided a better fit to the mapped peat area than models based on hydrological variables alone. Under UKCIP02 projections for high (A1F1) and low (B1) greenhouse gas emission scenarios, 7 out of the 8 models showed a decline in the bioclimatic space associated with blanket peat formation. Eastern regions (Northumbria, North York Moors, Orkney) were shown to be more vulnerable than higher-altitude, western areas (Highlands, Western Isles and Argyle, Bute and The Trossachs).

These results suggest a long-term decline in the distribution of actively growing blanket peat, especially under the high emissions scenario, although it is emphasised that existing peatlands may well persist for decades or even more or less indefinitely under a changing climate. There is evidence to suggest that at least below the 500 m contour line that the southern most blanket bog peatlands in the UK exists at the "marginal climatic zones for peat formation" (Worrall et al, 2007; Worrall et al, 2009). Marginal climatic zones for peat formation could hamper restoration to active blanket or raised bog (Clark et al, 2010), though restoration of a semi-natural mire habitat is likely to remain feasible throughout Wales, albeit with sometimes only a partial cover of active mire in the case of bogs. For fens, the prospects for restoring more extensive active mire under feasibly pessimistic climate change scenarios are better because of the opportunities which exist for engineering water retention.

There is much debate regarding the ability of southern blanket bogs to withstand predicted impacts of climate change (Belyea and Malmer 2004; Bonn *et al* 2009; Worrall *et al* 2009). The more optimistic view is that intact active peat bogs with *Sphagnum*-rich surfaces have the capacity to maintain their water logged conditions (Lindsay, 2010). There is clear evidence from the peat-archive that blanket bog even on the southern moors was growing healthily under warmer climatic optima than those predicted for 2050 (Bindler 2006). Lindsay (2010) suggests some shifts in the species composition but even under the worst climate change scenarios of 2050 (IPCC 2006) the main peat forming species *S. papillosum* will continue to grow throughout its current range.

In damaged blanket bogs, warmer drier summers, as predicted by climate change models, will lead to drying or peat surface layers and an increase in the likelihood of accidental fires (Worrall et al, 2009).

The impact of climate change on the overall net carbon balance is uncertain, as both increases and decreases in SOC stocks are possible depending on the balance between decomposition and net primary productivity (Smith and Gang, 2010). The reliance on precipitation makes blanket peat highly sensitive to climate changes that affect the net water balance (precipitation – actual evapotranspiration), as this alters the balance between decomposition and primary production (Heathwaite, 1993).

*Based on the literature findings the following **Criteria for assessment of the peat forming factors** are proposed:*

- *Topographic flatness*
- *Altitude (lowland or upland raised or blanket bog)*
- *Rainfall*
- *Temperature*
- *N deposition and*
- *Predicted climate change*

## *4.3 Potential for afforested restoration for biodiversity benefit*

The Joint Nature Conservancy Committee (JNCC) has produced a Common Standards Monitoring (CSM) condition assessment methodology which is used across the UK to assess the condition and thus conservation status of statutory sites (SSSI etc) (JNCC 2006). JNCC guidelines include the assessment of 5 key attributes which include vegetation composition, the extents of eroding and newly formed peat and disturbance from drainage, but unfortunately does not adequately cover the requirement for a significant % cover of *Sphagnum* (JNCC 2006). A high and stable water table in combination with a typically mixed ericoid/graminoid/ Sphagnum blend is more likely to be peat forming than vegetation with an impacted hydrology and vegetation composition.

It will take decades before damaged peatland recovers, though improvements in condition can be seen within ten years. Peatlands are to a degree resilient to damage and will recover to some extent through autogenic processes once a favourable hydrological regime and a semi-natural mire vegetation cover are established (Hilbert et *al.,* 2000; Belyea and Clymo, 2001). Rochefort et al., (2003) estimate that a significant number of characteristic bog species can be established in 3-5 years, a stable high water table in about a decade and a functional ecosystem that accumulates peat in perhaps 30 years. For example, five years after afforested peatland restoration was carried out at Talaheel plantation on the Forsinard reserve a reduction in the amount of bare ground and an increase of bog species such as *Eriophorum vaginatum*, *Eriophorum angustifolium* and *Sphagnum* species was found. Furrows across the site showed an increase in bog *Sphagnum* cover and a steep decline in species restricted to drier habitats. Despite a localised increase of non-blanket bog graminoids in mineral soil compartments, the vegetation within the study site as a whole appeared to be recovering, with elements of blanket bog vegetation now widespread and expanding across the site (Maier, 2004).

As forest plantations are normally drained prior to planting, and fertilised with phosphate and sometimes nitrate to aid early establishment of trees, remnants of moorland vegetation often survive in the drains, along boundaries and rides and in areas too wet for tree growth. These areas provide excellent places from which Sphagnum can spread following the removal of trees (Anderson, personal communication). Monitoring of the LIFE project 'Active blanket bog in Wales' showed that forest plus residue removal and blocking of main drains and plough furrows (viewed as the best rewetting method) allowed rapid recovery of cotton grass and *Sphagnum* mosses (LIFE project handbook, 2011). However, other evidence from a small unreplicated trial at Bryn y Gors-goch showed that scraping off the conifer litter layer resulted in almost pure heather. A better species mix (mainly heather and hare's-tail cottongrass) developed in the control plot, where the litter layer was left intact (Anderson, personal communication).

The rate of recolonisation of bog vegetation could be strongly influenced by the stage of the conifer crop that had been removed. Faster restoration can occur in non-canopy-closed bog forests where some of the previous bog vegetation still exists (e.g. Conaghan, 2009). Contrary to this, slower and less certain restoration potential was observed in fully closed forest canopy where all the bog vegetation has been shaded out (e.g. Conaghan, 2009). Therefore, stand age and rotation are important in assessing the potential for afforested peatland restoration. In older and second rotation stands, the influence of ground preparation and trees on peat drying and oxidising could be significant. Evidence from restoration of Longbridgemuir, South Scotland (Anderson, personal communication) suggest that parts of sites with peat cracking at an advanced stage (i.e. underground cracks between plough furrows) are probably not currently restorable or very costly to restore as they cannot be rewet sufficiently using current methods. Installation of impermeable piling or sheeting would be a possibility, but very costly methodology.

Natural regeneration in some restored sites posed questions about the balance between costs for management against ecological benefits. For example, at Bryn y Gors-goch, Clocaenog, cutting of conifer regeneration to maintain open raised bog was needed twice in 15 years and a third operation will soon be required (Anderson, personal communication). On smaller lowland raised bogs hand pulling of naturally regenerated birch tree seedling after clear felling combined with the raising of water levels has been used to reduce this problem (Lunt and Moon 2000).

Following rewetting, the topography of the clear felled site even with ridge and furrows was, along with the water chemistry (on coniferous sites), appropriate for the spread of *Sphagnum* (Lunt and Moon 2000).

Woodlands with open moorland vegetation have somewhat reduced potential for restoration, as peat is thinner and drier. Only upland moorland vegetation with established mature *Calluna* litter will adsorb sufficient water to reduce run off. If heather, grass and sedge density is reduced by tree crop shading, water adsorption will be limited until sphagnum regrows and hummocks, lawns and pools replace the degraded open surface.

At Castell Nos, as part of blanket bog restoration work, FCW dealt with standing dead trees resulting from a fire by using a 360° excavator to push them over, squash them down into the furrows and cover them over with peat. The resulting bare peat patches are in the process of revegetating but the ground is by no means as wet as would be desirable for bog restoration and renewed peat formation. This method is probably not suitable for dealing with live trees because of the much larger volume they occupy and because the peat would become nutrient-enriched through breakdown of the material unless the water table could be kept very near the surface continuously, which isn't easy on a sloping site like this. Nutrient enrichment of the peat would likely result in, at best, strongly Molinia-dominated vegetation. If peat dams had been used at intervals, with conifer brash squashed into grips between the dams, then a much better hydrological outcome could probably have been achieved (Peter Jones, CCW, personal communication).

At Bryn y Gors-goch, Clocaenog, FCW restored blanket bog adjoining Hafod Elwy Moor NNR, starting in 1993. A useful partnership has developed with CCW, which has allowed fencing and grazing of the site and NNR as one unit with grazing and hydrological management now entrusted to CCW.

There are now many afforested restoration sites, mostly bogs, and there are indications that it can be successful in achieving the re-establishment of bog vegetation. It remains to be seen whether the new vegetation will endure or be replaced by succession to other types.

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*Based on the literature findings and team expert judgement the following* ***Criteria for assessment of the afforested peatland restoration for biodiversity benefits*** *are proposed:*

- *Tree age and canopy closure and tree density*
- *Stand rotation*
- *Peatland type (decreasing importance): lowland raised bog, upland raised bog, any topogenous fen, lowland blanket bog, upland blanket bog, soligenous fen)*
- *Degree of Site disturbance from drainage and management and relative ease of restoration in relation to how pronounced planting ridges are*
- *Character of the surviving semi-natural vegetation cover (e.g.% cover of Sphagnum, etc.)*
- *Site proximity to existing open habitat*
- *Open space within stand*

- *Context (in relation to the role restoration might play in piecing together a larger unafforested site, or safeguarding the hydrology of an unafforested contiguous neighbour*
- *Topography – all being equal flatter sites are more likely to support a greater depth of peat and patterning and also achieve a good hydrological outcome.*
- *Morphological character of the peatland unit – for example if restoration can yield conifer removal from a whole raised bog or basin mire unit.*

*Last BP – suggest deleting 'a bit' and replacing with 'an area'.*

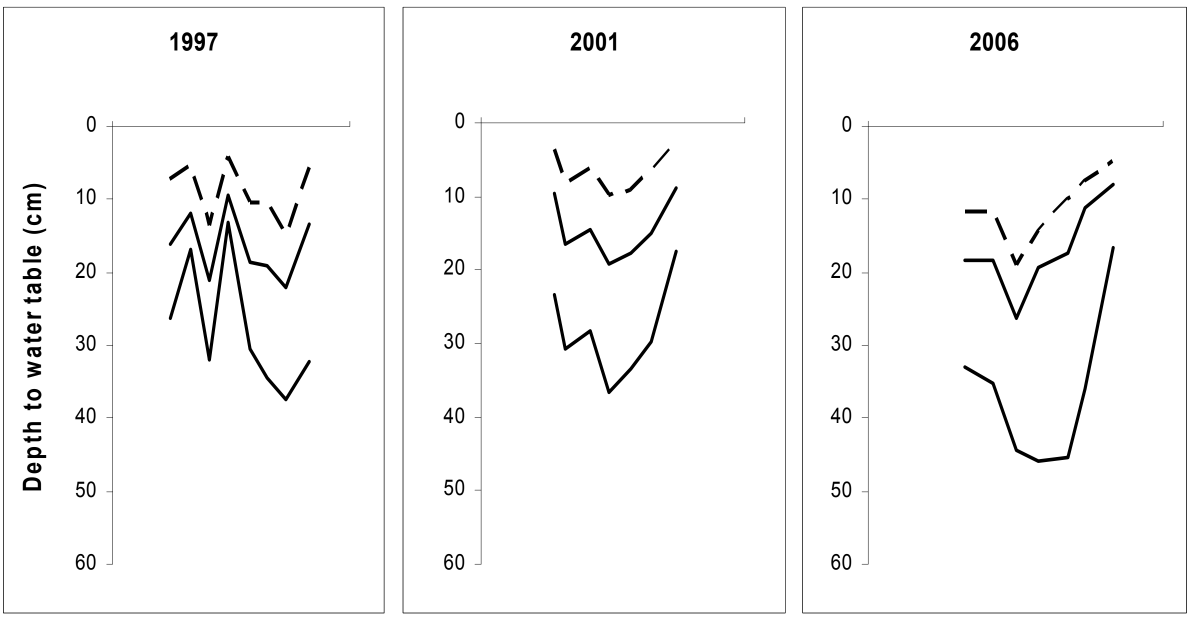
- 
- *Biogeographical context (this applied to the argument that a fragment of afforested bog in a part of Wales without much bog has significant merit as a restoration candidate*

## *4.4 Potential hydrological impact of restoring afforested peatlands sites*

Hydrological monitoring combined with the recording of *Sphagnum* cover can provided an accurate picture of the condition of the peat body since both are direct measures of peatland processes. Water quality parameters such as POC and DOC in the peat water and in run-off provide a good indication of the rate of erosion and activity of decomposition processes. The relationships between rainfall, discharge and water quality are important but the presence of colour cannot be used on its own to suggest a degrading peat body. Peat bodies and in particular the growth of peat is dynamic with seasons and years where the net accumulation of peat is zero. Provided the *Sphagnum* cover and the acrotelm layer remain largely intact in the medium to long-term the peat body has better potential to act as a carbon sink (Lunt et al, 2010).

### 4.4.1 Hydrological impacts

Blocking moorland grips to restore blanket bog in Wales caused a very gradual recovery in level and stability of the water table (Wilson *et al.*, 2010). At a Forest Research blanket bog restoration experiment in Caithness, the water table rose rapidly in response to restoration treatments but not to the level found in pristine bog (Figure 15, Anderson, 2010). Over the ensuing ten years it rose further (Figure 15), suggesting



that it may eventually reach the level found in pristine bog.

**Figure 15** Water levels in Caithness blanket bog one, five and ten years after restoration (middle line). Levels are also shown for an unrestored forested bog (bottom line) and for a pristine bog (top line) at the same site. (Anderson *et al*., In prep).

Water levels also rose dramatically in all treatments at a lowland raised bog restoration experiment near Stirling, Scotland following tree removal and drain blocking (Anderson, 2010).

Anderson (2001) summarised the effect of damming plough furrows on an afforested blanket bog in Caithness, suggesting that the combination of felling trees and damming plough furrows was more successful at raising the water table than either of those actions alone. In a dry summer, the water table on the section with tree-felling and damming was 31cm below ground surface, compared to 47cm depth on the unchanged (control) area.

Runoff from a peatland will depend on the physical property of the peat, e.g. plant type derivation (sedge, cotton grass or moss), compaction, decomposition status and the presence of macropores (e.g. pipes) and entrapped gas bubbles in addition to the level of the water table. For example ditch blocking reduced water runoff in the blanket bog restoration sites in Wales described by Wilson *et al.*, 2010. Unsaturated *Sphagnum* is able to adsorb a large volume of water, ensuring much slower run-off than other types of vegetation. For example, Holden et al (2008) investigated the velocity of flow over bare peat and different type of vegetation on slopes with blanket peat 2m deep in the Upper Wharfe catchment. *Sphagnum* cover showed significantly greater hydraulic roughness with the increased friction slowing flow velocity twice compared to flow over *Eriophorum* and three times over bear peat. The volume of water will depend on the water table depth and thus conditions of the peat; the lower the water table the greater the storage. Slower run-off will only be ensured during drier periods until rainfall rewets the sphagnum (Tom Nisbet, personal Communication). However, once saturated, it can be expected to readily generate saturation excess overland flow following rainfall, resulting in rapid run-off (Peter Jones, personal communication).

Blocking grips has led to less flashy peak flows and a longer water retention time (Wilson *et al.*, 2010). The greatest effect is expected to result from blocking grips with large upslope "catchments" (contributing area). The use of GIS calculated topographical indices such as slope, % peat bare area, % vegetated area and type of vegetation (S*phagnum* versus heathland common vegetation – air photo ID) can assist in deciding where restoration work may be most effective at slowing water flows. Ditches running up and down slope will produce more rapid flow velocities and are likely to lead to increased peat erosion compared to ditches excavated along the contours, but little direct effect has been found in the literature.

The effect of drain blocking on peak flows in other studies (e.g. SCAMP study, FD2114 and EA update report, Robinson et al, 1998) is less clear than indicated. Few, if any studies, have shown a significant effect on flood flows (>mean annual flood). However low mires could provide increased flood storage. The scale of restoration work is obviously very important, as different impacts can be observed at different scales.

There is also a need to consider the impact on low flows, with ditch blocking possibly having a negative effect on these if we extrapolate the results of drainage studies, such as at Coalburn (Robinson et al, 1998).

Slope is a key controlling factor and as such merits a strong weighting when considering the likelihood of restoration being successful. Blocking drains and/or plough furrows to rewet a site is less effective on sloping ground compared with flat ground. Rewetting the site is key to restoring many of the desirable functions of peatlands, including carbon sequestration through peat accumulation.

### 4.4.2 Water Quality impacts

Water quality in peatlands depends on the way water moves and how it interacts with the peat itself. Influencing factors include the underlying geology, the number and nature of water sources and the chemical composition from the atmosphere as well as the characteristics of the vegetation and the peat itself (permeability, presence of pipes etc.) (Labadz et al, 2010).

Peatlands degraded by drainage, erosion and disturbance can release higher concentrations of dissolved organic material into rivers and drinking water reservoirs. Water colour levels are rising with DOC levels in UK upland waters almost doubled since the late 1980's (Monteith et al, 2007). Clark et al, 2007 stated that peatlands are the greatest sources of DOC to natural waters and that most of it is transported during storm events. The underlying factors for DOC increase are still uncertain but climate change and recovery from acid deposition are likely to have highest influence. In England and Wales, water utility companies faced with millions of pounds of water treatment costs have chosen to pay for peatland habitat restoration as a long term cost saving exercise, with estimated benefits in some catchments of up to £2.5million.

Blocking grips reduced water colour and the yield of both DOC and POC over the first year following restoration, although DOC concentration increased slightly (Wilson *et al*., 2011).

However, at a lowland raised bog restoration experiment near Stirling, Scotland where trees were removed and drains blocked, nutrient release to waters decreased as P and N were better retained. The advanced felling and restoration of wide buffer areas may help to reduce nutrient run-off associated with the wider felling of a restoration site. For example, vegetated riparian buffer zones had lower P concentrations after felling compared to sites with no buffer zone (Anderson, 2010).

Vegetation cover can also impact on water quality. For example, greater heather cover can lead to enhanced dissolved organic carbon levels in waters in comparison to *Sphagnum*-dominated blanket bog vegetation (Holden et al, 2010).

Removal of conifer plantations from peatland continues to be a priority, particularly in Wales, Northumbria, Cumbria and Scotland (O'Brian et al, 2007; Natural England 2010). Restoration following tree removal has been possible where hydrological dynamics have been returned to the pre-planting state (McAllister 2009; Smith et al, 1995). However, in many situations humification and compaction of surface peat layers through tree growth has resulted in changes in hydrological function, increasing the risk of invasion by undesirable plant species after clearance (Rydin and Jeglum 2008; O'Brian et al., 2007; Lindsay 2010). Nevertheless, it might be sufficient to get the hydrology to a point *closer* to the pre-planting state than afforested state rather that to the *actual* pre-planting state.

Afforestated peat restoration will not always have beneficial effects on hydrology and water quality. For example, the clearfelling that precedes restoration can generate problems (e.g. nutrients, acidification and sediments), especially if the scale of work exceeds 'safe' thresholds (which has often been the case in the past; overlooking short-term adverse effects for longer-term gain) (Tom Nisbet, personal communication).

The most important consideration in the restoration of a degraded peat bog is the development of some form of acrotelm, which, by its capacity for hydrological self-regulation, will be able to stabilize and maintain a high water level (Smolders *et al* 2002; Lindsay 2010). However, acrotelms are only self-regulating up to a point and lack of drainage is critical. These conditions are required to support the growth of a *Sphagnum* rich surface layer. Degraded to a state with a semi-natural vegetation cover which although not necessarily actively forming peat is still protective of the underlying peat would be a legitimate outcome for many sites. Where the principle objective is the sequestration of carbon then annual recording of the percentage cover of indicator *Sphagnum* species (*S. magellanicum, S. capillifolium* and *S. papillosum*) in the surface layer should be the main form of monitoring and a key attribute for judging success. Other indicators could also be important such as a high and stable water table regime and presence of the three main stated floristic elements. *Sphagnum magellanicum* may not be a very good indicator because of its scarcity.

*Based on the literature findings and team expert judgement the following* ***Criteria for gauging the likelihood of success in restoring peat hydrology and a functioning acrotelm*** *are proposed:*

- *Buffer zones (>1% of the catchment), where restoration is possible for nutrient capture*
- *Availability of vegetated riparian buffer zones*
- *need for buffer areas on adjacent land to limit boundary effects*
- *Tree age, canopy closure and rotation*
- *Peatland type (Lowland or upland raised or blanket bog or fens)*
- *Degree of site disturbance through drainage and management*

- *Slope*
- *% area of bare peat and % vegetated area within the restoration site*
- *Vegetation composition*
- *Location of the afforested block in the catchment in respect to the headwater streams (see Defra ecosystem services of peat report (SP0572, section 4.2.2.4)*
- *Depth of peat and topography (flat)*

## *4.5 Potential for afforested restoration for GHG benefit.*

### 4.5.1 Peat soil C stocks

The estimation of the organic carbon contained in peat soils is difficult primarily because the depth varies very widely, and many surveys only assess soil characteristics in the range 0-80 cm. Clearly, if the soil has a deep peat layer extending below the survey limit, then the soil organic carbon content (SOC) will be substantially underestimated. Soils with deep layers of peat can extend to several metres (Smith et al., 2007; 2009). A second serious problem is the accurate determination of the bulk density rather than estimates, and how bulk density varies with depth and spatially.

Soil carbon stocks in peat soils under forestry were measured in the recent BioSoil survey of 167 forested plots across GB (Morison et al, 2010; Vanguelova et al, 2012). The BioSoil survey assessed soil profiles down to 80 cm in 5 depths, and calculated C stocks from measurements of soil C% and bulk density. The measurements from the five soil depths were used to extrapolate to 100 cm depth. Total organic carbon stock down to 100 cm soil depth of *shallow peat soils* (e.g. peaty gleys and podzols) was 350 ±40 s.e. t C $ha^{-1}$, while the stock in *deep peat soils* was 510 ± 55 s.e. t C $ha^{-1}$. Carbon stocks of deep peats are up-scaled using the updated afforested area on deep peats in Wales (FC plus WGWE woodland), which totals 13.5 Mt C with variations between 12 and 14.9 MtC. Uncertainties in total carbon estimations in peat soils due to up-scaling and the precision of soil mapping were calculated, based on the Gwydyr case study described in section 3.1.3.2 and Table 5. Results show that the 12% difference in area mapped by FC and the national mapping could result in a difference in total peat C stocks at Gwydyr site of 50 kt C (351 kt C based on FC compared to 400 kt C based on national mapping).

### 4.5.2 The GHG balance of peatlands

Restoration of previously afforested peatland involves a number of activities and disturbances, such as clear felling, drainage blocking and rewetting of the substrate, all of which will have a strong effect on the hydrology, soil temperature, vegetation composition and productivity and evapotranspiration of the system. Interactions between these variables may affect the magnitude of $CO_2$, methane ($CH_4$) and nitrous oxide ($N_2O$) fluxes differently so it is difficult to predict whether the net effect on the

GHG balance will be positive or negative (Yamulki et al. in preparation). For example, preliminary indications of DEFRA's SP1202 research on grip blocking techniques and GHG emissions suggest that infilling ditches by re-profiling may increase $CH_4$ emissions compared with damming the ditches (Dr Sophie Green, pers. comm.).

Peatlands supporting bog habitat in a favourable, sphagnum-rich state, or with rich bog vegetation communities, can deliver annual net greenhouse gas benefits through C sequestration of up to 0.5 – 0.7 t C $ha^{-1}$ $y^{-1}$ (RSPB, Scotland, 2009). Restoring (eroded or planted) peat bogs has the additional benefit of reducing losses of between 0.8 and 8 t C $ha^{-1}$ $y^{-1}$ depending on how badly damaged the sites are (carbon losses from bogs damaged by commercial peat extraction and conversion to agriculture are at the high end of the range). However, against that benefit, must be set the loss of carbon in the trees removed (the net effects depending on the end use of the material), and the loss of potential future $CO_2$ uptake by the trees. Clearly, richer peat soils support higher tree growth and $CO_2$ uptake, which may result in more positive GHG balances.

There have been a number of recent reports examining the available evidence on the C and GHG balance of peatlands in the UK. However, these reports have been constructed with different aims. For example, either focusing on vegetation interaction (Lindsay, 2010), survey of the actual available data on GHG fluxes based on soil type under different land use managements (Morison et al. 2010; 2012), and/or focusing on generating emission factors for managed or restored peatland (JNCC, 2010) that could be used to estimate GHG emissions from peatlands. For this study, we report results from the two most relevant reviews above that could be used to give an indication of the magnitude of soil GHG fluxes from peatlands in the UK under a range of management.

Results have recently been reviewed from more than 60 papers published between 1987 and 2010 where measurements of the flux of $CO_2$, $CH_4$ and $N_2O$ gases from forest soils (mainly in the temperate region) were made for at least a one year period (Morison et al. 2010, 2012). They can therefore be regarded as reliable estimates of GHG fluxes. Values were reported for UK forest soils from standing forests on mineral, organo-mineral and deep peat sites and from clearfelled and unafforested deep peat and other vegetation sites. Table 10 summarises the data on soil GHG emissions from UK standing forests, clearfelled and other peatland vegetations averaged for organo-mineral and deep peat sites.

**Table 10** Summary of soil greenhouse gas emission rates (t CO2e $ha^{-1}$ $y^{-1}$) measured in UK forests and peatlands sites. Values are ranges with mean; negative values indicates uptake (Morison et al., 2010, 2012).

| Peatland type | $CO_2$ | $CH_4$ | $N_2O$ | GWP* |
|---|---|---|---|---|
| Standing forest (organo-mineral soil) | 18.5<br>7.8-25.5 | 0.21<br>0.01-0.44 | 0.56<br>0.06-1.4 | 19.3 |
| Standing forest (deep peat) | 8.9<br>3.7-16.6 | 0.1<br>0.04-0.16 | 0.18<br>0.11-0.22 | 9.2 |
| Clearfelled (Organo-mineral) | 22.6<br>18.2-26 | 0.27<br>0.17-0.45 | 0.48<br>0.21-0.64 | 23.4 |
| Clearfelled (deep peat) | 5.5 | | | |
| Unafforested, other vegetation (organo-mineral) | 44.5<br>33.1-55.8 | 0.05<br>0.03-0.07 | 0.21<br>0.09-0.55 | 44.7 |
| Unafforested, other vegetation (peatland) | 22.7<br>21-25.4 | 0.02<br>0.01-0.05 | 0.06<br>-0.03-0.25 | 22.8 |

* Global Warming Potential, defined as the contribution to cumulative warming over time, usually 100 years, for a particular GHG, relative to $CO_2$. According to the IPCC (2007) the 'global warming potential', GWP, of the 3 GHGs considered here is equal to 1, 25 and 298 for $CO_2$, $CH_4$ and $N_2O$ respectively. Therefore, the GWP was calculated by multiplying the flux of each gas by its global warming potential (GWP) and summing.

It is clear from this table that the GWP associated with forest management increases in the order; standing forest < clearfelled < unafforested other vegetation. However, it is important to notice that these estimates of total GHG balance are based on soil effluxes only. At the net stand-scale $CO_2$ emissions will be offset by the photosynthetic uptake by trees and other vegetation, so that the contribution of non-$CO_2$ gases to the net GWP will be significantly larger.

The results in Table 10 agree, in general, with the GHG emission magnitudes for European undisturbed ombrotrophic bog and minerotrophic fen peatland management types reviewed by Byrne et al. (2004). The study concluded that when emission rates are summed as $CO_2$ equivalents per hectare, these types of peatland are generally sources of GHGs with emission intensities increasing in order:

- bog: forestry < mire < restoration < new drainage for forest/peat cut < peat cut < abandoned after harvest = grass < crop;
- fen: (restoration <) forestry <= mire < new drainage for forest < grass < crop.

The JNCC report (2010) used the GHG emission factors compiled by Natural England (2010) to generate a flux-weighted assessment of UK peat emissions, corrected for the area of bare soil and then applied to the UK to give estimates of GHG fluxes from UK peats (Table 11).

**Table 11** Emissions factors ($tCO_2eq\ ha^{-1}\ yr^{-1}$) used by Natural England to estimate greenhouse gas flux from England's peatlands under a range of management states. No factors were available for peatlands supporting woodland, scrub, semi-natural vegetation, purple moor-grass or with old peat cuttings.

| | Blanket Bog/ Raised Bog | Fen Peatlands/ deep | Fen Peatlands/ wasted |
|---|---|---|---|
| Cultivated & temporary grass | 22.42[a] | 26.17[b] | 4.85[c] |
| Improved grassland | 8.68[d] | 20.58[e] | |
| Extracted | 4.87[f] | 1.57[f] | |
| Rotationally burnt | 2.56[g] | | |
| Afforested | 2.49[a] | 2.49[a] | |
| Restored | 2.78[d] | 4.2[a] | |
| Bare peat | 6.00[g] | | |
| Gripped | -0.2[g] | | |
| Hagged and Gullied | -0.2[g] | | |
| Overgrazed | 0.1[g] | | |
| Undamaged | -4.11[g] | 4.2[a] | |

a Based on data from Couwenberg *et al* (2008).
b $CO_2$ and $CH_4$ factors from Couwenberg *et al* (2008), $N_2O$ from IPCC tier 1.
c $CO_2$ from Bradley (1997), $N_2O$ from IPCC tier 1.
d Emissions factors from Byrne *et al* (2004).
e $CO_2$ and $CH_4$ factors from Couwenberg *et al* (2008), $N_2O$ from Byrne *et al* (2004)
f IPCC tier 1 emissions factor
g Based on simplified version of Durham Carbon Model (Worrall *et al* 2009b)

Not all restored peatlands may be carbon sinks but the reviews above suggest that they are likely to have a smaller global warming potential than damaged peatlands. For example, for near-natural peatland GWP = -58 t $CO_2e\ km^{-2}\ yr^{-1}$, compared to -286 t $CO_2e\ km^{-2}\ yr^{-1}$ in damaged bogs (gripped, drained), compared with -256 t $CO_2e\ km^{-2}\ yr^{-1}$ in rewetted peatbogs (1-10 years) (Bain et al, 2011). These sort of analyses suggest that restoration is therefore likely to assist in net GHG emissions abatement as damaged bog is losing more carbon than rewetted bog. However, a very recent systematic review (Bussell et al. 2011) of the effect of re-wetting peatland on GHG emissions concludes that the current evidence is not sufficient to reliably estimate the combined effect of increased $CH_4$ and potentially decreased $N_2O$ and $CO_2$ emissions. Bussell et al. (2011) urge that we "should be cautious in assuming that re-wetting peatlands has a net benefit for short-to medium-term climate change mitigation". In addition, that review did not consider the C balance of the trees in afforested bogs, so only examined part of the restoration question.

The importance of considering the carbon balance of the trees when analysing restoration effects is shown by work in the LIFE Peatlands Project (2005), in Sutherland and Caithness. Felling took place at 22 sites ranging in size from 3 to 435 hectares, with a 15-20 year-old Lodgepole Pine/Sitka spruce mix on deep peat. For tree disposal 'fell into the furrow' was adopted as the most cost-effective method. Colls (2006) calculated the time that it would take the restored peatland to accumulate the same amount of carbon that it would be lost during decomposition of felled Sitka spruce (SS) and Lodgepole pine (LP) (Table 12). It would take the restored bog between 15-73 years to sequester carbon equivalent to that held in the more productive Sitka spruce trees.

**Table 12** Estimates of the time it would take a restored peatland, sequestering carbon at 0.1 tC $ha^{-1}a^{-1}$ and 0.5 $tCha^{-1}yr^{-1}$, to accumulate the same amount of carbon that would be lost via decomposition of the felled Sitka spruce and Lodgepole pine crop (A. Colls: PhD Thesis, 2006).

| | | | | Time (years) to sequester equivalent carbon in restored bog | |
|---|---|---|---|---|---|
| SS: Sitka spruce<br>LP: Lodgepole pine | Average tC $ha^{-1}$ (year 1) | Average tC $ha^{-1}$ (year 50) | % C loss after 50 years | If C sink is 0.1tC $ha^{-1}a^{-1}$ | If C sink is 0.5tC $ha^{-1}a^{-1}$ |
| SS trees decay on surface | 7.5 | 0.2 | 96.9 | 73 | 15 |
| SS trees decay in acrotelm | 7.5 | 1.6 | 78.1 | 59 | 12 |
| SS trees decay in catotelm/under water | 7.5 | 7.5 | 0.2 | <1 | <1 |
| | | | | | |
| LP trees decay on surface | 4.9 | 0.2 | 96.6 | 47 | 9 |
| LP trees decay in acrotelm | 4.9 | 1.1 | 78.1 | 38 | 8 |
| LP trees decay in catotelm/under water | 4.9 | 4.9 | 0.2 | <1 | <1 |

## 4.5.3 Forest carbon

The carbon stocks and dynamics of tree stands and debris are dependent on the tree species, yield class, management regime and the end use of timber. Two species are used as examples for this project, Sitka spruce, as the main species of afforested peatland in Wales and birch, as the species most naturally regenerated on deep peats and also after restoration of coniferous stands.

Methods to evaluate above-ground forest carbon stocks and long term values for a range of species, spacing and management are presented in the Woodland Carbon Code (Forestry Commission, 2011. West and Matthews, 2011, Randle and Jenkins, 2011). Modelled C stocks and dynamics from the FR CSORT model show that the standing (living biomass, including roots) of Sitka spruce, Yield Class 10 (expected yield class of SS on deep peat soils), 1.7m spacing, managed on a 'standard' management regime, clear felled at age 62 rises to about 100 t C $ha^{-1}$. The debris of such stands tend to fluctuate less, at around 10 t C $ha^{-1}$, but rising significantly after a clear-fell (Figure 16). However, estimating the wider C balance needs to consider what happens as it moves out of the forest into a finished product. As a product – e.g. work-top, timber joist etc. – an emissions cost associated with manufacture is required, but also the products' life-span (longevity) needs to be accounted for. The preference for what materials are harvested and what end use, will depend on the local context and wider policy environment, such as measures promoting wood-fuel, or the lack of processing plants/appropriate timber mills near-by. In the model it is assumed that if material is used for fuel, material is a blend of species, and as such the 'calorific value' remains constant despite species. Although fixed at present, the model allows this to be changed if necessary. A further issue arises in carbon accounting in terms of 'additionality': a timber joist locks up carbon, but would probably have been made anyway, however if the timber replaces something (for example a steel beam) then the additional substitution benefit can be considered. Further examples are that if wood is burned instead of coal, then less coal is needed, however the demand for the output of the system (energy, either from coal or wood) has not changed. If cladding is used instead of bricks, then one doesn't need to make the bricks. If the product or demand would exist anyway, then it doesn't necessarily have the additionality to improve the GHG balance. However, material removed from the forest needs to be (at least partially accounted for) as total extracted C.

If Sitka spruce (yield class 10, 1.7m spacing) is managed on a no-thin regime, but still clear-felled at age 62, it will reach standing C of around 160 t C $ha^{-1}$ before a clear-fell and its debris pool fluctuates less, except at time of clear-fell (Figure 17). If the stands were to remain un-felled, then litter would be expected to follow a more regular pattern, levelling at around 6 t C $ha^{-1}$ (Figure 18). This does not include any additional debris incurred from re-generation and understorey mortality. The rate of decay of debris into organic material and the associated release of GHGs during the process is modelled in a generalised way. Table 13 describes the basic assumptions of the decay characteristics.

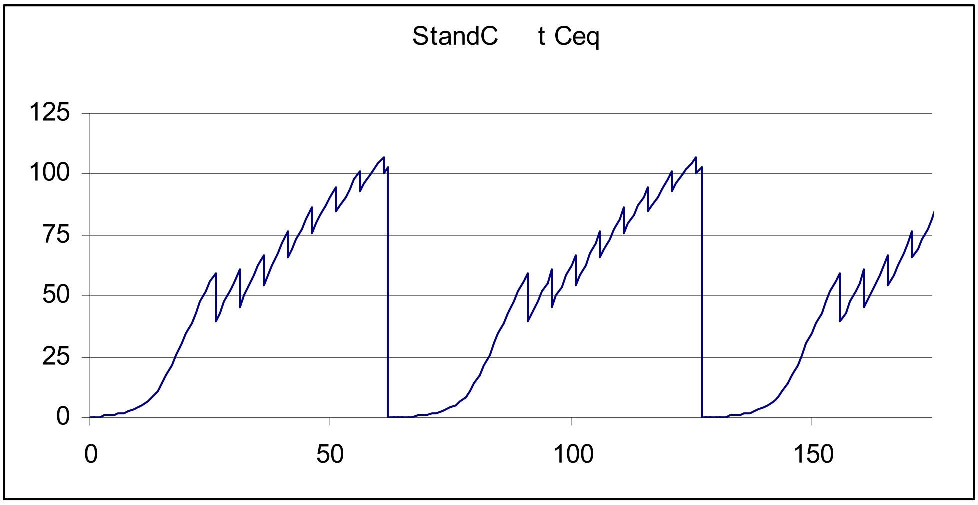
**Table 13** Decay functions of in-forest debris and residue pools. Residence is the period required to elapse before any decay commences. The 'decay period' in these linear functions is the time after residence which is required for the complete decomposition. Coarse-wood, decays and enters the Fine-wood pool. On decay, Fine-wood enters the non-wood pool.

| Debris Type | Function shape | Residence (years) | Decay period (years) |
|---|---|---|---|
| Coarse-wood | Linear | 2 | 20 |
| Fine-wood | Linear | 1 | 10 |
| Non-wood | Linear | 0 | 1 |

The uncertainty and variability in decay is substantial, and key issues relating to this are:

- Decomposition is likely to be site-specific and highly correlated with local climatic conditions and its ability to facilitate animal, fungal and microbial activity; it is likely that decomposition rates may be slower in bog sites as aerobic activity will be constrained.

- No account is taken of emissions from such activities (i.e. the actual release from the activity, only the $CO_2$ lost directly from the decaying material.
- Emissions of other GHGs (e.g. methane) during decomposition are not considered.



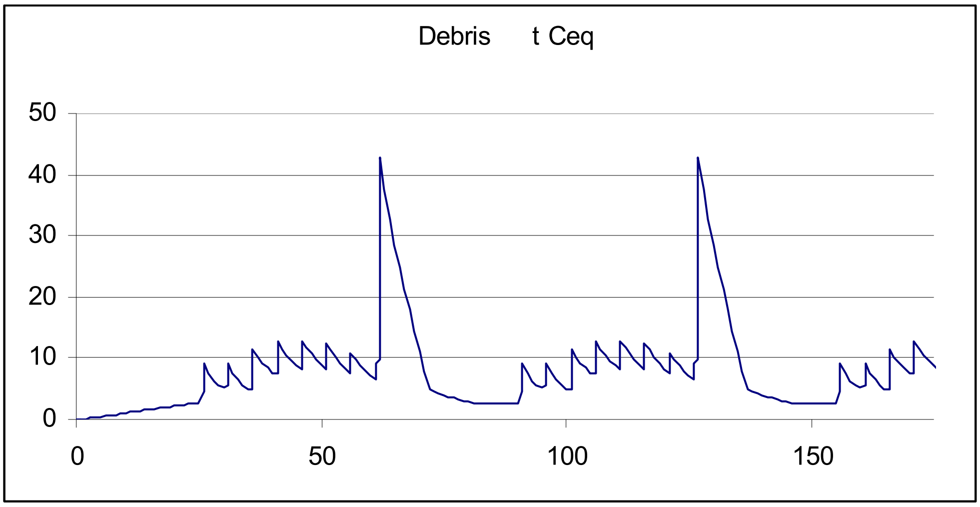




**Figure 16** Scenario 1: stand (top) and debris (bottom) carbon dynamics of Sitka spruce, Yield class 10, 1.7m spacing. Managed on a 'standard' regime, clear felled at age 62.

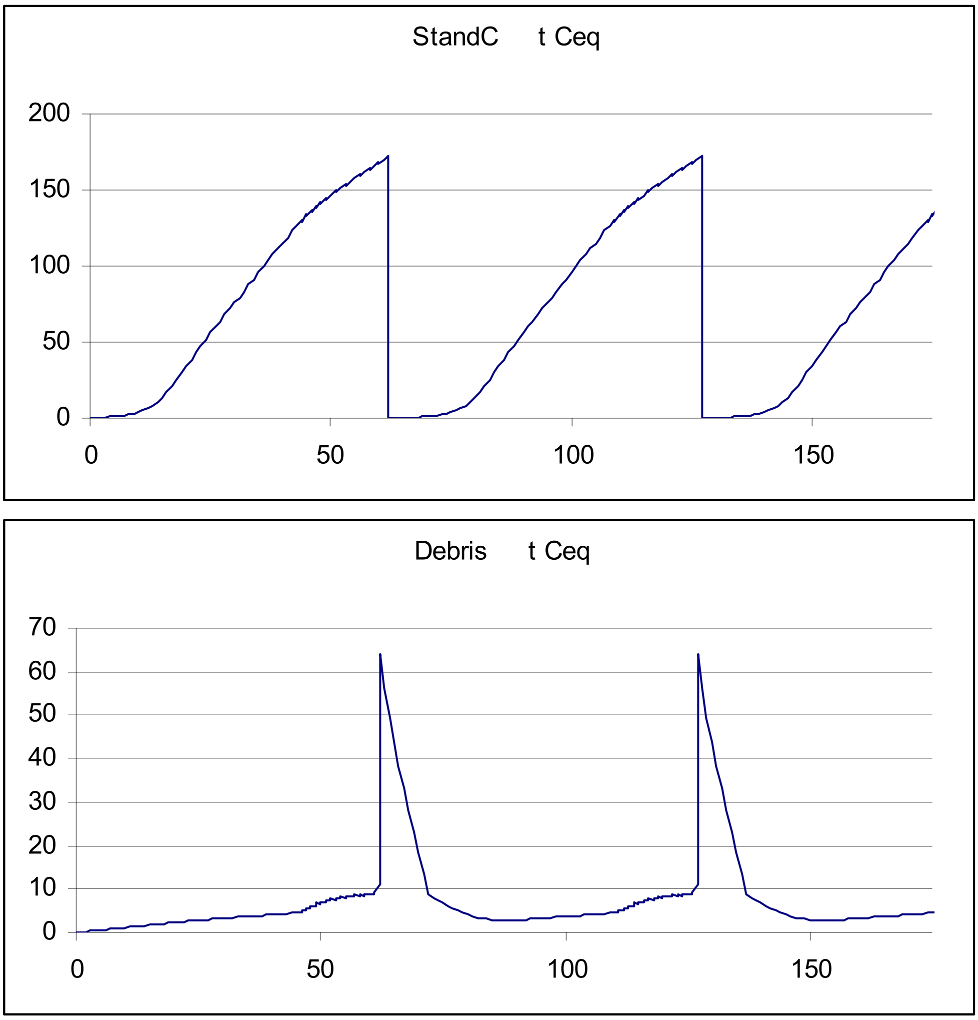



**Figure 17** Scenario 2: stand (top) and debris (bottom) carbon dynamics of Sitka spruce, yield class 10; 1.7m spacing. Managed on a 'no-thin' regime, clear-felled at age 62.

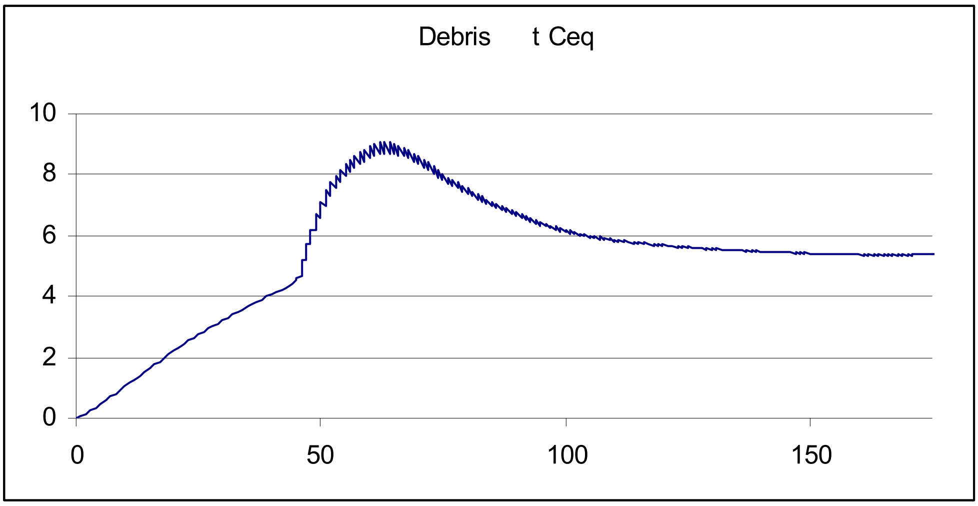


**Figure 18** Debris carbon dynamics of unfelled Sitka spruce stand, yield class 10, 1.7 m spacing. Managed on a 'no-thin' regime.

In comparison to the Sitka spruce, the standing crop of birch managed under regular thinning gives a smaller biomass per ha (up to 80 t C $ha^{-1}$), despite being more densely planted (spacing at 1.5m) (Figure 19). An unthinned Birch stand C stock rises to about 150 t $ha^{-1}$ which is much closer to an unthinned Sitka spruce stand (Figure 20) and debris levelling at 6 t C $ha^{-1}$ (Figure 21).

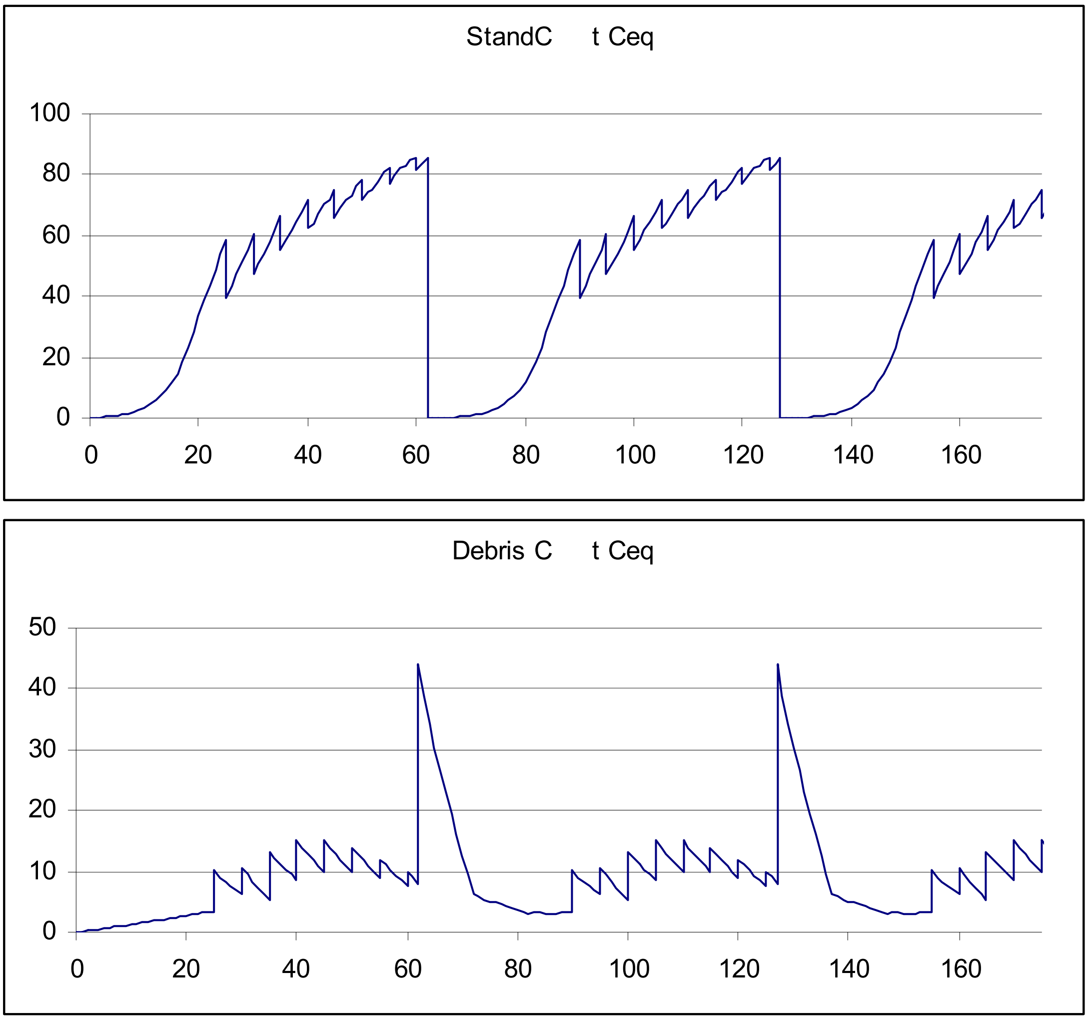



**Figure 19** Stand (top) and debris (bottom) carbon dynamics of Birch, Yield class 4, 1.5m spacing. Managed under 'regular' thinning, felled at age 62.

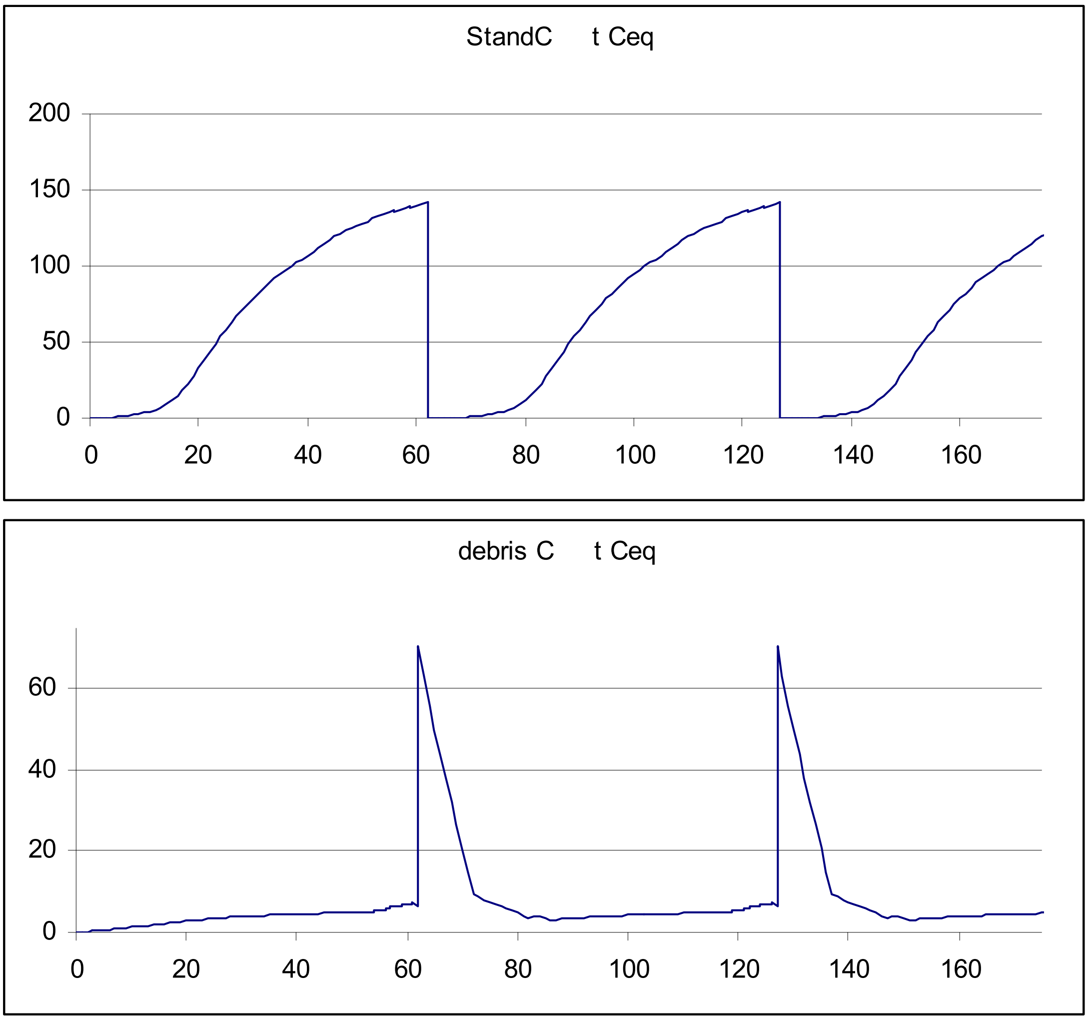



**Figure 20** Stand (top) and debris (bottom) carbon dynamics of Birch, Yield class 4, 1.5m spacing. Managed on a 'no-thin' regime, felled at age 62.

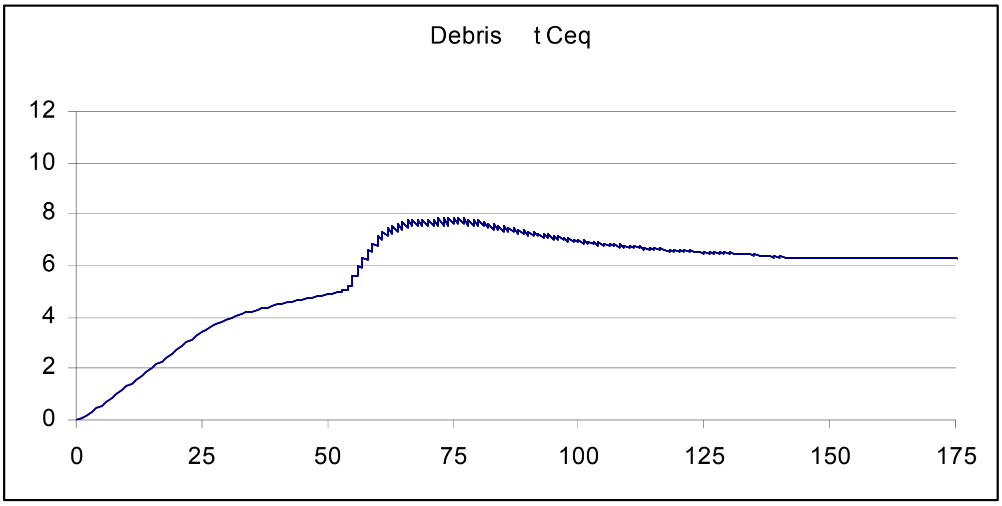



**Figure 21** Debris carbon dynamics of unfelled Birch stand, Yield class 4, 1.5m spacing. Unthinned until time of clear-fell.

## 4.5.4 Substitution using harvested wood products

Carbon in material removed from the forest doesn't just disappear; it develops a life-cycle of its own, before ultimately re-entering the atmosphere. In practice the carbon is 'locked up' for the life-span of the wood product. Beyond this if the product is re-cycled, further accounting may be needed. However, we consider only the first primary use, but allow for off-cuts etc to be utilised in a different way from the main product. Apart from carbon lock-up, it is possible to increase the effect of the stored-carbon by replacing an alternative product. As discussed above, there is a difference between additionally and substitution. We consider the following two categories of substitution.

### 4.5.4.1 Fuel

We largely consider that smaller material and offcuts are used as fuel; two pathways are possible, and we allow, 80% of material for small-scale heat, and 20% for co-firing electricity generation. We do not consider emissions from processing and transportation.

- As a direct fuel, for example as small-scale heat. In considering the material in this category, we allow for the non-use of other energy sources in proportion to their use (oil, gas, electricity, coal). Substitution is estimated as 0.43 t C per over dry tonne (odt) of wood.
- As a co-firing product for electricity generation. In electricity generation we need to allow for the make-up of the conventional supply, and the emissions avoided in substituting the material for wood. Szendrodi (2006) provides data which indicate that emissions saved, when co-firing with coal amount to 0.15 t C per odt of wood.

Although the small-scale heat value seems substantially higher, one must also consider the difference in useful use; electricity has a much wider series of potential applications than direct heat alone.

### 4.5.4.2 Medium and High rates of substitution

The end-use material in this category is somewhat varied but based on building construction. Materials substituted include (but are not limited to):

- PVC Doors and frames by composite board and timber
- Concrete screeding by chip-board
- Bricks by cladding timber.

Hence we present a range of values between medium and high, in this we do not consider financial differences in construction methodologies. Depending on the product substituted, sawn timber may 'avoid' between 0.4-1.7 t C per odt wood, compared to particle board, 0.5 t C per odt wood (Morison et al, 2011).

Tables 14 and 15 show the difference between a managed and un-managed stand of Birch and Sitka in simulations using the CSORT model

(Matthews *et. al.* in prep) specifically for this project. In the unmanaged (unthinned) stand, all material remains within the forest. In the case of managed stands, material is extracted in periodic thinnings however, when growth increment begins to reduce (after time of maximum mean annual increment), the volume thinned is reduced, so to leave a reasonable standing crop. The extracted material is then allocated to become either fuel or material. 'Extracted' is the amount of woody material removed from the forest during the interval. 'Fuel avoided' represents the fossil fuels which would need to have been burned to provide similar amounts of energy for heating and electricity generation. Substitution Medium and high give indications of energy saved through increased use of wood-based material, in place of 'current practice' house construction (ECCM, 2006). Note that Assumptions are made as to the priority of use of extracted material, and amount of material (eg brash) removed.

**Table 14** Comparison of $CO_2$ (t $CO_2$e $ha^{-1}$) during growth periods for (a) unmanaged, and (b) Managed, Birch yield class 4, initially planted at 1.2m spacing using the CSORT model. Biomass and debris are the average estimates over the period. Other values are total during the period. Reduced thinning volume means no thinnings are taken in the period 100-150.

(a) Unthinned Birch

| **Age** | **0-5** | **5-25** | **25-50** | **50-100** | **100-150** |
|---|---|---|---|---|---|
| **Live Biomass** | 1.69 | 86.53 | 102.31 | 522.70 | 583.85 |
| **Debris** | 0.62 | 6.89 | 21.40 | 43.05 | 30.42 |

(b) Thinned Birch

| **Age** | **0-5** | **5-25** | **25-50** | **50-100** | **100-150** |
|---|---|---|---|---|---|
| **Live Biomass** | 1.69 | 77.10 | 223.54 | 343.31 | 437.57 |
| **Debris** | 0.62 | 10.16 | 53.66 | 36.84 | 21.22 |
| **Extracted** | 0 | 56.84 | 55.88 | 32.63 | 0 |
| **Fuel avoided** | 0 | 47.99 | 14.12 | 7.94 | 0 |
| **Subs Med** | 0 | 0 | 36.36 | 21.56 | 0 |
| **Subs High** | 0 | 0 | 39.46 | 38.89 | 0 |

**Table 15** Comparison of $CO_2$ (t $CO_2$e $ha^{-1}$) during growth periods for (a) unmanaged, and (b) Managed, Sitka spruce yield class 12, initially planted at 1.7m spacing using the CSORT model. Biomass and debris are the average estimates over the period. Other values are total during the period.

(a)

| **Age** | **0-5** | **5-25** | **25-50** | **50-100** | **100-150** |
|---|---|---|---|---|---|
| **Live Biomass** | 1.27 | 70.84 | 453.51 | 786.42 | 945.18 |
| **Debris** | 0.53 | 4.87 | 31.32 | 59.84 | 30.76 |

(b)

| **Age** | **0-5** | **5-25** | **25-50** | **50-100** | **100-150** |
|---|---|---|---|---|---|
| **Live Biomass** | 1.27 | 73.64 | 272.53 | 487.06 | 561.40 |
| **Debris** | 0.53 | 7.44 | 46.37 | 30.81 | 17.79 |
| **Extracted** | 0 | 56.35 | 134.93 | 131.01 | 57.95 |
| **Fuel avoided** | 0 | 47.59 | 59.56 | 30.15 | 13.27 |

| | | | | | |
|---|---|---|---|---|---|
| **Subs Med** | 0 | 0 | 59.77 | 88.44 | 39.18 |
| **Subs High** | 0 | 0 | 136.03 | 249.83 | 114.06 |

In the case of Sitka, compared to Birch, total yield is clearly much higher, but also the magnitude of difference between the medium and high substitution. The primary reason for this is that Birch would not normally be used in substitution construction; whereas given appropriate quality, Sitka is able to replace a wider variety of building materials.

*Based on the literature findings and team expert judgement the following* ***Criteria for assessment of the afforested peatland restoration for overall GHG benefits*** *are proposed:*

- *Tree species, rotation length and yield class*
- *Plantation or natural forest*
- *Disturbance from drainage and site afforestation practices (depth of drainage, ploughing, fertilisation)*
- *Peat bog depth/volume and nutrient status*
- *N deposition and C/N status of peat*
- *Extent to which pre-impact hydrology can successfully be restored*
- *Likely quality of vegetation (as a proxy for likelihood of restoring active mire) post restoration.*

## *4.6 Afforested restoration management practices including management practices for woodland bog preservation*

Reviewing 56 peat restoration projects in the UK, Holden et al., (2008) reported that drain blocking and vegetation removal are the most common techniques adopted across the UK. Grazing control, scrub clearance, hydrological control and visitor access were seen as important peatland management issues requiring attention too.

There are a number of management practices which could facilitate restoration and help maintain the conditions needed for successful long term restoration of afforested deep peats. Some of these are listed below and more detailed information is available in Anderson (2003).

### 4.6.1 Encouraging a natural lagg at the edge of a bog

The lagg at the edge of a bog is an area of wet ground with a layer of peat perhaps 15-75 cm thick and a much better supply of nutrients than on the bog itself due to the influence of mineral soil water. The most basic requirement for a naturalistic lagg is sufficient open space at the boundary between bog peat and mineral soil. If this ground has been planted with conifers, they will need to be removed before a lagg can develop. The former lagg will usually have been a natural drainage route for water running off the bog and the adjacent mineral soil ground. The drainage will almost invariably have been improved by the digging of ditches. These need to be blocked or, preferably, filled in to allow the lagg to retain water again (Anderson, 2003).

### 4.6.2 Grazing bogs to maintain or increase plant species richness

Besides causing reductions in the productivity of the vegetation and the cover of heather and cottongrass, grazing increases the proportion of ground bare without vascular plants. A lower stocking rate could adversely affect the vegetation during wet years. An upper limit stocking rate of 1 sheep $ha^{-1}$ is suggested for avoiding overgrazing. Brooks and Stoneman (1997) suggest appropriate sheep stocking rates for bogs of <0.25 sheep $ha^{-1}$ for wet bog, 0.25-0.37 sheep $ha^{-1}$ for degraded bog and 1.0-1.5 sheep $ha^{-1}$ for wet heath. It would be best to follow the recommended Glastir rates for the various categories of mire.

### 4.6.3 Grazing to discourage tree establishment on dried bogs

Some degree of tree cover on bogs is now increasingly accepted as part of the natural scene (Chambers, 2001; Wilkinson, 2001). It is also a commonly expressed view that tree growth on Britain's bogs, particularly the blanket mires, has been suppressed by grazing and burning and limited regeneration due to the deforested state of the uplands (Chambers, 2001). The palaeoecological record shows that our omrbrogenous mires have been naturally treeless in recent millennia. Patchy tree cover would be expected on lagg fens and poor fens. Light grazing may be a useful practice where it is desired to continue to suppress trees. Roe deer can suppress tree regeneration but management of forest deer populations usually seeks to limit the population, possibly limiting their efficacy in this role.

### 4.6.4 Mechanical and chemical methods of discouraging tree establishment on dried bogs

On many raised bog nature reserves, scrub, especially regenerating birch, is managed by cutting it and applying glyphosate to the stumps. This generally doesn't work because the scrub regrows from stumps, seedlings or both (Meade, 2001). Scrub encroachment can actually be successfully prevented using herbicides. It is likely to be much easier to tackle scrub before hydrological restoration makes sites wetter. A range of treatments combining mechanical and chemical methods was trialled at Fenns and Whixall Mosses (Daniels, 2001). In general, attempting to deal with tree regeneration or scrub development is only worthwhile on degraded sites that are artificially dry, nutrient enriched or both in certain contexts. The drying or nutrient enrichment need to be reversed. Scrub or tree removal treatments may improve the scene temporarily but would need to be repeated at regular intervals and much expense. Grazing may be a solution but trials are only just beginning (Anderson, 2003).

### 4.6.5 Managing rides, road verges and forest edges in forests on deep peat

Rides and other unplanted areas in forests on former mires act as refuges for many of the mire plant species (Anderson, 1998; Anderson, 2000; Anderson, 2001) and for some of the associated invertebrates, amphibians and reptiles. There will usually be a tendency for these areas to be drier than their-pre-forestry condition due to the edge-effect of the cultivation and drainage of the adjoining compartments. On raised bogs and blanket bogs, however, some rides can remain wet and retain most of the bog species.

If the future management of the forest will aim to conserve part or all of the bog by deforestation and restoration then the refugia are immensely valuable as potential sources of the species which will one day be expected to recolonise the site. Conserving rides as species refugia entails protecting them as far as is possible against drying and nutrient enrichment. Blocking ride-side drains will often be incompatible with continued timber production from the adjoining compartments. Enlarging these areas as part of forest restructuring can allow some drain blocking and help to reduce the hydrological edge effects that tend to dry them (Anderson, 2003).

Red deer presence is often concentrated onto rides and unplanted areas. The stags use pools, flushes and wet hollows to wallow in, churning up the peaty surface and damaging the vegetation. Despite the obvious damage, such disturbance is probably beneficial for the mire ecosystem because it creates bare patches for small and pioneering plant species to regenerate and creates bare ground habitats for specialist invertebrates. Provided the deer population density is low enough for some of these wallows to revegetate, the benefits will outweigh the harm. If all the wallows are in such continuous use as to never revegetate then deer numbers need to be reduced if the rides are to continue to act as mire species refugia. Moderate densities of deer probably also help to suppress shrub and tree regeneration, keeping the vegetation open (Anderson, 2003).

## *4.7 Time scale impact on restoration benefits*

The impact of restoration on hydrology, biodiversity and GHG balance depend on the time spans over which they are assessed. The evidence and expert judgement on the short (2-5 years) and long term (5-20 years) effects on hydrology, biodiversity and GHG balance by a) afforested peatland restoration, b) post/during restoration management and c) management of woodland for bog preservation are summarised in Table 16.

Removing plantation trees from peatlands makes an important contribution to peatland restoration and provides long term carbon benefits. After felling, methane emissions can arise from peatland restoration and the restored bog vegetation could sequester C more slowly than the forest, so that initially, the restoration would be unlikely to deliver net GHG balance benefits. However, the C loss from the peat would be slowed, and successful restoration can outweigh the carbon benefits of tree growth, particularly in the long term (Natural England, 2010). Further research in this area is required but it is clear that peatland restoration has overwhelming long term benefits when considering all the ecosystem services provided by full-functioning peatlands (Table 16).

**Table 16** Short and long term effects of a) afforested peatland restoration, b) post/during restoration management and c) management of woodland for bog preservation on hydrology, biodiversity and GHG balance from literature reviewed for this project.

| **(a) Restoration of Afforested peatland** | **Hydrology (stability, height of water and water quality table)** | | **Biodiversity** | | **GHG benefits (peat stabilization and C sequestration)** | |
|---|---|---|---|---|---|---|
| | Short term (1-5 years) | Long term (5-20 yr) | Short term (1-5 years) | Long term (5-20 yr) | Short term (1-5 years) | Long term (5-20 yr) |
| Removal of woodland | Reduced water uptake (degree dependent on coniferous vs broadleaves), increase in water table depth, higher local peak flows and possibly higher low flows, potential increase in sediment runoff (depending on nature of practice), increase in nutrient (N & P) run-off, potential for reduced shading/higher surface temperatures | Higher and more stable water-table, higher local peak flows and possibly higher low flows, warmer water temperature | Start regaining natural bog vegetation | Regain natural bog vegetation, e.g. Sphagnum, cotton grass Molinia or Carex sp. Restored connectivity between mire units in certain contexts. | Eliminate C gains from forest C sequestration, increase in GHG emissions during felling operations, possible increase in emissions from disturbance | Long term reduction of C gains from wood, but increase C sequestration in plants and below ground peat. Felling can have a significant effect on the GHG balance of afforested peatlands by altering environmental factors, such as temperature, water table level, and root activity, which may lead to increase soil $N_2O$ and $CH_4$ fluxes. |
| Drain blocking/ Water management | Initially – rise in water table depth, reduced peat erosion and sediment runoff, potential reduction in peak flow; potential decrease in colour and [DOC] (unless bog very dry and cracked - likely initial increase). Ultimately - bog reaches field water capacity no delay in peak flow, potential reduction in low flow | Pollutant sink for N and P in the long term, increased water yield, potential reduced low flows | Regain natural bog vegetation, e.g. Sphagnum, cotton grass; re-vegetation of a gully floor | Regain natural bog vegetation, e.g. Sphagnum, cotton grass | Increases in $CH_4$ emission but reduced losses of particulate organic matter and slower respiration rate so less $CO_2$ release | Increase C sequestration by peat forming and its vegetation, peat C protection; peat accumulation in the gully, $CO_2$ sequestration overrides the initial temporary $CH_4$ release. |

| **(b) Post/ during restoration management** | **Hydrology (stability and height of water table)** | | **Biodiversity** | | **GHG benefits (peat stabilization and C sequestration)** | |
|---|---|---|---|---|---|---|
| | Short term (1-5 years) | Long term (5-20 yr) | Short term (1-5 years) | Long term (5-20 yr) | Short term (1-5 years) | Long term (5-20 yr) |
| Introduction of Sphagnum spp. to open pools - no current guidance for this methodology following clear felling, because as far as we are aware it hasn't been tried in this context | | | Hope to get abundant regeneration and spread of the introduced Sphagnum species but may require particular ground conditions | Hope to get a high percentage Sphagnum cover over an extensive area, favouring establishment of associate species | C uptake in vegetation | Possible regain of peat formation. There is evidence that highest $CO_2$ respiration and $CH_4$ emissions could be expected from Eriophorum (spp) with decreasing trend to Sphagna and lowest from forest moss communities and Calluna. vulgaris (e.g. Minkkinen and Laine, 2006; McNamara et al., 2008) |
| Management of tree natural regeneration (pulling / cutting tree seedlings manually) | No impact presuming no mechanical means of tree cutting are used | As across. | Bog vegetation develops in open light conditions | Bog vegetation continues to develop in open conditions and benefits from full incident rainfall | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Grazing for preventing regeneration on dried bogs (very low stocking density-no N addition needed). No evidence of whether this works | Potential bacterial contamination of water, potential compaction of peat resulting in greater erosion | As across. | Hope that stock preferentially browse and kill tree seedlings so that bog vegetation develops in full light conditions. Control of Molinia. | Hope that thickening cover of bog vegetation reduces the tendency for tree seedlings to establish. Control of Molinia | | Grazing may reduce peat formation. May have some impact on increasing $N_2O$ emissions, due to nitrification of the organic N deposited by animals. Magnitude depends on animal type / grazing & stocking density. Effect likely to be small. |
| Controlling foxes and crows to favour ground nesting birds | | | May increase numbers and/or breeding success of breeding ground-nesting birds. | Increased numbers and/or breeding success of ground-nesting birds? | | |
| Removing brash mats after clearing to control birch recolonisation and allow surface recovery | Management of brash mats will affect nutrient release. If removed, could be expected to reduce nutrient losses to water. | | | | | |
| Brash mulching, which has been used in places | Potential for increased nutrient and DOC release leading to risk of higher BOD and deoxygenation in local streams (during periods of lower flow). A risk of ground damage from trafficking, leading to increased compaction, rutting and erosion. | Impacts limited to short-term. | | | | |

| **(c) Management of woodland for bog preservation** | **Hydrology (stability and height of water table)** | | **Biodiversity** | | **GHG benefits (peat stabilization and C sequestration)** | |
|---|---|---|---|---|---|---|
| | Short term (1-5 years) | Long term (5-20 yr) | Short term (1-5 years) | Long term (5-20 yr) | Short term (1-5 years) | Long term (5-20 yr) |
| Open space preservation within existing woodland particularly if peaty soils | Higher water table | | More light, more water, less nutrient input and likelihood for moss development | | Higher water tables provide better peat preservation. However, the higher water table level will increase $CH_4$ emissions, as $CH_4$ production is strictly anaerobic | The expected higher water table level will increase the anaerobic sites in the top soil layer, thus further increases the reduction of $N_2O$ to N2 by denitrification reducing overall $N_2O$ emissions. |
| Reduce tree stocking density | Unlikely to affect evaporation losses unless there was a major thin as increased ventilation will partly compensate for canopy removal. Risk to water quality will depend on management practice; impacts from the perspective of good forestry practice, as per UKFS and guidelines. | | Increase direct rainfall should favour the moss species | Increase direct rainfall should favour the moss species, less trees will reduce litter input so likely to favour the moss development | Increased thinning activity may contribute to soil disturbance and C release. Low tree density, decrease in water interception and higher water input to peats could slow peat oxidation. Less litter input will be beneficial to peat processes. | Effects of thinning on overall soil C may not be detected in short term (Nilsen & Strand, 2008). However, reduced thinning activity may lead to a build-up of soil C due to both reduced soil temperatures and thus reduced soil respiration, and due to increased litter fall. The disappearance of ground vegetation due to high tree densities could reduce this effect (Nilsen & Strand, 2008). |

| | | | | | | |
|---|---|---|---|---|---|---|
| Encouraging a natural lagg at the edge of previous raised bog by cutting conifers and blocking existing ditches plus managing natural woody vegetation (birch and rowan) | Presumably the effects will be as per woodland removal and control of conifer regen but more localised? Peat re-vegetation can stop surface erosion within 3-4 years, minimising sediment and particulate organic carbon removal | | | | Beneficial for C due to encouraging peat formation | |
| Cutting back forest edges to prevent too much shading, discourage tree regeneration and allow rainfall to soil surface. | It will help rewet/raise and stabilise water-table, assuming the bog is receiving/downslope of conifer stand. Impacts on actual cleared area would be as per woodland clearance, although focus would presumable be on the bog itself? | | | | | |
| Change of tree species | Main impact would be where change is from conifer to broadleaved. This could contribute to re-wetting and a higher water-table. | Long term decrease in canopy water interception would favour higher and more stable water-table. | Likelihood of increase in moss species | Increase in moss distribution is likely. | Lower aboveground C due to tree specie change. Different litter quality input to peat, which could increase decomposition in top peat soil. | Lower C locked aboveground, but increase in long term peat C storage |

# 5. Assessment of restoration potential of the Welsh afforested peatlands.

**(Samantha Broadmeadow, Elena Vanguelova, Russell Anderson and Sirwan Yamulki)**

## *5.1 Restoration potential of afforested peatland in Wales*

Based on the appraisal of the available literature, expert judgement and the lessons learnt from the ground truthing sites, *national and field based schemes* of rule-based criteria, factors and thresholds for the assessment of the potential for restoration of an afforested peat site have been developed. These have been tested by ground truthing a number of potential sites in Wales, described in Section 6.

The *national scheme* was applied in an assessment to identify potential sites that were viable for restoration to a functional deep peat habitat in Wales. The *national assessment scheme* (section 5.2) applies GIS and spatial datasets to assess a) current status of the peat; b) hydrological integrity of the site; c) consequence of restoration in terms of greenhouse gas emissions; d) ecological integrity of the site and e) climatic integrity of the site.

Once a site has been identified as potentially restorable by the *national assessment scheme*, a follow up *field assessment scheme* will be required to validate the desk-based national assessment. A *field site assessment scheme* was developed, with a set of rule-based criteria, factors and thresholds based on field observations (section 5.3). The *field assessment scheme* is intended to be used by FC Wales staff (planning or conservation officers) responsible for the strategic planning of an afforested peat site e.g. during the revision of the Forest Design plan or identification of sites for compensatory restoration action within the WGWE Wind Energy Programme.

The criteria, factors and thresholds within both *national and field based schemes* can inform decisions about the most appropriate goals for restoration, and land use and management for sites that are unsuitable for restoration.

Four potential restoration options are considered which are discussed briefly below. The application of the *national assessment scheme* to the peat resource in Wales is described in section 5.2 and the *field based assessment scheme* is illustrated in section 5.3.

### 5.1.1 Option 1: remove crop and restore open mire habitat

*Sites where restoration of an open peatland habitat is feasible and is likely to provide the tangible benefits in terms of carbon, hydrological and biodiversity gain.*

Afforested peatland restoration via the re-creation of an open peat forming mire habitat is feasible if a reasonably deep layer of peat remains on the site (>0.5 m) and the required hydrological conditions (high water table) can be maintained. Where these conditions are satisfied, restoration or recreation of mire habitat should be the preferred option, particularly if the site is adjacent to an existing peatland.

Best potential sites would include:

- young first rotation conifer plantations, prior to canopy closure with a good ground cover of *Sphagnum* (which typically persists under the tree canopy for 15-20 years), adjacent to existing mire, rainfall >1200 mm and N deposition <10 kg N $ha^{-1}y^{-1}$. It is possible to restore the original peatland ecosystem function (habitat, carbon store and sequestration) on sites which met all the above conditions.
- young second rotation stands with an open canopy which have retained a good ground cover of *Sphagnum* following its regrowth after the first stand was clear felled or
- sites with good potential for the restoration of semi-natural bog or fen vegetation conforming to definitions of unmodified mire, or
- sites in contexts where the restoration of any form of semi-natural mire vegetation would be desirable – for example to improve connectivity between peatland units'.

However, these criteria may be setting the bar very high for making judgements on viable restoration sites in Wales, because much of the Welsh uplands is subject to deposition rates of >10 kg N $ha^{-1}y^{-1}$ (Hall et al, 2011) and many welsh mires support only modest and not very oligotrophic *Sphagnum* cover.
The timing of restoration at sites identified as suitable may be driven by local and regional forest policy and timber markets. Traditionally conifer stands are clearfelled some time after they reach maximum annual productivity, typically around 45 – 70 years old depending on local conditions. If stands are felled prematurely there will be a significant potential loss of revenue which may influence the age at which a stand will be considered for restoration. Sites on which peat restoration is considered to be feasible should not be restocked with conifers and may require subsequent management to ensure that the peat resource is secured.

Brash management, during the felling process is a key to protection of poor load bearing peat soils during harvest and the success of subsequent efforts to restore peatland vegetation. Efforts to extract timber and brash to ride-side in a saleable form to local markets e.g. woodfuel may partly off set habitat restoration cost (Webster & Ireland 2003).

### 5.1.2 Option 2: remove crop and convert to native wet woodland cover.

*Sites where it is not viable to re-establish blanket bog and mire where the protection of the existing peat resource would be best achieved through the retention of existing tree cover or the establishment of native upland mixed woodland.*

It will not be possible to restore functional peatland habitat on sites where it is impossible to maintain high water levels. The cost of restoring the hydrology of an eroded bog (code 14, FC soil classification) may be prohibitive but with continuous improving of the techniques in recent years, restoration of eroded sites can actually be less expensive. On sites, which currently retain some peat, the best option to minimise the rate of loss may be the retention of a reduced tree cover, to minimise peat erosion and continue to lock up C above-ground, via the conversion from conifer to native bog or fen woodland.

### 5.1.3 Option 3: remove crop and convert to other open/wetland habitat.

*Sites where it is not viable to re-establish blanket bog and mire, where the protection of the existing soil and peat resource would be best served by creation of another open habitat type such as wet heath or acid marshy grassland.*

On sites where there is little peat remaining and limited scope for peatland restoration or recreation, there is still potential for biodiversity gains. In such cases the creation of wetland habitats that, while not active peatland areas, may still perform an important ecological function (including some of the function of the previous peatland wetland) is worthwhile.

At sites where only a thin peat layer will remain after the stand is felled and a permanently high water table cannot be guaranteed, a more suitable target habitat for restoration is likely to be heathland. On sites where the peat surface has been lowered to bring it under the influence of the groundwater, the best target for restoration may be fen. The target habitat will be dependant on the chemical composition of the groundwater, at sites with a combination with base poor bedrock this may result in a poor fen or acid flush habitat.

Other wetland habitats, including open water and wet grassland, are also important and should not be ruled out as restoration options. These may be viable options in areas where much of the peat is lost but water level control is still possible.

### 5.1.4 Option 4: improve current habitat management to ensure effective restoration of open mire habitat.

*Sites within a woodland plantation with existing open habitat, such as Molinia-dominated bog, that require better management to ensure effective restoration to blanket bog.*

Tree cutting to improve the 'lagg' edge on raised bog and attempting to deal with tree or scrub regeneration is not worthwhile on degraded sites that are artificially dry or nutrient enriched. Unless the site is rewetted and the nutrient enrichment controlled, efforts to keep the bog free of trees will require repeated intervention at regular intervals and incur considerable expense. Grazing by cattle may be an effective solution but would need to be light, so that additional N is not added to the system. Trials are only just beginning to assess these effects (Anderson, 2010).

The type of *Molinia* bog, is very wet and most suited to leaving for rewetting through active management of natural processes and the development of bog woodland with Salix and other pioneer tree species such as birch (Morison et al, 2010). Within the category of eroded deep peats, the likelihood is that the high water table will prevent successful machinery use and require motor-manual felling thus the most sensible choice will be open space management through limited intervention. Mowing and follow up grazing can help convert *Molinia* monocultures to more mixed typical mire vegetation, especially if combined with hydrological repair.

### 5.1.5 Option 5: maintain current crop until planned felling date

*Sites with shallow peat and sites where it is uneconomic to fell standing timber.*

The economic argument is difficult. The particular circumstances of an individual site might justify relatively limited clearfell, even if not ideal from an economic standpoint. Also, felling as part of a windfarm scheme (i.e. as a compensatory element within Habitat Management Plan) does not necessarily have to meet economic criteria. The subsequent management of the site may involve the conversation to native woodland or open habitat, or an alternative low impact silvicultural system.

## *5.2 Application of rule-based criteria in a national assessment of the restoration potential of afforested peatlands in Wales using GIS and national spatial datasets*

### 5.2.1 Rule-based criteria, factors and thresholds

The rule-based criteria, proxy factors and thresholds used for the *national restoration potential scheme* are illustrated in Table 17. The scheme has been devised to make use of nationally available spatial datasets to classify afforested sites using relevant criteria and threshold values derived from the evaluation of the scientific literature collated for this project (Section 3); team expert judgement; experience from existing restoration projects and the lessons learnt from visiting the ground truthing sites (Section 6).

The objectives of the assessment were:

- using the best available spatial data, determine the relative suitability of an afforested site for restoration to an open peatland against five criteria
- to determine which afforested sites in Wales offer the greatest potential for restoration

The five main issues against which each site was assessed were:

1. current status of the peat
2. hydrological integrity of the site
3. greenhouse gas balance consequences of restoration
4. ecological integrity of the site
5. climatic integrity of the site

**Table 17** National issues, criteria, proxy-factors and threshold values/classes for prioritisation, potential and viability for restoration of afforested land in Wales.

| SITE POTENTIAL | **ISSUE** | **$WF_I$** | Criterion | $WF_C$ | Proxy - Factor | Threshold values/classes<br>Most advantageous<br>Score 2 | <br>Advantageous<br>Score 1 | <br>Least advantageous / Neutral / Disadvantageous<br>Score 0 |
|---|---|---|---|---|---|---|---|---|
| SCORE: *x* out of 10. | **CURRENT STATUS OF THE PEAT** | **1** | Proportion of original peat left on site ~ likely depth to water table ~ probability of restoration success | 1 | New Welsh peat map / FC soil survey | Areas of deep peat: New National Peat Map (expect earthy peats) / 8a, 8b, 9b, 9e, 10b & 11b | Earthy peat soils: 1022a & 1024a / 8c, 9a, 9c & 9d | modified deep peat / 14 & 14h |
| | **HYDROLOGICAL INTEGRITY OF THE SITE** | **1** | Can water be retained on site? | 0.5 | Slope | <4% | 4 - 6% | >6% |
| | | | Hydrological impact of drain blocking on adjacent wetlands | 0.25 | Located upstream of existing mire/bog/fen habitat | vulnerable habitat present downstream of the afforested peat - opportunity to significantly improve water supply to the adjacent open peatland | vulnerable habitat present in the catchment - upstream of the afforested peat - limited opportunity to improve water supply to the open peatland | vulnerable habitats not present in the catchment |
| | | | Impact on drainage water quality | 0.25 | Located within catchment of potable water supply | Not used for drinking water | | Within catchment of reservoir |
| | **GHG BALANCE** | **1** | Potential C sequestration in above ground carbon stock | 1 | Species [Canopy type in NFI or SCDB] & YC [SCDB] | Marketable: High YC≥10 | Marginal: YC 8 | Uncommercial: Low YC≤8 plus Broadleaves |
| | | | Non-C GHG emission consequences of peatland | | Sirwan's model [rainfall, temp, N dep and SW DOC] | Non-C GHG no trees; $NO_2$ - low nutrient soil status/low N deposition | | |

| SITE POTENTIAL | **ISSUE** | **$WF_I$** | Criterion | $WF_C$ | Proxy - Factor | Threshold values/classes<br>Most advantageous<br>Score 2 | Advantageous<br>Score 1 | Least advantageous / Neutral / Disadvantageous<br>Score 0 |
|---|---|---|---|---|---|---|---|---|
| | | | restoration | | | | | |
| | **ECOLOGICAL INTEGRITY OF THE SITE** | **1** | Rarity of restored peatland habitat | 0.25 | Current canopy species - NFI_IFT & BAP | conifer plantation | broadleaf | Native wet woodland BAP habitat |
| | | | | 0.25 | Rarity habitat mapping/ soils data + FC soil survey | potential lowland raised bog habitat =sites listed in the LRB inventory + 10a | potential fen peat habitat - fen peat soil associations + 8a | potential blanket bog habitat |
| | | | Potential nature conservation of restored site assuming removal of conifer forest | 0.5 | Functional connectivity to combined dataset of CCW potential wetland habitat networks1 | inside core low-cost conifer bog habitat network | inside focal low-cost conifer bog habitat network | outside bog habitat network |
| | **CLIMATIC INTEGRITY OF THE SITE** | **1** | Current climatic suitability | 0.75 | BBOG-GAM model output for baseline (61-90) data | 0.25 - 1.0 (area covered contains 75% of the mapped blanket peat) | 0.1 - 0.25 (area covered contains 90% of the mapped blanket peat) | 0 - 0.1 (area covered contains 10% of the mapped blanket peat) |
| | | | Modelled future climatic suitability under predicted climate change | 0.25 | Combined model outputs ESM8_LO.2080 (Clarke et al 2010) | 4 - 8 models | 1 - 3 models | none |

$WF_I$ Weighting factor for each ISSUE, used to calculate the combined SITE POTENTIAL score
$WF_C$ Weighting factor for individual Criteria, used to calculate the combined ISSUE score
Score in the top 3rd : Best potential for restoration - highest priority sites
Score in the middle 3rd : Consider restoration in time as part of the normal forest planning process.
Score in the bottom 3rd : Less potential - site may be better suited for continued use as broadleaf or LISS conifer forest

For each issue, one or more criteria were assessed using proxy factors, for which national spatial data was available. The spatial data was classified using threshold values and classes to distinguish between afforested peat sites based on their potential to form a viable peat-forming habitat, following the removal of the existing canopy and the blocking of drains (Table 17).

The purpose of creating rule-based criteria is so they are used to score a site's potential for restoration, so that the sites with good potential to become peat forming habitats have higher scores than those which can merely retain the existing peat. Each spatial dataset was classed into three categories in which a high score (**value of 2**) indicates that restoration of the site would result in beneficial consequences to the remaining peat resource; a reduced score (**value of 1**) indicates that restoration of the site will have little or no affect on the criteria being considered or magnitude of the beneficial consequences is undetermined, and **no score** indicates that there may be detrimental consequences following restoration or the beneficial consequences are likely to be small, unsustainable or short term. It should be noted that although a scenario may score **highly** for one criterion there may be no gain or even negative consequences for one or more of the other ecosystem services included in the assessment. Where suitable spatial data exists for more than one element of a criterion to be considered, each element was classified and then combined using the weighting factors in column $\mathbf{WF_C}$ to calculate a weighted score for each criterion.

At national level, each issue has been assessed and mapped separately (peat condition, hydrology, GHG balance, biodiversity, and climate integrity) (See maps in Appendix 5). The five issues are then combined using the weighting factors in column $\mathbf{WF_I}$ to determine the final score for each site (in this case the maximum possible score is 10). A final map with all the issues combined using equal weighting illustrates which sites offer the greatest overall potential benefits from restoration (Figure 22). The *national scheme* can be modified to identify sites that offer the best opportunities for a specific objective or priority, for example funding may be available for sites that help meet the objectives of the WFD or sites may be needed to be included in a GHG balance project. This can be achieved by either adjusting the values in the $\mathbf{WF_I}$ column, to favour the contribution of an issue to the final score, or restricting the assessment to include only the criteria relevant to the single issue.

A detailed description of the GIS methodology, selection of the criteria used and classification thresholds for each issue assessed in the national scheme is given below.

## 5.2.2 <u>Issue 1:</u> Current status of the peat: how much of the original peat profile is currently retained under the trees?

The current status of the peat was considered using the best available soil information: for land not included in the FC soil survey (a), the factors assessed were new peat map plus the NSRI soil map unit; whereas for land included in the FC survey (b) the factor assessed was the FC soil classification.

a) For land not covered by the FC soil survey [Table 18 (a)], areas mapped as **Deep Peat** in Figure 1 are assigned the higher score except; earthy fen peat soils which are assigned the lower score, and the areas mapped as a 'modified deep peat habitat' in the initial Phase 1 Habitat Survey of Wales, (Figure 3) which, are given no score. The fen peats [NATMAP soil associations: 1022a - fibrous grass-sedge fen peat and 1024a - eutro-amorphous humified peat] have been assigned the reduced score because it is assumed that the high soil fertility would have lead to the land being extensively drained for agricultural use prior to its subsequent afforestation (Holden et al., 2007) although Taylor (1963) states that there is little tradition in Wales for the cultivation of peatland for crops. Within the area identified as afforested peat, the modified peat habitat (E1.7, E1.8, E3.1.2, E3.2.2 & E3.3.2) will be restricted to small open areas within forest landscape. The forest canopy has been mapped mostly as conifer (A1.2.2), so the area classed as 'modified deep peat' will therefore be an open habitat and represent a limited opportunity to improve the peat resource of the site.

b) In the land covered by the FC soil survey [Table 18 (b)] it is possible to make a more informed assessment of the probable success of restoration. This area is assessed using a slightly different set of factors to distinguish between areas with a higher potential to establish peat forming habitat from those that present a greater challenge.

**Table 18** Classification and scoring of factors used for sites prioritisation for afforested peat restoration in terms of the current status of the peat and likely consequences of restoration.

| **Restorable** | **Marginal** | **Neutral** |
|---|---|---|
| Score 2 | Score 1 | Score 0 |
| **(a) land not included in the FC soil survey** | | |
| Areas of deep peat identified in New National Peat Map that are not earthy peats | Earthy fen peat soils 1022a (fibrous grass-sedge fen peat) & 1024a (eutro-amorphous humified peat) | modified deep peat |
| **(b) land included in the FC survey** | | |
| **8a** fen/valley mire<br>**8b** basin bog – very rare | **8c** good soil nutrient status may lead to excessive natural regeneration | **14 & 14h** - difficult to access with machinery; best suited for open space management through limited intervention |
| **9b & 9e** | **9a** very wet difficult to access with machinery for felling and extraction of timber<br>**9c & 9d** typically occur in extensive areas in flat landscape therefore adjacent land use can compromise on-site conditions and reduce restoration success | |
| **10b** raised bogs - very rare | | |
| **11b** | | |

All areas of deep peat should be considered for restoration, however the intrinsic conditions of some peat types will present more problems than others. For example, the high nutrient status of flushed juncus bogs may lead to competition from grasses and conifer regeneration particularly on FC soil type 8c (*Juncus effusus* bogs).

The rapid regrowth of *Calluna vulgaris* on flushed (soil types 9b and 9e) and *Vaccinium myrtillus* on unflushed blanket bogs (soil type 11b) can lead to phosphate limitations requiring the use fertilizer top dressing subsequent to planting. However, where the goal is the restoration of an open bog habitat the competition from these native shrub species may be highly beneficial in reducing the problem of conifer regeneration. Therefore, blanket bog sites with *Calluna* present should be prioritised for open habitat restoration to avoid the detrimental consequences of further enriching the nutrient status of the peat so that the continued loss of Soluble Organic Carbon will eventually be stopped. However, the potential for restoration will depend on the state of the peat and other site factors.

All areas of flat and raised sphagnum bog (soil type 10) sites should be considered for restoration due to the scarcity of this peatland habitat across Wales (Patterson and Anderson, 2000). The oligo-fibrous peat typical of raised bogs and unflushed blanket bogs (soil type 11) is less prone to cracking and formation of gullies and therefore may be easier to rewet (Anderson, 2001).

Native bog woodland is also very rare in Wales and therefore soil type 9a is a high priority for restoration and most suited to leaving to rewet through active management of natural processes and the development of bog woodland with Salix and other pioneer tree species such as birch (Morison et al, 2010).

Traditionally, the drains on very wet and deep peat sites would be reprofiled, several years prior to their planned felling date, to prepare the ground for the heavy machinery and improve the conditions for restocking. On sites where the goal is the restoration of peatland habitats lowering the water table in this way is highly undesirable. This is due to the logistical problems of (a) removing trees from very wet sites (Soil type 9a) and (b) effectively blocking drains on eroding sites (soil type 14 and 14h) so these sites can be expensive to restore. Ideally motor-manual felling and extraction via Skyline cables should be used to avoid disturbance to the peat. Where this is not possible the use of deep brash thatching will be necessary to minimise compaction. The brash mats and other residues should be removed from the site after felling to avoid enriching and acidifying the soil.

On the other hand, the restoration of bare peats and eroded bogs offers some of the greatest gains in terms of increased carbon retention on sites and improvements in GHG balance. Typically in Wales, the erosion at these site is fairly localised and eminently restorable, so on a case by case basis there could be strong arguments for conifer removal and restoration in such situations (Pete Jones, personal communication).

A recent Natural England (2010) report on peatlands concluded that after felling, the restored bog vegetation would sequester C more slowly than the conifer plantation so that initially the restoration would be unlikely to deliver net GHG balance benefits. However, the rate of C loss from the peat would be slowed, and successful restoration would deliver long-term gains in C sequestration (Natural England, 2010).

There may be scope to restore small pockets of deep peat habitat within a more extensive heathland restoration scheme. Wet heath, with *Erica* species, is a highly valued open habitat and if the site is not too wet it may be possible to re-activate the seed bank after the trees are removed with a light scarification of the soil. Similarly, in the lowlands, acid dry heath is also valued. These open habitats can be kept free from regeneration by light grazing (in Northumbria this is 1 sheep per 3 acres). Subsequently, peat forming habitats become established in the wetter areas such as marshy hollows (soil type 9b & 9c) or beside the stream courses (8c & 8b).

### 5.2.3 <u>Issue 2:</u> Hydrology: can the site be successfully rewetted and the potential detrimental consequences of retaining water on the site avoided?

Three main factors of the site were considered: a) the slope, b) the hydrological impacts of drain blocking within the stand on adjacent wetlands and c) the potential impact of rewetting the site on drainage water used as a potable water supply (Table 19), which provided the basis for developing three hydrological layers for the GIS assessment.

**Table 19** Classification and scoring of factors used for sites prioritisation for afforested peat restoration in terms of the hydrological integrity of the site and likely consequences of restoration.

| **Restorable** | **Marginal** | **Unrestorable** |
|---|---|---|
| Score 2 | Score 1 | Score 0 |
| **(a) slope** | | |
| Flat ground is the best opportunity, but attempts to block drains of <4% have been reported as having a good chance of success (Armstrong et al., 2009) | 4 – 6% | >6%: drains on steep hill slopes are expensive to block and maintain and their upslope zone of influence on the water table will be small |
| **(b) water supply to adjacent wetlands** | | |
| The upper catchments of all the Welsh peatland SAC sites [active raised bogs (7110), degraded raised bogs still capable of natural regeneration (7120) & blanket bogs (7130)] were identified using a catchment shapefile created by FR for a previous FC Wales project. The catchment boundaries were used to select the afforested peat sites located adjacent and upslope from an SAC sites. These present an opportunity to significantly improve the water supply to the open peatland. | The sites located within the catchment, but not draining through, are given the reduced score as there is limited opportunity to improve the water supply to the open peatland. | The afforested peat outside the SAC catchments are not scored. |
| **(c) potable water supply** | | |
| Afforested peat sites not located within the catchment of a potable water supply. | | Afforested peat sites within the catchment of a potable water supply. |

a) On flat sites, blocking drains at key points can rewet large areas but the area affected rapidly diminish with increasing slope requiring greater effort and expense. Peat shrinkage and cracking beneath plantations may hinder restoration by forming a secondary drainage system which is very difficult to block. Cracking occurs on non-fibrous peat under any tree species including deciduous ones (Pyatt et al 1987). On flat sites, drain blocking at key points will retain the water on site even where the cracks remain open so the water table is effectively raised and bog vegetation can be supported (Anderson, 2001).

The slope was derived from the DTM 10 m grid using a standard ArcGIS tool. To better represent the slope at the scale of an individual stand of trees the data was aggregated to a 100 m grid. The tool calculates the maximum change between any single cell and the adjacent cells. It therefore calculates the slope of the hillside rather than the ditches and drains which would tend to run across the slope on steeper sites.

b) To fully determine the hydrological consequences of restoration on an adjacent wetland it would be necessary to conduct a detailed site survey to identify the surface and subsurface drainage across the landscape and to assess the sensitivity of the ecology of the adjacent wetland to the potential new water regime. It is not possible to investigate the scale and consequence of drain blocking on the afforested peat sites and their adjacent wetlands at a national scale, however, it is possible to identify which sites have the greatest potential to influence the water supply of important vulnerable peatlands by identifying those sites adjacent or upstream of all SAC peatland sites.

c) Water quality data (DOC and colour) for the streams draining the afforested peat catchments was requested from EA Wales for this project. Data from over 500 sites across Wales was supplied. The review of the literature could not define relevant water quality thresholds that could be used to prioritise individual sites for restoration (Section 3.4.2). However, provided information of the stream water sampling locations (about 100) within the catchments of potable water supplies has been included in the national assessment. The high cost of treating coloured stream water presents a significant problem to water companies who often temporarily refrain from using water from impacted reservoirs rather than treating the water. Several authors have reported increases in water colour following restoration although this seems to be a short-to-medium term response (Table 16). Afforested peat sites that were not located within reservoir catchments were therefore considered to be preferable to peat sites draining to a reservoir.

The three hydrological layers were combined with the greater weight being given to slope and equal reduced weight given to the hydrological connectivity to vulnerable peatlands and reservoirs (Table 19).

### 5.2.4 Issue 3: Greenhouse gas emissions: which sites offer the best opportunities to reduce carbon and other GHG emissions?

The consequences of restoration for GHG balance depends upon the fate of the above ground carbon stored in trees currently growing on the site following restoration and the impact of the rising water table on the C stocks, DOC and GHG emissions from the peat and drainage waters.

A suitable method to identify the relative merit of restoration for individual sites, using nationally available datasets, for non-carbon greenhouse gas balance, was difficult to define. Non-C GHG emissions are largely driven by the water table depth and nitrogen status of the soil. Water table depth can only be assessed in the field as part of a field-based assessment using the *field criteria scheme*. However, it is unlikely that the short term increase in methane emissions following restoration would be a driving factor in the selection of sites for restoration in light of the likely long term peat carbon sequestration benefit from peatland restoration.

For an assessment of the consequences of restoration in terms of carbon emissions, the sites considered to be the highest priority for restoration are those with the most marketable crop as the use of the timber offers the best opportunity to reduce future fossil fuel $CO_2$ emissions. Additionally, the sale of the standing crop can be used to offset the expense of the restoration. The interpolated forest type information from the new National Forest Inventory was used to determine the canopy type of the afforested peat sites. For sites within the Welsh Government Estate additional information is available in the sub-compartment database, including species and Yield Class. For ease of processing, only information on the principal component of each sub-compartment was used in the assessment. Table 20 illustrates the selection thresholds (tree species and Yield Class) for the three classes.

To maximise the potential GHG balance benefits from restoration, the best sites are those with no trees, as the removal of trees from drained land causes significant increases in the loss of methane. Therefore, the recently felled and unplanted cultivated ground were also included in the high priority class as these open stands present a timely opportunity to restore the peat before trees are established on the site and the water table is lowered further.

**Table 20** Classification and scoring of factors used for sites prioritisation for afforested peat restoration in terms of the carbon balance consequences of restoration.

| Marketable | Marginal | Uncommercial |
|---|---|---|
| Score 2 | Score 1 | Score 0 |
| **Outside FC Wales estate: Interpolated Forest Type from the new National Forest Inventory (Wales) map** | | |
| Conifer, Mixed conifers, Ground prepared for planting, Felled | Young trees | Broadleaf, Mixed broadleaf, Shrub |
| **Inside FC Wales estate: data for principal component of the sub-compartment** | | |
| SPPS in (NS, OMS, SS, XS, CP, LP, SP, HL, JL, DF, NF, | SPPS in (NS, OMS, SS, XS, CP, LP, SP, HL, JL, DF, | SPPS in (NS, OMS, SS, XS, CP, LP, SP, HL, JL, DF, NF, JL, DF, |

| | | |
|---|---|---|
| JL, DF, NF, XF, JCR, WH, MC, XC) and YC >10 | NF, JL, DF, NF, XF, JCR, WH, MC, XC) and YC = 8 | NF, XF, JCR, WH, MC, XC) and YC < 8 |
| | | SPPS in (AH, BE, BI, CAR, MB, OK, XB) |
| SPPS = NULL and LUSE in (PFA, PFE, PBU) | SPPS = NULL and LUSE in (PIB, PWB) | SPPS = NULL and LUSE in (AGR, EMM, EMO, FMD, FMQ, FMW, FRC, FRO, LHP, MOW, OPN, UNP) |
| Failed, felled and burnt | Intruded broadleaves and windblown | Open land and non cropping/land management codes |

### 5.2.5 Issue 4: Ecology: Biodiversity gain through Mire restoration, can a desirable peatland community be established on the site?

The potential ecological integrity following restoration of each afforested site was determined by a) assessing the value of the existing woodland habitat, b) the rarity of the restored peatland type in the Welsh context and c) the functional connectivity of the site to other wetlands (Table 21).

**Table 21** Classification and scoring of factors used for sites prioritisation for afforested peat restoration in terms of the ecological integrity of the site.

| **Restore** | **Marginal** | **Retain** |
|---|---|---|
| Score 2 | Score 1 | Score 0 |
| **(a) value of existing woodland habitat** | | |
| NFI-IFT: Conifers | NFI-IFT: Mixed and broadleaves | Native wet woodland: sites within the boundaries of bog woodland (91D0) & alluvial forest (91E0) SACs |
| **(b) value of existing peatland** | | |
| Sites adjacent to Mire habitat class E1.6.2 and included in the national inventory of lowland raised bogs (Lindsay and Immirzi, 1996); ***more recent CCW inventories***[1] plus FC soil 10a | Sites within the fen peat soil associations plus FC soil type 8a | All other sites |
| **(c) functional connectivity** | | |
| The afforested peat within the core network were given the highest priority as these sites offer potential for species that require large habitat patches, are very dispersal limited and have high specificity to bog: thus representing well connected sites. | Afforested peat sites within the focal network. These represent sites suitable for species requiring relatively little habitat, with moderately good dispersal ability which are capable of persisting in a wider range of habitats. | Sites outside the bog habitat network. |

*[1] advice should be sought from CCW who are currently in the process of updating and expanding the national lowland raised bog inventory to include upland fringe locations (P.Jones pers. comm.)*

a) The interpreted forest type information in the National Forest Inventory spatial dataset was used to distinguish between coniferous and broadleaved and mixed woodland cover. Areas of native wet woodland were identified using the NFI in combination with spatial data for bog woodland and alluvial forest SACs, which was obtained from the JNCC website. It was assumed that broadleaf woodland within the boundary of an SAC would be likely to be one of these priority habitats.

b) In terms of the value of the restored peatland, the potential to restore lowland raised bogs would be the highest priority as this habitat is rare in Wales, following that fen peat which is scarce than blanket hill peat.

c) Data was provided by CCW for open bog habitat networks across Wales. The data included both modelled 'standard' networks which had been created using existing habitat cover and permeability costs to give a prediction of the extent of current bog habitat connectivity, and 'low cost conifer' versions which have been modelled using a much lower permeability cost for conifers to demonstrate the potential for increasing connectivity if conifer plantations were to be converted to open habitat or managed, for example, with more open space, continuous cover etc. The 'low-cost conifer' networks were used to identify the areas of afforested deep peat that could be reconnected to existing bog habitat if the current conifer stands between the afforested peat and open habitat were removed.

The three datasets were combined. The canopy and peatland type scores were combined to provide a combined score for rarity which is then combined with the network connectivity score to provide the overall score for ecological integrity for each site.

### 5.2.6 <u>Issue 5:</u> Climate: is the current and projected climate at the site suitable for peat formation?

Climate change may reduce the viability of some areas of bog, and may also result in increased sensitivity to hydrological impacts. The potential effects of climate change on rainfall and temperature should be considered when assessing a site for restoration (CCW, 2010). For example, marginal climatic zones for peat formation need to be included in the spatial assessment for peatland restoration potential. In damaged blanket bogs, the projected warmer drier summers, may lead to drying of peat surface layers and an increase in the likelihood of accidental fires (Worrall et al, 2009). There is evidence to suggest that in the southern UK, below 500 m elevation, blanket bog peatlands exists at the "marginal climatic zones for peat formation" (Worrall et al, 2007; Worrall et al, 2009). It is unclear how much of our semi-natural peatland resource is active in peat formation, and the rate of growth at many locations may be very slow or even nil. However, there remains a significant conservation value in restoring a semi-natural vegetation cover and retaining the existing peatland habitat. In these situations a strong case can still be made for restoration measures which preserve the peat that remains in these areas.

The vulnerability of blanket peat to climate change has been the subject of the QUEST research programme funded by the Environment Agency and NERC. One output from this research were models of the bioclimatic envelope for blanket peat under current and projected climate scenarios (Clark et al., 2010) which were kindly supplied by Dr Clark for use in this project. The models project the distribution of peat as the percentage blanket peat cover in each 5 km grid cell.

(a) To assess the current suitability of a site for blanket peat, the output of the BBOG_GAM model using the UKCIP 1961-1990 baseline climate data was used. The BBOG_GAM model best matched the mapped distribution of deep peat across Wales.

(b) To assess the impact of predicted climate change on the bioclimatic space for blanket peat, the output of 8 bioclimatic envelope models using the UKCIP02 low emission scenario for 2080 were used.

Current a) and predicted b) climate criteria were used to classify and score the sites in terms of their prioritisation for restoration according their climatic integrity (Table 22).

**Table 22** Classification and scoring of factors used for sites prioritisation for afforested peat restoration in terms of the climatic integrity of the site.

| Viable for restoration of peat forming habitat | Marginal | Not viable: retain existing peat for as long as possible |
|---|---|---|
| Score 2 | Score 1 | Score 0 |
| **(a) Current climate** | | |
| Sites within the 'core zone': that is the area of Wales in which 75% of the mapped blanket peat cover was located. | Sites within the 'peripheral zone': which covered up to 90% of the mapped peat. | The afforested peat outside these zones |
| **(b) Predicted climate** | | |
| Sites in the area of Wales covered by >4 bioclimatic envelope models. This area is likely to remain suitable for peat formation. | The area of Wales covered by 1-3 models: considered to be marginal and therefore less of a priority for restoration. | The area of Wales predicted to become unsuitable for peat formation i.e. not covered by any of the model outputs. |

The peat already present at the "marginal" sites may persist for a long time if managed well, even if the climate becomes unsuitable for peat formation. Thus it may be more appropriate to reduce the significance of the predicted bioclimatic space by adjusting the weighting of the two scores when the two data sets are combined. The sites within the zone which is predicted to become less climatically favourable for peat formation in the future may be considered as priorities for urgent restoration to ensure they are placed in the best possible condition as early as possible to withstand climate change.

### 5.2.7 Combined scores in the national assessment

The individual scores of the five issues were combined with equal weighting to provide a final score for the national afforested peatland restoration assessment. The sites with the highest final score should be considered as greater priority for restoration. Maps illustrating the spatial distribution of the scores for each of the individual issues are shown in Appendix 5.

The results of the national assessment are summarised in Figure 22a and 22b. It can be seen that although the range in value of the final-combined scores is broad (values range from 0.75 to 10) they are skewed slightly towards favouring restoration (scores 6 and 7) although few sites gain the highest scores (Figure 22a). To identify the forest blocks with the greatest potential, the final combined scores were classified using quantile values (Figure 22b) to discern four classes of equal extent, shown in green in Figure 23.

The top ten priority forests are listed in Table 23. These are the forest blocks with the greatest extent of the high final-combined score in the national assessment. Two of these ten key sites are owned and managed by the private sector. The results of the national assessment reveal that the best opportunities on the FCW estate are in the Snowdonia National Park, Tywi forest and Coed y Mynydd regions.

Colleagues in CCW with direct experience and expert knowledge of other sites have noted that there are sites known to be good candidates for restoration which have not been identified as priorities for restoration in the national assessment (for example Carnedd Wen at Llanbrynmair and parts of Trannon near Carno). These sites may have been undervalued due to the limitations of the national datasets for example they are not listed in the lowland raised bog inventory.  This result is an inevitable consequence of using nationally available spatial datasets and suggests that the national assessment can only be used as an initial guide and that ground truthing is an essential next step.

(a) (b)

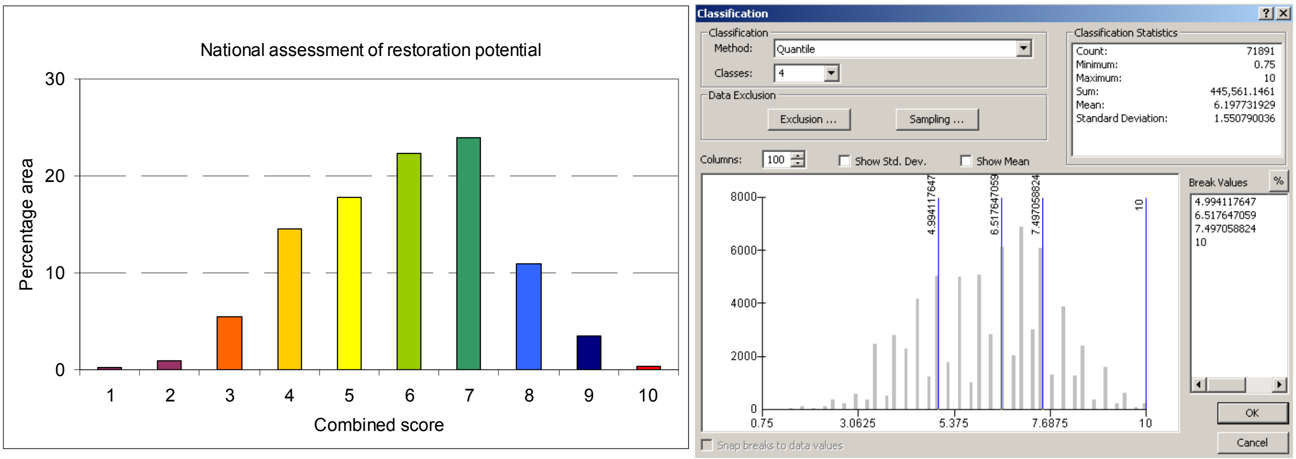



**Figure 22** The distribution of the final combined scores in the national assessment of the restoration potential of afforested peat illustrated as (a) integer values, and (b) Quantile classes, as used in Figure 23.

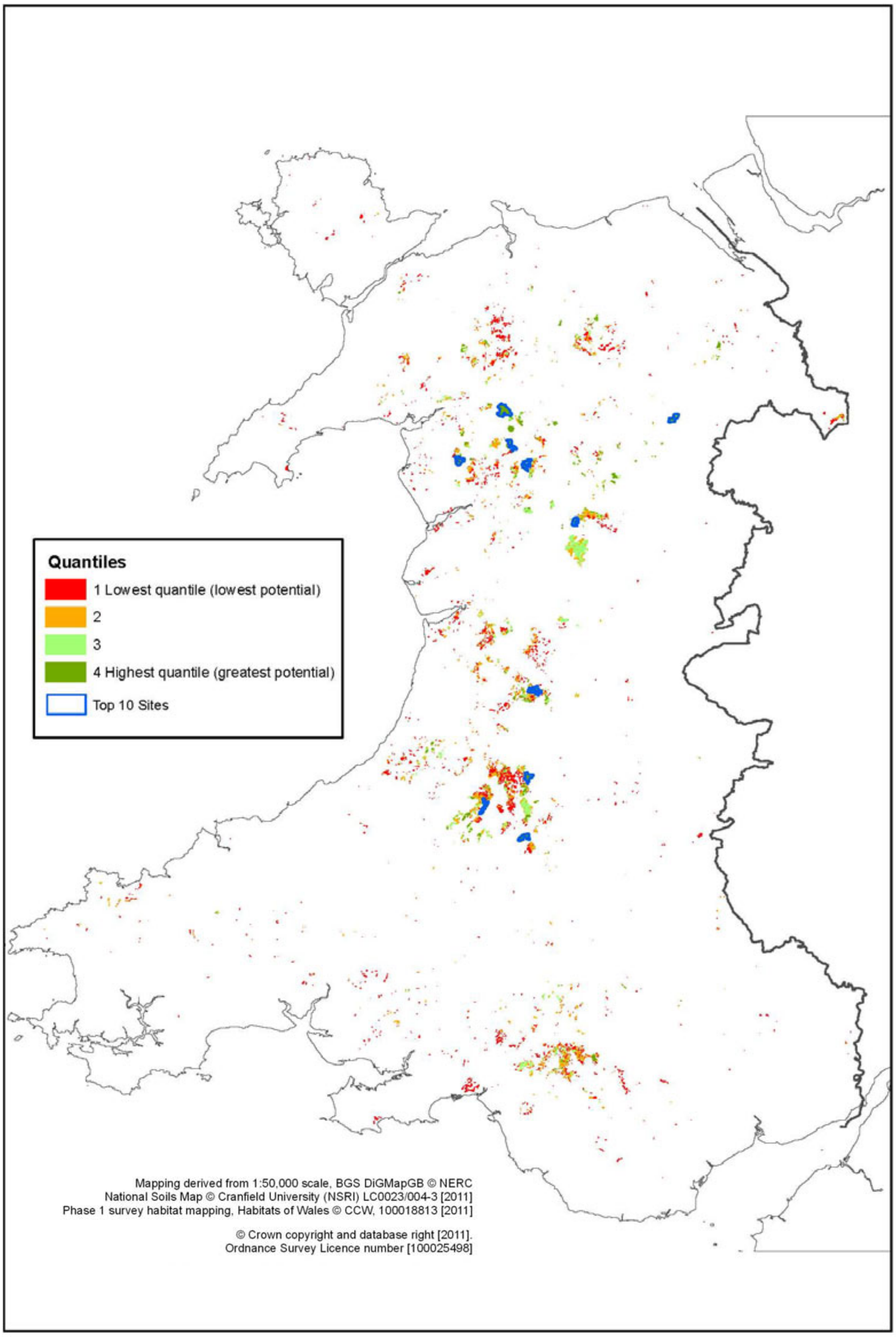



**Figure 23** Spatial distribution of the sites in Wales with final combined scores classified by quantile.

**Table 23** The ten sites with the largest extent of the highest score class in the national assessment.

| Location [Forest block] | Grid reference | Extent (ha) | FC |
|---|---|---|---|
| Pont–y-lladron | SH77753962 | 525 | ✗ |
| Mynydd y ffynnon | SN84317957 | 285 | ✓ |
| Penaren | SH81292714 | 273 | ✓ |
| Trawsfynydd | SH68152882 | 228 | ✓ |
| Tywi North | SN82986089 | 227 | ✓ |
| Cwm Berwyn | SN73615466 | 218 | ✓ |
| Llangollen | SJ13753758 | 217 | ✓ |
| Mynydd Trawsnant | SN82034817 | 213 | ✗ |
| Trawsfynydd | SH79233204 | 195 | ✓ |
| Tir Rhiwlog | SH92901566 | 191 | ✗ |

In this exercise the scores of the five issues were combined with equal weighting; this could be modified to favour sites which offer specific potential benefits from restoration. For example, to identify sites for restoration under the first round of Glastir Targeted Element agreements, for which the current policy objectives include improved carbon storage and water management, it is possible to increase the weighting of the GHG balance and hydrology criteria in order to prioritise the sites that best meet these objectives through afforested peatland restoration.

A recent Defra project, reviewed the objectives and justification of 56 peat restoration projects in the UK (Holden et al., 2008). The stated aim of most projects was the restoration of the ecological and hydrological function, or 'whole ecosystem' function of a site. Of the reasons given to justify the work, the biodiversity case was stated strongly for all projects (Figure 24), and the need to restore hydrological function was the second most important factor. Carbon was used as justification for 62% of the projects, but it was only considered extremely important in three cases. The authors note a recent shift in emphasis as the preservation of carbon stocks is becoming of more importance than previously (Figure 24). It is therefore important that the national assessment scheme is flexible and can be adjusted to reflect the contemporary policy drivers and funding incentives to identify sites that best match the objectives of a particular project.

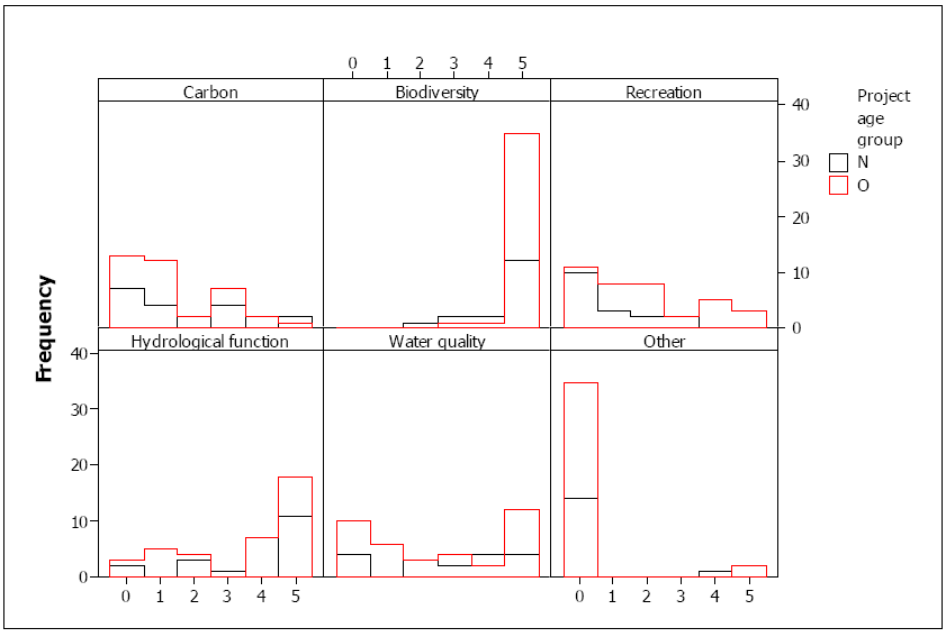



**Figure 24** Histogram illustrating the frequency of different criteria used to justify peat restoration projects and the relative scores attributed to each criteria; where 0 is unimportant and 5 is extremely important. The plots show the number of projects giving each score with N = projects started since 1 Jan 2005 with O = projects which started prior to 1 Jan 2005 (DEFRA project SP0556, 2008).

## *5.3 Application of rule-based criteria and field observations in a site assessment of the restoration options for an afforested deep peat*

Sites which were identified in the national assessment as potentially restorable should be flagged within the FC Sub-Compartment Database (SCDB). It will then be possible for FC Wales staff to determine the extent of the afforested peat resource within a forest block and assess on site the most appropriate future management option for the peat, in the preparation of the Forest Design Plans. The *field-based assessment* takes the form of a series of questions structured in a dendrogram (decision tree) (Figure 25); which should be considered on site using a set of rule-based criteria, factors and thresholds based on field observations (Table 24). It is important that the use of the *field-based assessment* is encouraged even on sites which do not yield high scores in the national assessment.

It is intended that the member of staff responsible for the site (e.g. the local planning forester) ensures the site is assessed either, prior to felling when the crop is surveyed to predict the harvestable yield of the stand, or ideally during the preparation of a strategic plan for the regional afforested peat resource.

The operational staff can use Table 24, out on site, to resolve the answers to the questions posed in Figure 25. On some sites, it may not be necessary to consider all the criteria, for example on flat sites it is anticipated that it will be easier to ascertain if it will be possible to raise and maintain the water table than on sloped sites. The answers to the questions can then be used to inform progress through the decision tree which has been conceived to select the most appropriate management option for the site.

## 5.3.1 Decision tree

The key issue to the likely success of attempts to restore afforested peat is **Q1** - Is it possible to raise and maintain a high water table across the site? On very flat sites blocking drains at key points can rewet large areas, but the area affected diminishes with increasing slope (Anderson, 2001). On sites where the peat has cracked, drain blocking may be insufficient as water flow can bypass the dams. Such sites can be restored through the use of continuous impermeable barriers, however, the costs are substantial. Flat sites resaturation can be achieved even where cracking has occurred.

If the water table can be raised and maintained it is then necessary to consider **Q2** - Can the standing crop be cost effectively removed from the site? The age of the crop and topography of the site will determine the most cost-effective means of removing the trees. If restoration is delayed until the end of the rotation the costs incurred can be offset with the income realised, however, on very wet sites where growth has been poor there may be very little marketable value in the standing crop. The net costs vary not only with the age of the forest but also with the harvest operation required to clear the site. The use of a light-weight mini forwarder to extract whole trees from a bog restoration site can cost twice as much as felling trees to waste by hand. Skyline extraction, using cables, is well suited to fragile bog restoration sites, to remove whole trees with minimal ground disturbance. At the most sensitive sites, helicopters can be used to extract whole trees from the site where no alternative options are available. Once the fate of the standing crop has been decided the next issue to consider is **Q3** - Is open mire habitat the most suitable objective for the site? A functional peatland habitat should re-establish on cleared sites if a high water table can be maintained, however, the restoration of pristine bog vegetation community may require active management and the suitability of elements of native bog woodland should be considered.

If the water table can not be raised it is pertinent to consider **Q4** - Is there a significant peat resource remaining on the site? Sites with discrete pockets of deep peat should be treated differently from those with shallow peaty soil types. Care should be taken to identify peat pockets which should then be kept clear and rewetted within the next rotation of the forest design plan. On sites with organic soils but lacking deep peat consider **Q5** - Is there merit in restoring open habitat? Sites with peaty soils, in close proximity to peatland, may be well suited for restoration to an open habitat to improve the connectivity of existing priority habitat.

However sites with peaty soils within the forest may be best suited for continued woodland cover as a productive broadleaf or conifer plantation.

## 5.3.2 Rule-based criteria and thresholds

The criteria, factors and thresholds for the *field assessment scheme,* presented in Table 22, are based on the literature review and personal experience of the project team. These have been also intensively tested in the field by ground truthing a number of potential sites for restoration in Wales (Section 6).

The key sources of additional information which may be of use in the field assessment are:

1) aerial photographs of the forest stand showing the boundary of the sub-compartments,
2) the digitised soil maps produced by the FC soil surveyors. These maps may assist the identification of the deep peat which can often be identified by assessing growth within stands. In addition, sometimes it is possible to distinguish boundary of deep peat from peaty soil by visually assessing the density/colour of tree canopy (reflecting different tree growth, YC) from the aerial photography,
3) the species and age of the crop can be obtained from the sub-compartment database,
4) FC Field Guide: The Identification of Soils for Forest Management. Kennedy (2002). The guide includes keys to identify deep peat soils using topographical and vegetation information and is illustrated with key peatland species.

A "Field Assessment Tool" for use by practitioners, has been developed and is available on the FC Wales website.

**Figure 25** Decision tree: management options for afforested peat stands.

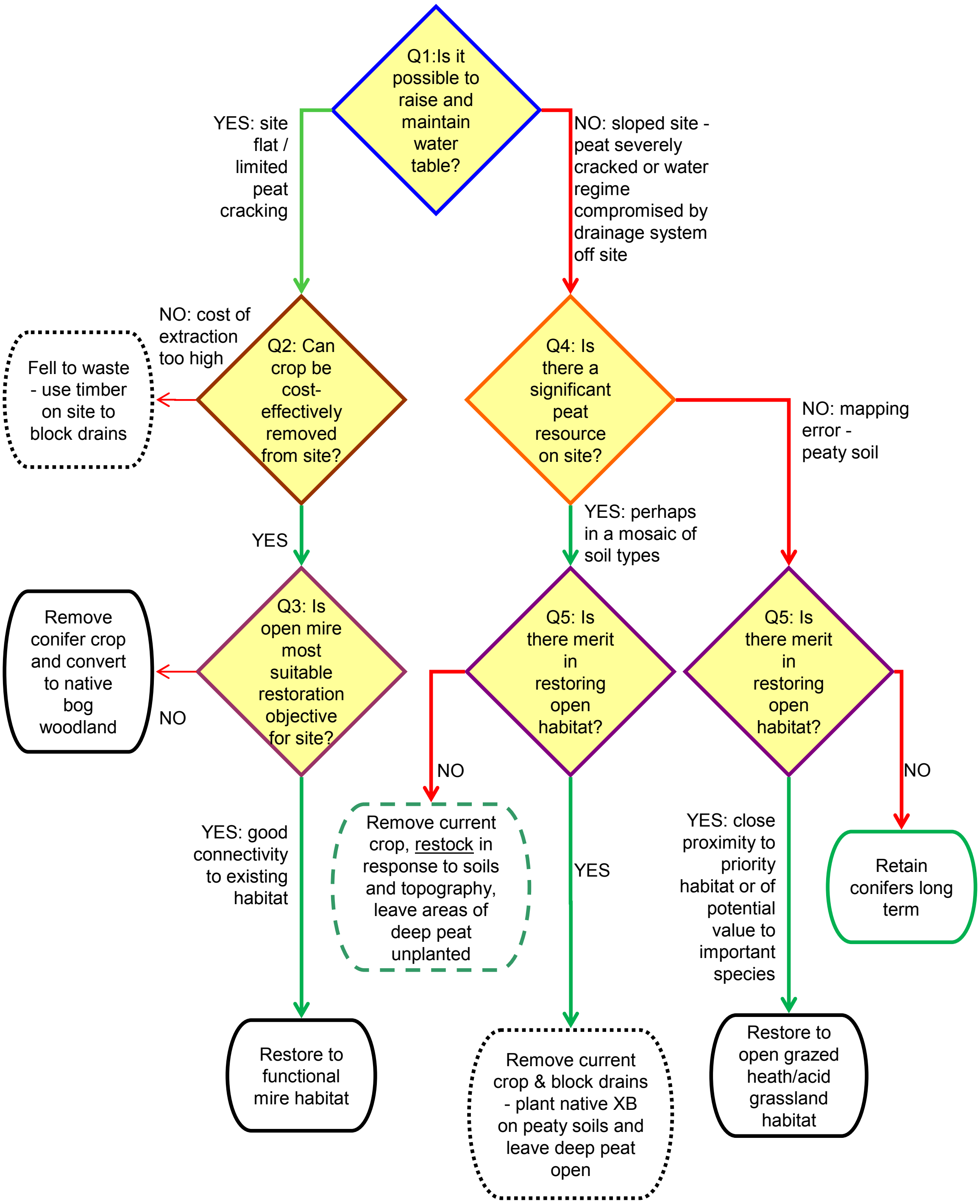


**Table 24** Local criteria, factors and threshold values/classes for checking on site basis for their suitability for restoration at forest district level.

| ISSUE | Criteria | Factor | Threshold values/classes: Advantageous to cost effective restoration | Threshold values/classes: Disadvantageous to cost effective restoration | Threshold values/classes: Difficult/expensive to restore successfully |
|---|---|---|---|---|---|
| | | | ☒☑ | ☒☑ | ☒☑ |
| **Q1: Is it possible to raise and maintain water table?** | **Hydrological integrity of site** | Slope | Flat sites | <4% | >4% |
| | | Slope / peat cracking | Flat sites and/or no cracking | Peat not cracked between plough furrows | Peat cracked between plough furrows |
| | | Drainage: drain depth & condition | Infilled with sphagnum? <30 cm | >30 cm | >60 cm/eroded to mineral layer - flow suffcient for drains to be self cleaning: therefore difficult to block |
| | | Drainage: is it possible to block the drains by damming the dranage network at a key point within the restoration site? | Yes key point for drain blocking present on site | No, but few dams required | No, many dams required on site |
| | | Drainage: is it possible to modify/control drainage across the wider landscape to ensure appropriate water supply to site | water regime on site near natural and appropriate | drain network on upslope/adjacent sites requires modification to mainatain suitable water supply to peat on site | unable to maintain suitable water regime on site due to condistions of off site drainage |
| | | Bog Edges | Intact | Cutaway | Eroded |
| **Q2: Can conifer crop be cost effectively removed from site?** | **Current economic viability of standing timber** | Species - relevant to brash management during opperations plus the need to control of regen. | SS or SS/LP | Other conifer | Broadleaf |
| | | YC | YC<8 | YC 8 - 10 | YC>12 |
| | | Distance to road | <1 km | | > 1km |
| | | Tree age | End rotation age | Mid rotation age | Early rotation age |
| **Q3/Q5: Is open mire most suitable restoration objective for site?** | **Ecological integrity of site** | Scarcity of peatland type in Wales | Basin mires, raised bogs & bog woodland: FCST 8, 10 & 9a | unflushed peat: FCST 11 | Hill peat: FCST 9 |
| | | Field layer and ground layer species | Remnant bog vegetation including sphagnum | Juncus | Bramble? Mollina? |
| | | Sphagnum coverage in adjacent rides | high cover | scattered cover | not present |
| | | Proximity to phase 1 peatland habitat or open wetland habitat within forest | adjacent | <200 m | >200 m |
| **Q4: Is there still significant peat on site?** | **Current status of peat** | Soil Type - FC classification | 8a, 8b, 9b, 9e, 10b, 11b | 8c, 9a, 9c, 9d, 14 | 14h, 6p |
| | | Duration of afforestation - PY of first rotation | < 15 y | 15 - 50 y | > 50 y |
| **Are there any additional benefits?** | **Community interest in forest** | Scheduled Ancient Monument | absent | | present |
| | | Forest block is a flagship recreational site e.g. has visitors centre etc. | present | | absent |
| | | Distance from car park/bike route/footpath | <100 m | 100 - 500 m | >500 m |
| | **GHG Balance** | Current Water Table depth | <50 cm | 50- 100 cm | >100 cm |
| | | Depth of peat oxidated layer | <20 cm | 20-50 cm | >50 cm |
| | | DOC/colour of drainage water | highly coloured | visible colour | clear |

# *6. Ground truthing sites*

## (Russell Anderson, Sirwan Yamulki, Samantha Broadmeadow and Elena Vanguelova)

A number of sites have been visited in Gwydyr and Alwen forests in north Wales in addition to sites in Nant-y-moch and Tywi (Bryn Brawd area). The aims were to (a) ground truth the soil and stand information used in the new national peat map and (b) test the suitability of the decision tree and rule-based criteria, factors and the scoring thresholds developed for the *field assessment scheme* of afforested peatland restoration potential.

Gwydyr was selected as suitable site for the field work because spatial data of the FC soil survey for the forest had been digitized and was made available for this project. This forest was therefore an example of what assessments are possible on land included in the FC soil survey. Currently, in other forests the soil information stored within the sub compartment database is not always very accurate or complete. Alwen forest was selected as a suitable site to investigate the accuracy to existing soil information. Nant-y-moch area is part of the Nant-y-moch Wind Farm Project and the area ground-truthed made a part of the peatland restoration area in the Wind Farm habitat management plan to be implemented to mitigate the identified significant ecological effects and provide ecological improvements, which should ensure neutral residual effects to ecology overall. Bryn Brawd area was included with sites a little further south of Nan-y-moch Esgair Maern / Twyi close to Tregaron. There was an SSSI (Fign Blaen Brefi) and another open / failed planting area at Esgair Llethyr. In addition, the Bryn Brawd area's new planting proposal on the open hill was viewed and discussed.

The ground truthing sites were selected using GIS to identify a variety of stands of conifer forest and broadleaf woodland growing on a range of deep peat soil types. In Gwydyr forest 5 areas of afforested peat were visited. The areas chosen (see maps in Appendix 4) included sizeable stands of mature first rotation Sitka spruce, Lodgepole pine and younger second rotation stands across a variety of deep peat and peaty soil types. In the five visited areas, 13 separate stands were assessed according to all criteria, factors and threshold listed in the field assessment scheme in Table 24. Main site characteristics, restoration potential and recommendations for follow on management are included in Table 25. In Alwen forest an additional three stands from two areas were visited. In Nant-y-moch, two sites within the peatland restoration area were visited, one at the top of the hill and one at the bottom (see maps in Appendix 4). At Bryn Brawd area, four individual sites were visited.

The restoration suitability score has been assigned to each ground truthing site, based on field observations, scored against the rule based criteria, factors and thresholds from the *field assessment scheme* (Table 22) and expert judgement of the team. Main site characteristics and restoration suitability are summarized in Table 25. Sites classified in Table 25 as **suitable** and **very suitable** correspond to the

**Advantageous** to cost effective restoration threshold in Table 24; **marginal** correspond to **Disadvantageous** to cost effective restoration and **unsuitable** correspond to **Difficult/expensive** to restore successfully.

The following gives a description of the ground truthed sites including the conditions observed on the ground and the justification for the categorisation of their peat restoration potential listed in Table 25.

## *6.1 Sites at Gwydyr forests*

The soils in area 1 are mapped as '9d/9b/6p' indicating the area has an intricate mosaic of peat and peaty soil types. Both sites, **1A and 1B** (see pictures in Appendix 4) were considered to be **marginal** for restoration, but the return may be small for the efforts involved due to limited extent and patchy distribution of the small pockets of deep peat. The site is restorable as the trees are young SS, PY1999 and PY2007-9. The vegetation under the trees was rich despite the stands being second rotation conifers the ground was covered by sphagnum and other mosses with *Calluna*, bramble and *Juncas*. Peat depth was highly variable across the site due to both the expected spatial variability in mosaic of peat types and as a consequence of the dig, dollop and dump cultivation method, which has left the ground surface very uneven and created some large hollows under the tree canopy. There was good evidence of restorability of site 1A proved by the good condition of the open riparian zone (up to 30 m width) created during the planting of the second rotation. Amongst the stumps of the first rotation the peat depth was 1.5 m and the water table was close to the surface of the soil, showing good recovery of peat forming conditions. The open riparian zone was vegetated by willow, bramble, heather, *Juncas*, cotton grass, and a continuous carpet of mosses including sphagnum. The rich vegetation indicates relatively higher soil fertility possibly due to the previous cultivation creating variability in peat depth and bringing mineral substrate closer to the surface.
It appeared that a significant proportion of the deep peat in this valley head had been protected by the policy to retain open riparian stream margins within the planting design of the second rotation. However, the planting had not taken into account the full extent of the peat pockets and trees had been planted within terraces that are likely to contain pockets deep peat. It would be possible to improve the forest design to ensure better protection for the peat resource in the area however the amount of afforested peat at these sites is quite small and the return in terms of benefits gained for the effort involved may make the prospect low priority because it is not best use of resources.

Area **2, sites 2A, 2B and 2C,** (see pictures in Appendix 4) (were all considered to be **suitable** for restoration as the peat depth and condition was good despite the presence of trees for the last 60 years. At 2A the moss flora under the trees of the hill slope lacked sphagnum species, but on the flat ground where the trees were not as vigorous the moss cover was good and included *Sphagnum* species and at the bottom of the hill slope there were large mounds of sphagnum growing in small open areas amongst the trees towards the edge of the stand. The trees on deep peat in site 2A were growing around open basin of *Juncus* vegetation. Comparing the Lodgepole pine in sites 2C with an adjacent Sitka spruce stand, and the SS canopies at 2A and 2B, more light reached the ground surface under the LP so that there was better ground cover including *Vaccinium* and mosses. The LP stand had more failed and fallen trees than the adjacent SS stand. These had fallen and created open patches in the canopy. The LP trees seem to have come down in patches, there were a range of tree sizes, some have reached a good size but many crowns have split leaders and brown needles indicating signs of aphid infestation. There were many spruce seedlings in site 2C, which could bring potential additional post-restoration cost if management of natural tree regeneration is needed. Under the LP, the humps and hollows created by the fallen trees have increased the micro-scale variation of the surface topography, which could aid recovery of the biodiversity value of the flora.

Site **3c** (see pictures in Appendix 4) was considered as **unsuitable** for restoration to a peat bog due to apparent loss of peat depth currently 0.8 m, mapped as 9b, and the complete absence of ground vegetation and sphagnum. This site, however, may be more suitable for broadleaved natural regeneration.

Site **4A** (pictures to be included in Appendix 4) was considered to be **very suitable** for restoration as peat depth was substantial (of <7 m), water table was high and peat oxidative layer was thin, field and bog ground flora was abundant and even Sphagnum was very abundant. In addition, the stand was adjacent to a large open bog habitat, which should make restoration very successful.

## *6.2 Sites at Alwen forest*

Sites **6A and 6B** (pictures to be included in Appendix 4) are considered to be **unsuitable** for restoration as the peat depth was between 0.3 and 0.55 m which is below or on the threshold for the soil to be classed as a peaty soil rather than deep peat. In addition to shallow peat depth, the sites had almost no field or ground vegetation species typical of bog vegetation communities. Although not suitable for peat bog restoration, these sites may be suitable for protection of the existing soil and peat resource by creation of another open habitat type such as wet heath or acid grassland. Similar conditions were observed at site 3c in Gwydyr forest (see pictures in Appendix 4) where the apparent loss of peat depth and absence of ground vegetation made the site unsuitable for bog restoration, but more suitable for broadleaved natural regeneration.

## *6.3 Sites at Nant-y-Moch Wind Farm peat restoration area*

The first ground truthing site **7A** was on the top of the peat restoration area, east of Lluest-y-rhos (SN756917) (map and pictures in Appendix 4). The open ground and rides were tussocky Molinia vegetation with herbs (*Viola palustris*, *Potentilla erecta*). The forest was closed-canopy and a

reasonably well-grown P83 Sitka spruce stand. Peat depth was ~1.4 m. The top of the site was more steeply slopping part of the block and it was ploughed with fairly deep furrows running straight up and down the slope. There was no peat cracking as checked in two furrows. One had crumbly, black, strongly humified peat under the root/litter mat in its base, 10-15 cm deep. The other had saturated fibrous peat under the root/litter mat. The water table was as high as the top of the furrow in places and down to 40-50 cm on other places. Vegetation and peat depth along a diagonal forest ride down slope was similar; *Molinia*-dominated with some *Erica tetralix*, *Eriophorum vaginatum*, *Vaccinium myrtillus*, *Sphagnum palustre*, S*. fallax* and other *S. spp.* and peat depth was over 1 m the whole way. The lower part of this slope was less steep, had poorer tree growth and probably deeper peat. The forest there had a gappy canopy visible on the aerial photography.
The top part of the forest had some **suitability for restoration** but it would be expensive because it would require damming of the furrows at intervals of perhaps 2-3 m to completely rewet it. The Wind Farm plans are to harvest the timber, remove as much of the brash as possible and dam the furrows at 10-15 m intervals, which would not be enough to rewet the more steeply sloping top part of the block.
There was a good Sphagnum colonisation of drains or natural streamlets in the diagonal ride indicating a potential for self-restoration but it was difficult to predict whether self-restoration of the furrows would also be likely to occur. If so, less frequent damming of the furrows might result in restoration in the longer term. The lower slopes of site **7A** are undoubtedly **suitable** for bog restoration, requiring far fewer dams than further up.

The second site (**7B**) ground truthed at Nanth-y-Moch was the basin bog at Bryn Glas (SN751908), which was planted with P57 Lodgepole pine stand (pictures in Appendix 4). The stand was very open due to failure of many of the trees and stunting of most of the others, with overall very poor LP growth. Apart from the tree species, it was in some ways similar to natural bog woodland. The peat was 4.2 m deep at the point we probed. The vegetation was dominated by *Eriophorum vaginatum* with *Calluna*, *Molinia*, *Vaccinium myrtillus*, *Sphagnum capillifolium* (some massive cushions) and *S. papillosum*. The ground was quite flat but there were occasional drains, including one 1.5 m deep. Even this deep drain had a large cushion of *Sphagnum papillosum* growing on the side near its base.

This site (**7B**) was a definite **very suitable** candidate for restoration. The most open area could be left with the stunted trees growing as artificial bog woodland or these could be felled along with the denser woodland around it. It would be a difficult site to harvest the trees from, possibly requiring winch extraction. The alternative of felling to waste might be acceptable, provided the trees were shredded and cross-cut so that the material lies flat on the ground. It would be important to dam the drains but dams could be spaced quite far apart because the site is relatively flat.

## *6.4 Sites at Tywi (Bryn Brawn area)*

The first site at Tywi was was Esgair Maen **8A** (SN719514) which was a very good Sphagnum-rich bog site (see pictures in Appendix 4) along a ride at the forest edge. The forest stand assessed was where the stream enters above Llethr Gwyn. This was gappy P74 Sitka Spruce stand, although reasonably well grown in patches. The FC soil map indicated type 9b. In the area of better grown SS, there were no cracks found in the couple of furrows checked. Uphill of this SS site, the slope was steepened, which coincided with a contour drain and a change to Lodgepole pine and mineral soils (opposite of the more familiar situation of LP on the deep peat and SS on the mineral). There was a lot of iron oxide in the needle-dammed drain and furrows below this boundary. The ground layer under the trees was made of Mollinia with patchy Sphagnum. Sphagnum carpet has dominated the furrows and drains at the site. Overall, all factors assessed point to a site **8A** being **suitable** for bog restoration.

The open ground to the right of the forest stand was a small part of the Bryn Brawd new woodland site. It consisted of a large Molinia-dominated boggy basin with the only visible green grass on the sides of the Llethr Erwast ridge. It has been noted that in the last five years, Molinia had spread onto some areas of quite steeply sloping ground on the ridge side in response to reduced stocking density of sheep. It was clear that the peaty basin and perhaps also the flatter shelves on the ridge were not suitable for tree planting.

The second site at Tywi, **8B** was a Tilhill restocked coupe SW between Bryn Catel and Bryn Mwysau (SN702506). The whole coupe has been mounded, new drains dug and Sitka Spruce planted. The small area of more sloping ground close to the road has no peat but the flatter ground below this has peat 1-2 m deep (see pictures in Appendix 4). The predominant early colonising species in the vegetation are *Juncus bulbosus* and various *Sphagna*. Here the mounds are of peat, varying from black and well-humified to brown and fibrous. Many of the trees have been planted beside or through the mounds into the original furrows.

The deep peat area at **8B is very suitable for restoration** and it should not have been restocked, however, as this area was quite a mosaic with deep peat pockets amongst peaty soils, the omission of deep peat in planting procedures is difficult to be achieved in practice. In principle, the digger driver should stop making mounds when his bucket starts to come up with only peat and no mineral soil reached. However, there is a need to distinguish ground for planting from that for restoring peatland habitats in the planning process, not just in the planting process. Incorporating a peat depth check into the coupe plan together with the aboveground assessment would not take long but it will inform planting before practical operations.

The third site at Tywi **8C**, was a large FC restock site between Draenllwyn-Du and Bronbyrfe (SN714522), which has been mounded and planted with birch. Peat depth was variable. The area ground truthed was near the road and had deep peat and heathery vegetation with a lot of *Carex* *echinata*. There was a short steep slope with no peat and vegetation dominated by *Juncus squarrosus*. Most of the ground covered had peat more than 1 m deep.

As the site was patchy in terms of peat and also different slopes, it prompted discussion on the scale of management. Is detailed, fine-grained management feasible and desirable? The scale of peat depth variation here was such that no existing soils data set is likely to be precise enough, thus it would have been difficult to include in the planning process, in addition to practical difficulties to plant one part and restore the other. So, overall this site **8C** would have been inefficient and **not suitable** to restore although possible at some locations.

The last site **8D** ground truthed at Tywi was the FR Lodgepole pine provenance trials, which are at a saddle mire occupying a broad, flat valley at Waun Ochr-fach (SN733539) (pictures in Appendix 4). Walking down a steep field and entering the forest along a ride, the peat depth increased gradually from 45 cm at the start of the ride to 2 m half-way along it. The vegetation was dominated by Molinia with a little *Eriophorum vaginatum*.

In the middle section of the ride there were straight banks that appeared to be the edges of old peat cuttings, perhaps cut by past occupants of Llether Farm.

The LP provenance plots varied greatly in the quality of the crop. Most were poor and gappy with an open canopy and modified but almost complete ground vegetation and a large amount of SS regeneration. A few LP were better grown, tall with a closed canopy and no presence of ground vegetation. *Sphagnum* cover was abundant in forest rides and furrows. The furrows were unfilled, with water up to 10 cm off the surface.

Cracks in furrows were not found except a few traces. However, cracks were found under pooled water in the base of a cross-drain at the edge of the provenance trial.

All criteria and factors tested point to this site **8D** being a **very suitable** site for bog restoration but the large amount of SS regeneration under some of the more open LP stands suggests that regeneration is likely here. There are also bracken and rhododendron and control of the latter will be very critical for successful restoration of this bog.

**Table 25** The main characteristics of the sites visited by FR team during June/July and October, 2011 for ground truthing the maps and assessment of the proposed restoration criteria.

| Forest | Site no. | Forest type | FC soil type | Peat depth (m) | Peat aeration depth (cm) | Field layer dominants | Ground layer dominants | Sphagnum abundance | Restoration suitability |
|---|---|---|---|---|---|---|---|---|---|
| Head - water of Afon Glasgwm | 1A | SS, PY1999 (2 rotation) | 9d/9b/6p | >1.5 | 5-10 | Willow, bramble, heather, juncus, cotton grass, willow herb | Sphagnum and other mosses | Some presence | Possible, but the return may be small for the efforts involved due to small pockets of deep peat |
| Head - water of Afon Glasgwm | 1B | SS, PY2007-9 | 9d/6p | <1m | 10-20 | Sphagnum and other mosses with calluna, bramble and juncas | Continued carpet of mosses including sphagnum | Some presence | Possible, but the return may be small for the efforts involved due to small pockets of deep peat |
| Gwydyr | 2A | SS PY1966 | On a pocket of 8c | 1.3 | 5 | No field layer | Moss flora but lacking Sphagnum species | Rare or absent | Suitable |
| Gwydyr | 2B | SS PY1966 | 11b | 1-1.3 | ~ 20 | No field layer | | | Suitable |
| Gwydyr | 2C | SS/LP | intricate mosaic of 11b/6p | 1 at top of furrow and <0.4 at bottom of drain | | Better ground cover under LP than SS, Vaccinium | Mosses | Only along the bottom of the drains | Suitable |
| Gwydyr South (Tophill) | 3A | SS PY1952 (low YC stand) | 11 d or b | 0.5-0.8 | 5 | No field layer | Very little moss on the ground | Absent | Restoration may be possible as peat rewettable |
| Open next to stand | 3B | Open space within stands | 9b | 1.2-1.4 | | | Good cover of sphagnum and other mosses | Good cover of sphagnum | Good evidence that site 3A may be restorable |
| Gwydyr South (Tophill) | 3C | SS PY1952 (high YC stand) | 9b | 0.8 | >5 | No field layer | Very little moss on the ground | Absent | Unsuitable for restoration may be suitable for BL via natural regeneration |

| Forest | Site no. | Forest type | FC soil type | Peat depth (m) | Peat aeration depth (cm) | Field layer dominants | Ground layer dominants | Sphagnum abundance | Restoration suitability |
|---|---|---|---|---|---|---|---|---|---|
| Gwydyr | 4A | Ride beside failed P72 SS | Mapped as 11b Actually 11c | 7.4 | 11 | Trichophorum Calluna | Sphagnum cap. Cladonia port. | Abundant | Very suitable |
| Gwydyr | 4B | P72 LP | 11b | 7.4 | 13 | Mostly no field layer | Sphagnum cap. Pleurozium Hypnum cup. | Common | Suitable |
| Gwydyr | 4C | P72 SS | 9d | 2.25 | 45 | No field layer | Mostly no ground layer | Rare or absent | Possible but likely to get pure Molinia |
| Gwydyr | 4D | 2nd rot. P99 SS not closed canopy | 9b | 0.9 | 35 | Calluna | Sphagnum | Common | Possible |
| Gwydyr | 5 | 2nd rot. P97 SS not closed canopy | 9b | 1.0 | 60 | Calluna | Sphagnum cap. Pleurozium | Abundant | Possible |
| Alwen | 6A | 2nd rot. P07 SS Mound planting + regeneration | Flushed bog | 0.55 | 10-15 | Eriophorum v. Juncus squar. | | Occasional | Unsuitable (might get wet heath or acid grassland) |
| Alwen | 6B | P63 SS | Unflushed bog | 0.3 | 0.3 | No field layer | Mostly no ground layer | Rare | Unsuitable (might get acid grassland) |
| Alwen | 6C | Restored starting 1996 | Unflushed bog | 3.1 | 22 | Calluna Eriophorum v. | Sphagnum cap. | Abundant | Has proven very suitable |
| Nant-y-moch | 7A | P83 SS | 9c | 1.4 | 10-15 | No field layer (Molinia in ride) | Forest floor mosses | Common in furrows | Top marginal. Bottom suitable |
| Nant-y-moch | 7B | P57 LP | 11b/d | 4.2 | 0-5 | Eriophorum vaginatum | Sphagnum capillifolium | Abundant | Very suitable |
| Tywi | 8A | P74 SS | 9b | >0.8 | 20 | Molinia | Patchy Sphagnum | Common | Suitable |
| Tywi | 8B | 2nd rot. P2011 SS | 8b | 1-2 | 40 | Mostly no field layer | | Abundant | Highly suitable |
| Tywi | 8C | 2nd rot. P20010 Birch | 8d | 0-2 | 30-50 | Calluna/Carex echinata/Juncus squarrosus | | Common | Patchily suitable |
| Tywi | 8D | LP Provenence trial | 9b | 1-3 | 0-5 | Sparse Molinia | | Abundant | Very suitable. Expect regeneration |

# 7. Cost of management options

**(Elena Vanguelova)**

## 7.1 Payments for peatland restoration

Under the present Kyoto Protocol carbon accounting methods, emissions from Land use, Land-Use Change and Forestry (LULUCF) do not currently recognise the benefits of avoided losses through peatland restoration. However, under the UN Framework Convention on Climate Change the international community is considering proposals for avoided losses through peatland restoration to be included in national greenhouse gas inventories. One of the constraints on the adoption of such a measure will be the need to develop accurate and cost effective methods to verify carbon stored through peatland restoration. Detecting changes in large peat C stocks is difficult, and establishing by measurement the rate of C sequestration into specific peatland areas in different states of restoration will probably be impractical. Approaches using agreed default values will probably be the way forward.

There may be potential to package payments for carbon sequestration with those for other ecosystem services provided by peatland restoration, such as downstream water improvements and increases in biodiversity. There are already schemes in place to monetise cultural ecosystem services (see for example the recent UK NEA, 2011), which will greatly help in assessing the value of peatland restoration. It is important to emphasise that any scheme which is marketed primarily on the basis of carbon or climate benefits must consider how it may affect other services provided by peatlands, such as the provision of drinking water and biodiversity. For example, peatlands degraded by drainage, erosion and other damage such as burning can release high concentrations of dissolved organic material into rivers and drinking water reservoirs. One of the negative effects of this is water discolouration, which is costly to address. In England and Wales, water utility companies faced with spending millions of pounds for water treatment have chosen to pay for peatland habitat restoration as a long term cost saving exercise, with estimated benefits in some catchments of up to £2.5 million.

## 7.2 Cost information for recent restoration projects

The peat restoration projects compendium produced by the DEFRA SP0556 project provided summary results and detailed analysis of 56 peatland restoration projects in the UK. There were more lowland raised bog projects than any others, but these tend to be small in area compared to the blanket bog restoration projects which were more than three times greater than the area of all the other types of peatlands put together. The median budget per project was £241K. The median project budget per hectare was £1600. The positive relationship between peatland site area and project budget is shown in Figure 26 based on all 56 UK peatland restoration projects; those where land purchase was required were usually more expensive. Figure 27 shows data on how budgets were allocated to practical works, monitoring and land acquisition. Expenditure on practical works formed an average of 55% of project budgets. Two-thirds of projects had expenditure dedicated to monitoring and the proportion of funds for monitoring was greater for the smaller projects (DEFRA SP0556, 2008). Most projects reported that one of their main challenges was physical access for machinery to undertake practical works on site. Purchase of equipment for bunding peat or baling heather, removal of vegetation such as trees or scrub and archaeological survey costs were all expensive investments for a number of projects. Indeed, 32% of projects had to consider archaeological needs for their site. Health and safety considerations were found to be another key challenge, particularly where land was accessible by the public.

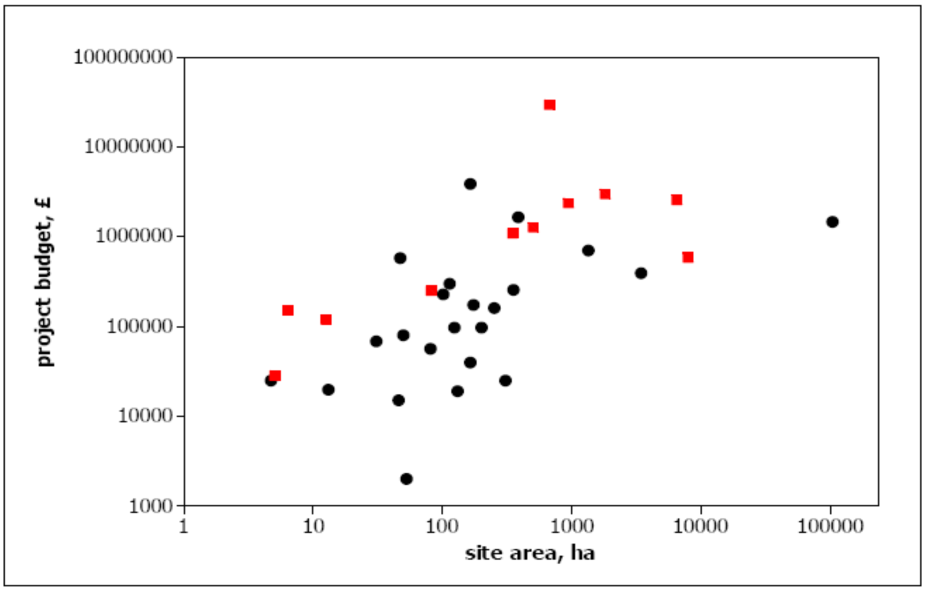



**Figure 26** Graph illustrating the relationship between peatland site area and project budget. Red squares distinguish those sites that have bought land as part of their budget (DEFRA report SP0556, Holden et al, 2008).

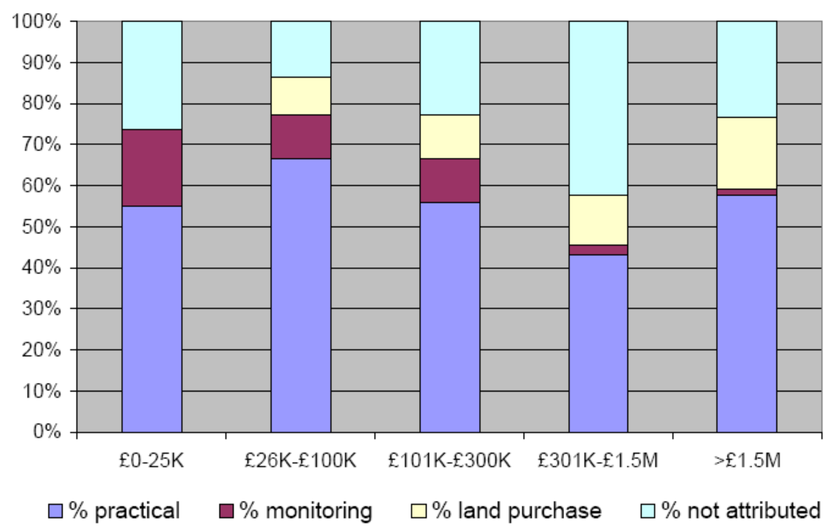



**Figure 27**. Histogram of the mean proportional budget spend on practical works, monitoring and land acquisition for projects of different sizes. To avoid bias caused by larger projects within each category the mean percentage values are

shown as determined from the percentage of each project (rather than a percentage of the sum of budgets for all projects within a category) (DEFRA report SP0556, Holden et al, 2008).

## 7.3 Estimated relative costs of different restoration activities

For this project the aim was to provide an indicative relative costing of the different management options associated with afforested peat restoration or preserving peatland resources. Relative and some actual costings are provided in Table 26. These are based on approximate costs reported in the literature, on expert judgement and some actual costing from DEFRA SP0556 report, (Holden et al., 2008). These costings need to be verified by district and local forest managers.

**Table 26** Management options and their relative costs based on the literature review and team expert judgement and actual costs from DEFRA SP0566 project, 2008.

| ***1. No action – retain existing tree cover and leave site undisturbed*** | |
|---|---|
| **Management activity** | **Relative/Actual costs** |
| Carry out a normal management/thinning | Medium |
| | |
| ***2. Retain existing tree cover and manage with low impact woodland management*** | |
| **Management activity** | **Relative/Actual costs** |
| Low silvicultural management activity | Low |
| | |
| ***3. Retain tree cover but change tree species composition favouring native woodland species*** | |
| **Management activity** | **Relative/Actual costs** |
| Tree species management | Medium/High |
| Management of open space within/outside woodland | Low /Medium |
| | |
| ***4. Careful mixture of management systems to encourage native woodland & open space*** | |
| **Management activity** | **Relative/Actual costs** |
| Open space preservation within existing woodland particularly if peaty soils | Low /Medium |
| Managing vegetated riparian buffer zones | Medium |
| Reduce tree stocking density | Medium /High |
| Change in site management | Low |
| Encouraging a natural lagg at the edge of previous raised bog by felling conifers and blocking off existing ditches plus managing natural woody vegetation (birch and rowan) | High |
| Cutting back forest edges to prevent too much shading, discourage tree regeneration and allow rainfall to soil surface. | High |
| Change of tree species | Medium /High |
| | |
| ***5. Remove tree cover permanently, actively restore bog habitat and maintain open habitat*** | |
| **Management activity** | **Relative/Actual costs** |

| | |
|---|---|
| Tree felling | Medium /High |
| Archaeological survey | High |
| Damming main drains | Low/ £1000 – 6500 per km |
| Damming furrows | High/> £6500 per km |
| Removing lops and tops from site by WTH | High/extra cost to conventional harvesting |
| Removing brash mats | High/extra cost to conventional harvesting |
| Post-restoration natural regenerated tree control | High/£1000-10000 per ha |
| Planting (revegetating) | Very High/>£2700 per ha |
| Mowing Post restoration control of e.g. Molinia (£128-200 per ha) | Low/£128-200 per ha |
| Grazing for preventing regeneration on dried bogs | Medium |

**Notes:**
1. Cost of thinning and tree removal operations will depend very substantially on whether trees are felled to waste, or whether material is sold, and its value.
2. Tree species change costs will depend on whether there are seed sources present, or other forms of regeneration, or whether new planting will be required.

# 8 Conclusions

This report provides a strategic assessment of the afforested peatland resource in Wales. It assesses the distribution of the Welsh peatlands, based upon the best available spatial information on the extent and location of peat soils, geology and peatland habitats. It delivers a definitive (improved) distribution map of the upland blanket peat and deep peat soils resource at the highest resolution currently possible. Comparison of the new national map with available field survey soils information and peat probe data revealed an acceptable level of accuracy. This report also includes an improved map of the distribution of afforested deep peat in Wales using recent spatial data on woodland cover from the new National Forest Inventory. This map is further improved with the spatial data for the Forestry Commission soil surveys across Wales. The historic FC soil data greatly enhance the spatial resolution of the afforested peat resource and provide critical information on the type of peat, which has proved to be an important element in the assessment of the potential success of restoration.

The report provides an overview of the available literature on the impact of afforested peatland restoration and management on the restitution and maintenance of peat-forming site conditions, and the possible implications of restoration for biodiversity, hydrology and greenhouse benefits in a Welsh context. There is a paucity of evidence from medium to long term afforested peatland restoration projects. It is not always possible to use reported evidence from open peatland restoration projects to predict the likely outcomes of afforested bog restoration. Neither is it always possible to apply reported outcomes from other countries to Welsh sites. There is still insufficient data and information to provide definitive recommendations of best practice for restoration of afforested peat. We attempted to provide information on the likely outcomes of a range of management options, but it is very important to include monitoring and reporting of the outcome of such efforts in terms of the medium and long term success of any restoration project to provide evidence that informs future decisions. For example, the lack of research and monitoring of non-C GHG emissions from previously-afforested peatland areas needs to be addressed before conclusions can be made on the likely GHG implications of restoration.

*National and field based schemes* of rule-based criteria, factors and thresholds for the assessment of the potential for restoration of an afforested peat site have been developed for this project and tested by ground truthing a number of potential sites in Wales. The results of the national assessment reveal that the best opportunities on the FCW estate are in the Snowdonia National Park, Tywi forest and Coed y Mynydd regions.

Once a site has been identified as potentially restorable by the *national assessment scheme*, a follow up *field assessment scheme* will be required to validate the desk-based national assessment. The *field assessment scheme* developed for this project includes a decision tree and rule-based criteria, factors and the thresholds to be used in scoring the advantageous or disadvantageous restoration potential for a specific site. Testing the proposed *field assessment scheme* on a number of ground truthing sites, it proved possible to identify sites with good restoration potential within the Gwydyr and Alwen forests in north Wales in addition to sites in Nant-y-Moch Wind Farm peat restoration and Bryn Brawd/Tywi areas.

The criteria, factors and thresholds within both *national and field based schemes* can inform decisions about the most appropriate goals for restoration, and land use and management for sites that are unsuitable for restoration.

Overall, this project is a significant step in collating spatial data, evaluating available knowledge and developing and testing *national* and *field* based assessments in order to improve information on the distribution of Welsh peatlands and strategically assess the restoration potential of afforested peat in Wales.

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## **Appendix 1:** Shepherd classification of NSRI NATMAP soil associations

WELSH NATMAP ASSOCIATIONS: **KEY PEATY SOILS** = 695.3 $km^2$ deep peat

| MAP UNIT | NAME | Definition | Typical depth of peaty soil (cm) | Estimated extent of peaty deposits in mapping unit |
|---|---|---|---|---|
| 1013a | CROWDY 1 | Humified peat | 40+ | 80% |
| 1013b | CROWDY 2 | Humified peat | 40+ | 100% |
| 1022a | ALTCAR 1 | Grass-sedge peat | 40+ | >80% |
| 1024a | ADVENTURES 1' | Humified peat | 40+ | 100% |
| 1024b | ADVENTURES 2' | Humified peat | 40+ | >80% |

WELSH NATMAP ASSOCIATIONS: **INTERMEDIATE PEATY SOILS** = 3,802 $km^2$ extensive shallow peaty soils

| MAP UNIT | NAME | Definition | Typical depth of peaty soil (cm) | Estimated extent of peaty deposits in mapping unit |
|---|---|---|---|---|
| 311a | REVIDGE | Loamy or peaty lithoskeletal sandstone | 20 | 55% |
| 311b | SKIDDAW | Loamy or peaty lithoskeletal mudstone, sandstone or slate | 10 | 75% |
| 311e | BANGOR | Loamy or peaty lithoskeletal acid crystalline rock | 25 | 50% |
| 651b | Hexworthy | Loam over lithoskeletal acid crystalline rock | 20 | 65% |
| 652 | MAW | Loam over lithoskeletal sandstone | 10 | 80% |
| 654a | HAFREN | Loam over lithoskeletal mudstone, sandstone or slate | 10 | 50% |
| 654b | LYDCOTT | Reddish loam over lithoskeletal sandstone | 10 | 60% |
| 654c | Gelligaer | Loam over lithoskeletal sandstone | 15 | 70% |
| 721a | PRINCETOWN | Loamy or peaty lithoskeletal acid crystalline rock | 20 | 75% |

| MAP UNIT | NAME | Definition | Typical depth of peaty soil (cm) | Estimated extent of peaty deposits in mapping unit |
|---|---|---|---|---|
| 721c | WILCOCKS 1 | Loamy drift with siliceous stones | 20 | 45% |
| 721d | WILCOCKS 2 | Loamy drift with siliceous stones | 20 | 60% |
| 721e | WENALLT | Reddish loamy drift with siliceous stones | 20 | 95% |

WELSH NATMAP ASSOCIATIONS: **OTHER ORGANIC SOILS** = 811.4 $km^2$
soils with peaty pockets

| MAP UNIT | NAME | Definition | Typical depth of peaty soil (cm) | Estimated extent of peaty deposits in mapping unit |
|---|---|---|---|---|
| 541o | MALHAM 1 | Medium silty material over lithoskeletal limestone | 10 | 20% |
| 612a | PARC | Medium loamy material over lithoskeletal mudstone, sandstone or slate | 20 | 15% |
| 631a | ANGLEZARKE | Light loamy material over lithoskeletal sandstone | 5 | 80% |
| 713c | FFOREST | Reddish medium silty drift with siliceous stones | | >10% |
| 713e | BRICKFIELD 1 | Medium loamy drift with siliceous stones | 20 | 13% |
| 813a | MIDELNEY | Clayey over peaty river alluvium | | <5% |
| 871a | LAPLOYD | Light loamy material over lithoskeletal acid crystalline rock | 15 | 40% |

## **Appendix 2:** The Forestry Commission soil classification system

| Soil Group | | Soil Type | Code |
|---|---|---|---|
| TABLE 1 SHALLOW PEATS SOILS (peat <45 cm) | | | |
| Soils with well aerated subsoil | 3. Podzols | Peaty podzol | 3p |
| | 13. Rankers | Peaty ranker | 13p |
| Soils with poorly aerated subsoil | 6. Peaty gley soils | Peaty gley | 6 |
| | | Peaty podzolic gley | 6z |
| TABLE 2 DEEP PEAT SOILS (peat>45 cm) | | | |
| Soils with poorly aerated subsoil | 6. Peaty gley soils | Deep peaty gley (peat >45 cm thick) | 6p |
| Flushed peats | 8. Juncus bogs (basin bogs) | *Phragmites* fen | 8a |
| | | *Juncus articulatus* or *acutiflorus* bog | 8b |
| | | *Juncus effusus* bog | 8c |
| | | *Carex* bog | 8d |
| | 9. Molinia bogs (flushed blanket bogs) | *Molinia, Myrica, Salix* bog | 9a |
| | | Tussocky *Molinia* bog; *Molinia*, *Calluna* bog | 9b |
| | | Tussocky *Molinia*, *Eriophorum vaginatum* bog | 9c |
| | | Non-tussocky *Molinia*, *Eriophorum vaginatum*, *Trichophorum* bog | 9d |
| | | *Trichophorum, Calluna, Eriophorum, Molinia* (weakly flushed blanket bog) | 9e |
| Unflushed peats | 10. *Sphagnum* bogs (flat or raised bogs) | Lowland Sphagnum bog | 10a |
| | | Upland Sphagnum bog | 10b |
| | 11. *Calluna, Eriophorum, Trichophorum* bogs *Calluna*, (unflushed blanket bogs) | *Calluna* blanket bog | 11a |
| | | *Eriophorum vaginatum* blanket bog | 11b |
| | | *Trichophorum*, *Calluna* blanket bog | 11c |
| | | *Eriophorum* blanket bog | 11d |
| | 14. Eroded bogs | Eroded (shallow hagging) bog | 14 |
| | | Deeply hagged bog | 14h |
| | | Pooled bog | 14w |
| TABLE 3 MINERAL SOILS | | | |
| Soils with poorly aerated subsoil | 5. Ground-water gley soils | Ground-water gley | 5 |
| | 7. Surface water gley soils | Surface-water gley | 7 |
| | | Brown gley | 7b |
| | | Podzolic gley | 7z |
| Soils with well aerated subsoil | 1. Brown earths | Typical brown earth | 1 |
| | | Basic brown earth | 1d |
| | | Upland brown earth | 1u |
| | | Podzolic brown earth | 1z |
| | 3. Podzols | Typical podzol | 3 |
| | | Hardpan podzol | 3m |
| | 4. Ironpan soils | Intergrade ironpan soil | 4b |
| | | Ironpan soil | 4 |
| | | Podzolic ironpan soil | 4z |
| | 2. Man-made soils | Mining spoil, stony or coarse textured | 2s |
| | | Mining spoil, shaly or fine textured | 2m |
| | 12. Calcareous soils (soils on limestone rock) | Rendzina (shallow soil) | 12a |
| | | Calcareous brown earth | 12b |
| | | Argillic brown earth (clayey subsoil) | 12t |
| | 13. Rankers and Skeletal | Brown ranker | 13b |

| Soil Group | | Soil Type | Code |
|---|---|---|---|
| | soils (rankers = shallow soils < 30 cm to bedrock, skeletal = excessively stony) | Gley ranker | 13g |
| | | Rock | 13r |
| | | Scree | 13s |
| | | Podzolic ranker | 13z |
| | 15. Littoral soils (coastal sand and gravel) | Shingle | 15s |
| | | Dunes | 15d |
| | | Excessively drained sand | 15e |
| | | Sand moderately deep water table | 15i |
| | | Sand shallow water table | 15g |
| | | Sand very shallow water table | 15w |

**Appendix 3:** Site Types in Forests of North and Mid Wales

| Site Type | | Soil Type | Code | Description of Peat | Drainage | Fertilizer | Cultivation | N availability |
|---|---|---|---|---|---|---|---|---|
| Soils with poorly aerated subsoil | (peat >45 cm thick) | Deep peaty gley | 6p | 5 – 45 cm (commonly 20 - 30 cm) of black amorphous peat, overlies clayey subsoil > 60 cm of mineral soil under peat. | | None required at planting, may require top dressing of Phosphate were growth not seriously inhibited by water logging. | Poor drainage - subsoil impeded requires deep double mouldboard ploughing down slope with deep cross drains on steep slopes. | |
| Flushed peats | Flushed Juncus bogs - basin sites e.g. valley bottom bogs. | *Phragmites* fen | 8a | 45 - 120 cm of black or dark brown amorphous peat in flushed sites often containing layers of mineral material. Dries into hard blocky crumbs. | | Flushed peats are relatively fertile and produce good spruce crops without fertiliser application. LP better suited to frosty sites where competition from grasses may be a problem for SS. | Usually small areas within peaty gley and treated with the same ploughs | Sufficient N available for tree growth |
| | | *Juncus articulatus* or *acutiflorus* bog | 8b | | | | | |
| | | *Juncus effusus* bog | 8c | | | | | |
| | | *Carex* bog | 8d | | | | | |
| | Molinia bogs - blanket bogs in gentle slightly convex or straight plateau sites. | *Molinia, Myrica, Salix* bog | 9a | 45 (30 at Tywi) - 90 cm deep black peat over layer of mineral soils over parent material. Ranges in texture from amorphous to pseudo fibrous with a tendency to natural fissuring. When dry it crumbles to hard | Wet/very wet | Poor/ very poor the bogs have moderate nutrient status for SS but Phosphate and Potassium deficiencies can occur in young crops. Apply Phosphate as top dressing 5 – 15 years after planting. | Where peat < 75 cm treat as peaty gley | Sufficient N available for tree growth |
| | | Tussocky *Molinia* bog; *Molinia*, *Calluna* bog | 9b | | | | | N limited due to competition from heather |
| | | Tussocky *Molinia*, *Eriophorum vaginatum* bog | 9c | | | | | N limited due to slow mineralisation and competition |

| Site Type | | Soil Type | Code | Description of Peat | Drainage | Fertilizer | Cultivation | N availability |
|---|---|---|---|---|---|---|---|---|
| | | Non-tussocky *Molinia*, *Eriophorum vaginatum*, *Trichophorum* bog | 9d | | | | | |
| Un-flushed peats | *Sphagnum* bogs and *Calluna, Eriophorum, Molinia* bogs - basin sites e.g. shallow toughs and shelves on hill slopes creating flat or raised bogs. | *Trichophorum, Calluna, Eriophorum, Molinia* (weakly flushed blanket bog) | 9e | 120 – 200 cm deep (occasionally much deeper) dark brown peat, typically amorphous to pseudofibrous at depth and more fibrous near the surface. | | SS requires high fertilizer input, due to low nutritional status, at planting plus subsequent top dressing of potash and phosphate. May also require use of heribicide (or nitrogen fertilizer) to control Calluna | Requires special peat ploughs: D60/--/t for planting ridges with S90/--/t for cross drains | N limited due to very slow mineralisation |
| | | Lowland Sphagnum bog | 10a | | | | | |
| | | Upland Sphagnum bog | 10b | | | | | |
| | *Calluna/ Eriophorum* blanket bogs (**Hill Peat**) of flat hill tops | *Calluna* blanket bog | 11a | 45 – 200 cm of dark brown to black peat of a densely fibrous (felted) structure (occasionally amorphous – pseudofibrous). Often overlies an iron pan soil profile or rock. Greasy when moist. Often fissured and hagged (sometimes severely see below). | | Low in P and K, often applied at planting. P alone could induce symptoms of K deficiency. Calluna controlled to prevent competition for N in early growth. | As above | N limited due to slow mineralisation and competition from heather |
| | | *Eriophorum vaginatum* blanket bog | 11b | | | | | |
| | | *Trichophorum*, *Calluna* blanket bog | 11c | | | | | N limited due to very slow mineralisation |
| | | *Eriophorum* blanket bog | 11d | | | | | |
| | Shallow peat over rock and eroded bogs | Eroded (shallow hagging) bog | 14 | Peat of Hill Peat types <45 cm deep over fragmented bedrock. Includes severely eroded Hill Peat areas. | Difficult to drain due to shallow bedrock and irregular terrain. | Usually can only be planted if erosion limited to <25% of the surface, phosphate essential at planting top dressing required as above. | Difficult to access with large machinery. Attempt D45/T60/m down slope | |
| | | Deeply hagged bog | 14h | | | | | |
| | | Pooled bog | 14w | | | | | |

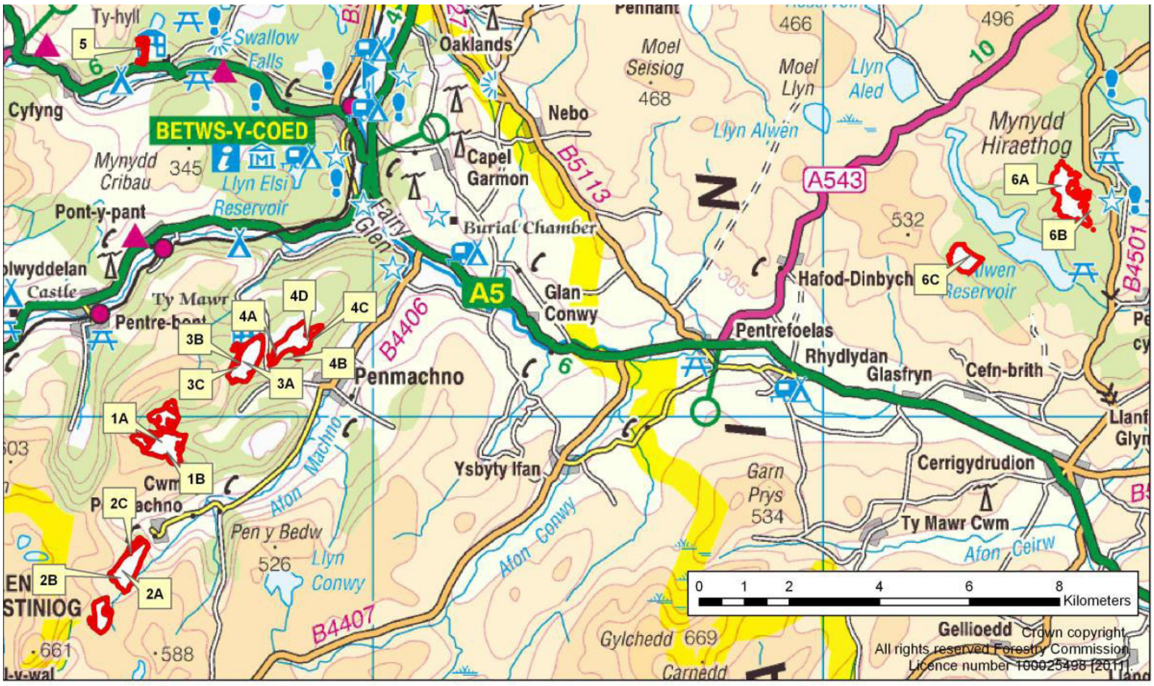
| Site Type | | Soil Type | Code | Description of Peat | Drainage | Fertilizer | Cultivation | N availability |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | with cross drains where possible S60/--/t. | |

Plough nomenclature

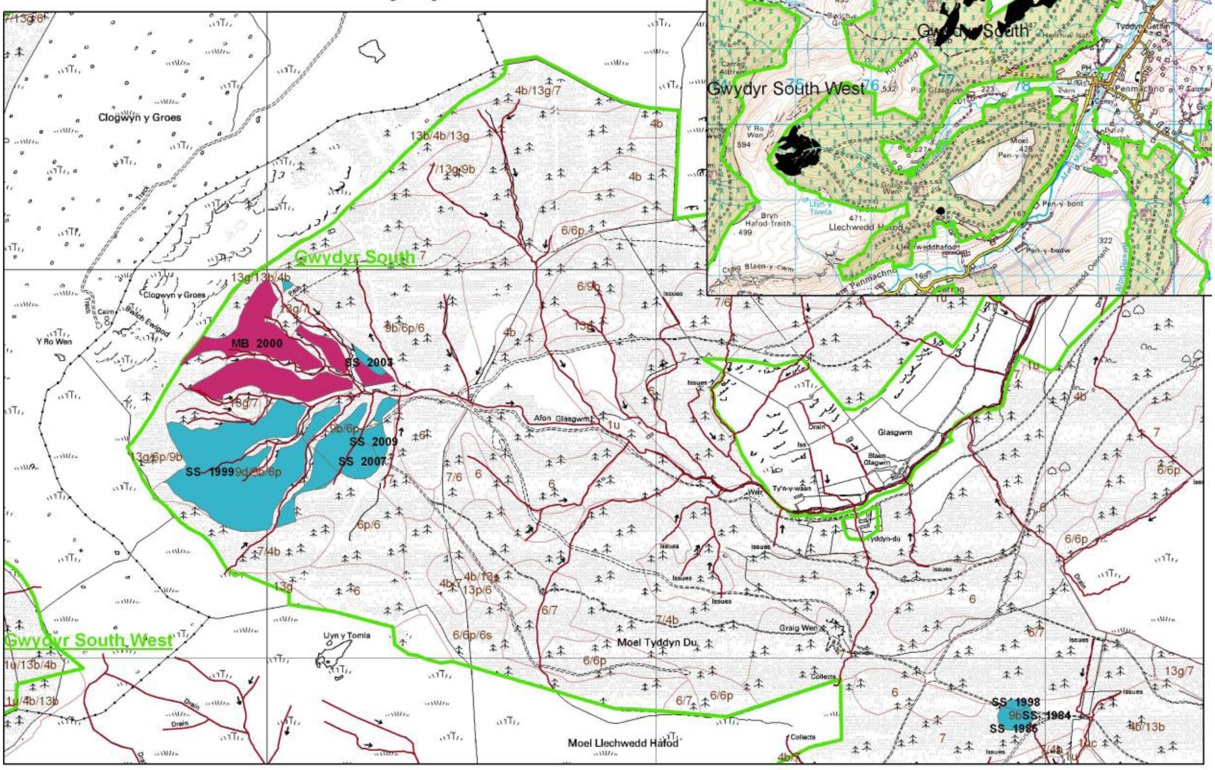
D90/T90/t: Deep double-mouldboard tine plough, trailed
D45/T60/m: Shallow double-mouldboard tine plough, mounted
D60/--/t: Shallow double-mouldboard turfing plough, trailed
S90/--/t: Deep single-mouildboard draining plough, trailed

**Appendix 4**: Afforested peat sites in Gwydyr, Alwen forests, Nant-y-Moch Wind Farm and Tywi (Bryn Brawd area) to ground truth the national maps and the rule-based criteria developed in the *field assessment scheme* in this project.

Location of afforested peat sites in Gwydyr and Alwen forests visited by FR during June & July, 2011 for ground truthing the national and field assessments of restoration methodology. Table 25 includes details of observations from individual sites.

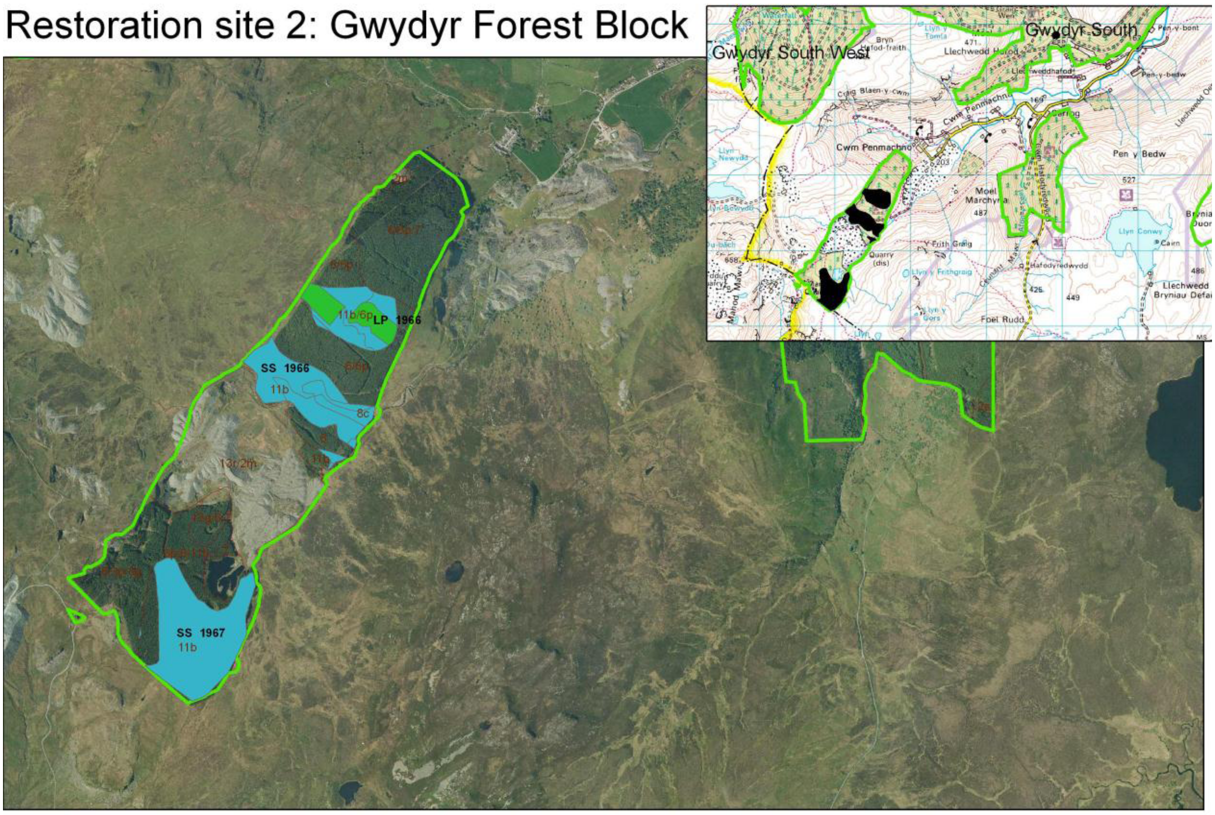


## Restoration site 1: Gwydyr Forest Block



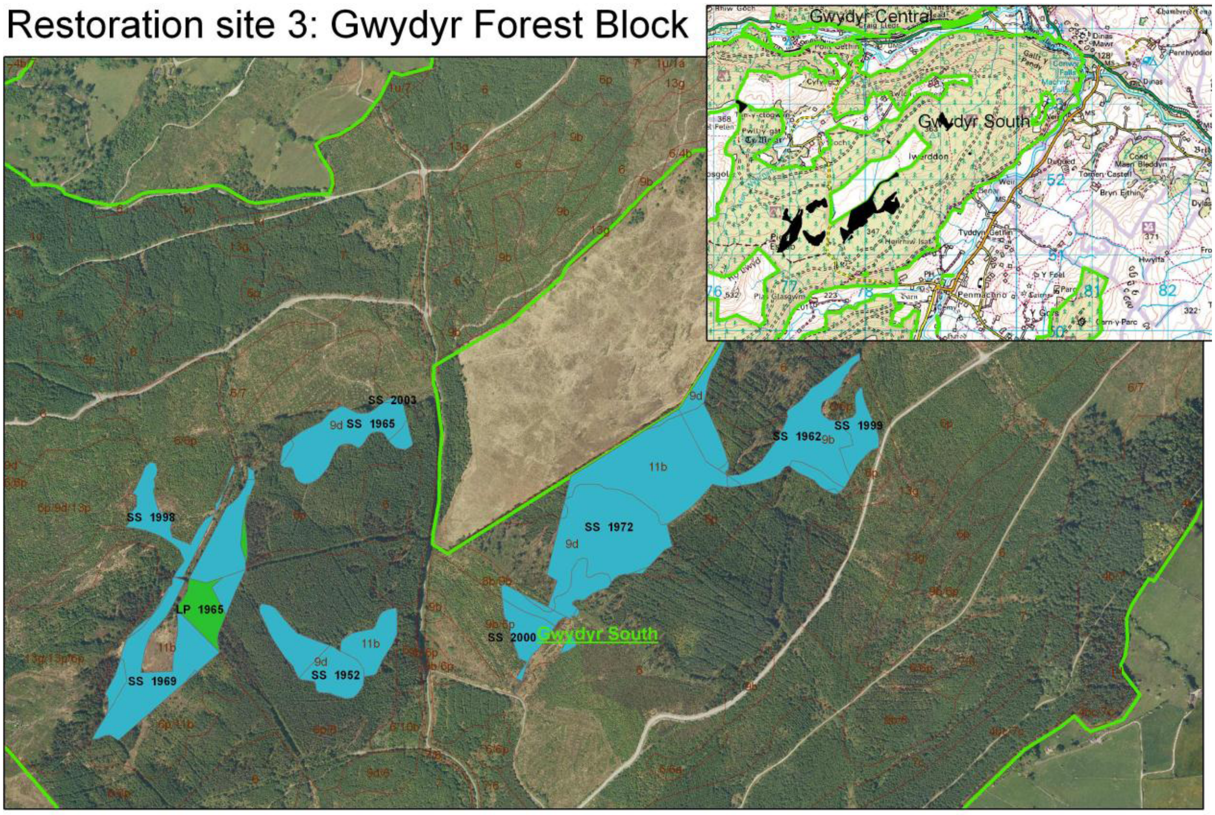

Headwater catchment planted with stands on MB and SS crop still young is there any opportunity to remove SS and restore rescue peat?

## Restoration site 2: Gwydyr Forest Block



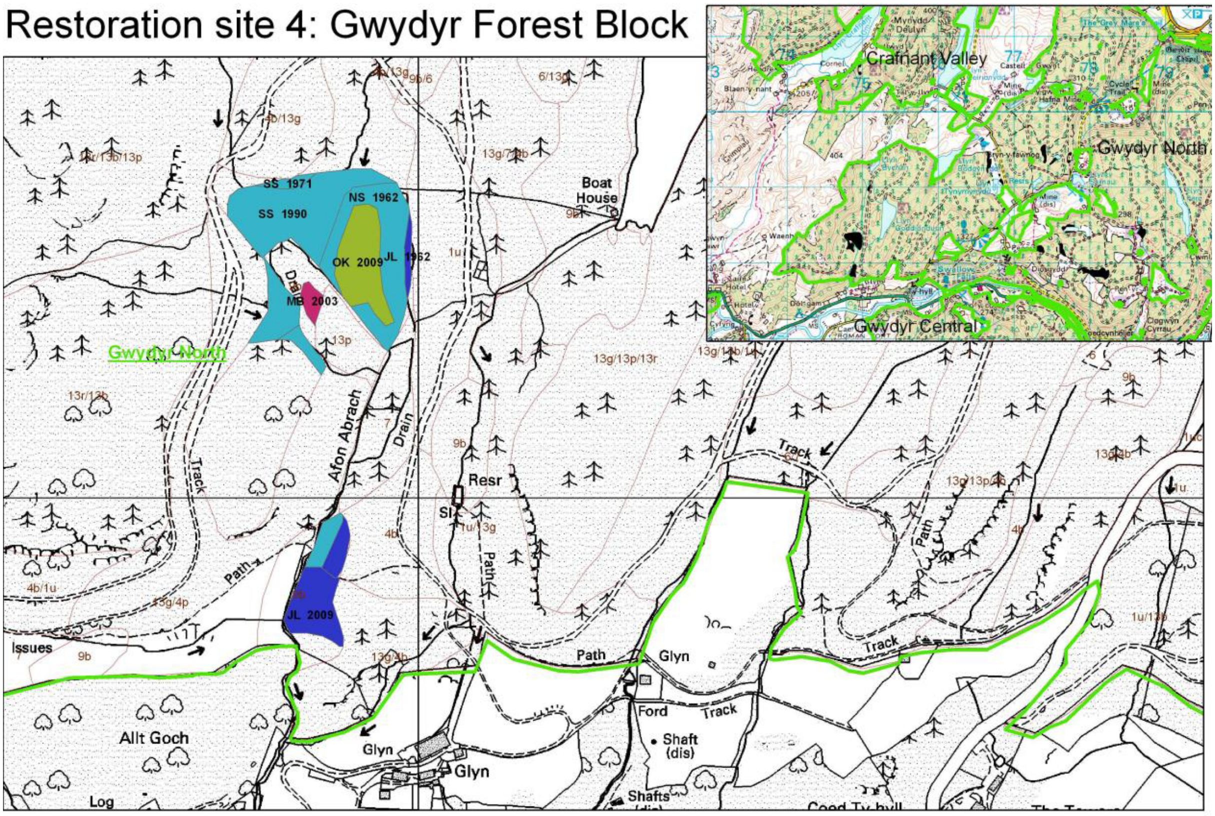

Mature trees at the top of a hill - quarry

## Restoration site 3: Gwydyr Forest Block




Mature trees on flat saddle - close to open ground

## Restoration site 4: Gwydyr Forest Block




Pocket of deep peat surrounded by skeletal soils with very varied tree cover in the flat valley floor of a steeply side U shape stream valley.

Photographs of sites referred to in Table 25.


1A


1A open riparian zone


1B


2A


2B


2C


**3C**

4A

4A

4A

4C

4C

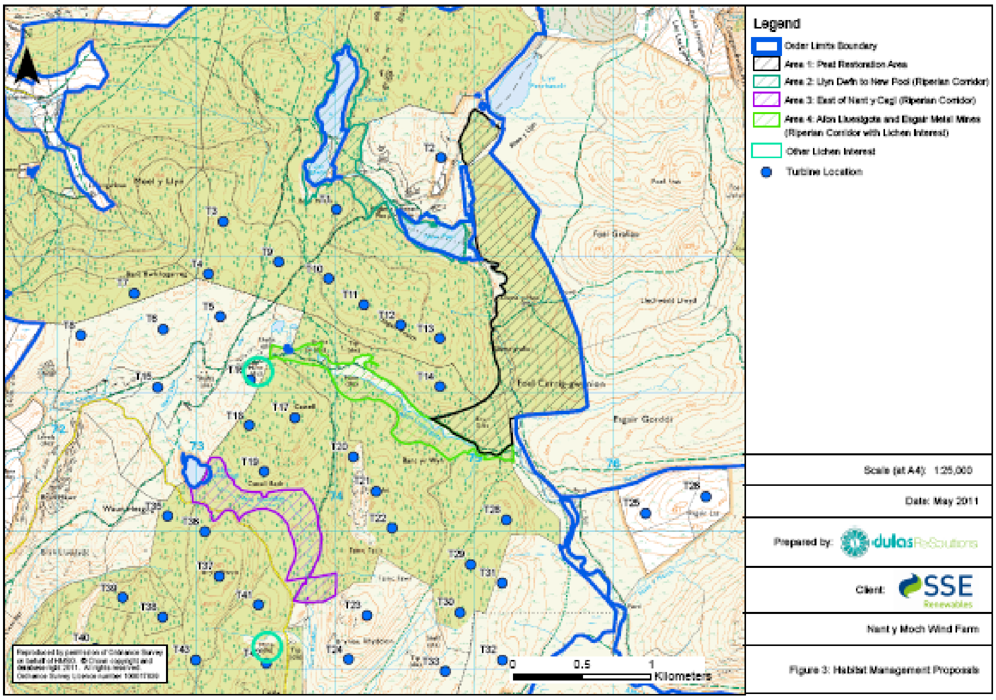
6A

**6C**

**6C**

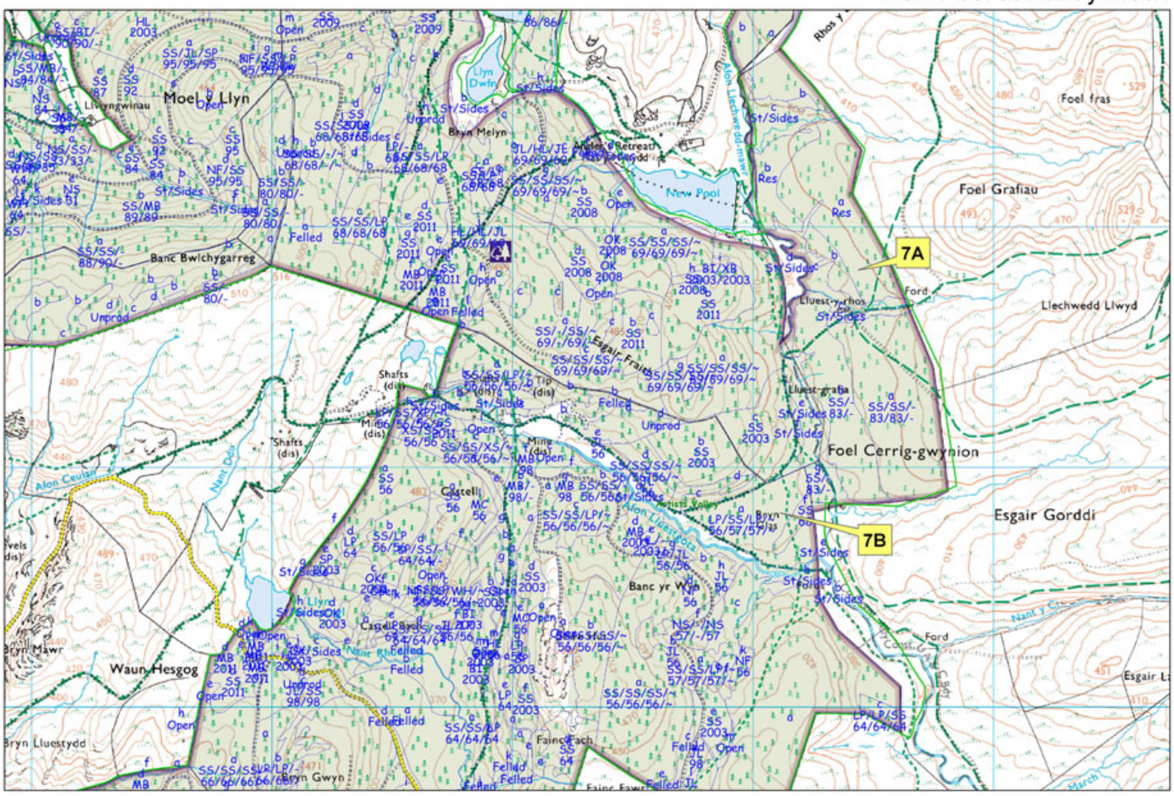
**6C**

Habitat management proposals for wind farm scheme at **Nant-y-Moch**. The black hatched area is marked for peatland restoration. The blue green and purple areas are marked for enhanced riparian habitat.




Location of sites in peat restoration area at Nant-y-Moch wind farm, visited by FR during October 2011 for ground truthing the *field assessment scheme* methodology. Table 25 includes details of observations from individual sites.

New Pool at Nant y Moch



Photographs of sites in Nant-y-Moch Wind Farm peat restoration area, with site details listed in Table 25.

**7A**

**7A**

**7A**

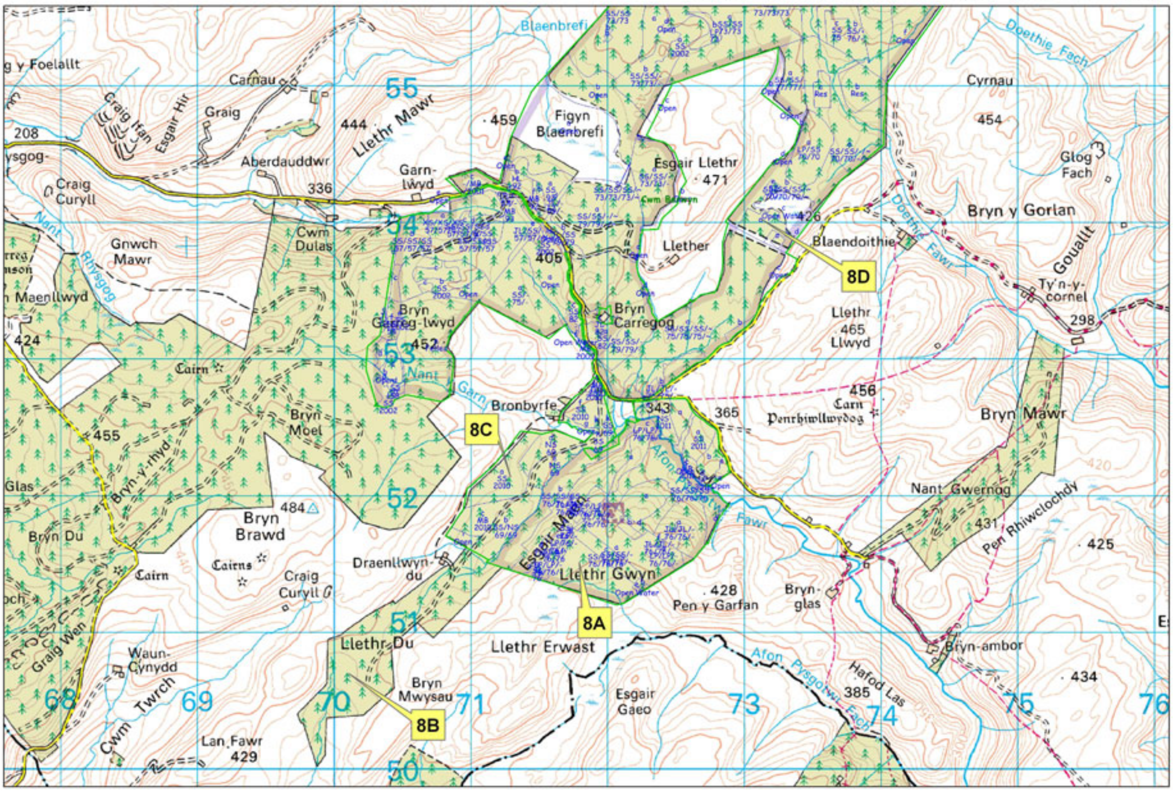
**7B**

**7B**

**7B**

Location of sites in Bryn Brawd area, visited by FR during October 2011 for ground truthing the *field assessment scheme* methodology. Table 25 includes details of observations from individual sites.

Bryn Brawd area, at Esgair Maern at Twyi




Photographs of sites in Bryn Brawd area, with site details listed in Table 25.

Photographs of Bryn Brawd area

8A

8A

8A

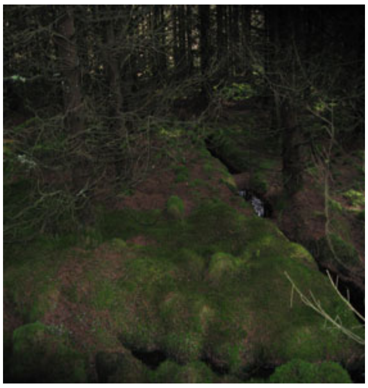
8B

8B

8B

8C


8D


8D

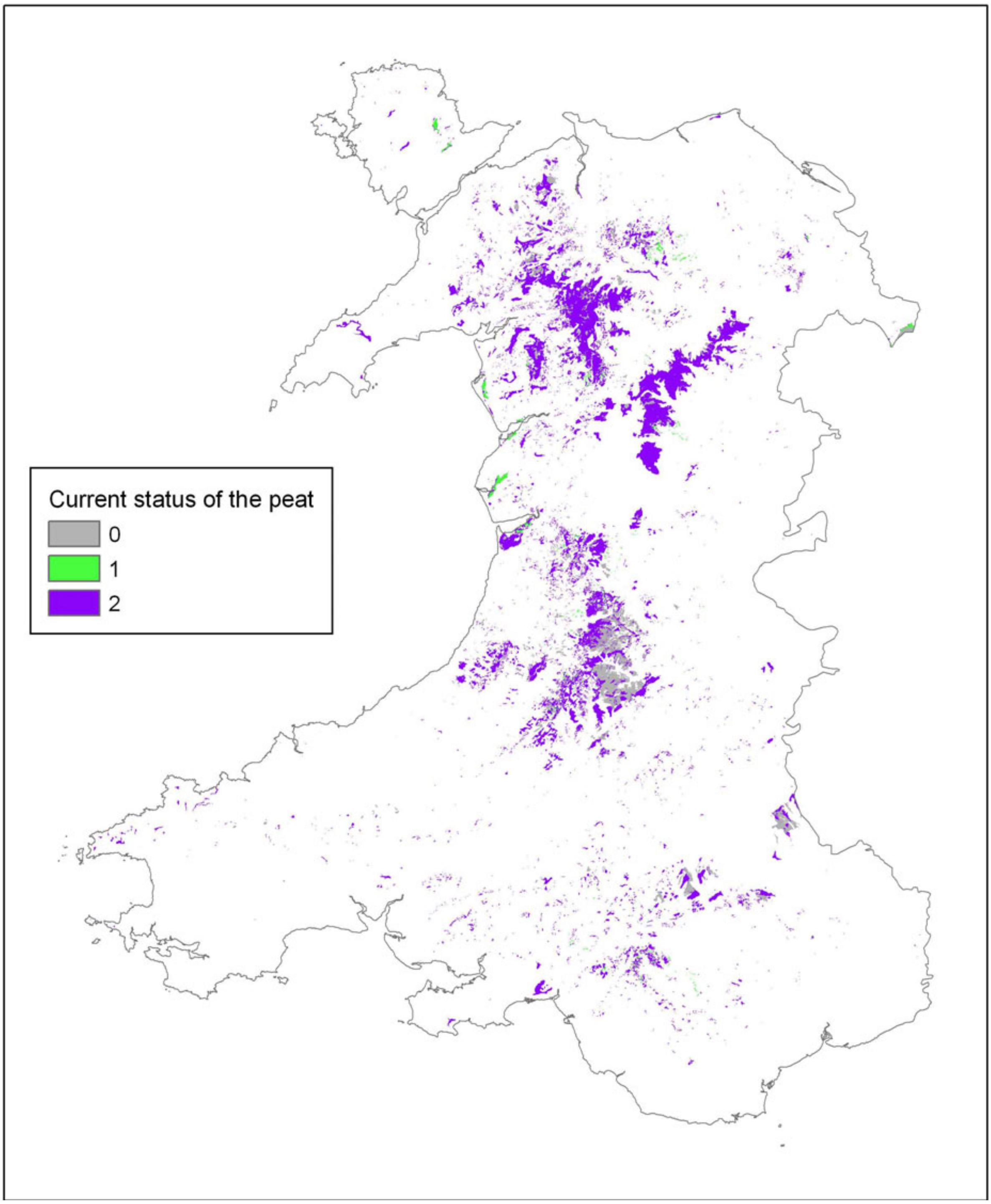

8D


8D

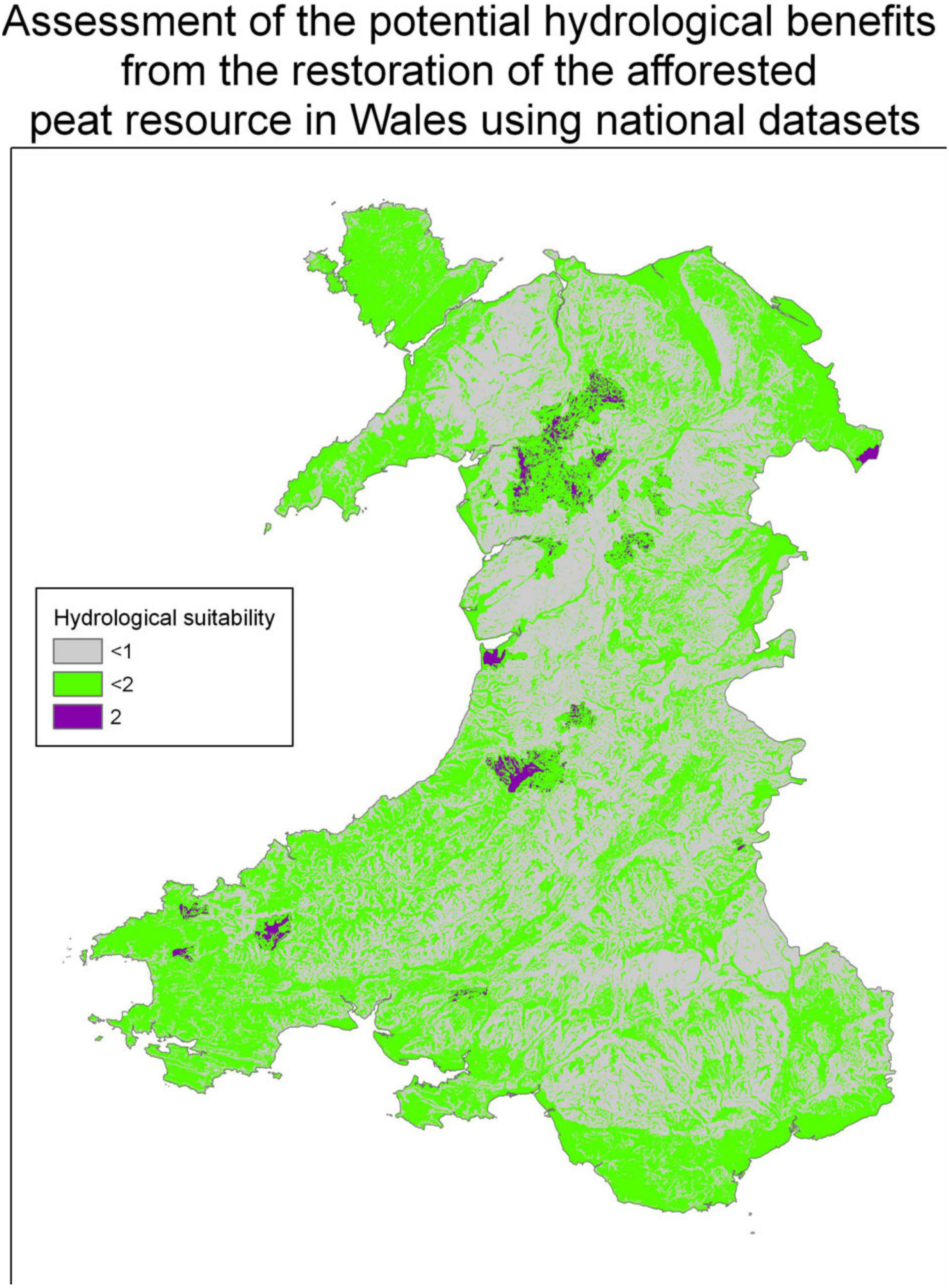
**Appendix 5:** Mapping outputs of the rule based criteria for the *national assessment scheme* of the restoration potential of afforested peat

## Map 1

Assessment of the current status of the afforested peat resource in Wales using national datasets

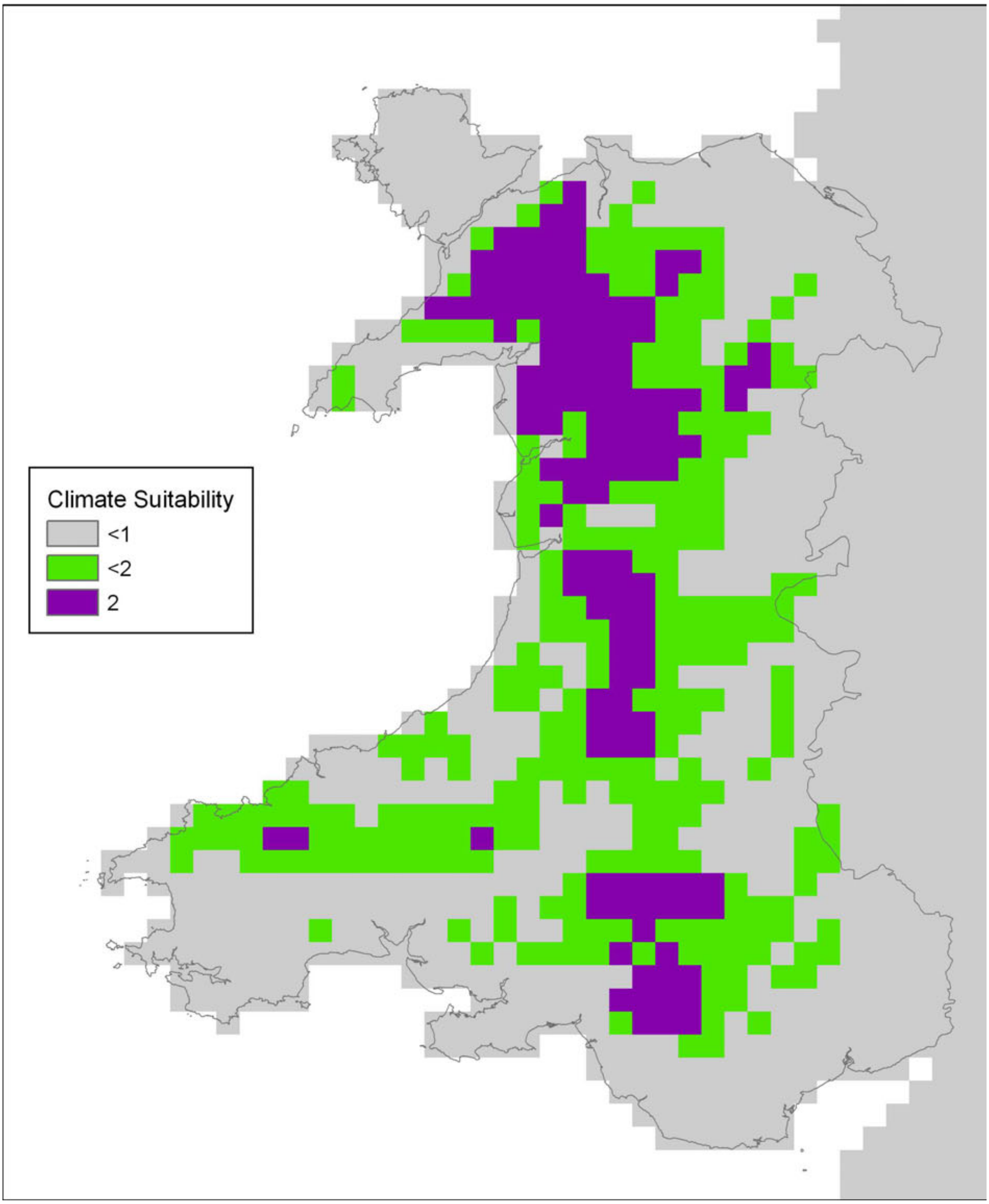


**Map 2**


Assessment of the potential hydrological benefits from the restoration of the afforested peat resource in Wales using national datasets
Hydrological suitability
<1
<2
2

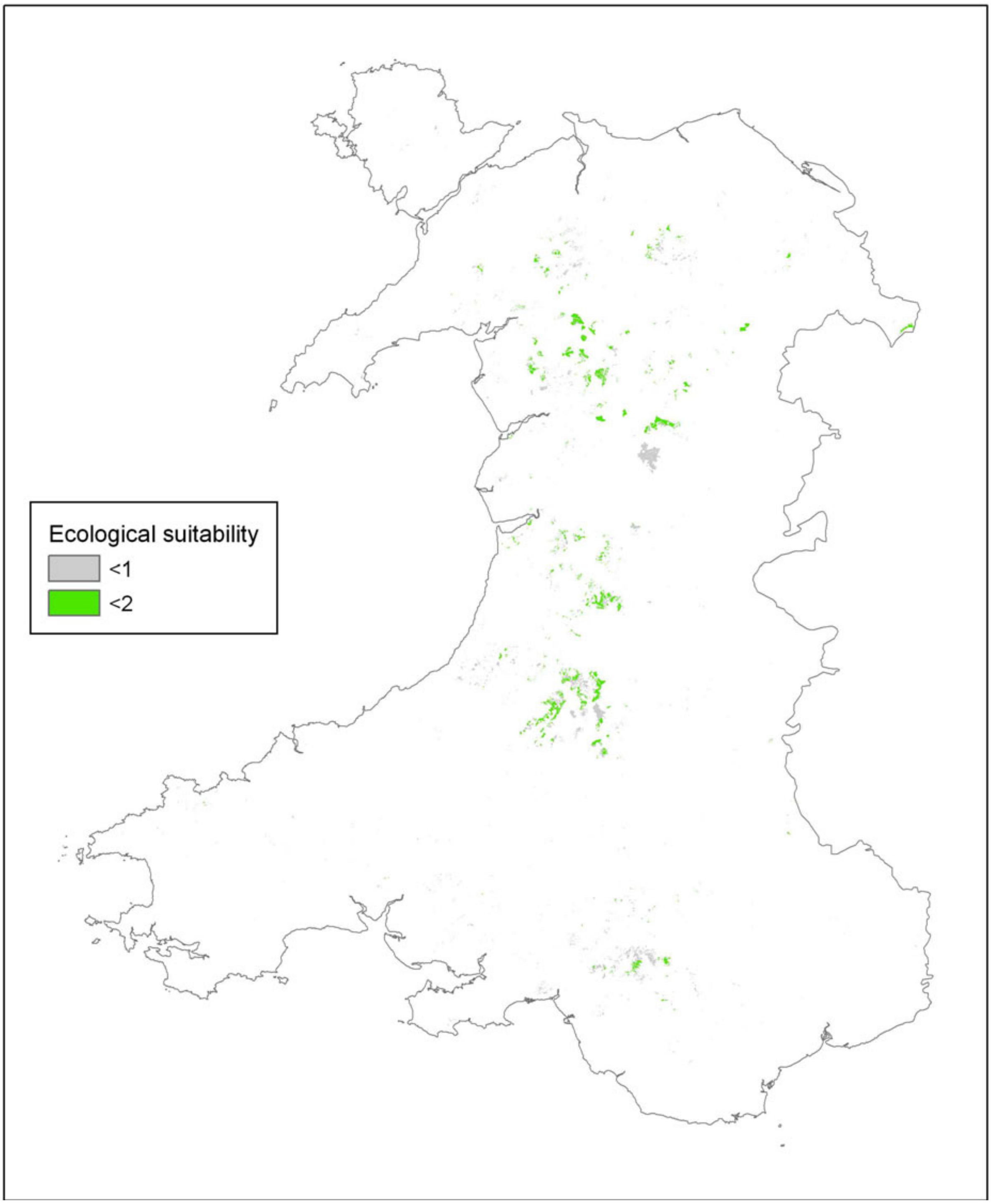
**Map 3**

# Assessment of the potential greenhouse gas balance benefits from the restoration of the afforested peat resource in Wales using national datasets



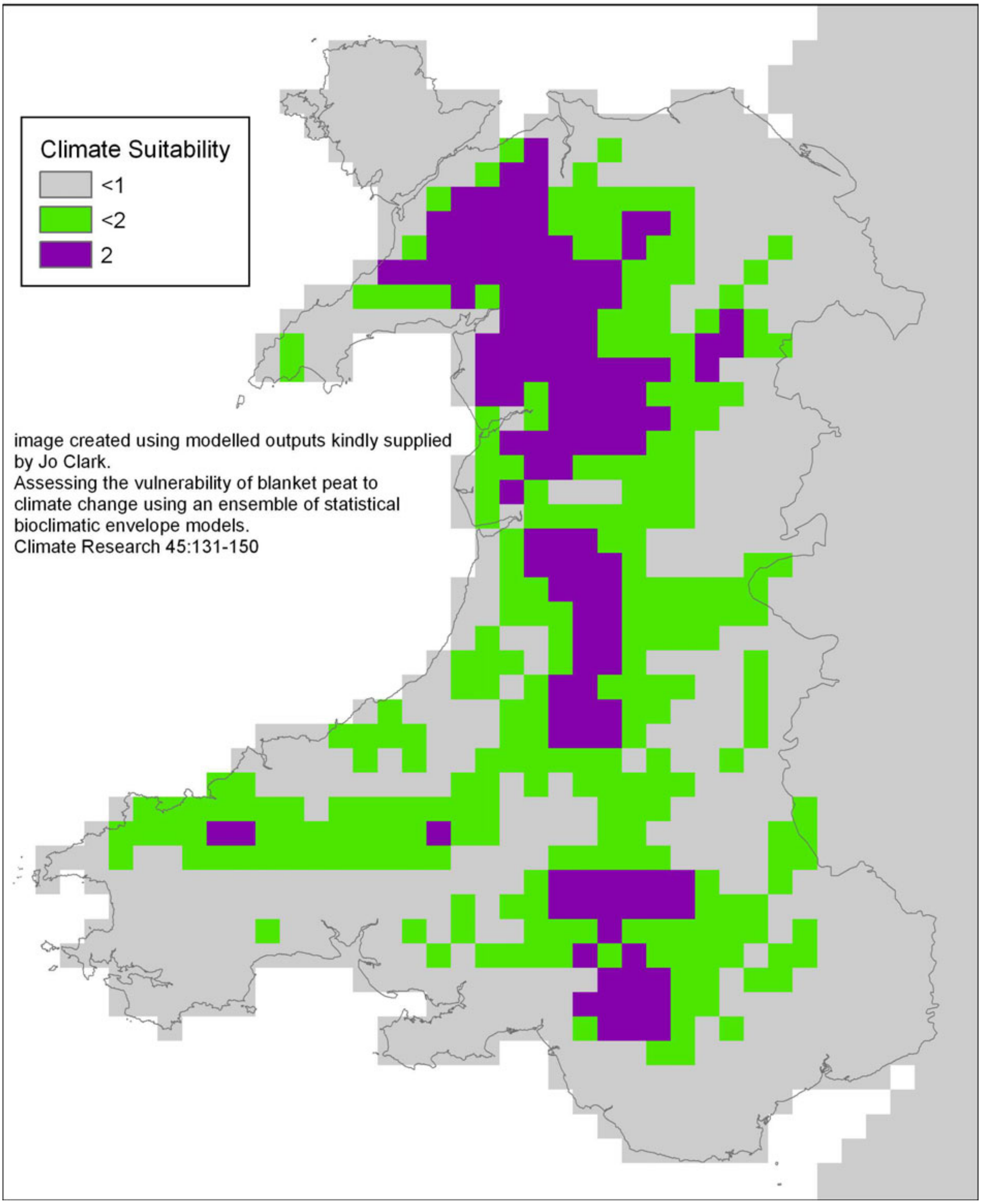
**Map 4**

## Assessment of the current status of the afforested peat resource in Wales using national datasets

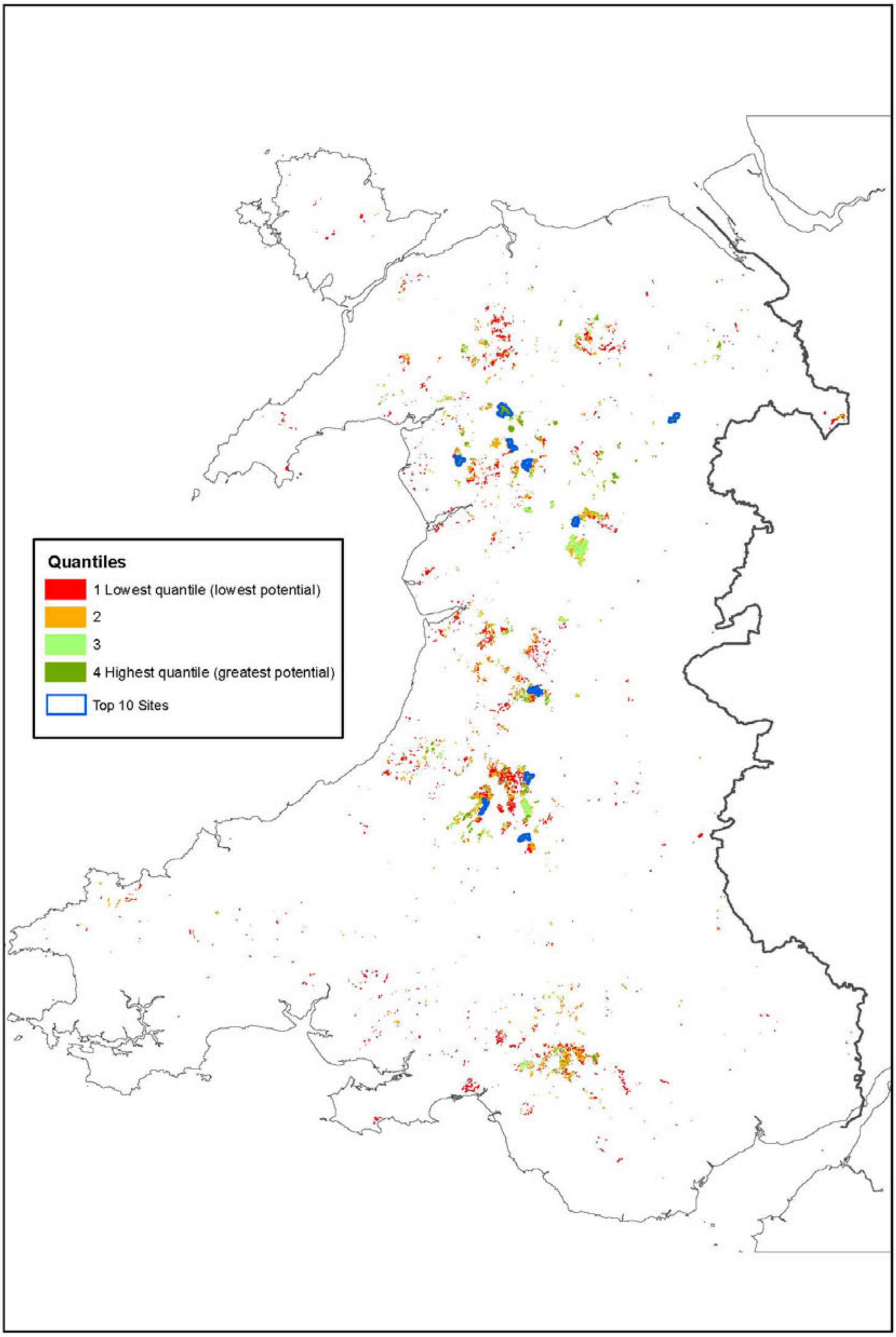


## Map 5

Bioclimatic envelope model of suitability for blanket bog (Clark et al 2010)

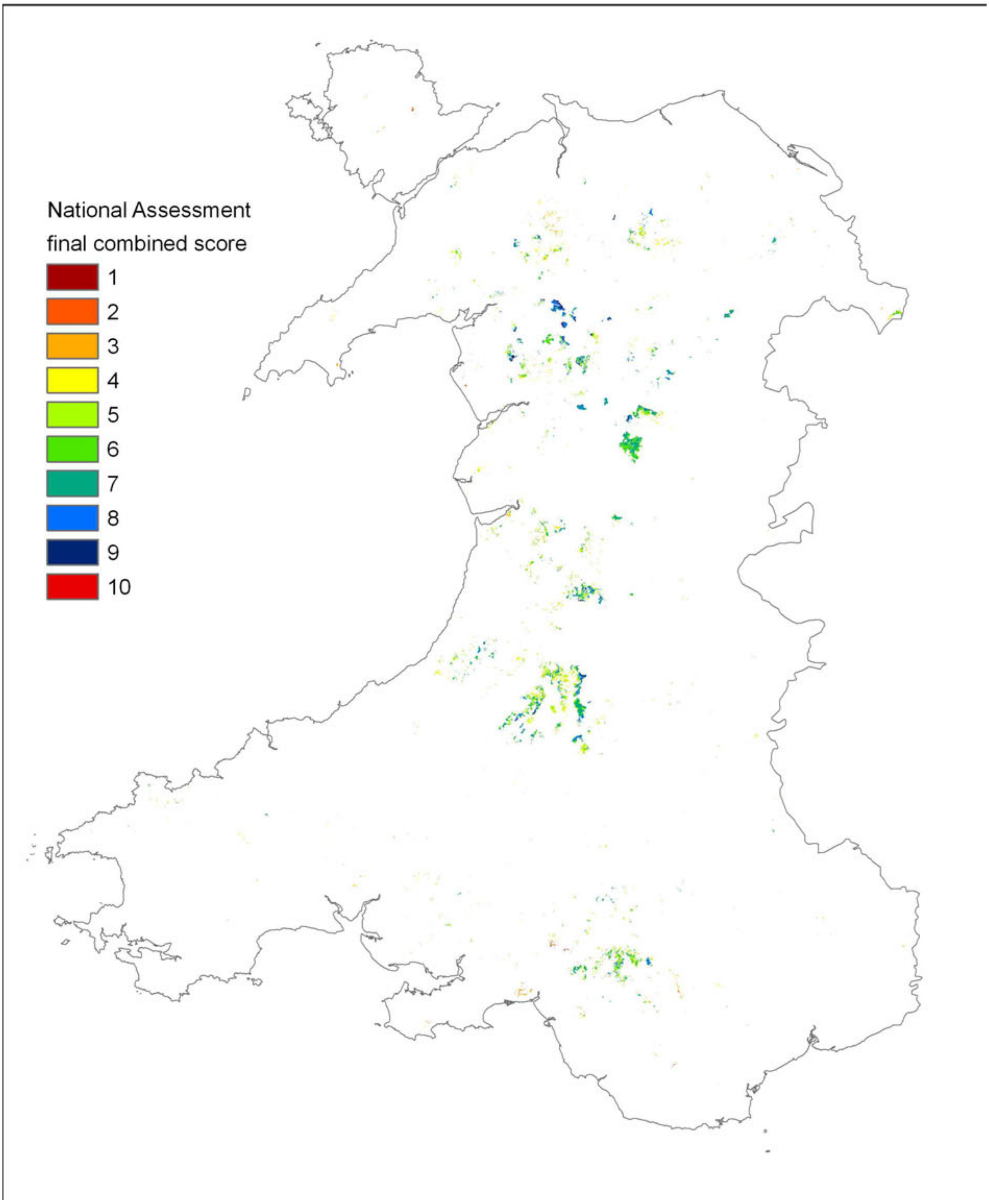


## Map 6 Classification of final national assessment scores to identify sites with the greatest potential to deliver multiple benefits from restoration



**Map 7**

## Assessment of potential multiple benefits from and viability for restoration of the afforested peat resource in Wales using national datasets



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